KNOWLEDGE SHARING IN ENGINEER-TO-ORDER (ETO) MANUFACTURING ENTERPRISES

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By

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I dedicate this work to my Mum and Dad

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ABSTRACT

Sharing Knowledge is considered an important part of managing new product development (NPD) research on the process of NPD and Knowledge Management methods have influenced industry in various ways. For example the management of the NPD process, the use of tools, techniques and the organisation of teams, and the integration of the marketing and manufacturing have resulted in considerable progress within NPD process. Prior studies on the NPD problems have delivered various models of the NPD process and a variety of supporting methods, tools and techniques in a generic context. A more realistic scenario however, is to consider the needs of firms that develop products on a Make-to-Order (MTO) or Engineer-to-Order (ETO) basis.

The research methodology adopted was based on extracting a preliminary ETO model supported by variety of Knowledge Management methods, tools and techniques from the review of literature. To examine the applicability of these models and methods and also the influential factors on the NPD process a survey by questionnaire and structured interviews in UK industrial companies was carried out. Findings were bound together to provide a generic model of the ETO process and a framework for the knowledge sharing on the specific needs of ETO manufacturing companies. IDEF0 technique was used to develop the preliminary and the generic models.

The objective of this research is to construct a structured and practical framework for supporting the opportunity for knowledge sharing within 'one-off' projects. The knowledge sharing framework referred to as 'Sharing-ETO-Knowledge' (SETOK) was translated into a computer program using the "MS Visio' enterprise modelling systems. It was examined by applying the system program to the data of the two cases that had been obtained at the case study stage. The framework has been fruitful in the provision of a guideline for the implementation of the knowledge sharing in various NPD-ETO projects.

The SETOK framework may be viewed as a practical, robust generic tool to assess the process performance of ETO manufacturing projects. The outcome of this study would help ETO manufacturing companies in their knowledge sharing and decision making processes with regards to NPD-ETO manufacturing projects.

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Chapter 1 - INTRODUCTION

1.1 Introduction

This thesis explores the development of a framework to support knowledge sharing of within engineer-to-order (ETO) manufacturing projects. In doing so makes two contributions to knowledge. First, it brings together the fields of New Product Development (NPD) and Knowledge Management (KM), of which have their own literature and research activity and have remained somewhat detached from the 'customer-driven manufacturing'[1]theories. Second it develops a framework to support the analysis and performance of NPD-ETO manufacturing projects.

In this first chapter, the topic of ETO manufacturing through to product development and uncertainty are briefly discussed. Following on from this Sections 1.2 to 1.6 explore the research problem, how the research developed, the research aims and objectives, and the methods used to support the research.

1.2 Overview of thesis structure

The thesis draws on a number of sources to address the research aims and objectives, as shown in section 1.4, it uses the information and data gained from the literature, industrial practitioners from engineering and manufacturing organisations that Make-to-Stock (MTS) to ones that ETO which took part in the survey, the interview case studies and the two longitudinal case studies.

1.3 The communication and co-ordination problems

The individual's who have the responsibility for their firm's NPD process, or specific tasks or phases within it, are under increasing pressure to reduce the levels of risk and uncertainty. The ability of an ETO firm to produce to time, cost, quality, and with full functionality depends on their ability to efficiently allocate resources and to

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[1] In this thesis Customer Driven Manufacturing refers to the combined definitions of Make-to-Order (MTO) and Engineer-to-Order (ETO).

coordinate their specialised knowledge and technologies to solve development problems and prevent costly feedback loops. Since the extent of any redesign work impacts negatively on the productivity of the project, the economic emphasis is on uncertainty.

Uncertainty exists relative to both possible outcomes and their likelihood of occurring. NPD projects face the challenge of identifying the factors that affect them relative to uncertainties. The cost and availability of components, materials, environmental conditions and the ability of the project team to perform as well as the ability to detect problems. Under ideal conditions, the project would be able to identify all unknowns and implement a risk management programme to systematically address them. In reality, projects have limited resources, so must therefore decide which uncertainties to explore and reduce. Both the acquisition of outside knowledge (e.g. through searches, consultants) and the development of internal knowledge (e.g. through tests and experiments) is critical to resolving uncertainty effectively. Muntslag (1994) identified three uncertainty factors namely:

- Product specification uncertainty
- Process specification uncertainty
- Product mix and volume uncertainty

In order to help managers improve on the performance of these ‘uncertainty factors’ within the NPD-ETO process requires a proposed framework to assist ETO manufacturers in knowledge sharing by capitalising on the experiences gained from previous ETO projects.

A key challenge faced by such organisations is how to acquire knowledge and manage sources of uncertainty in order to reduce the risk of failure of either the project or the resulting NPD product. The product can “fail” due to intrinsic problems (e.g. does not meet performance, reliability, or safety requirements in the environment for which it was designed) or extrinsic problems (e.g. flops in the market, changes in regulations), while the project can “fail” by violating constraints (e.g. late, over budget), not delivering the product, or being beaten by the competition.

1.4 Research Aim and Objectives

The hypothesis underpinning this research is that:

- The effective management of NPD-ETO manufacturing projects requires a structured approach and supporting tools to manage the process effectively

The supporting hypothesis is that:

I. By understanding the issues and problems of ETO manufacturing projects, managers can identify the potential risks and uncertainties best suited to the knowledge sharing opportunities within their company

II. By measuring the process quality in a ETO manufacturing project, the process can be optimised to reduce the project risk and uncertainty within the NPD-ETO process and improve knowledge transfer on future projects

In light of the above considerations, the aim of this research is to develop a framework for knowledge sharing within the NPD-ETO process by achieving the following objectives to support the hypothesis.

1.4.1 Research Lifecycle

The first stage involved a detailed review on NPD practices, the characteristics of customer-driven manufacturing, knowledge management and knowledge sharing practices, was reviewed within a historical context. The aim was to establish chronologically and logically the emergence and development of NPD-ETO process models, and methods. The main body of the literature review is presented in chapter 2. This chapter is divided into three main sections:

- The NPD process
- NPD-Manufacturing interface
- Capital Goods manufacturing projects; methods, tools and techniques
- Knowledge Management-specific methods and influential factors on the NPD-ETO process and knowledge sharing methods.

The second stage involved a survey of UK based manufacturers and engineering based companies to provide an insight into the application of NPD tools and techniques, and to establish a picture of current NPD practices (Appendix A).

The third stage involved a number of case study interviews of four MTO/ETO manufacturers and one manufacturing consultancy based within the UK to provide the researcher with an insight into characteristics of MTO/ETO manufacturing projects. The fourth stage involved the undertaking of two case study companies to examine the application of the defined framework for 'uncertainty', and the structured measure for 'process robustness' developed at stage three. The fifth stage involved the development of the proposed system to support knowledge sharing of ETO manufacturing projects. The sixth and final stage examined in the initial hypothesis in light of the conducted research. Conclusions and recommendations for future work were proposed.

1.4.2 Research Aim

To achieve this aim, a number of research objectives were established:

I. Identify the issues and problems which affect new product development within engineer-to-order manufacturing organisations

II. Develop a methodology for highlighting the critical decision-making process within engineer-to-order product development projects

III. Develop a structured approach and the framework to support and manage the effective knowledge sharing ETO projects

The research objectives form the basis for a new contribution to the field of knowledge, in the areas ETO product development and the support tools for knowledge sharing.

1.5 Research Approach

The framework for the research was clear from the outset. The investigations would be company-driven, with the project managers and engineers defining the boundaries (specification) of the analysis methodology. This would be supported by an in depth literature review in the relevant areas and discussions with experts in the associated fields. Below is an overview of the salient features of the research methodology, which is described, in greater detail in Chapter 3.

The research method that was developed to meet the aims and objectives discussed above is shown in Figure 1.1 below:

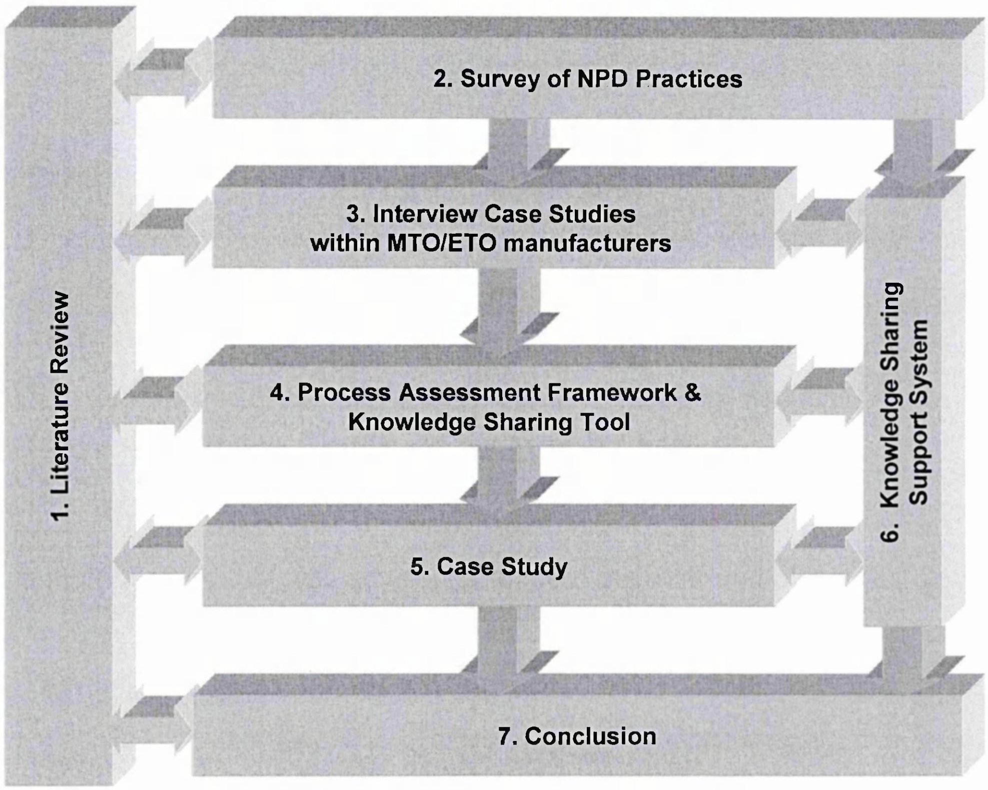

Figure 1-1; Research Methodology

1.6 Overview of thesis structure

The thesis draws on a number of sources to address the research questions, as shown in Figure 1.2 it uses the information and data gained from the literature, industrial practitioners from engineering and manufacturing organisations that MTS to ETO which took part in the survey, the interview case studies and longitudinal case studies.

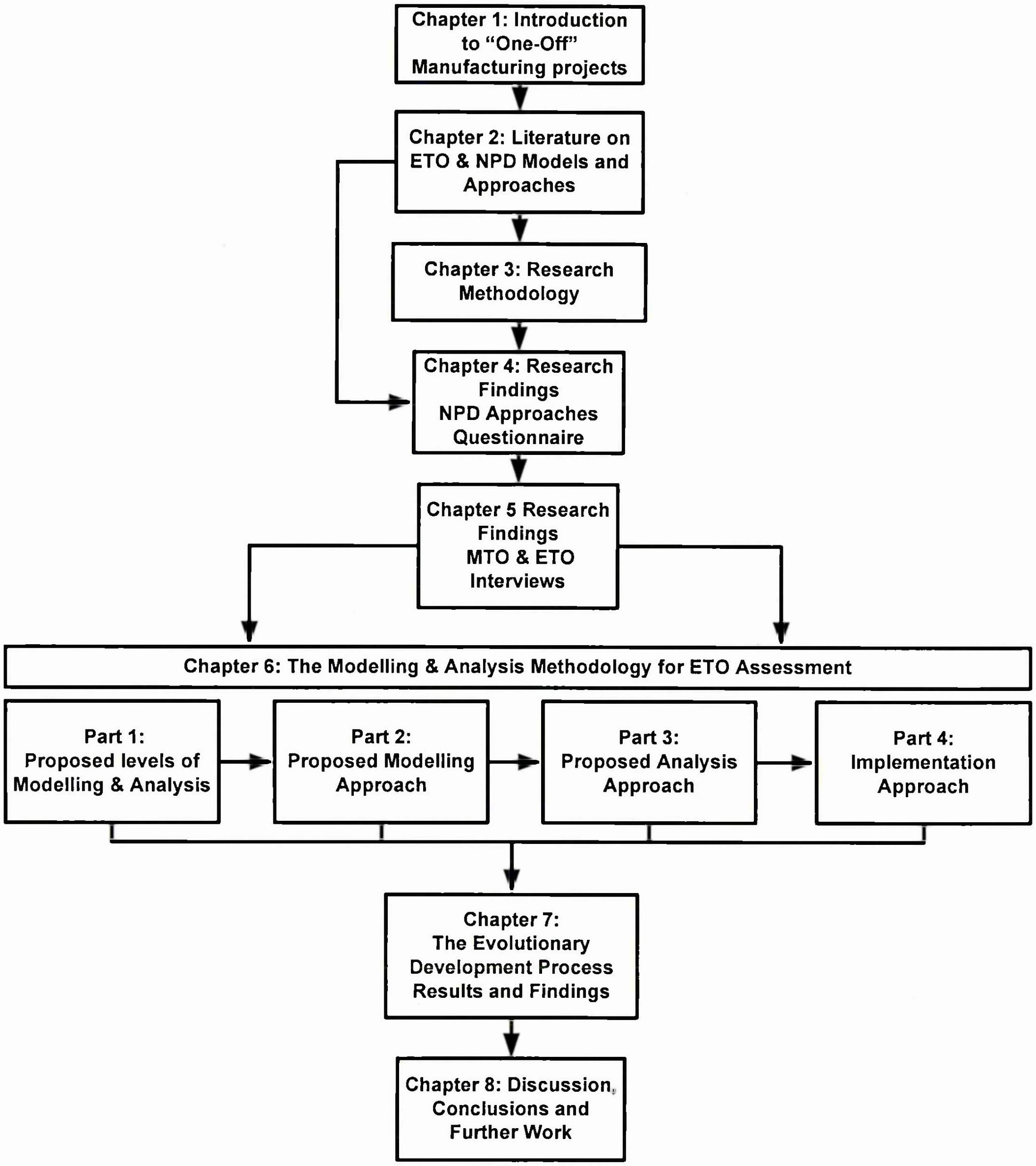

Figure 1-2; Research approach and major activities

Chapter 2 presents the current state of knowledge in the area of NPD and product development process in MTO & ETO manufacturing enterprises. Extensive reference is made to the literature in order to review the differences from companies that MTO to one that MTS and to describe what are currently regarded as 'good practice' NPD approaches.

Chapter 3 explains the underlying research philosophy of this thesis and the strategy followed. It describes the instrument designed to investigate knowledge sharing within NPD as practised ETO organisations.

Chapter 4 continues from the findings of the mailed questionnaire survey on NPD found in Appendix A. Chapter 4 presents the viewpoints of industrial practitioners from four ETO/MTO customer-driven manufacturers and one management consultancy which were interviewed for the purpose of a detailed study of the application and characteristics of the NPD process. Specific attention was paid on the factors affecting the critical NPD activities and opportunities to knowledge sharing within ETO manufacturing projects.

Chapter 5 describes and discusses the SETOK framework and supporting methodology for diagnosing the NPD-ETO process and analysis assessment. It presents the resulting levels of the analysis and the implementation framework.

Chapter 6 presents evolutionary development of the SETOK tool. It describes the outcome of an eighteen month longitudinal case study within one ETO manufacturing organisation in terms of how the methodology has evolved, how to carry out the analysis using the tools developed, and the analysis of the results and testing, during live NPD-ETO projects.

Chapter 7 is a conclusion of the research process and the outcomes of the research, and discussed the extent to which the research aims and objectives were met and the contribution this research makes to different bodies of knowledge it has used, and provides directions for future research.

In the research process and the main activities undertaken are presented using the IDEF0 diagrams.

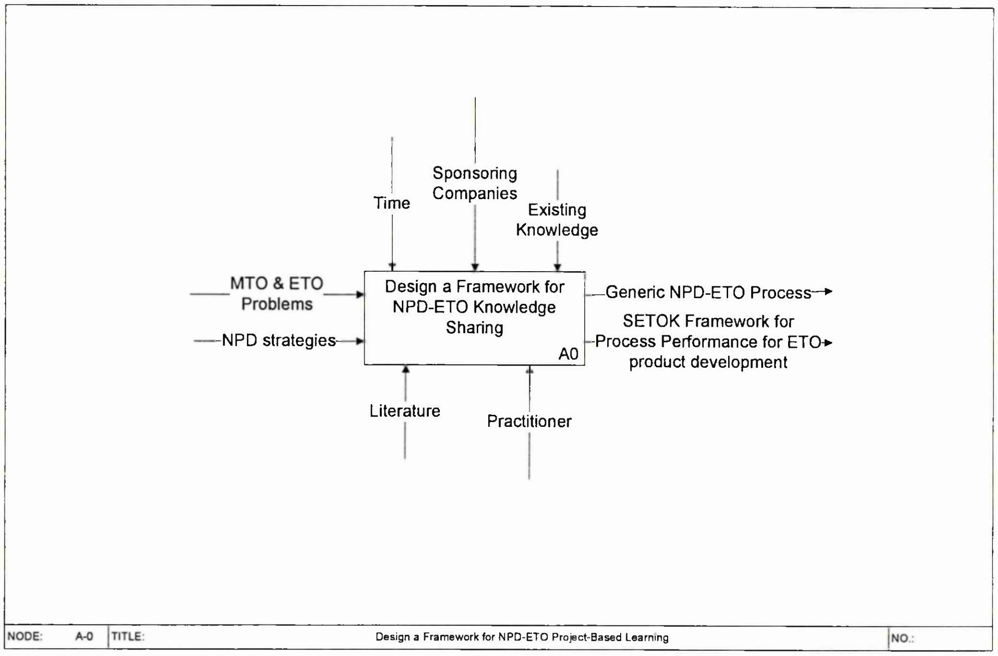

Figure 1-3; Research Process IDEF0 diagram

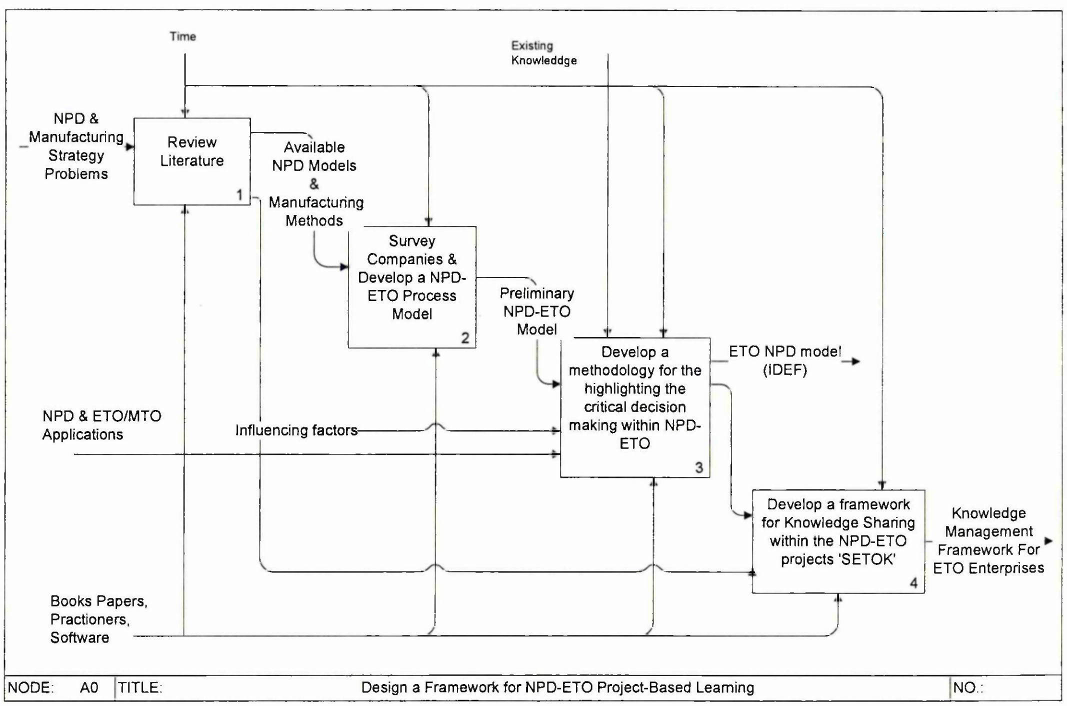

Figure 1-4; Research Process IDEF0 diagram, A0

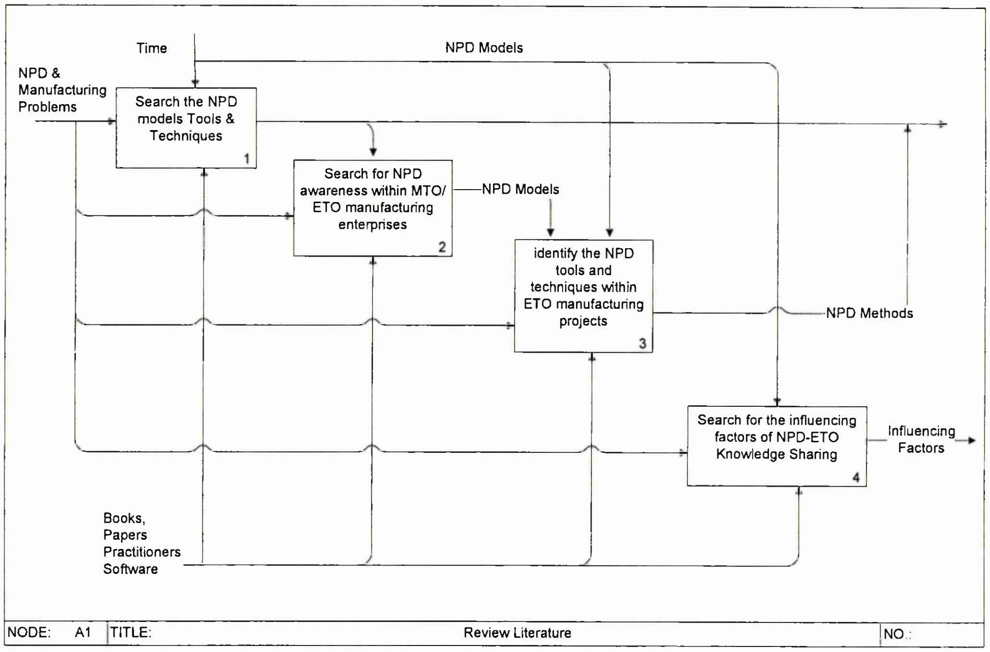

Figure 1-5; Research Process IDEF0 diagram, A1

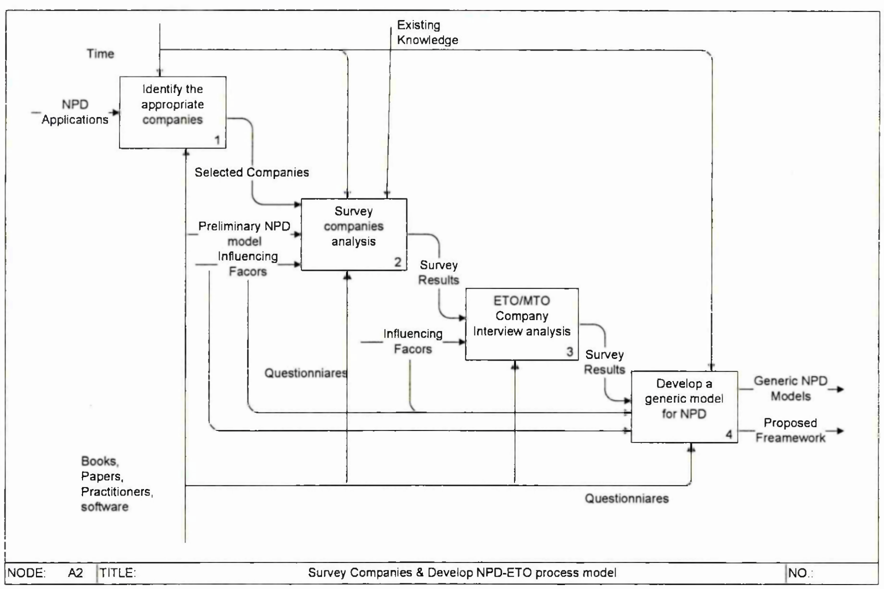

Figure 1-6; Research Process IDEF0 diagram, A2

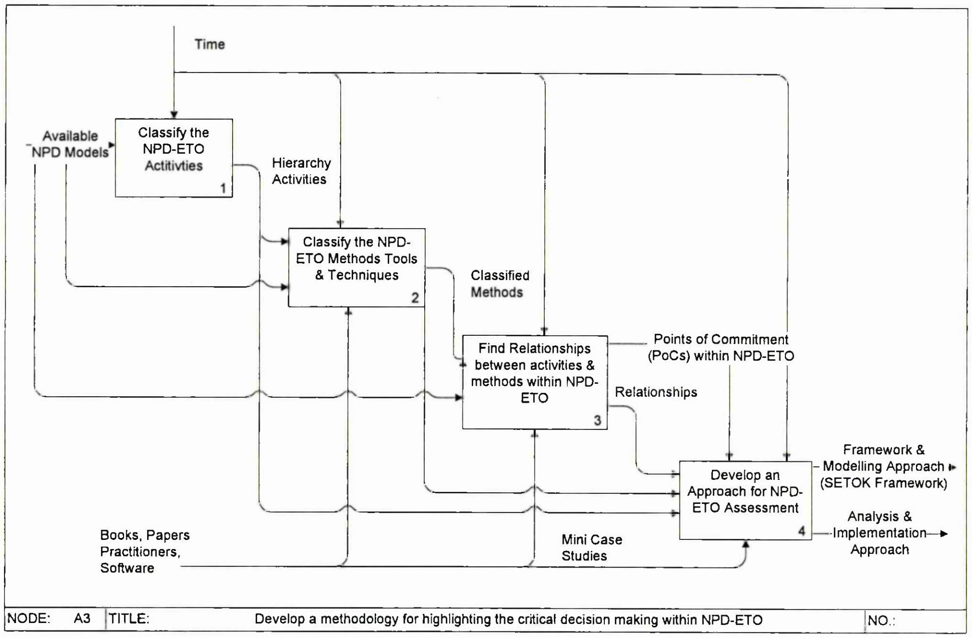

Figure 1-7; Research Process IDEF0 diagram, A3

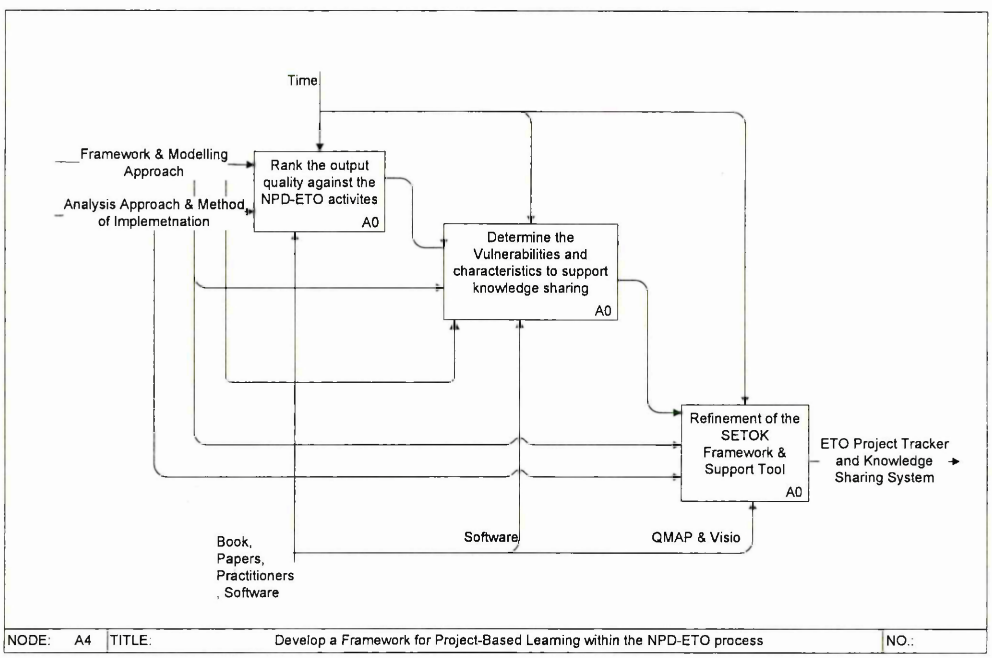

Figure 1-8; Research Process IDEF0 diagram, A4

Chapter 2 - THE CHARACTERISTICS OF NPD & ETO PRODUCT DEVELOPMENT

2.1 Introduction

The overall theme of this thesis is the development of a framework to support knowledge sharing of within engineer-to-order (ETO) product development projects. This chapter will present the current state of knowledge surrounding such manufacturing enterprises that operate on both a make-to-order (MTO) and ETO basis and consider how knowledge management techniques can support the concept of learning within 'one-off' manufacturing projects. Before examining the findings of the new research carried out to investigate this issue, it is appropriate to review the relevant literature in the fields of NPD, customer-driven manufacturers that MTO/ETO and finally to define the scope the knowledge management practices in ETO product development. In this chapter will focus on the current state of knowledge surrounding NPD and to what extent it is are being applied and consider the multi-faceted nature of the NPD process.

The main aims of the chapter are:

- To demonstrate the 'Best Practices' of NPD tools and techniques and to what knowledge sharing is being applied to support NPD projects
- To present an argument for the extension of NPD models to MTO and ETO manufacturing enterprises
- To demonstrate the emerging consensus amongst writers to the need of managing the ETO product development process more systematically

In order to achieve these objectives and to provide the background necessary to understand the context of MTO and ETO product development, which is central to this thesis, the bulk of the chapter is given over to the discussion of the elements currently considered to represent how capital goods manufacturers manage their NPD process. Several themes found within the literature are of particular relevance to this thesis, namely, systems modelling, knowledge sharing and project learning, and they will be explained in more depth.

However before moving into more detail of MTO and ETO practices we will take a holistic view of the customer driven manufacturing enterprises, addressing the questions: What is MTO and ETO? How does MTO and ETO product development compare to manufacturing companies that MTS? Different aspects of ETO process will be represented, showing how they have evolved over time and it is used as a starting point for the present investigation into the application of project-based learning within the content of ETO. Several themes found within the literature are of particular relevance to this thesis, namely, knowledge management, business process and project learning and they will be explained in more depth. However before moving into more detail of NPD practices we will take a holistic view of ETO, addressing the questions: What is ETO? How should the process of ETO product developed be managed? Different representations of NPD process will be represented, showing how they have evolved over time and salient features of current and emerging models will be highlighted.

2.2 Current NPD 'best practice'

There are a number of 'best practices' reported in the NPD literature (Hart 1995, Wheelwright, 1992, and Griffin, 1997). Whilst some of these are wide in scope for example, organisational style or recognition of the importance of learning, others relate to aspects of NPD can be more narrowly defined, for example those concerned with people or with performance. The following discussion will start by considering the broader themes related to the overall approach to NPD with the organisation. It will then examine two or more narrowly defined clusters of practices. People and Operational characteristics and the roles they play in NPD, the resources that are available within the NPD process and the factors involved in the operational activities of the process. These three areas have been reviewed during the progress of this research and is highlighted in sections people and operational issues.

Typically these activities include some or all of the following tasks listed by Cooper and Klienschmidt (1986):

- initial screen
- preliminary market assessment
- preliminary technical assessment

- detailed market study/market research
- business/financial analysis
- product development
- in-house product testing
- customer tests on product
- test market/trial sell
- trial production
- pre-commercial business analysis
- production start up
- market launch

The extent to which these activities take place, how they are organised, and the manner in which they interact varies between companies. What is considered as 'best' and 'good' practice depends on the current climate of the organisation and may change over time. Before looking at what constitutes current 'good practice' we will review briefly some of the key approaches to NPD and models of the process that have been proposed in the literature.

There are many 'good practices' practices reported in the literature. While some of these are wide in scope, for example organisational style and recognition in the importance of learning, others relate to the aspects of NPD, that can be more narrowly defined, for example, those with people or performance. The following discussion will start by considering the broader themes related to the overall performance of NPD with the organisation. According to Caffyn (1998) the two main areas selected for review to achieve 'good practice' and continuous improvement within NPD are people and processes. The individual themes appear under the following headings:

- process view
- strategic approach
- interfirm integration
- organisational style and control

- flexibility
- learning

The extent of which theses activities actually take place, how they are organised, and in the manner in which they are enacted varies between companies. What is considered 'best' or 'good' practice changes over time. Before looking at what constitutes current 'best practice' we will review briefly some of the key approaches to NPD and models of the process that have been proposed in the literature. The following overview of NPD models covers a broad spectrum, ranging from highly theoretical frameworks devised by academic to more practical methodologies adopted by practitioners and industrialists. The main categories into which they fall are summarised in Table 2.1 below. The discussion will be at a generic level, through the course there are many variants within each category, and in practice firms modify the processes in order to suit their particular needs.

Types of Models	**Description**
Departmental-stage	The innovation moves sequentially through various departments as it progress from concept to finished product
Activity-stage	The process is described in terms of the activities undertaken to develop the new products
Decision-stage	The process is broken down into a series of decisions. The decisions may be grouped according to department or activities they affect, or shown in sequence in which they are to be addressed
Conversion-Process	The process is represented as a 'system' which transforms inputs (e.g. scientific knowledge, customer needs) into outputs (new products)
Response Models	The process comprises the stages involved when a firm develops a response to an external or internal stimulus, which results in it adopting or rejecting an innovation
Additional Categories	
Holistic	A project team works together throughout the process, which takes the form of overlapping development phases
Networking	The emphasis is on inter-organisational collaboration and the integration of internal and external networks

Table 2-1; Taxonomy of Models of the NPD process, based on Saren (1984)

Many models of the NPD process have been produced over the years (Table 2.1). In his review Saren (1984) classifies conceptual models of the innovation process in the firm according to his taxonomy of five different types; departmental-stage models, activity-stage models, decision-stage models, conversion models and response models. Some of the models, especially those falling into the first three categories, do reflect NPD processes enacted by companies (for example, the department-stage model reinforces the functional approach which is characterised by an 'over-the-wall attitude to communication). However, such models were often developed to help academics understand the innovation process better, or as a framework for further research, rather than practical guidelines to help firms improve the way they develop new products. in order to ascertain current 'best practice' and what it replaces we will look at some models which capture types of process applied in practice and which were considered 'best practice' in their time.

People

- top management
- supportive management style
- roles
- shared values within innovative culture

Operational Issues

- structures
- integration
- parallel approach
- effective communication and knowledge sharing
- tools and methods
- manufacturing strategies
- product design strategies
- Agile and lean product development

As well as discussing what is written about each of the 'best/good practices', the extent to which the practice has been adopted by organisations is reported, were quantitative data is available. In several cases, writers have expressed reservations about a practice and these too, are noted.

2.2.1 Process view

There is a widespread consensus that taking a process view is a 'good practice' feature of NPD (Wheelwright and Clark, 1992; Alder, Mandelbaum et al., 1996; Davenport, 1993). Even so, by the early 1990s relatively few companies had adopted a process view and institutional it into a formal product delivery process (Cooper and Kleinschmidt, 1993). A 1990 survey in the US found that only 54.4% of companies had a well defined NPD process (Page, 1993). The Figure in the UK companies is very similar. Here a study found that 52.5% of firms used the form of new product guide to help manage their development process, and for most of them use of such a guide was relatively new (Barclay, 1992b). However, formal processes for managing NPD are becoming more common and by 1995 around 60% of survey US firms had some form of cross-functional stage-gate process (Griffin, 1997).

2.2.2 Strategic approach

Strategy, including the linking of NPD to corporate strategy orientation and synergy with existing activities, is one of the six themes identified in the literature as being crucial to the success of NPD (Hart, 1995). Adler et al (1989) contrast the traditional, tactical Approach to NPD with an emerging, strategic approach. Under the latter business managers rather than technical specialists are responsible for development downstream functions are actively involved in each phase of the product development; product generation maps are used for planning; competitive advantage is protected by continuously renewing the know-know and capabilities; and development projects are seen as being an integral to extending technological capabilities. However, changing a firm's product development strategy in order to build the capabilities needed may require a major effort to overcome established organisational structures and company politics and policy (Karisson and Åhlström, 1997).

Strategic factors involved in sustained corporate innovation include a long term corporate strategy in which innovation plays a key role, to build on past success and capabilities on emerging strengths, and long-term commitment to major projects (Rothwell, 1992). If development projects are designed and managed strategically they can be used to build new development capabilities (Bowen, Clark et al., 1994a; Wheelwright and Clark, 1992, p109). For example, a project may provide an opportunity to introduce a new CAD system or to try out a new approach to project organisation. Companies adopting the holistic approach, 'rugby[2]' approach are warned to recognise that NPD will result in more than new revenue-generating products. the hectic pace and sense of crisis that comes from carryout NPD in this way that enables it to act as a catalyst to bring about change in the organisation (Takeuchi and Nonaka et al., 1985).

Developing a vision and setting appropriate goals are important aspects of a strategic approach to NPD. High performing companies have been found to strengthen their communication capability by, amongst other things, setting goals to focus the effort, these goals are specific, aggressive, limited in number, and used for several years (Nevens, Summe et al., 1994a). The holistic approach followed by some Japanese companies involves top management deciding on a broad strategic direction and setting goals with challenging parameters but letting the development team operate how they want to achieve the goals (Imai, Nonake et al., 1985).

Strategic management of the development organisation also requires that a broad view is taken across the entire portfolio of projects, and that there is a process for setting priorities and allocating resources among projects (Wheelwright and Clark, 1992; Davenport, 1993; Copper 1994). The product development process should fit the company's objectives (Thomas, 1993). If, for example, the emphasis is on improving the quality a process is built around Quality Function Deployment would be appropriate, but if the breakthrough product was sought by a more 'chaotic' approach would be better. All effective development processes make sure that the process is consistent with competitive, market and technical challenges a project faces (Wheelwright and Clark, 1992, p163). Despite the growing recognition in the literature is of the importance of the role of strategy in product development, only 56.4% of US

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[2] A study of the innovation process in five Japanese manufacturing companies found that they adopted a holistic overlapping approach to phased management, instead of the analytical and sequence approach of phase project planning (PPP) (Imai, Nonaka et al., 1985). The holistic approach involved team working together during the entire process.- the game rugby was used as an analogy to contract it with the 'relay race' approach exemplified by PPT (Takeuchi and Nonaka, 1986).

companies surveyed in 1990 had specific NPD strategy (Page, 1993) increasing to 62.7% by 1995 (Griffin, 1997).

2.2.3 Interfirm integration

Interfirm integration is becoming more increasingly relevant to NPD. (Rothwell's (1992) predictions for NPD in the 1990s include more collaboration during product development, a large increase in collaboration in pre-competitive research, and a growing number of strategic technology-based alliances. R&D partnerships and technology sourcing alliances offer powerful learning opportunities and lead to tangible performance improvements, but need to be properly managed (Ingham and Mothe, 1998; Imkpen, 1998, Lame and Spekman, 1997). Many UK companies are now engaged in some form of collaboration. A recent survey into innovation practices found that 82% of manufacturing companies were involved in collaboration activities with academics, 80% were collaborating with other companies, 78% with consultants and around 70% with Government and commercial research organisations (CBI/Natwest, 1996).

Close relationships with customers and suppliers are a feature of product development in Japan (Funk, 1993). There interorganisational networks of suppliers have helped speed up product development and increasingly flexible (Imai, Nonaka et al., 1985). Several studies have found that integrating key suppliers early on in the product development process can significant improvements including, for example, innovations in system architecture, improvements in product design, more consideration given to design for manufacturability (Bozdogan et al., 1998; Ragatz et al., 1997; Wasti and Liker, 1997). It is important, though, that customers give their suppliers an appropriate level responsibility, to avoid wasting their supplier (e.g. by involving suppliers too early in the concept sessions) and those of their supplier (e.g. by requiring suppliers to develop capabilities which will not be fully utilised) (Kamath and Liker, 1994). As noted earlier, strong upstream supplier linkages are characterised of the fourth generation 'integrated' innovation model, and strategic innovation with primary suppliers, including co-development of new products linked CAD systems, is a feature of the fifth generation model) see section 2.2.6 Learning, process improvement and Q- man0 below (Rothwell, 1992)

Customer focus is a basic principle that applies to all effective development processes (Wheelwright and Clark, 1992). we already have seen that a well-designed stage-gate process is market orientated (Cooper Kleinschmidt, 1993) and the close coupling with leading edge customers is a feature of the fourth generation innovation model (Rothwell, 1992). The more successful innovators actively involve customers in the development process (Rothwell, 1992) Customer needs change so it is important for a company to maintain interactive communication with major stakeholders throughout the development process (Thomas, 1993).

2.2.4 Organisational style and control

There is agreement among a number of writers that an organic organisation is conducive to innovation while a mechanistic one stifles innovatory activity (Baker, Brown et al., 1983; Rothwell, 1992; Johne and Snelson, 1988b. Rothwell (1992) has extracted from the literature the characteristics of organic and mechanistic organisations. The former is participative and informal, non-hierarchal, outward looking, flexible, lacks rigid rules; in this type of firm many views are aired and considered, departmental barriers are broken down, information flows downward as well as up, and the communication is often face to face. The mechanistic organisation, on the other hand, is hierarchal and bureaucratic; there are rigid demarcations between departments, many rules, formal reporting and long decision chains; individuals have little of action and while information flows upwards, directions flow downwards.

However, the degree of innovation required at different stages of the NPD process varies and the management style needs to reflect this. The organic style is best suited to the early, more creative part of the innovation process. As the project moves through prototype production to manufacturing and into the market, the innovation becomes better defined and the activities required are more routine, making the use of more formal controls appropriate (Baker, Brown et al., 1983, Rothwell, 1992, Johne and Snelson, 1988b). In other words, the recommended approach is for firms to shift between 'loose' and 'tight' forms of coordination and control during the NPD process.

2.2.5 Flexibility

Flexibility is a feature of good practice of NPD. Corporate flexibility and responsiveness to change is a strategic factor involved in sustained corporate innovation, and flexibility – of the organisation, the product, and manufacturing –is increasingly important (Rothwell, 1992). The NPD process should be flexible enough to cope with different types of new products (e.g. breakthrough, incremental) and to allow for continuous improvements to be made in response to changes in the environment and customer needs (Cooper, 1994 Thomas, 1993, Barclay 1992b) Flexible or agile design allows firms to quickly develop a broad portfolio of niche markets, build products to order, mass customise individual products at mass production speed and efficiency, and introduce a steady stream of 'new' (variant) products (Anderson, 1997).

2.2.6 Learning

The connection between learning and successful product development with certain Japanese companies was highlighted in the mid 1980s (Ima, Nonaka et al., 1985, Takeuchi and Nonaka, 1986). These companies possessed "an almost fanatical devotion to learning" and had adopted strategies to assist the transfer of learning, while recognising the need to 'unlearn' the past. the researchers coined the phrase 'multilearning' to reflect the nature of learning: a continual process of trial and error ('learning by doing') which took place at the individual, group, and corporate level and across functions. The 'learning in breadth', where 'non-expert' members of development teams are encouraged to acquire the necessary skills and knowledge on the job, contrasted with 'in-depth' specialisation by functional experts favoured in the west. Nonaka (1991) described how the Japanese firms like Honda, Canon and Matsushita, noted for their ability to rapidly develop new products and dominate emerging technologies, manage the creation of new knowledge, using techniques to make tacit insights and learning of individuals available to the rest of the organisation (see section 2.9 below).

The issue of learning in the context of NPD has been taken up by other authors. Mckee (1992) describes the role of organisational learning in innovation, While Thomas (1993) stresses that NPD should be viewed as an 'ongoing process of learning and renewal'. A study in Europe concluded that systematic learning from past experiences is fundamental to effective management of the early phases of product development process, and essential for successful forward-feeding planning (Verganti, 1997). The most successful development projects in another research study were found to be those where teams operated in a learning environment where the emphasis on learning included learning objectives for development projects and learning audits (Bowen, Clark et al, 1994a). Alders, (1992) research into design for manufacturability (DFM) identified several factors that seem particularly powerful in encouraging a firm to adopt a more aggressive learning path: business crises; demands from above; technical pressure; and environmental pressures (Alder, 1992). Adams (1998) found that some people are able to overcome the organisational barriers which impede learning about markets for new products by building on leveraging from established routines.

2.2.7 Top management

There is agreement in the literature that the behaviour of top management is a critical factor in NPD (Hart, 1995). Top management commitment is visible support is essential for successful NPD (Johne and Snelson, 1998b Rothwell 1992). Authors and researchers give many prescriptions for how senior managers should behave in order to support the NPD process. For example, senior must accept risk and know how to learn from failures (Rothwell 1992). As a company moves towards a strategic (as opposed to tactical) approach to NPD top management should become more deeply involved in NPD and pay particular attention to managing the interfaces between the key business functions (Alder, Riggs et al 1989). Firms which are good at NPD make commercialisation capability a top management priority and get managers directly involved in the commercialisation process, to speed up actions and decisions and to demonstrate to the rest of the organisation that it should be taken seriously (Neven, Summe et al, 1990). Another important role of senior executives in product development is to develop effective leaders by expecting leadership, supporting leaders and rewarding leaders (Bowen, Clark et al., 1994b).

Imai et al (1985) show how in Japanese companies following a holistic, over lapping approach, top management act as a catalyst by setting goals which are vague but have been very challenging parameters, thus creating a tension which, if managed properly, “helps to cultivate a ‘must do’ attitude and a sense of cohesion’ among project team members. To support the iterative and dynamic process characteristic of this holistic approach management must adopt a highly adaptive style (Takeuchi and Nonaka, 1986). Examples of actions senior managers can take to support heavyweight development teams include drawing up the project charter, which include a mission and broad performance objectives, and acting as an executive sponsor (Wheelwright and Clark, 1992). The latter role involves coaching and mentoring the team and its leader, and serving as a liaison channel between the team and other executive staff.

2.2.8 Supportive management style

A review of a number of research studies, carried out from the 1950s to the late 1980s, which had looked at factors influencing NPD success found that many of these factors were associated with "open-minded, supportive and professional management" Barclay 1992a). In fact, this attribute accounted for 30 of the 140 factors identified in total and had been identified in over three quarters of the studies. Other research had led to the conclusion that an organic management style is better than a mechanistic approach in helping develop a culture appropriate to innovation, while a more horizontal management style with increased decision-making authority at lower levels influences speed to market (Rothwell, 1992), Recent work in the UK suggests that practice may be moving in the same direction as theory with an increasing number of companies adopting "a more democratic, professional and supportive management approach" (Barclay, 1992b).

2.2.9 Roles

There is some discussion in the literature of the specific roles associated with successful NPD. For example, Roberts and Fursfield identified the following work roles as being critical to innovation: idea generating; entrepreneuring and championing; project leading; gate keeping; sponsoring and coaching (Hart, 1995). The gate keeping role may be fulfilled by a 'technological gatekeeper' a while a 'product champion' embodies the entrepreneuring and championing role. A technological gatekeeper brings into the firm the relevant technical information gathered from seminars, conferences, a network of external contacts and literature, and disseminates this information internally to others with R&D (Rothwell, 1992). A product champion enthusiastically supports the innovation and is personally committed to it, helping the project maintain momentum when it runs into difficulties.

Despite the importance given to this role in the literature, a 1990 US survey found that only 43.4% of companies encouraged product champions, 18% were different and 6.9% had none or discouraged them (Page, 1993). In a similar survey carried out five years later 15.4% of responding firms made no use of product champions, while 77% used champions to lead and/or support the more innovative projects (Markham and Griffin, 1998). A study of eight of discontinuous product development projects found that champions were the driving force in but all one of the projects (Veryzer, 1998).

The data from the PDMA's 1995 survey led by Markham and Griffin (1998) to conclude that although champions seem to have indirect impact on firm-level performance by improving programme performance and operating in concert with processes and strategies, using champions does not lead generally more successful NPD. They also suggested that, as more firms adopt NPD processes, the role of champions may be changing from leading projects to supporting the processes in which projects are embedded.

2.2.10 Shared values within innovative culture

A feature of best practice NPD is shared belief in the value of change. Acceptance of the need for change is a prerequisite NPD (Johne and Snelson, 1988b). Sustained corporate innovation requires an organisational culture that is "innovation-accepting" and "entrepreneurship-accommodating", and is best achieved "when 'championing change" becomes an integral part of the firms culture (Rothwell, 1992). Openness and interchange between the different functions and units at all levels of the organisation can help to foster such an innovating culture (Johne and Snelson, 1988b). Highly innovative companies in the US, Japan and Europe share a set of characteristics, qualities and behaviours and recognise the importance of strong alignment between the organisation and personnel purpose (Zien and Buckler, 1997).

2.2.11 Structures

Organisational structure is another of the themes identified in the literature as crucial to the success of NPD (Hart, 1995). A variety of structures, leadership styles and the ways of organising NPD have been described, including the merits of matrix structures, organic structures and free standing business units (Johne and Snelson, 1988b). However there is a growing recognition that different types of structure are appropriate to different types of product development projects (Johne and Snelson, 1988b); Bowen, Clark et al., 1994b; Wheelwright and Clark, 1992; Hart, !995). Current 'best practice' in this respect can therefore perhaps be described as having the understanding and ability to apply the most appropriate form of organisation structure on a project by project basis.

Wheelwright and Clark (1992) review the strengths and weakness of each of the four basic categories of development team structure: functional, lightweight, heavyweight, and autonomous. The key distinction between these structures is the extent of which responsibility and the authority rest with functional managers or with the leaders of development projects. While the author stresses that organisations tend to have a 'dominant orientation' which determines the range of approaches the firm can hope to apply successfully. The functional and heavyweight models represent dominant orientations. A firm with a functional orientation will be able to run lightweight teams but is unlikely to succeed with heavyweight teams. However, a company with a heavyweight team as the dominant orientation should be able to adjust the standard approach to accommodate all types of team. The recommendation is, therefore, that if a firm wants to have the capability to run heavyweight teams must create the heavyweight team with a dominate orientation.

The popularity of heavyweight teams have increased, no doubt influenced by the practice of successful Japanese companies. For example, self-organising teams which are completely autonomous, devise their own very challenging goals, and enabling cross-fertilisation of thought processes the behaviour patterns between members from different disciplines, have been identified as contributing to speedy and flexible product development in certain Japanese firms (Imai, Nonaka et al., 1985). However, some companies have found that a combination of large engineering organisations and heavyweight project managers can result in too much product variety (Cusumano, 1994). These firms are now placing limits on the budgets and discretion of heavyweight project managers in an attempt to reduce the number of unique parts and product variety.

2.2.12 Integration

As seen in the review of the NPD process above, the current prevailing view is that the development process should be designed to enable the inputs of separate functions to be integrated effectively. It is now over forty years since Lawrence and Lorsch (1967) highlighted the links between cross functional integration and performance, and since then much has been written about the need for better cross-functional coordination and the use of multi-discipline development teams. Concurrent Engineering is an important approach achieving integration encompassing a range of mechanisms and is discussed below under 'parallel approach'.

Functional coordination has been identified in the literature as crucial to the success of NPD (Hart, 1995). Integration, including joint decision making among all functional units and divisions involved in the project, is a key element in optimising development (Bowen, Clark et al., 1994a). Kahn (1996) defines the integration as compromising of both interaction (i.e. meeting, documented information flows) and collaboration (i.e. various departments working collectively towards common goals). He found that although a certain level of interaction between departments is necessary throughout the NPD process, it is collaboration that differs between success and failure. Survey data indicate links between collaboration and performance, and between collaboration and employee satisfaction (Kahn and McDonough, 1997). Another study found that the strongest drivers of cross-functional co-operation and NPD performance were perceived to be internal facilitators such as evaluation criteria, reward structures and management expectations (Song et al., 1997)

Much attention has been given to the need to improve the R&D/Marketing interface and to build marketing activities into the development process from the outset (Johne and Snelson, 1988b; Cooper, 1988; Pearce and Ball, 1993; Hart, 1995; Griffin and Hause, 1996). Souder et al. (1988) found that although R&D/Marketing integration and direct R&D/customer integration both have a positive impact on NPD effectiveness they affect it in different ways. Others emphasis the need for early manufacturing involvement and for integrated product and manufacturing strategies such as design for manufacturability (DFM) (Rothwell, 1992; Wheelwright and Clark, 1992). Wood and Coughlan (1990) argued that in addition to DFM techniques and cross functional teams, integration of design, manufacturing and marketing requires a disciplined management approach, such as that provided a stage-gate procedure. Quality Functional Deployment (QFD) is put forward is a mechanism for dealing with issues at the interface between engineering, manufacturing and marketing, though the best suited to projects concerned with the incremental product innovation rather than radical change (Davenport, 1993). Firms leading the field in terms, of commercialisation of technology have gone between QFD and DFM in their quest to developing cross-functional skills, for example by building extensive networks connecting R&D, manufacturing, sales, distribution and service (Nevens, Summeet al., 1990; Harryson, 1997).

The cross functional, multidisciplinary team is seem as an important mechanism for achieving integration (Cooper and Kleinschmidt, 1993. A team approach can help overcome the differences and resistance to change among people from different parts of the organisation who should work together (Thomas, 1993). Japanese companies have a number of practices to promote multi-functional problem solving. these include, for example, getting engineers involved in a wider range of tasks (e.g. purchasing, marketing, sales, manufacturing cost analysis) and evaluating subunits and employees against a broader set of performance measures than in US firms (Funk , 1993).

Use of multi-disciplinary teams is an aspect of 'good practice' NPD which many companies have adopted The PDMA's 1995 survey found that multi-disciplinary teams were used for 64% of all projects (Griffin, 1997). Although in general they were much more in common for innovative projects, the best performing firms used multi-disciplinary teams in the majority of their NPD projects regardless of the level of innovativeness. An earlier study of product development in UK firms revealed "an increased emphasis on teamwork and teamwork training (Barclay, 1992b).

However, not all writers favour integration. Several suggested that some differentiation should be preserved to allow high quality of inputs derived from specialised expertise. Hart (1995) takes a contingency view, proposing that mangers select the most appropriate approach, on the continuum from 'boundary spanning' to 'boundary elimination', depending on particular project in question and the organisational content. Similarly, although Wheelwright and Clark (1992) stress the importance of integration across the functions and propose a framework for cross-functional integration with integrated milestones, they also point out that not all development projects need deep, cross functional integration. Alder (1992), too, advocates to contingency approach to the use of co-ordination mechanisms with a product and process design. The amount and kind of integration needed depends on the specific circumstances such as the phase of the project and the inherent project complexity (Griffin and Hauser, 1996; Song et al., 1998).

2.2.13 Parallel approach

Parallel processing with a development project, with the activities taking place concurrently rather than in series, is a feature of all good/best practice models reviewed earlier: the holistic, overlapping ('rugby') approach; a modern stage-gate process; the 4^{th} generation 'integrated' innovation model; the convergent process model (Imai, Nonaka et al., 1985; Copper and Klienschmidt, 1993; Rothwell, 1992; Hart, 1995). Parallel processing provides the means to have complete development process while reducing time-to-market and, because of the simultaneous involvement of different functions, avoiding ineffective hands-off between departments (Cooper, 1988).

Overlapping the stages of the NPD process inevitably leads to at least some parallel activity, during the overlap. As noted above the review of the Japanese holistic approach, the degree of overlapping observed there varied between companies with some having overlap only at the border of adjacent phases, and others ensuring that overlapping extended overall several phases. US companies have adopted the practice of overlapping phases and incorporated it into their stage-gate processes. However, they managed overlapping differently to the Japanese: the latter start die design and cutting earlier but still have lower cost for re-engineering changes (Clark and Fijimoto, 1989). The explanation given for this is that many US companies have failed to introduce the intensive information processing necessary to make the most of overlapping. Research in Europe found that over lapping was successful in those cases where it was an explicit approach and the flexibility it needs was properly planned and activated (Verganti, 1997).

Some commentators seem to use the phrases 'parallel development and 'concurrent engineering' (CE) interchangeably (.e.g. Davenport, 1993). This thesis takes the view that parallel development is a wider concept, applying to all activities e.g. business analysis, market investigation and supplier involvement, not just to engineering and design tasks. Harts (1995) is a good interpretation. CE "consists of the paralleling of the design and manufacturing activities of the product". (Pawar and Riedel, 1993) and is considered a good practice feature of engineering and design processes (Davenport, 1993). The phrase CE encompasses a range of integration mechanisms and companies use different combinations of them depending on their particular situation and needs (Swink et al., 1996). Pawar and Ridel (1993) have reviewed a number of studies from which they identify the following generic elements amongst the integration mechanisms:

- cross-functional teams;
- computer integrated design and manufacturing methods such as CAD, CAM, and CAE
- analytical methods to optimise a product's design and its manufacturing and supporting processes, including Design of Experiments, Taguchi Methods, Design for Manufacturability and Assembly, and Quality Function Deployment

Techniques for achieving the integration necessary for effective CE include TQM, co-location of design and manufacturing engineers, up-fronting, design modification control, integrative prototyping, and production modification control (Pawar and Riedel, 1993). Ward et al. (1995) have described a variation on CE which they call 'cell-based concurrent engineering'. Under the system engineers and managers delay decision making and give suppliers partial information, while exploring numerous prototypes. The researchers found this method to be prevalent at Toyota and believe it is the reason for that company's speed and efficiency in product development.

Some firms using CE have documented savings in overall product development costs of approximately 20%, and reductions in engineering design changes from 40-45% (Swink et al, 1996). However, despite the benefits to be gained from parallel processing, a comparison of the time companies spent on each development activity with the reported time to develop a new product suggested, that in the early 1990s, US firms were not engaging in much concurrent engineering (Page 1993).

2.2.14 Effective communication and Information sharing

The importance of communication and co-ordination for successful NPD is a recurrent theme in the literature (Barclay 1992a Hart 1995). The current emphasis on parallel processing means the effective information flow between those involved is essential for the smooth working of the 'best practice' NPD process models.

For Clark and Fujimoto (1989) the main reason why US companies apply the concept of overlapping development stages less effectively than Japanese firms rest in the difference in their approaches to information processing. They claim that a typical US company follow the overlapping approach engages in 'batch information processing' at the end of the upstream stage. This means that those involved with downstream activities have had to start work without any early information about the upstream output. The common approach in Japanese companies, however, is for a continuous upstream of data on upstream events to be released downstream, and vice versa. Such 'intensive information processing' voids any confusion or surprise when the project moves downstream. Wheelwright and Clark (1992) have defined four models of interaction between upstream and downstream groups.

In short, a feature of current best practice NPD is effective information processing and dissemination. Rosenthal and Tatikonda (1992) identified six information processing functions associated with product design and development[3] and illustrated how particular design tools and practices (e.g. DFA, QFD, CAD, Gantt Charts can strengthen one or more of these functions.

2.2.15 Lean product development

Some of the new practices listed in Tables 2.2 and described above are encompassed within the concepts of 'lean product development'. The 'Lean' label was originally coined to describe the manufacturing and engineering practices in Japanese automotive industry which led to much higher levels of productivity and flexibility. Continuous process improvement is one of the principles underpinning the

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[3] Roseenthal and Tatikonda's six processing information-processing functions are: translation,; focused information assembly, communication acceleration, product enhancement; analytical enhancement; and management and control.

lean prescription. in the context of product development, 'lean' refers to a number of interrelated techniques taken together: supplier involvement from the beginning of the project, cross functional teams; concurrent engineering; integration (as opposed to coordination) of various functional aspects of each project; use heavyweight team structure; and strategic management of each development project by means and visions and objectives rather than detailed specifications (Karisson and Åhlström, 1996).

However, lean production development has been without problems, Honda and other Japanese companies used the shorter development cycles it brought to follow a strategy of rapid product replacement and frequent model-line expansion. These were high cost strategies. The problems caused by too much product variety, environmental concerns and recycling costs caused the companies to rethink (Cusumano, 1994). These companies subsequently decided to produce fewer model replacements and variations, and to increase the sharing of parts across and the amount of parts and materials recycling. To force more commonality across products project managers were made less 'heavyweight' by limiting their authority.

2.3 NPD Tools and Techniques

Tools and techniques represent an important way to improve NPD output. They can be used to improve management's decision quality at different stages of the NPD process, and thus to improve the overall success rate of new products (V. Mahajan and J. Wind, 1992). They assessed the role of NPD tools and techniques in supporting and improving the NPD process in the United States and concluded that the use of tools and techniques is relatively low, although large differences in penetration exist between tools (see also D.K. Rigby, 1994). The adopters of NPD tools and techniques use them to identify problems and improve on or predict new product success. Nijssen and Lieshout (1995) provided initial support for a positive relationship between the use of NPD tools and performance. More recently Edwin J. Nijssen and Ruud T. Frambach (2000) studied 70 firms on NPD tools and techniques by industrial firms and found that there was an increase of use of NPD tools and techniques by individual firms over the past decade. However, growth seemed to have slowed down, resulting in some degree of saturation.

Pugh (1991) and Hollins (1990) have introduced the concept of a dynamic versus static state as key determinants of the need for radical innovation versus incremental improvements in NPD. Hollins has also presented a framework for classifying products based on their static versus dynamic status, relating this to key disciplines that should be emphasised during design. The most important effect of this classification process relates to the order in which "product specifications" and "concept generation" activities are carried out. As mentioned earlier this was a big challenge between the opponents of problem-oriented design methods and those of the solution-oriented methods. Hollins and Pugh implicitly found the solution in the different configurations of the design process for two distinct situations. In the case of static products, according to Pugh and Hollins, designers can normally begin with an existing concept, and from this they can determine product specifications for an improved product. On the other hand with dynamic products where radical innovations may occur, such a concept rarely exists and so designers begin with the determination of product specifications from which concepts are created. These authors have also suggested automation and the use of the computerised tools (e.g. CAD/CAM) for the development of static products, as opposed to manual and traditional tools for use in dynamic situations.

NPD "drivers" have been classified as belonging to 'market pull' and 'technology push' categories (see, for example, Pugh 1996, Ulrich 1995). Market pull refers to those products that trigger certain aspirations within users, whereby technologies lag the market. As a result, attention should be paid to market research activities to ensure sufficient pull exists within the marketplace. Technology push products in contrast to those situations whereby the market lags the available technologies. More often than not, these products are characterised by high R&D spending, and the search for new and suitable technologies.

There are a number of tools and methods associated with 'best practice' NPD. They include:

- Quality Function Deployment
- Design for Manufacture
- Design of Experiments
- Computer-based tools

- Stage Gates
- Prince 2
- Innovation Compass

2.3.1.1 Quality Function Deployment (QFD)

One common tool is Quality Function the Deployment, sometimes known as "House of Quality", which is a planning and problem solving tool that is used for translating from customer requirements into engineering characteristics of a product. It was developed in the Japanese shipbuilding industry by Mitsubishi Heavy Industries. QFD is also communication and planning tool that helps to focus the product development process by seeking out customer needs and ensuring that these are met (Cohan, 1995). QFD begins by matching customer requirements with the necessary product features and subsequently product design requirements. This in turn is matched with the corresponding production requirements and capabilities. It consists of a graphical method that includes: customer requirements, competitive assessment, importance rating, engineering characteristics, together with a relationship matrix that illustrates linkages between customer requirements and engineering characteristics, and correlations between engineering characteristics. Various rankings are also included.

Benefits claimed from the application of QFD include: better understanding of customer needs; comparison and analysis of competitors' products are facilitated; shorter product development cycles; fewer design changes, fewer manufacturing start up problems; improved quality and reliability; cost savings through product and process design optimisation. (Eureka, 1988, King 1989) pilot application of QFD within European multi-national company had a positive impact on the fuzzy front end of the innovation process, bringing clarity and consistency to problem-framing and definition.(Debackere et al., 1997) However, it has been pointed out that a lot of development activity takes place between the matrices (e.g. testing a concept would come between the first and second matrices) and so is not included as part of the formal QFD method (Ettlie, 1992) although in western firms QFD is the most commonly used as a technique for translating the requirements of one functional group into the supporting requirements of a downstream functional group (e.g. marketing to product engineering to manufacturing), it can also be used as a comprehensive organisational mechanism for planning and control of NPD (Rosenthal and Tatikonda 1992).

Although QFD is a popular tool, several problems can be encountered during the implementation. Errors introduced at one stage of implementation can propagate unchecked to successive stages (Brodie, 1994; Suttler, 1994) and it is a time-consuming process requiring a high level of detail at an early stage of the process (Brodie, 1994; Shen, 1994; Zairi and Youssef, 1995). Han (2001) addresses these problems by introducing six-stage hierarchical framework, which provides step-by-step guidelines during the QFD planning process to improve the effectiveness of decision-making.

2.3.1.2 Design for Manufacture & Assembly

DFM/A is bringing the issues of manufacturability into the design process earlier. it encompasses a wide variety of methods including: design rules, which state the boundaries within which the manufacturing process is capable of meeting design requirements; and design for producibility, which concerned with the interaction between specific parts and products and manufacturing system (Ulrich 1995). Analysis of over 60 applications of one particular design for manufacture/assembly analysis (DFM/DFMA) methodology found an average part count reduction of 46% and average assembly cost savings of 47% (Miles and Swift 1998).

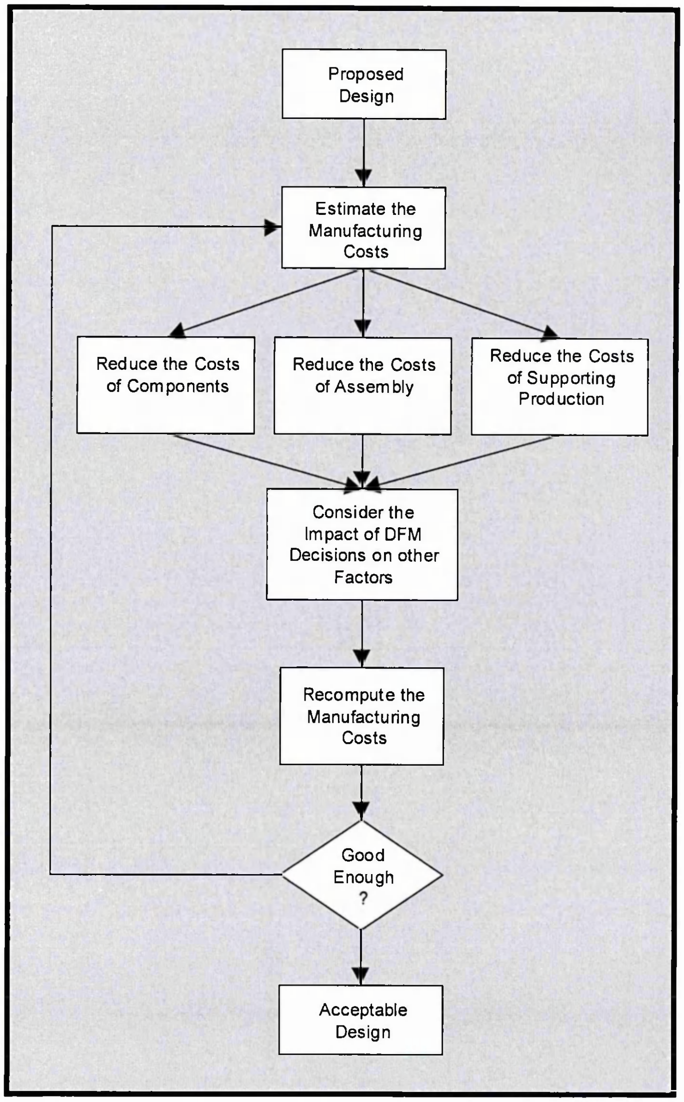

Figure 2-1; Design for manufacturing (DFM) methodology (Ulrich 1995)

2.3.1.3 Design of Experiments

Design of Experiments involves taking a disciplined, systematic approach to planning experiments rather than responding to problems in a haphazard manner. Statistical methods are used to determine the optimum settings for one or more product or process parameters (Rommel Buck et al 1996) A number of techniques have been developed to overcome the difficulties in analysing experiments that occur when the repeatability of measurements is low and the effects of a factor depend on the settings of the others. These include Taguchi methods (used mainly in the design and problem prevention) Shainin Methods (used mainly problem solving in the process), and evolutionary optimisation (used for the gradual improvement of current processes (Bandurek 1992). Although usually associated with design and engineering, design of experiments can be a useful tool for other functions within the innovation process and it has many applications in sales and marketing (Starkey et 199&).

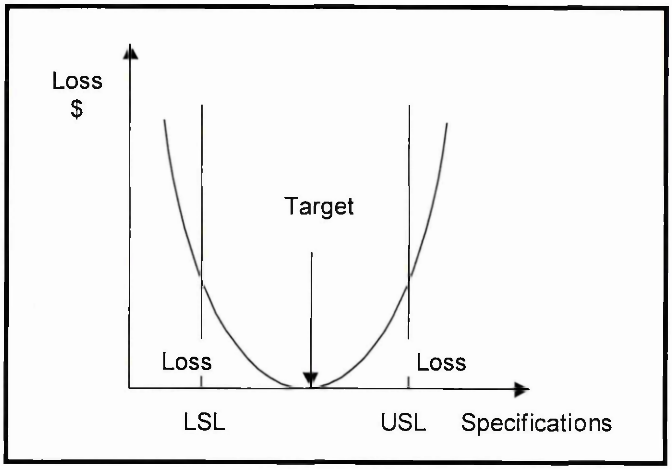

Figure 2-2; The quadratic loss function (Eureka 1988).

2.3.1.4 Computer – based tool

Technology has helped to cut development time. For example, in the mid 1980s Cannon's semi-conductor equipment division used CAD tools to eliminate some phases of project management and overlapping others. The results were impressive: development costs were cut by 30% and time-to-market by 50%, and the division launched two generations of equipment in the time it took competitors to introduce one (Nevens, Summe, et al., 1990). Several writers (e.g Davenport, 1993, Rothwell, 1992) suggested other ways in which technology can influence speed to market, including:

- groupware technology such as lotus notes

The Stage-gate tool is a common tool that is used within organisations to facilitate the NPD process. Cooper (1990) (see Figure 2.3) defined the use of stage-gate systems as a way of improving the control of product development activities. Under the stage-gate system the NPD process is separated into a number of distinct stages. The process is monitored and controlled by evaluating the outcomes of a specific stage before starting the next stage. Although stage-gate is popular within organisations (Phillips, Neailey and Broughton, 1999), its' application have predominantly focused on its use to identify whether the expected outcomes of each stage have been achieved or not. Without sufficiently detailed operational information, it does not provide a measure of how well the process is operating. Since stage gate reviews are usually carried out on a strategic level they therefore have limited inherent diagnostic value for identifying what is wrong with an on-going process.

The "Innovation compass" is a diagnostic tool, aimed at helping organisations to understand and appreciate their product development process and provides them with the ability to benchmark their performance in the same broad areas as other organisations through the development of a database (Noke and Radnor 2004). The database contains quantitative and qualitative data which acts as "Innovation Factors Inventory". The quantitative data is based on a large sample group of organisations obtained through questionnaires based around structure, leadership, outputs and teams. The technique depicts the process as three concentric circular regions. The first inner circle (A) of the innovation compass offers an organisation the opportunity to benchmark on a quantitative basis against other similar groups from the database. Qualitative data concerned with individual organisation's structure, leadership, outputs, teams and context, obtained through interpretive means are presented in the middle circle (B) of the innovation compass to substantiate and elaborate on the quantitative findings. The outer circle C, labelled "context", presents specifically unique features of the individual organisation under assessment, providing a contextual understanding of the companies' product development process which is considered to be an important factor in ensuring an effective product development process. The data relating to each of the dimensions, particularly the quantitative element consists of a number of factors. Further explanation of the factors can be found in Rickards and Moger (1999), Rickards et al. (2001) as sited Radnor and Noke (2002).

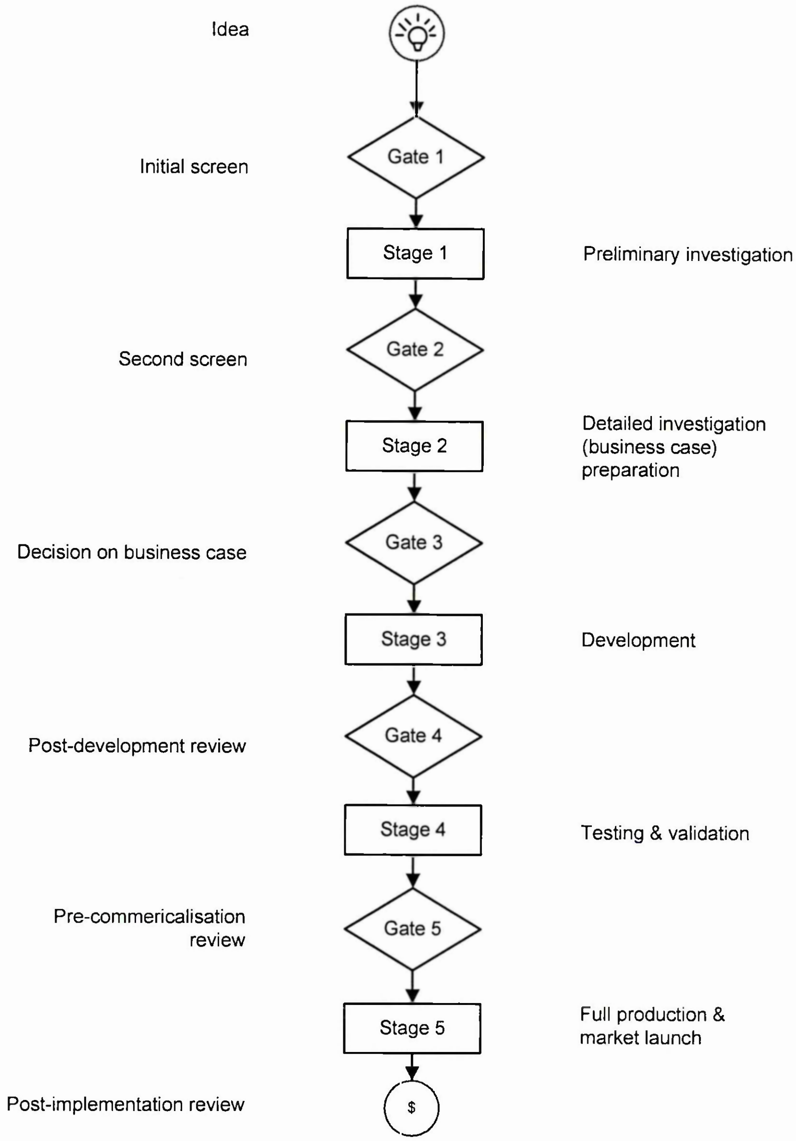

Figure 2-3; The Stage Gate System (Cooper 1990).

Product process risk assessment matrix is used to reduce the risk associated with developing new products and to alert NPD mangers to those critical process activities that are essential to successful product development (Poolton, Ismail and Shahidipour, 2001). The tool uses historical performance as means of assessing risk. The approach starts with a knowledge-capture stage to establish a link between company capabilities, market features and new product characteristics. This helps in identifying the factors affecting the performance of product development at each stage of product development process. The information is entered in a tabular form and the likelihood of failing score from 1 to 10 is given against each stage and similarly a score for the effect of failure on the success of product development. The score are subsequently multiplied to indicate the criticality of the stage; a risk indicator is calculated at every stage to represent the overall cumulative risk.

"Projects in Controlled Environments 2 (PRINCE 2)" is a formal project management methodology covering the organisation, management and control of projects (CCTA, 2002). It's a standard used extensively by the UK government and it is widely recognised and used in the private sectors, both in UK and internationally. PRINCE2 projects are divided into a sequence of stages. Each stage is driven by a series of sub-processes, which has a defined set of products and activities, a finite life span, control elements, and an organisational structure. Acceptance of these products, to the agreed quality standards, marks the completion of the stage. Acceptance of all stages marks completion of the project. Elkington and Smallman (2002) examined the project risk management practices in a British utility, which manages its information systems and business change projects using the Prince2 method. They found that this method has greatly increased the success rate of projects run within the company, but has little in the way of directing project managers in handling project risk.

Shahidipour et. al. (2000) proposed an IDEF0 based methodology for representing the NPD process that was customisable to a specific business environment in an attempt to improve the performance of the process. Starting from Coopers (1990) thirteen NPD steps the customisation was carried out using an expert system supported by a knowledge base to select the most critical stages in the process and identify those tools and technologies appropriate at each stage. The process did not include any mechanisms to measure the effectiveness of selected processes but was useful for the rapid configuration of the NPD process and tool selection. The key to success in process management is to know how well the process is performing and to make sure that these processes are functioning effectively to anticipate and prevent problems rather than react to them as they occur. The aim is therefore, to monitor how well the process is operating and, if necessary, intervene in a timely manner when it does not perform as planned (Syamil, Doll, Apigian, 2004).

Rosenthal et al (1992) has considered some of the design tools and techniques in an information-processing framework (Susman 1992). He identified six information-processing functions to be central to successful design and development. These are:

translation, focused information assembly, communication acceleration, productivity enhancement, analytical enhancement, and management control. These six functions then were grouped into two sets with different capabilities: (1) cross-functional integration and (2) efficient and effective NPD process. For each function of these groups he then suggested a set of design methods to support those functions. This classification is show in Table 2.2 below.

Cross-Functional Integration	Efficient and Effective NPD Process
1. Translation Quality function deployment (QFD) Design for assembly (DFA) Customer use into test requirements Target cost into yield objectives Computer aided process planning (CAPP) Planning bills-of- material (BOM) Value engineering **2. Focused Information Assembly** Early vendor involvement Early manufacturing involvement Simultaneous engineering Co-located of design and manufacturing engineering Quality function deployment (QFD) Design for assembly (DFA) Design reviews Manufacturing system simulation **3. Communication Acceleration** Computer aided design (CAD) Group technology (GT) Electronic data interchange (EDI) Early specification to vendors Computer integrated manufacturing (CIM) Planning bills- of-materials (BOM) Preliminary prototypes Rapid prototyping Early product information to field service Early product information to marketing/sales	**4. Productivity Enhancement** Computer aided design (CAD) Computer aided software engineering Project evaluation review technique (PERT) Computer aided engineering (CAE) Group technology (GT) **5. Analytical Enhancement** Manufacturing simulation Learning curve analysis Computer aided Design (CAD) Finite element analysis (FEA) Robust Engineering Statistical design of experiments Taguchi methods Design for assembly (DFA) Quality function deployment (QFD) **6. Management Control** Gantt charts Project evaluation review technique (PERT) Contract books Formal performance reviews Milestone gate reviews Design for manufacturing (DFM) checklists Manufacturing sign-offs Group sign-offs

Table 2-2; Classification of NPD methods (modified Susman 1992)

These activities, and to the extent to which companies have control over each of the processes can have a major impact on the structure of design. Size of the company, company type, and the level of technology employed by companies are the main internal factors that affect the design process. Company size has been found to have an important influence on the type of design projects undertaken (Brown 1989).

There has been a good deal of work, which has sought to customise design processes and methods based on the needs of smaller firms (e.g. see the work of Urban 1993, Wu 1995, Haynes 1994, Taylor 1997 & 1998, Cutherell 1996, Kagioglou 1998).

With respect to company-type, the main classification system used is that based on original equipment manufacturer (OEM) or sub-contractor. Hence, the design process can be all-inclusive, or alternatively partial, involving specific stages relevant processes depending on sub-contractor involvement in the development of the product. In relation to market type and its effect on NPD, some authors have classified products based on the extent to which they can be categorised as either business products or consumer goods. Based on this classification, Paul (1996) has demonstrated a series of factors, which have ripple through effects on idea generation activities, marketing, and data gathering. Similarly, research undertaken by Honna (1995) has identified business product companies as placing more emphasis on R&D activities, the importance of cross-functional teams, and the primacy of core technology in design. Consumer product companies in contrast, were identified as more representative to product management and development-based groupings, with more decision-making authority delegated to marketing functions, and more intense customer involvement as a main source of ideas for new products.

Classification systems also exist with respect to industrial versus consumer product categories, and the extent to which products can be classified as being durable versus non-durable (e.g. Booz, Allen & Hamilton 1982, Johne 1994, 1998). In the case of industrial product companies, it has been observed that more emphasis is usually given to the identification and satisfaction of technological objectives, with more time being spent on development steps, and fewer product ideas needed to generate successful new products. Consumer product firms, in contrast were identified as placing more emphasis on market requirements, spending more time on NPD commercialisation steps, and drawing upon a much larger pool of new product ideas for each successful new product developed, on average.

Market share can be considered both from the point-of-view of relative size, and also positioning within the market. Increasing market share may necessitate the search for new segments and niches in the marketplace, which in turn may require more bold initiatives in NPD markets. Another important factor related to the market situation relates to the volatility of the marketplace, which is mostly dependent on factors such as competitive dynamics, product variety, and existing levels of technology.

From the marketing and sale view of the design process Pugh (1991) believes that marketing and sale activities in the design process can be synonymous or completely separate, according to product and market type. The selling stage in Pugh's view differs according to whether the product is a large one-off manufacture, small/medium batch manufacture or mass-produced product.

Rosenthal (1992) has compared three different competitive strategies regarding to the use of design methods: For companies that compete on multiple dimensions, he suggested design tools and practices that promote the simultaneous search for low cost, high quality, and short delivery time. Communication between design engineer and manufacturing are likely to be the focus of the information processing functions in these situations. For companies that compete in multiple segments, perhaps the most important information-processing functions are translation between marketing and other functions, coupled with an associated focus on the assembly of information.

For competition by continuous product improvement, the speed and effectiveness of entire NPD process are critical. Here, communication acceleration, productivity enhancement, analytical enhancement, and managerial control become particularly important. In the light of these considerations the applicability of overly generalised models has questioned it and is argued that firms-specific models of NPD may be more appropriate (Poolton 1994, 1999).

2.4 NPD 'Good Practice' Summary

Earlier ways of organising and managing product development activities have been modified or replaced with methods and practices considered to be more desirable. the NPD literature includes many reports of such practices which, taken together with the process models, shed more light on what might be regarded as 'best practice' Table 2.2 shows how the features of current 'best practice' compare with the traditional approaches.

With the support of a successful management system, an enterprise must be able to determine the right products or features to be developed, the right time to develop and launch. The right amount of development investments and its effective implementation, etc. As it can be easily understood, no NPD operation can be accomplished without effective and timely decision-making. An important corner stone of the new product management is the idea selection and new product project launch decision. Several researchers have suggested that it is difficult for managers to end NPD projects once they are begun (Cooper, 1994; Schmidt and Calantone, 1998). For this reason, here we focus especially on increasing the accuracy of the necessary decisions before a new product project launch.

This review of current 'good practice' within NPD presents a very different picture to the traditional approach. As highlighted in Table 2.3, many of the new practices are diametrically opposed to earlier custom (e.g. formal process vs. no formal process; functional integration vs. function segregation, parallel activities vs. serial activities). Other practices, such as the emphasis on learning and increased exploitation of technology, are additions or extensions to the old way of doing things and reflect new awareness of what is important. Despite coverage the new practices have received in the literature, some elements of them may not be appropriate for every organisation. Several recent studies suggest that what represents best practice for any one company will depend on its particular content (Griffin, 1997; Maffin et al., 1997).

Traditional NPD in Practice	Current NPD 'Best Practice
No formal process	Formal process, process view
Tactical approach	Strategic approach
Decisions taken on a project by project basis	Portfolio approach to prioritising and resourcing projects
Take customers and suppliers for granted	Horizontal cooperation (joint ventures, strategic alliances
Tight or loose or no control	Close links with customers and suppliers
Not responsive	Loose-tight control
Learning not an issue	Responsive to changes in the environment and customer
Top Management have little involvement	Emphasis of learning
Management style autocratic	Top management involvement, supportive teams and leaders
Ignorance or hostility to new technology	Management style democratic, supportive
Gatekeeper- product champion	Key roles e.g. technology gatekeeper, product champion are recognised and encouraged
Culture is a resistance to change	Widespread acceptance of change
Rigid- all projects are treated the same	Flexible – projects may differ and require • different processes • different structures (types of team
Functional segregation	Functional integration, especially R&D, marketing and manufacturing Methodologies to improve integration e.g. QFD, DFM/A
Individuals and functional groups	Teams, cross-function, multidisciplinary, collaborative teams
Sequential stages	Overlapping stages
Activities carried out in sequence	Activities carried out in parallel
The new product and the tools used in manufacture and developed separately	Concurrent Engineering
Upstream –downstream communication: serial/batch communication, one way, at end of upstream phase	up-stream-downstream communication: intensive two-way information processing from start of the project
Limited use of technology	Evaluative information including market and technical expects
Limited use of tools and techniques	Exploitation of technology e.g. CAD/CAM/CA; PDM, electronic databases; electronic communication and linkages
Design strategy: each product is unique	Greater use of development tools and methods e.g. FMEA, Design for Experiments Better use of prototypes
Manufacturing Strategy: Make-to-Stock (MTS) or Make to Order (MTO)	Manufacturing strategies: mass customisation

Table 2-3; A Literature Source Matrix Table Categories of 'Traditional' and 'Best' practice in NPD (Caffyn 1998)

To replace the traditional practices with contemporary 'best practice' implies major changes in the conduct of NPD. Changes are necessary at a strategic level, at an operational level, at a group level, and at an individual level. However, in practice firms may start to adopt some of the new practices as they learn from outside sources about the benefits of, say, multi-discipline teams or closer links with customers and suppliers. A thread running through many of these new practices is flexibility: at the same level of the firm, in its response to changes in the external environment, at an operational level, in the terms of applying the practices and structures that are most appropriate for a particular development project; and at a level of individuals and groups, who need to be open to change and prepared to adapt accordingly.

The new practices described here have been stimulated by the changes in the NPD context in which organisations operate, for example, new technology; customer demands for greater product customisation; and increased competition on a global scale. The practices are consistent with such changes and are helping companies to cope with the demanding situations the find themselves in. However, even if the organisations are able to survive in the present climate, the future will bring challenges, thus the need to improve remains. The next section will look at the underlying processes of customer-driven manufacturing and knowledge management practices that may help ETO manufacturing enterprises move from where they are now and were they are now to where they need to be.

The way in which successful NPD for effective manufacturing is achieved will depend on the volume and type of products to be manufactured. In the series of DTI publications in "Managing into the 90s Program" three situations of products have been considered with regard to the design for effective manufacturing (see DTI 1990a):

- High-volume products
- Low-volume products
- Product variety

Also with respect to the classification of products, Roth (1982) has identified three types of design projects. These are "New Design", "Function Design", and "Shape

Design". However, the language used in design classification is not consistent. Variations on this classification system include "original or new design", "adaptive or transitional design" and "variant or extensional design" (e.g. Jones 1970; Andreasen 1987; Schmitt 1991; Cross 1994; Birmingham 1997). Wheelwright and Clark (1992) also divided commercial development projects into three categories: "breakthrough projects, Platform projects, and derivative projects".

A more comprehensive classification of design projects is given in the work of Booz, Allen & Hamilton (1982). In their survey of US firms, for example, they identified six categories of new products produced by firms, based on their newness to the company, and newness to the marketplace (Table 2-4). With respect to new-to-the-world products, and product improvements projects, technological superiority was identified as an important factor, whilst fitness with internal company strengths and top management support were identified as key factors with respect to new product lines.

High	New Product Lines		New-To-World Products
Newness to Company	Improvements/ Revisions to Existing Products	Additions to Existing Product Lines	
	Cost Reductions	Repositioning	
Low	*Newness to Market*		High

Table 2-4; Categories of new products (Booz, Allen & Hamilton 1982)

The next section moves from looking at the specific NPD practices and methods within organisations that operate on a MTO/ETO basis– in other words, at the type of development organisation firms are being encouraged to adopt academics, consultants, government and industrial bodies.

2.4.1 Manufacturing-NPD Interface

There are a number of reasons why manufacturing should be involved in the NPD process. First, innovation is a form of learning (Argyris and Schon, 1996). and (Nonaka and Takeuchi, 1995) and manufacturing both has knowledge, expertise and other resources that are relevant to NPD. In addition, manufacturing needs to develop knowledge that is relevant to NPD. Second, involving manufacturing early can significantly speed up the NPD process in a number of ways. As detailed in Pisano and Wheelright (1995), tremendous time advantages are possible by integrating process development into the NPD cycle. Slow or inadequate process development can negatively impact prototype development and testing. Prototypes may have long lead times and be of low (or unpredictable) quality, which means delayed tests or tests that have to be redone. Process development also means that the firm can then quickly ramp up production so that "normal" levels of manufacturing performance can be achieved sooner. A quick ramp-up has significant implications for costs, productivity, quality and so on, and a slow ramp-up may mean slow market penetration, lost sales, angry customers, wasted advertising dollars, and giving competitors time to catch up. The quicker the ramp-up, the quicker NPD costs can be recouped and the quicker resources (for example, engineers) can be assigned to the next NPD project. Third, thorough process development leading to superior process technology can positively affect the ability of the firm to deliver on product quality and function. This is because product characteristics and process technology are tightly linked, particularly in some industries like biotechnology. Superior process technology can also be extremely difficult to imitate, especially when the process is protected by patents. As stated by Pisano and Wheelright (1995): "in many high-tech markets in which product technology is rapidly evolving, manufacturing process innovation is becoming an increasingly critical capability for product innovation" (p. 94, emphasis added; see also Clark and Wheelwright).

For the reasons listed above, it is important for manufacturing to be intimately involved in the NPD process. Since the specific focus in this research is the manufacturing considerations when developing capital goods, the researcher is focused on predicting two outcomes that the literature associates with the effective management of this relationship.

2.4.2 Manufacturing Strategies

Manufacturing strategy is the allocation and coordination of manufacturing resources and activities to support a selected product-process focus aimed at gaining a sustainable advantage (Chase & Aquilano, 1992) and Walker et al., 1999). Manufacturing strategies range on a continuum from pure MTS to pure MTO, the basic distinction being the timing of customer orders relative to final assembly. MTS companies are usually associated with high volume production and for other classifications the production volumes are either low or medium. In MTS, final goods are assembled in anticipation of customer orders (Marucheck & McClelland, 1986), and hence demand forecasts are critical in avoiding excessive finished goods inventory. Most of the operations management and production literature would classify the non make-to-stock companies into three types, assemble-to-order, make-to order and engineer-to-order (see, for instance, Wortmann, 1992), as defined below:

(1) Assemble-to-order (ATO) production. The final products offered to customers, although presenting some degree of customisation, are produced with (common) standardised parts, which can be assembled in number of different options. The receipt of an order initiates the assembly of the particular finished product that meets customer requirements. The component parts used in the assembly or finishing process, whether purchased or fabricated internally, are planned and stocked in anticipation of future customer orders.

(2) Make-to-order (MTO) production. Most or all the operations necessary to manufacture each specific product are only done after the receipt of a customer order. In some situations even materials and component parts may have to be procured on the receipt of a particular order. The capability for product customisation is greater than in ATO producers.

(3) Engineer-to-order (ETO) production. Products are manufactured to meet a specific customer's needs and so require unique engineering design or significant customisation. Thus, each customer order results in a unique set of part numbers, bill of material, and routing.

MTS strategies have traditionally been viewed as entirely distinct from and incompatible with MTO strategies (Tsubone, Ishikawa, & Yamamoto, 2002).

However, in today's competitive environment, it is important to recognize that MTO and MTS are not mutually exclusive. For example, increased product variety and drastic changes in market demand may necessitate manufacturing systems that can produce both MTO and MTS products; often, they share a common production line with limited capacity, making changeover flexibility critical.

In MTO, manufacturing or assembly is undertaken after the order is received as the product is customized to meet customer preferences (Vickery, Dröge, & Germain, 1999). MTO enables agile responsiveness to customers' demands and thus is a key aspect of manufacturing flexibility (van Hoek, 2001). The characteristics of companies in the low-volume industries (i.e. organisation, products, markets and so forth), their competitive environments and their range of strategic and operational choices are both complex and diverse (Maffin and Braiden, 2001).

2.5 Capital Goods Manufacture

Today, markets are generally perceived to be demanding higher quality and higher performing products, in shorter and more predictable development cycle times and at lower cost (Maffin and Braiden, 2001). The evolution of the competitive manufacturing context in recent decades has led firms to face a more dynamic and uncertain environment where the main feature is the necessity of offering a higher and higher level of customisation. Furthermore, customers have become more demanding in terms of quality, delivery time and cost requirements. This means that all kinds of industrial organisation have to adopt new management tools if they want to survive and to be competitive in this new scenario.

Manufacturing strategies can range from completely make-to-stock (MTS) to completely make-to-order (MTO). MTS products are based on forecasts of overall customer demand while MTO waits until customer orders are received. Generally, MTO strategies are considered more flexible (Figure 2.4).

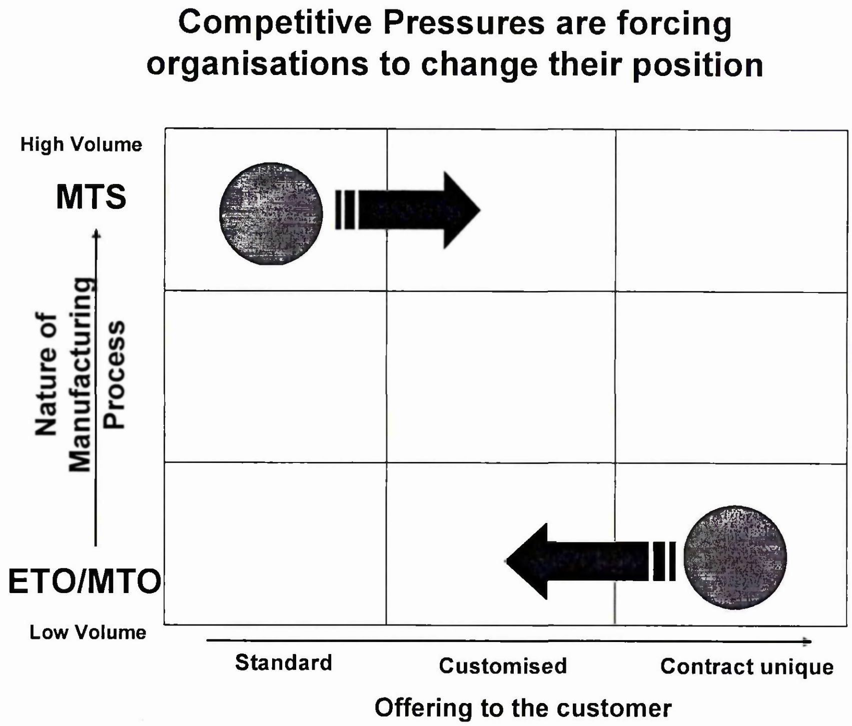

Figure 2-4; Phases in integrated product development (Andreasen 1987)

The manufacturing enterprises of MTO and ETO suppliers of capital goods are an important sector of the world economy. In 1995, overall production in the Mechanical and capital goods industries in the EU was ECU425bn (Maffin and Thwaites, 1998). Despite the importance of this sectors contribution to the UK economy, it has been neglected to some extent by academic research.

2.6 MTO Manufacturing Strategy

Firms use an MTO strategy for a number of reasons (Spring and Dalrymple, 2000). First, MTO creates a competitive entry barrier. Second, MTO is used as a vehicle for learning about new organizational or technological capabilities. Third, an MTO strategy sends symbolic messages to enhance brand or firm image. Fourth, MTO can reduce costs by reducing inventory. Finally, an MTO strategy can make money because customized products may attract higher prices, less financing of finished goods inventory is required, and typically finished goods obsolescence rates are lower. As competitive pressures intensify, MTO strategies are becoming progressively more important as strategic initiatives (Vickery et al., 1999).

These MTO/ETO manufacturing organisations cover a wide range of companies associated with capital goods and intermediate product markets, their products tend to be manufactured for downstream industrial producers to use in the production of other goods and services, rather than for final or household markets. These range from large, complex, high-value capital goods (e.g. offshore structures, power generation plant, etc.) through to low-complexity intermediate products (e.g. pumps, valves, etc.) and are supplied to a range of industries (e.g. mechanical handling, power generation, oil exploration and recovery). Both MTO and ETO manufacturing companies mainly produce customise products, for the purpose of this thesis ETO includes (transport, power generation, process equipment and materials handling) and can be identified as of the following:

- High value, low volume (often one-offs)
- At least customised, and often unique to the customers need
- Both produced by and sold to, large industrial users (hence the better name industry to industry)

Given the general characteristics of the low-volume industries and the diverse range of factors which are unique to any one company, companies may find that approaches suitable for MTS are not easily implemented in their own context (Maffin and Braiden, 2001). Bozarth and Chapman (1996) demonstrated how differences between ETO, MTO, ATO and MTS manufacturers result in the need to use different approaches to implement time-based competition. Furthermore, in the ETO environment different products are being developed simultaneously at different stages for different customers with different requirements which will further complicate the NPD process. Duplicating methods successfully applied in MTS may not necessarily yield the same benefits for ETO.

MTO is probably the most commonly employed high customization strategy. Here, batches of items are produced that are carefully specified by the customer. The assemble-to-order (ATO) strategy is appropriate for those situations where fast (but not immediate) response is highly valued but only limited variety need be offered. The quick response is obtained by stocking end-stage components that can be quickly assembled late in the build cycle into the final product desired by the customer. However, the use of this strategy assumes a production and cost environment characterized by two requirements that may not always be met: (1) the product must be able to be "customized" at the very end of its production process and (2) the cost to hold end-stage components must not be too high.

2.7 The complexities of ETO product development

A distinctive feature of the development of products in engineering companies is the need to manage various types of development project. These include contract projects where the product is developed to a customer's particular requirements, and product development projects to develop a new or improved product either for sale as a standard item or customising to customers' individual requirements. The characteristics in such low-volume MTO/ETO manufacturing enterprises (i.e. organisation, products, markets, and so forth), their competitive environments and their range of strategic and operational choices, are both complex and diverse.

The limited research has been undertaken in the low volume ETO sector has focused on production control (Bertrand and Muntslag, 1993), information systems (Wortman, 1995) manufacturing systems (Canron and Fiore, 1995) Coordination of marketing and manufacturing (Konijnendijk, 1994) and supply chain management (Hicks). Research conducted into MTO companies has focused on strategy (Marucheck and McClelland, 1986) and the planning of subcontract engineering job shops (Hendry and Kingsman, 1989, 1991, 1993) as summary of these finding are presented in Table 2.5 below.

Companies making both MTO & ETO products are essentially project (value stream) driven and are typically involved in several concurrent projects at any one time. Products are most usually sold on performance, the technologies involved are frequently very advanced and at the boundary of knowledge. The major business activities in such MTO & ETO manufacturing companies encompass tendering, design, manufacture, assembly and also erection/construction, commissioning and through-life support including decommissioning and cleanup. The business processes, design and manufacturing systems involved are complex and dynamic (Braiden et al., 1993). Each customer order is at least partly unique, this means that MTO companies are in a very specific product development process. Therefore, the process of MTO warrants a separate product development approach compared to MTS companies.

Timescales	1990	1995	2000	2006
Research Timeline across the Manufacturing Enterprises	Muntslag, D., 1994; Wortmann. H., 1995; Hill, A.,1995 Bozarth, C., Chapman, S., 1996 Hendry, L., Kingsman, B., 1999; C Hicks Brainden 2000; Maffin and Braiden, 2001; C.Hicks,2002 Cameron and Braiden 2003; Olhager J.,2003 Rahim A., and Baksh, M., 2003			

Literature Contributions	MTS	ATO	MTO	ETO
Operations Management & Production	Hendry L and Kingsman, B., 1989; Vollmann et al., 1988; Wortmann, H., 1992),			
Supply chain			Hicks, C., McGovern T., & Earl, C.F., 2000	
Information Systems			Wortman. H., 1995 Hicks. C., & Brainden, P., 2000	
Knowledge Base System	Kingsman, B., Suza, A., 1997		Kingsman, B. & Suza, B., 1997	
Knowledge Management			Hicks, C., 2002	
Scheduling			Bertrand J., & Ooijen H., 2000	
Strike Rate & Order Penetration Point	Kingsman, B., 1997 Olhager , J., 2003			
NPD				Rahim A., Baksh, M., 2003

Table 2-5; A Literature Source Matrix

In pure customisation, the product is developed from scratch based on the individual need of each customer. Therefore the need for the firms to customise their production increases the significance of the customer-driven manufacturing sector of

MTO and ETO, has traditionally received relatively little research attention. For ETO, the product is produced initially on a one-off basis and the design and manufacturing process as well as the sequence of operations are most likely dissimilar from one product to another. Repeat order is possible for certain products and the same design and fabrication process will be used. The NPD MTO or ETO projects generally have a deep and complex product structures, which gives rise to many levels of processes. Some components and systems are technologically advanced, such as control systems, as well as commonality items such as structural steel work. As well as certain items being highly customised, whilst others are standardised and need to be coordinated and controlled These factors influence the selection criteria applied at the design stage and the frequency with which various elements within the knowledge base need to be updated. Perhaps the simplest way of illustrating the defining characteristics of MTO is to distinguish them from mass-produced goods (or made-to-stock) as shown in the Table 2.6 below.

Characteristic	MTS Companies	MTO Companies
Product Demand	Demand for standard products can be forecast	Demand is volatile and unpredictable
Product Mix	Many standard products	Few standard products
Resources	Standard Designs, Specialist Machinery & Forecast	Specialised Engineering Design Multi-task machinery and workforce
Capacity Planning	Based on a forecast demand, planned well in advance	Based on receipt of customer order Cannot be planned far in advance
Lead Times	Unimportant to the Customer	Vital for customer satisfaction, Agreed with customer
Prices	Fixed by the Producer	Agreed with the customer during the quotation phase

Table 2-6; A Comparison between MTS and MTO Manufacturing Companies

The product complexities give rise to considerable problems in specification development and in its deployment down the business functions. Since the products are most usually sold on performance, the technologies involved are frequently very advanced and at the boundary of knowledge. However, other factors such as cost of ownership and the ability to customise the product are also important. Increasingly, the impact of these products on society and the environment is becoming a major issue and hence design for sustainability is also important.

Both MTO and ETO products tend to be highly specialised capital goods and sometimes can be very complex, highly technical in nature and have high added value. Production output is very low and revenue is not based on unit sales volume but on high profit margin. Customer requirements are very specific, technical and precise. Occasionally, strict regulatory requirements and design codes have to be adhered to. The most important requirement is usually the functional requirement as compared to aesthetics or trends which are common for consumer goods. Product specifications are sometimes jointly developed with the customer, contractor and supplier. Most of the products produced are capital equipment types of products, such as machinery, equipment, plant, power generator or oil exploration rig mainly for industrial customers to be used in downstream operations. Hicks (1998) classified ETO companies according to the depth of product structure and the type of processes employed, he identified that many companies have a mix of different types of production processes that need to be co-ordinated to meet the assembly requirements. Since the MTO and ETO products are most usually sold on performance, the technologies involved are frequently very advanced and at the boundary of knowledge. However, other factors such as cost of ownership and the ability to customise the product are also important. Increasingly, the impact of these products on society and the environment is becoming a major issue and hence design for sustainability is also important.

2.8 The characteristics of ETO manufacturing project

2.8.1 Business Processes

Supply in the ETO capital goods sector is characterised by the high levels of uncertainty in terms of specification, demand, process durations and lead times (P.A Konijnendijk 1994). High complexity arises from: deep and complex product structures; the combination of different types of production systems; and uncertainties due to incomplete or missing information and engineering revisions caused by overlapping of manufacturing and design activities. The nature of the NPD-ETO process changes through the life cycle of an ETO manufacturing project. As stated at the start of a project the specification may be vague. The structure and information content of the specification.

As mentioned above the major business activities include: tendering, design, manufacture, construction and plant commissioning. The business process, design and manufacturing systems are complex and dynamic. The production of ETO products is a multi-stage process involving tendering, contract execution, operational support and maintenance. These tasks are all complex, interrelated and knowledge based. Within the NPD-ETO process, it is possible to distinguish two types of processes: non-physical, which includes engineering design and planning activities and physical which compromises component manufacturing, assembly and installation (Bertrand and Muntslag, 1993).

From the understanding of business processes in ETO, the ways in which the relationships with other processes can be improved, Hick (2000) identified. First, the effective sharing of knowledge and information requires the use of common systems that support tendering, design, procurement, and project management. This requires records of previous designs, standard components and subsystems together with costing, planning, vendor performance and sourcing information. This knowledge is a key source of competitive advantage for ETO companies.

The following section describes the core business processes within the product development process of ETO goods.

2.8.1.1 Customer Specification

The type of specification provided by a customer is often determined by their in-house expertise. In capital goods markets deregulation has had a large impact, since customers (such as power generators) have reduced their engineering and research development capabilities. Prior privatisation invitations to tender were based on technical specifications. They are now predominately functional specifications, with contracts often requiring “turn key” solutions that include through- life support. In many cases this has expanded the range of expertise and competences required with MTO/ETO capital goods companies. However, an increased focus upon high value adding activities such as design, assembly, construction, and commissioning has increased the tendency to outsource component manufacture which has reduced the requirements for certain types of expertise (Hick 2000). A challenge for ETO companies is to control the design and supply, to minimise the risk and costs by retaining the expertise to integrate subsystem performance specifications to meet stated and understated customer requirements.

2.8.1.2 ETO Tendering Phase

ETO companies under normal circumstances do not carry out market research to identify customer's needs as compared to MTS companies. In an ETO company, the activity starts with the bidding process. At the same time, an ETO company should also consider capacity preparation. Production planning and scheduling is very much dependent on resource availability. Once the tender is awarded, only then can other activities start. The two most important characteristic of these firms are:

- Each order typically requires different amounts of processing work on the work centres of the firm, the use of a different number and/ or different sequence of work centres. The orders are for a small number of units of the product, often being only one in capital goods manufacturing. Batch production, with some inevitable work-in-process stocks between work centres, is the production system to be used. It is very difficult to make forecasts of the loads on facilities a long way ahead.
- The firms are involved in competitive bidding for orders. When a customer makes an enquiry for a product, they will usually ring several other suppliers at the same time and will then compare quotes before choosing the company with which to place their order. Tobin et al. found that the strike rate, the proportion of quotes that become firm orders, varied from 3% to virtually 100%.

The bid these companies make in response to a customer enquiry must contain realistic and currently competitive delivery date and price. These are the crucial factors in winning the order, although other aspects such as the company reputation for technical skill and quality, the financing package etc., may be important also.

2.8.1.3 ETO Design Phase

ETO Product development has two forms (Vincenti, 1991), the first "normal" design, which involves the development modification or customisation of existing products to meet such customer requirements. The second is "radical" design, where the product is new and there is only a limited amount of relevant knowledge. This may require engineers to work from first principles supported by substantial experimentation and modelling activity. These two situations may give rise to different organisational structures. In the first case, there is sufficient knowledge to have established formal processes; each of which have procedures, information, data and working practices derived from previous experience. In the second case, it is common business processes to be developed as required for each project. The situation has been described as "extreme" engineer-to-order (Riley, Braiden, and Hills, 1993).

The design process may be considered to occur in a numbers of stages. The first *conceptual design* involves developing a number of possible solutions and selecting the best concept. This involves identifying the customer's needs, clearly defining the problem and what has to be accomplished to satisfy the customer's requirements. This may include an analysis of the competitors' products, establishing the target specification and listing the constraints and trade-offs. *Concept generation* is concerned with creating a broad set of concepts that potentially satisfy the problem statement. This is often a team based activity. This is followed by concept selection. The second stage is *Embodiment Design*, sometimes called preliminary design, which includes three major elements, product architecture, configuration and parametric design. *Product architecture* is concerned with dividing the overall design system into sub-systems and modules. It is decided how the physical components can be combined and arranged. C*onfiguration design of parts and components,* means determining what features (curves, holes, threads etc) will be present and how they are arranged geometrically. *Parametric design of parts and components* involves starting with the configuration and then establishing exact dimensions and tolerances. Major changes become very expensive beyond this stage. The third stage is *detail design* which completes and engineering description. This involves adding information on form dimensions, tolerances, surface properties, materials and manufacturing processes. The design process moves from situation characterised by high levels of uncertainty and low levels of knowledge towards low levels of uncertainty with increased knowledge. Thus, knowledge and the product description evolve through the design process.

Figure 2.5 shows that only a small fraction of the cost of the product is spent in the design process, however the design process consists of the accumulation of many decisions that result in design commitments that affect about 70-80% of the manufacturing cost of the product (Dieter, 2000). The majority of cost commitments are therefore made under conditions of high uncertainty when there is relatively low level of knowledge. In ETO companies the conceptual design and some of the embodiment design occurs in the tendering stage, which is often subject to severe time constraints and limited resources. Tendering involves trade-offs between different risks. On one hand the tendering effort may be wasted it is unsuccessful in the bidding process. However, on the other hand, the contact may be unsuccessful if errors or omissions lead to excessive costs/delays at the contract execution stage.

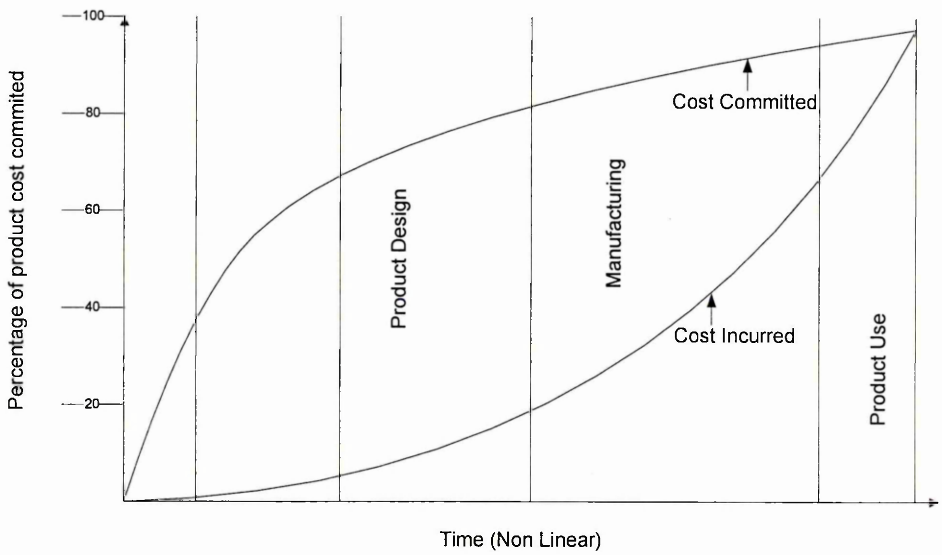

Figure 2-5; Product Cost Commitment during phases of the design process (Dieter, 2000)

Engineers tend decompose complex problems into smaller parts that are easier to manage. There are two main approaches. The first is physical decomposition, where a product is considered in terms of assemblies, subassemblies and components. Designers conceptualise at a high level and break the overall smaller ideas based upon the functionality of systems. Manufacturing is concerned with identifying geometrically similar parts that can economically processed within manufacturing. Assembly requires information on how the product physically fits together. The information and knowledge requires information on how the product physically fits together. The information and the knowledge required in each different case have different structure and context and is used in distinctly different ways. Another important issue is the interactions, connections and the couplings occur between functional and physical subsystems that give rise to emergent properties. Effective knowledge management needs to support these multiple viewpoints and product descriptions.

2.8.1.4 Installation phase

Another factor that is also unique for some of the ETO products is that some preparation at the customer site should be carried out before the product is delivered. For example, some machinery such as an injection moulding machine requires pneumatic lines, a three-phase power supply, a cooling tower and a very strong and stable foundation to place the machine. This has to be planned in parallel with the NPD process.

2.8.2 The Risks associated with NPD-ETO

The MTO/ETO sector experiences high uncertainty in terms of specification, demand, process duration and lead-time. They are dynamic organisations in which their internal structures and boundaries of the firm are often reconFigured to match the external requirements (Hicks & Earl 2000). From the understanding of business processes in ETO, the ways in which the relationships with other processes can be improved, Hicks, McGovern and Earl (2000) identified First, effective sharing of knowledge and information requires the use of common systems that support tendering, design, procurement, and project management. This requires records of previous designs, standard components and subsystems together with costing, planning, vendor performance and sourcing information. This knowledge is a key source of competitive advantage for ETO companies. Second, limiting customisation using modular configurations and standard items provides more flexibility in the timing of procurement decisions, as well as reducing costs and lead-times. This approach also gives higher quality planning data earlier. Third, proactive procurement implies participation in the development of specifications. This requires technical liaison with tendering and design based upon knowledge of potential vendor capabilities and performance. This infrastructure is necessary to make supply chain management strategic in ETO companies.

Another key characteristic is that at the start of a project when major commitments are made, there are high levels of uncertainty and sparse knowledge. As the project progresses uncertainty reduces as the knowledge base expands as the product model develops. At the end of the project is considerable knowledge and low uncertainty. The appropriate reuse of this in future tenders and contracts is a key challenge (Hicks 2004).

In order to obtain best performance from NPD-ETO, the efficient and effective management of the product development process is vital. However, project non-conformances are substantial and the cost of rework is large, and this makes successful ETO product development rather a complicating task to be exercised with caution.

The NPD-ETO process is to translate customer's needs into a tangible physical asset, is structured around well defined phases; each phase encloses many decision points, where management decides about the future of the project. The decision maker must take into account the customers' needs, the company's strategies as well as technological opportunities and the company's resources, and deduce the goals based on these factors for a successful NPD. With the NPD-ETO activities, it is aimed to create value for enterprises while renewing and developing (Matheson and Matheson, 1998). As we have pointed out earlier, NPD-ETO has a vast working area and it addresses different strategic, tactic and operational managerial levels in the organisation. This is why methodologies, assumptions, goals and realisation stages vary among companies. Although different organisations can make different choices and may use different methods, all of them make decisions about a collection of issues such as the product concept, architecture, configuration, procurement and distribution arrangements, projects schedule, etc.

2.8.3 Uncertainty and decision-making methods

Uncertainty management is an integral part of ETO product development projects and so it can be observed that different approaches exist in the literature to define and analyse uncertainty in NPD. Fox et al. (1998) combine three dimensions of uncertainty as technical, market and process. They rate and categorise uncertainty along each dimension as being either low or high. For technical uncertainty, when uncertainty is low, the technologies used in the development of the project are well known to the organisation and relatively stable. When technical uncertainty is high, technologies used in the development of the project are neither existent nor proven at the start of the project, and /or are rapidly changing overtime. For market uncertainty, when uncertainty is low the organisation has good market data on both customers and competitors, and product is being sold through familiar channels of distribution. When market uncertainty is high, the organisation has little information regarding who the customer is, how the market is segmented and what are the needed channels of distribution. For process uncertainty, when uncertainty is low the engineering, marketing, and communications (both internal and external) processes used in this project are well tested, stable, and embedded in the organisation. When process uncertainty is high, a significant portion of any or all of the engineering, marketing, and communications processes are relatively new, unstable, or evolving.

Similarly, Mullins and Sutherland (1998) identified three levels of uncertainty that confront companies operating in rapidly changing markets. First, potential customers can not easily articulate needs that a new technology may fulfil. Consequently, NPD managers are uncertain about the market opportunities that a new technology offers. Second, NPD managers are also uncertain about how to turn the new technologies into new products that meet customer needs. This uncertainty arises, not only from customers' inability to articulate their needs, but also from managers' difficulties in translating technological advancements into product features and benefits. Finally, senior management faces uncertainty about how much capital to invest in pursuit of rapidly changing markets as well as when to invest.

Consequently, NPD can be defined as a process including many "generic decision" points, likewise "decision perspective" of Krishnan and Ulrich (2001). In their related work, Urban and Hauser (1993) recommend a 5-step decision process for NPD: opportunity identification, design, testing, introduction and life cycle management. These phases are briefly illustrated in Fig. 2.6. To conclude, NPD process may be accepted as a dynamic decision process where each decision point must be evaluated, selected, and prioritised. All the stages of the process are affected by uncertain, changing information and dynamic opportunities, which will now be summarised.

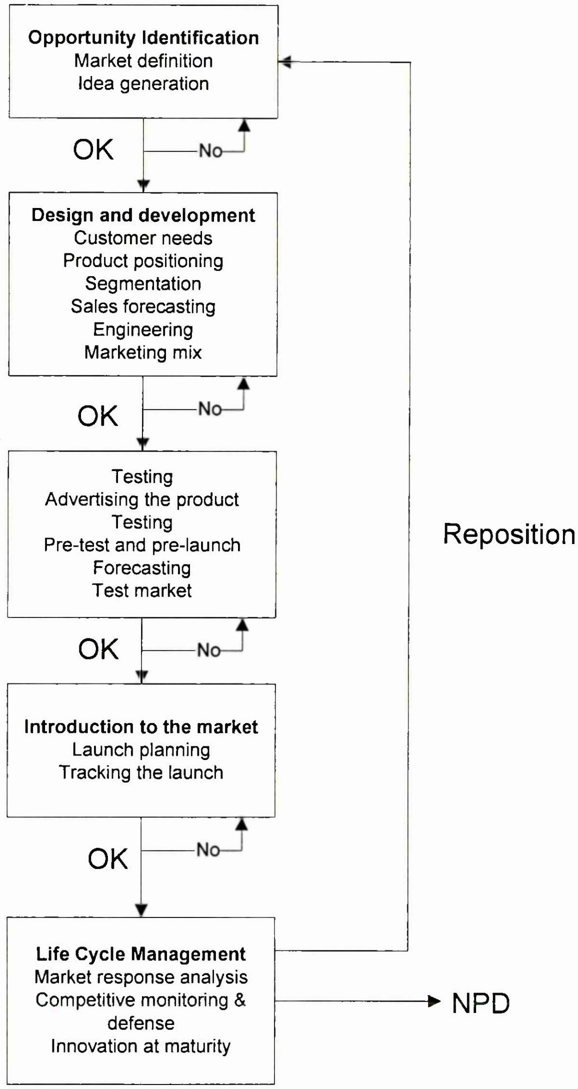

Figure 2-6; NPD process (Matheson and Matheson, 1998)

2.8.4 What is Risk?

Risk is defined as the combination of possible consequences and associated uncertainties (uncertainties of what will be the consequences), whereas vulnerability is defined as the combination of possible consequences and associated uncertainties given a source. Hence risk is the combination of sources (including associated uncertainties) and vulnerabilities, see Fig. 2.7.

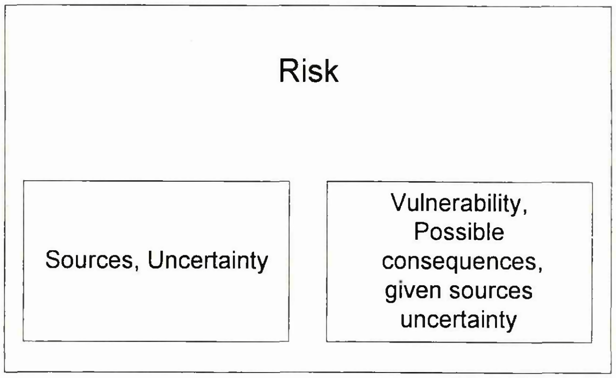

Figure 2-7; Risk viewed as combination of sources and vulnerabilities

A common definition of vulnerability is a fault or weakness that reduces or limits a system's ability to withstand a threat or to resume a new stable condition. Vulnerabilities are related to various types of objects such as physical, cyber, human/social and infrastructure,

2.9 Uncertainties within product development process

Uncertainty related to market changes, emerging technological developments, and the evolving competitive situation have continually introduced an element of risk and "fuzziness" (Thompson, 1967) when attempting to devise approaches to effectively operate in a business environment. This factors contributing to this fuzziness is beyond the control of all but a few large companies. These factures have a direct effect on the product development process and it is therefore necessary to identify, clarify and measure the effect that these factors have at each process stage, activity and tool.

Gupta and Wilemon (1990) stated that uncertainties and ambiguity in new product development result from a number of factors, which were reduced to following key factors:

- Increased domestic and global competition
- Continuous development of new technologies that quickly obsolete existing products
- Changing customers' needs and requirements

- Increased need for involvement of external organization in the product development process, e.g. customers, vendors, and strategic partners

More recent studies have shown that product development managers perceive at least three sources of uncertainties, Zhang and Doll (2001): the customer requirements; the changing technology and the nature of competition. Customer fuzziness such as "uncertainty about product characteristics" makes an effective management of the product development process very difficult to achieve. Technology fuzziness such as, "uncertainty of process functions, input characteristics specification" or "uncertainty of suppliers' design and manufacturing capability" introduces uncertainty in product integrity and product development cost. Likewise, the uncertainties and ambiguities of a competitors' new product developments, technology adoption, and so on, directly threatens a companies product development success in terms of securing market share or achieving a first in the market status. Faced with this ambiguity and uncertainty, Zhang & Doll (2001) stated that the product development process and tools require coping mechanisms to measure the reliability of the process and to identify means to avoid, adjust to, reduce, or take advantage of the process uncertainties.

2.9.1.1 Risk in NPD process

Miller and Lessard (2001) identify three main risk categories for engineering projects: "completion risks" group formed by technical, construction and operational risks, "market related risks" group formed by demand, financial and supply risks and finally, "institutional risks" group formed by social acceptability and sovereign risks. We refer also to the recent work of Riek (2001) where NPD risks from uncertainty are organised into three general categories such as technical risks, commercial risks and NPD personnel. If we analyse NPD from different perspectives, we can precise risk structure in a more detailed manner. As an example, we can allocate product positioning, pricing and customer uncertainties to marketing; organisational alignment and team characteristics uncertainties to organisations; concept, configuration and performance uncertainties to engineering design; supplier, material, design of production sequence and project management uncertainties to operations management. As it can be observed, uncertainty factors highly depend on the way of how to focus and investigate the theme. However, we can briefly state that, all kinds of uncertainties for NPD can be classified generally in two main categories:

uncertainty caused by external factors and uncertainty caused by internal factors. External factors can be further subdivided into two groups: market factors regarding to competitors, customers and suppliers, and technological factors.

By the same reasoning, internal factors can be subdivided into to personnel and project management factors. While considering the decision points in whole NPD process, we require to minimise the side effects of uncertainties described previously and to increase the effectiveness of the decisions. Different decision methods have been developed to over come the uncertainty related problems. Some of the methods that can be used in NPD process are summarised below (Davila, 2000; Doctoretal., 2001; Infanger, 1994; Li, 2000; Trittle et al., 2000).

The ability of ETO firms to produce to cost, schedule and with full functionality depends on their ability to efficiently allocate resources and to coordinate their specialised knowledge and technologies to solve design problems and prevent costly redesign feedback loops. Since the extent of any redesign work impacts negatively on the productivity of the project, the economic emphasis is on 'uncertainty management'. Uncertainty refers to the inability to completely understand or accurately predict some aspect of the environment as it relates to NPD project decisions (Gifford, Bobbitt and Slocum, 1979). Uncertainty arises primarily from two sources: the technology and market (Lynn and Akgun, 1998). For example, an NPD project leader may be faced with a product technology that is well understood, highly developed and, thus, straightforward in application. Alternatively, the product technology may be perceived as undeveloped and unknown and, thus, as requiring trial-and-error research. Muntslag (1994) identified three uncertainty factors namely:

- Product mix and volume uncertainty
- Product specification uncertainty
- Process specification uncertainty

A key question therefore is; by what means are these 'uncertainties' managed and by what processes can new knowledge be captured, managed, embedded and disseminated to support future projects? In parallel to this research, efforts have been made to develop a design and manufacturing framework for ETO. In the process of NPD, an enterprise always faces potential risks in various areas. Common questions that are asked include: whether the performance, quality, variety and specification of products meet the demand of customers, whether the delivery of goods is on time, whether the price of products is rational, whether the marketing and service are thoughtful, whether the products have competitive advantage, whether the new business opportunity is recognized by the market, and whether the newly developed market opportunity is easily lost to the competitors. With the analysis of potential risk and consequence analysis on the design/process using (DFMEA/PFMEA) (Besterfield, 2003), effective measure and action can be taken to reconsider the projects, and the risk and loss in efficiency and scrap afterwards can be reduced as a result.

Having defined risk, we can define risk analysis as an analysis of risk. Similarly we define vulnerability analysis. As vulnerability is a part of risk, a vulnerability analysis is a part of the risk analysis. Note that this is not the case for the definitions used by Einarsson and Rausand (1998). To emphasis that we specifically address vulnerability, we write risk and vulnerability analysis.

2.9.1.2 The Risk Diagnosing Methodology (RDM)

The Risk Diagnosing Methodology (RDM) is one such technique which has evolved to address risk at the project, process and product level to improve the chance of success. It is applied in systematic successive steps through risk identification, risk assessment and risk response development and control. It is developed to diagnose risks associated with technology, organisation and business at the end of the feasibility phase of the product development process. It assists in guiding and controlling decisions made on issues such as consumer and trade acceptance, commercial viability, competitive reactions, external influences, human resource implications and manufacturability (Keizer et al. 2002). A study conducted by Keizer, Halman and Song (2002) on the application of risk diagnosing methodology at Unilever proved very useful and concluded that conducting an RDM increases a company's innovation success rate.

2.4.1 Application-specific Tools and Techniques

The previous section discussion showed the key business processes during the NPD-ETO process highlighting a wide range of problems and risks that are experienced by companies engaged in the production of complex engineered to order (ETO) products (capital goods) and systems. These companies are thus being driven to improve the integration of the design, manufacturing and procurement functions. By investigating the NPD Framework, tools and techniques from a project driven viewpoint, each of the NPD-ETO activities can be viewed as a process of converting specific input(s) into output(s) subject to a series of constraints. These necessities along with the hierarchical nature of the proposed NPD-ETO process are well suited to IDEF0 methods.

2.9.2 NPD Frameworks

Therefore, the objective of this study is to identify the special nature of NPD-ETO and propose a methodology for investigating uncertainty issues in this sector. There has always been a need in these companies for efficient design processes for product performance and conformance and this has led to the development of special design techniques. The nature of the product description changes in both form and detail as the design activity moves from an initial situation characterised by ambiguity, sparse description and uncertainty towards a full product description and limited uncertainty. The type of knowledge required changes during this process. Furthermore, different functions view the product from different perspectives, which need to be supported by effective knowledge management systems.

Similarly, the specialised nature of manufacturing in ETO companies often requires the development of particular product-specific processes. However, the nature of these companies is changing. Whereas, previously, the emphasis was on fully utilising expensive capital intensive resources, which, for example, led to subcontract machining and spares being produced in-house, companies are now increasingly outsourcing manufacturing, retaining only that associated with the core product technology. This requires not merely efficient design, manufacturing and business processes, but effective knowledge management throughout the entities involved in the NPD-ETO process.

ETO companies that carry out pure customisation, due to the nature of their operations must design a new product every time there is a customer order. A generic framework or model needs to be developed to suit the diverse requirements of ETO companies. The structure of the framework should address certain requirements that will meet the unique needs of the users in the ETO environment. NPD for ETO products should be approached accordingly from different perspectives due to many operational differences.

2.9.2.1 Framework by Pugh

Pugh (1991), proposed a design core model as shown in Figure 2.8. The framework is quite technical in nature. The framework starts from identifying market needs and ends with marketing and sales which is very common for MTS companies. The framework is mainly meant for the designers due to the technical aspects and emphasis on the design flow. Technical areas such as solid mechanics, kinematics, electronics and control are included in the framework which is mostly relevant to the design engineers. The framework does not show the kinds of tools and techniques to be used at various stages of the model which can be a setback to a company that wants to apply it. The framework does not show the use of current technology such as CAD/CAM during the process. Concurrency is not emphasized and it seems that there could be significant iteration back and forth between each phase of the model. The front end of the model which starts from market needs activity indicates that the model is meant for MTS production. The involvement of accounting is only at the final stage of marketing and sales which is typical for an MTS company. For an ETO company, the involvement of accounting is early in the design stage to estimate the production cost.

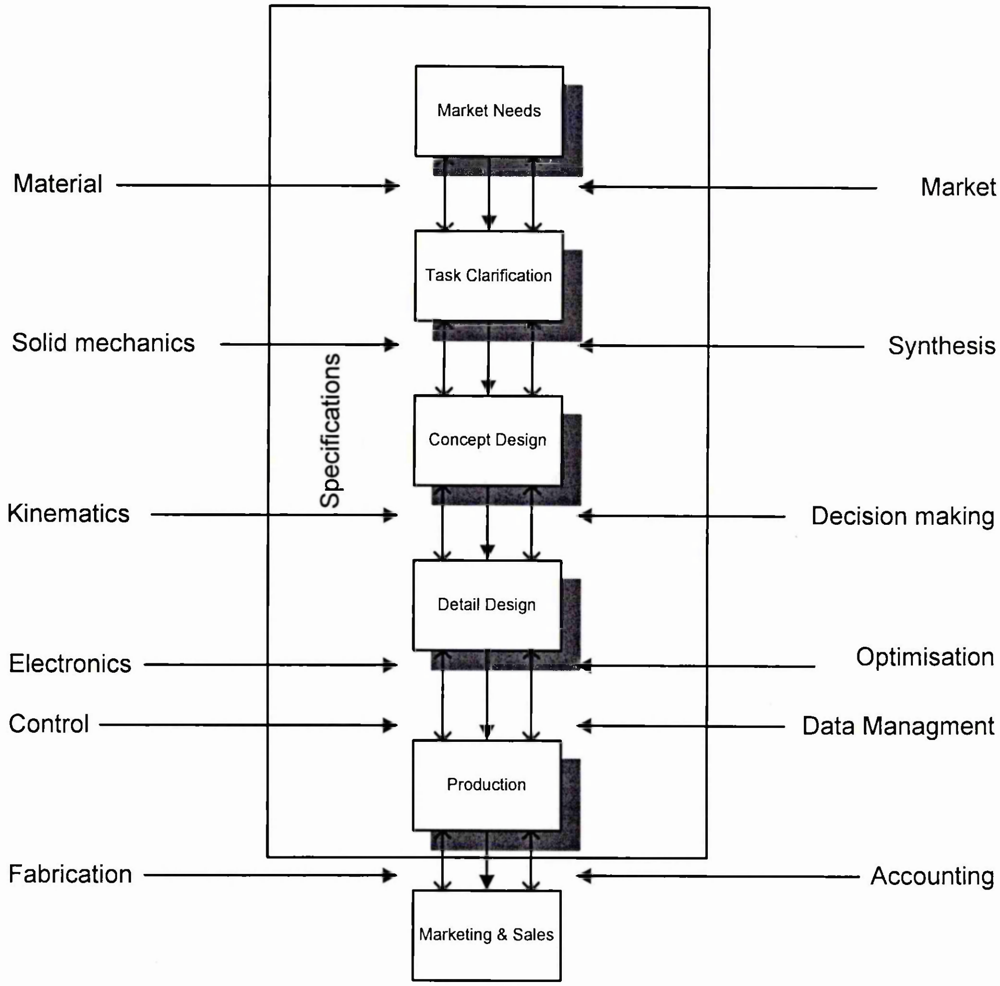

Figure 2-8; Adapted from Pugh (1991)

2.9.2.2 Framework by Boothroyd et al.

Boothroyd et al. (1994) presented a framework or typical steps in concurrent engineering a shown in Figure 2.9 The steps proposed are biased towards the use of design for manufacture/assembly (DFMA) techniques, while the NPD process should also make use of other tools such as failure mode and effect analysis (FMEA), quality function deployment (QFD), fault tree analysis (FTA), Taguchi methods and other techniques.

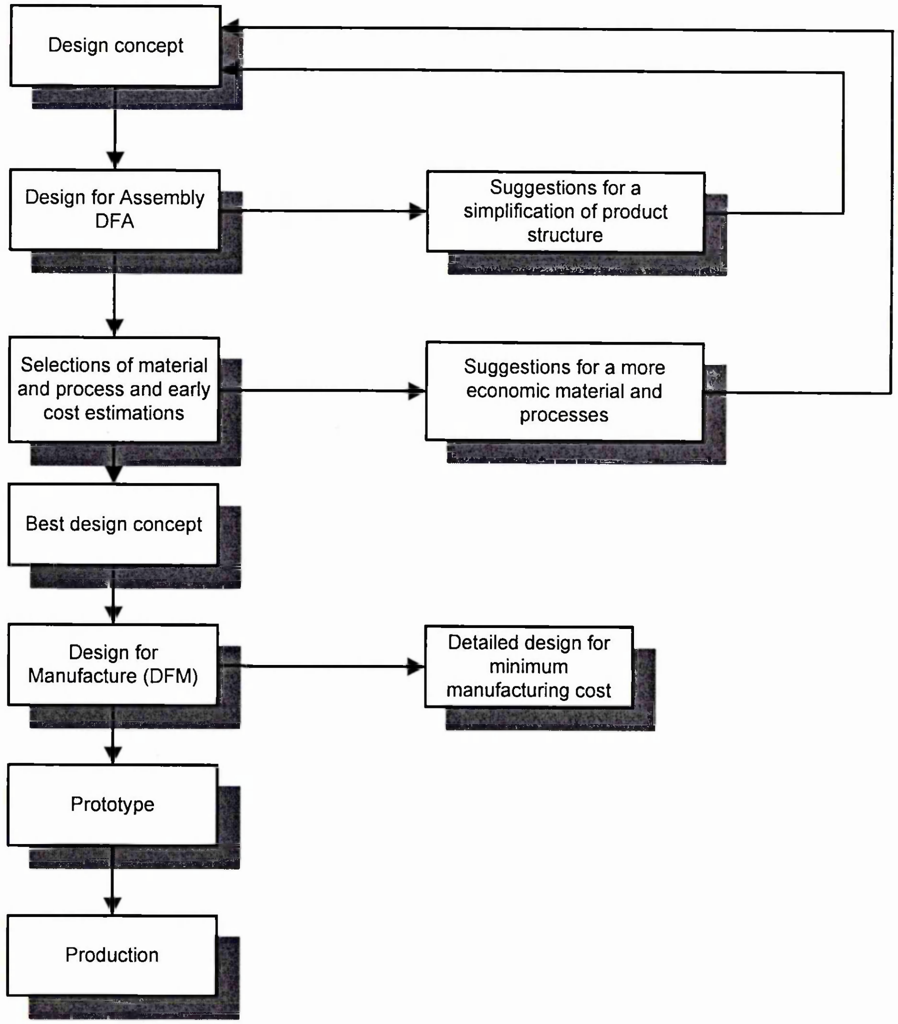

Figure 2-9; Boothroyd et al (1994)

This framework is also meant for MTS because there is one step for making the prototype right before production. The steps proposed are simplified because it started from a design concept assuming that customer requirements had been captured earlier. The steps are heavy on technique but lack other issues such as human interface, technology as well as techniques for monitoring the whole project. Emphasis on minimum manufacturing cost reflects that the use of the framework is for MTS. The framework proposed is meant for designers and disregards other parties involved in the project.

2.9.2.3 Framework by Peters et al.

Peters et al. (1999) proposed a generic framework for the management of the NPD process as shown in Figure 2.10. This framework is the most comprehensive to date where the coverage is much wider and includes tools and techniques, process summary as well as facilitation issues. However, this framework is not suitable for an ETO product because the process starts with the generation of ideas during the pre-design/development stage. In an ETO product, the process starts with customer enquiry and project bidding. Although QFD is included, only QFD (1) is proposed for use in the framework. Theoretically, all four houses of quality in QFD can be used sparingly with other tools from determining customer requirements to product realization. NPD processes in the model seems to be carried out in sequential order rather than parallel and this event can de-emphasize the application of the concurrent engineering concept.

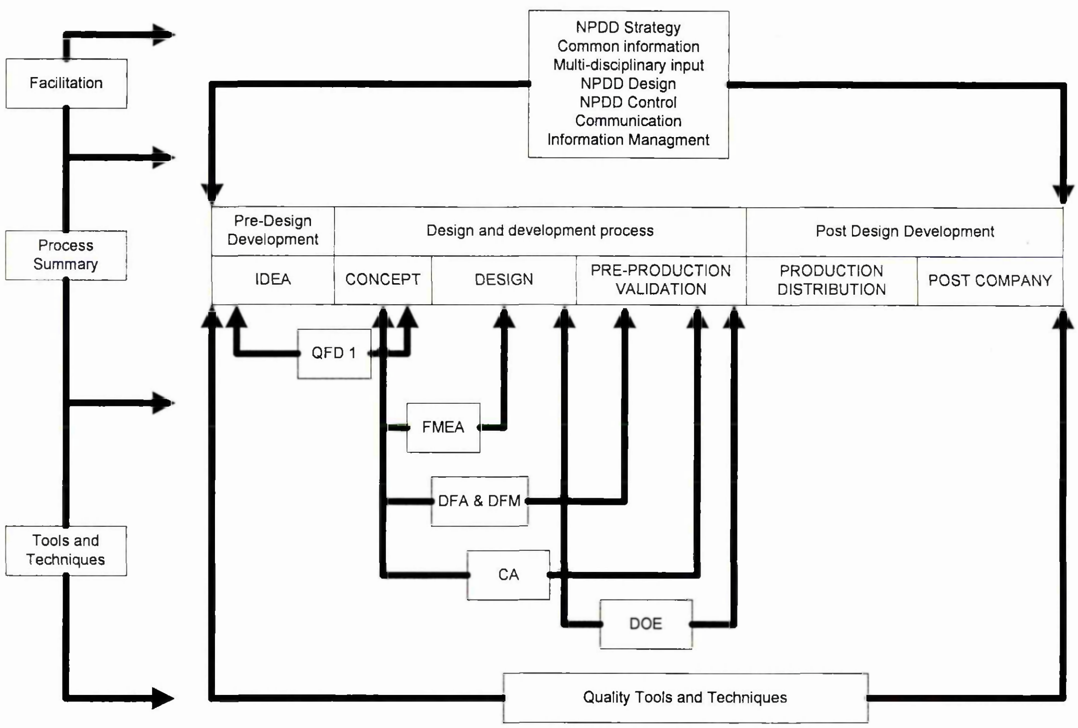

Figure 2-10; Peters et al (1999)

Quality tools and techniques are recommended for use, but the framework does not specify which one to use at different stages of the NPD. The framework also does not highlight the relationship between manufacturers and other interested parties. This is the only framework that proposed the use of design-of-experiment (DOE) in the design and pre-production/validation stage. The application of DOE techniques for ETO and MTS products should not be at the same stage of the project. For an ETO product such as machinery, DOE techniques can only be applied after the product has been assembled and tested to determine the optimum parameter for the process. DOE is carried out on the product in an ETO company, while in an MTS company DOE is carried out on the production process.

The framework does not show input requirements of the NPD process which is necessary during the design stage. FMEA technique can actually be applied not only during the concept and design stage but also in pre-production validation and actual production through process FMEA. For an ETO product, the model should start earlier than the concept stage and the use of tools and techniques is extended further to include the post-company stage.

2.9.2.4 Framework by Ulrich and Eppinger

Ulrich and Eppinger (2000) proposed a generic product development process which consists of six phases as shown in Figure 2.11 The structured approach can help designers to plan and execute their tasks accordingly. However, the generic framework proposed is mostly suited for MTS companies because in Phase 5, there is a process for production ramp-up. For an ETO product that is produced in a batch of one or a very low volume, there is no production ramp-up process. For an MTS company, it is a common practice to do production ramp-up after the prototype or pilot product has been tested and refined. Process improvement is usually carried out during the ramp-up period.

The proposed development process is targeted for designers because it includes all the steps involved in product design and manufacture but excludes other parties such as purchasing, marketing or maintenance from the process. From Figure 2.11, it seems that all the processes are carried out in sequential order even though some of them can be executed in parallel. The framework did not include what tools to be used at which stage and did not show other factors such as technology and customer input that are necessary for the success of any NPD project. The framework is incomplete and not suitable for ETO companies even though it is very simple and easy to understand.

Most of the NPD frameworks from the literature are meant for an MTS company. The design framework or models proposed for an MTS company are not suitable to be applied by an ETO company due to various differences discussed in the previous section. Very little attention is given to an ETO company that produces products on a low volume basis especially in terms of an NPD framework. Most of the works on ETO in the literature are in machine design and the content is quite technical in nature (e.g. Agerman, 1991; Ito et al., 1989; Siegert et al., 1997; Takeuchi et al., 1989). There is no discussion about the framework used in developing the products. Rahem (2003) highlighted most NPD frameworks centred round MTS manufactures, furthermore the work focused developing a NPD-ETO framework.

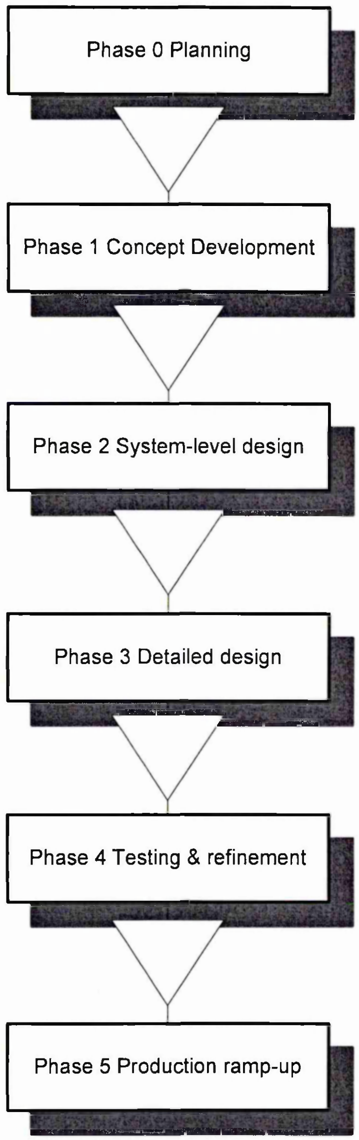

Figure 2-11; Adapted from Ulrich & Eppinger (2000)

The previous NPD frameworks discussed above in Section 2.6 are based on the findings of Rahim A., and Baksh, M., (2003), they highlighted that most of the NPD frameworks where unsuitable for MTS companies. A summary of the frameworks is shown in Table 2.7. The common features of the frameworks which make them not suitable for ETO are:

- Do not include other parties in the process (e.g. customer, supplier, contractor)
- Do not show after assembly or manufacturing activities such as delivery, commissioning and hand over to the customer which is common for an ETO product
- Do not to show concurrency between activities
- targeted for designers and manufacturers and leave out other parties
- Do not show the use of concurrent engineering tools and techniques in detail at different project stages; and flow of activities represent MTS operations

Author	Target Organisation	Target Audience	Design and Development Process	Tools Applied	Design Management Issues
Pugh (1991)	MTS	Technical	Yes	No	No
Boothroyd et al (1994)	MTS	Technical	Yes	DFMA	No
Peters et al (1999)	MTS	Technical and management	Yes	QFD, FMEA, DFM/A, CA	No
Ulrich & Eppinger (2000)	MTS	Technical	Yes	NO	No

Table 2-7; Summary of previous NPD frameworks (Rahem et al 2003)

2.9.2.5 Framework by Rahim and Baksh

Rather than adopting the generic model or framework proposed for an MTS, an ETO manufacturing company needs to use a new set of framework (see Figure 2.12) that reflect its needs and business operations. Differences between ETO and MTS identified further emphasized the need for a dedicated NPD framework for an ETO company.

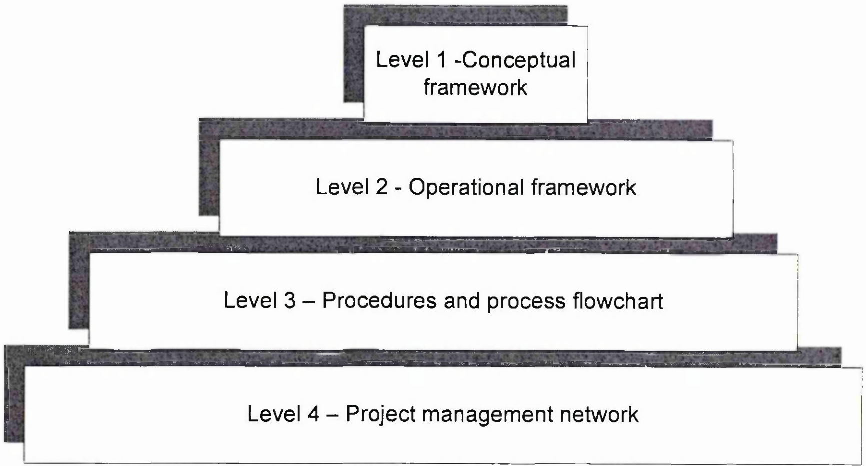

Figure 2-12; Levels of NPD framework for ETO (Rahem et al 2003)

The framework addresses some of the issues related to concurrent engineering as this will help in speeding up design and manufacturing as well as reducing iterations and backtracking between activities. The NPD framework was developed to ensure that the product can be delivered on time, especially for new products that need to be developed from scratch. As well as support the intensity of the design activity making, project planning as well as the implementation stage. Due to the unique operations of ETO Rahim et al (2003) also recommended that the framework should included the following additional features:

- Covers all aspect of design conception to product delivery and handover
- Clear link and shows relationship among all activities and processes
- Shows all elements that will determine the success of ETO operations
- Easy to understand and straight forward structure
- Not too prescriptive in nature
- Act as roadmap for project planning; and
- Specify the tools and techniques to be applied at each phase of the framework

Similar to all decision problems, NPD decisions are affected by many uncertainty-causing elements that confuse the decision maker to reach targeted performance.

Uncertainty is an information defect (Spender, 1993), which may be defined as the difference between the amount of information required to perform a particular task and the amount of information already possessed (Galbraith, 1973). It arises from a multiplicity of sources including technical, management and commercial issues, both internal and external to the project. It is also widely recognised and accepted that successful management of uncertainty is intimately associated with project success, as the proactive project manager constantly seeks to steer the project towards achievement of desired objectives (Hillson, 2002). Thus, it is critical to use a structured approach that can minimise the uncertainty at NPD projects.

2.10 Knowledge Management in ETO

The previous section discussion showed a number of tools, techniques and methodologies of the NPD process have changed over time in an attempt to become more efficient and effective. Earlier ways of organising and managing product development activities have been modified or replaced with methods and practices considered to be more desirable. The NPD literature includes many reports of such practices which, taken together with the process models, shed more light on what might be regarded as 'best practice' Table 2.3 shows how the features of current 'best practice' compare with the traditional approaches.

2.10.1 Knowledge Management

Before we discuss knowledge management, let us clarify what we mean by some common terms in this field. The term knowledge is defined in the Oxford Dictionary and Thesaurus (1995) as: "awareness or familiarity gained by experience (of a person, fact, or thing)", "persons range of information", "specific information; facts or intelligence about something", or "a theoretical or practical understanding of a subject". A more philosophical (and positivist) view of knowledge is to see it as "justified true belief" (first introduced by Plato, according to (Nonaka and Takeuchi, 1995). Davenport and Prusak give a broader definition of knowledge (Davenport and Prusak, 1998): "Knowledge is a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experience.

2.11 Knowledge Sharing

In the literature knowledge sharing is used in two ways. For some authors, knowledge sharing is mainly seen as part of exploitation (e.g. McElroy, 2003) and others consider it part of the exploration phase (e.g. Swan et al., 1999). Exploitation refers to the processes where existing knowledge is captured, transferred, and deployed in other similar situations. Exploration, on the other hand, involves processes where knowledge is shared, synthesized and new knowledge is created (McElroy, 2003). In our opinion there is a difference between knowledge sharing as part of knowledge exploration (production) and knowledge sharing as part of knowledge exploitation (integration). Knowledge sharing in order to integrate knowledge takes place from one actor to many others at once ("broadcasting"). Knowledge sharing as part of knowledge production takes place more in the form of discussions, working together to solve a problem: actors define the problem together, discuss options, share knowledge to find a solution together. Within this view, knowledge sharing is not as wide and random as in the previous view, but more focused and structured. Since we view new product development as problem solving, and are interested in knowledge sharing that facilitates problem solving, in this research we consider knowledge sharing as part of the knowledge production process. This means that we assume members of NPD teams to actively and keenly share knowledge, but do so directly with others who may need this knowledge, rather than using broadcasting mode. As a result, within this view it makes much sense to study knowledge sharing as a network.

2.11.1 The richness of knowledge sharing

Knowledge management is an ongoing procedure that refines raw information and shares it across boundaries in the organization. It is a "bottom-up" process that develops and exploits the "tangible assets and intangible knowledge resources" of the organization (Smith, 2001, p. 313). Some have described this process as "reusing intellectual assets" (Davenport et al., 2003).

2.11.1.1 Explicit Knowledge

Most explicit knowledge is technical or academic data or information that is described in formal language, like manuals, mathematical expressions, copyright and patents. This "know-what," or systematic knowledge is readily communicated and shared through print, electronic methods and other formal means. Explicit knowledge is technical and requires a level of academic knowledge or understanding that is gained through formal education, or structured study. Explicit knowledge is carefully codified, stored in a hierarchy of databases and is accessed with high quality, reliable, fast information retrieval systems. Once codified, explicit knowledge assets can be reused to solve many similar types of problems or connect people with valuable, reusable knowledge. Sharing processes often require major monetary investments in the infrastructure needed to support and fund information technology (Hansen et al., 1999). Acts of gathering and using explicit knowledge assume a predictable, relatively stable environment. Marketplace competition, changing customer needs, among other factors, reduce stability.

Examples 1 and 2 illustrate the use of explicit knowledge.

- Example 1. The 82,000 worldwide employees of Ernst & Young are creating a global brain of explicit knowledge to include cultural differences. Their repository of global "best practices" is founded on sharing and documenting knowledge. They approach business issues from an array of perspectives. No matter where in the world a problem occurs, there is "no one right answer" but many workable approaches. Ernst & Young view knowledge objects as templates of core insights that can be used in any cultural environment (Wah, 1999a).
- Example 2. Andersen Consulting (now Accenture) created elaborate ways to codify, store and reuse explicit knowledge. Its "people-to-documents" approach extracts information from the person who developed it and makes it independent of its developer. All client-sensitive information is removed and selected information is reused. Information is transformed into a proven, successful solution that can be used in the same or similar industry (Hansen et al., 1999)

2.11.1.2 Tacit Knowledge

Tacit knowledge is defined by Michael Polanyi as knowledge that cannot be articulated or verbalized; it is a knowledge that resides in an intuitive realm. Polanyi (1966, p. 4) concisely captures this notion with the phrase:

"We know more than we can tell".

Tacit knowledge is the antithesis of explicit knowledge, in that it is not easily codified and transferred by more conventional mechanisms such as documents, blueprints, and procedures (Kreiner, 2002). Tacit knowledge is derived from personal experience; it is subjective and difficult to formalize (Nonaka et al., 2000). Therefore, tacit knowledge is often learned via shared and collaborative experiences (Nonaka and Takeuchi, 1995); learning knowledge that is tacit in nature requires participation and "doing".

The literature of knowledge management (Baumard, 1999; Nonaka et al., 2001; Choo, 1998) describes the knowledge transfer process as including the following sequence of steps:

- Tacit to tacit (often called "socialization," which occurs through apprenticeship, mentoring, or collegial relations; this step has also been described as "implicit learning" or "learning by doing").
- Tacit to explicit (often called "externalization" or "articulation;" this step includes knowledge that is usually written down or communicated in some permanent or semi-permanent way; stories, narrative, multi-media presentations, group reflection, conversations, e-mails, and memos are all examples of this type of knowledge transfer).
- Explicit to explicit (often called "combination," usually through a standardized and systematic procedure; an example would be a computer database or an expert system).
- Explicit to tacit (often called "internalization," which results in the distribution of knowledge throughout the organization and beyond; this often comes through active participation and repetition).

According to knowledge management theorists (Zack, 1999; Choo, 2000; Kesner, 2001b), there are generally three separate but related steps in codifying knowledge once it has been made explicit. First, the organization should create "warehouses" of explicit knowledge, a process known as internal codification (Choo, 2000). These materials can be collections of paper documents, links to Web pages, rough drafts in electronic form, e-mail messages, or notes from discussions or interviews. Second, the organization should create mechanisms that will refine the collected explicit knowledge, extract valuable content, and turn it into a more usable form. This step will add value to the knowledge through a taxonomy that will include controlled vocabulary and appropriate cross-referencing. Third, the organization must provide for appropriate technologies that will support this entire process. This "delivery platform" must be able to push and pull content (through subscriptions and through searchable databases) for various groups in the organization. These three steps turn raw knowledge into refined knowledge.

2.11.2 Sharing Knowledge in NPD

A number of studies (e.g. Petrash, 1996; Gupta and Govindarajan, 2000; Olivera, 2000; to name a few) indicate that practicing knowledge sharing (KS) results in improved organizational effectiveness. Moreover, Knapp (1998) proposes that knowledge assets concern all sectors of the economy. This suggests that hoteliers implementing KS would find the costs in terms of time, effort and money would be repaid in terms of overall hotel effectiveness. Consequently, owners would gain more assets in terms of knowledge that can improve business outcomes.

2.11.2.1 What is Knowledge Management to NPD-ETO?

Now, we will first discuss the term Knowledge Management in general and capital goods product development, and then introduce a model for what a knowledge management initiative, or system, can be in a company. Finally, we discuss some success factors in working with knowledge management initiatives in companies.

There are many interpretations of knowledge management, and of how to describe computer systems to support it in companies. In 1974, the book "The Corporate Memory" was published (Weaver and Bishop, 1974), arguing on the benefit of collecting information from different sources in a company and making it "searchable". At this time, the information was gathered on paper, and "search" would mean to submit a form to a department who would manually search through their files. The word corporate memory is still in use, but now meaning a database for storing documents from many people in a company. The word "corporate brain" is also used to describe such a database. Another related word is "organizational memory", which does not really have a clear definition, but "intuitively, organizations should be able to retrieve traces of their past activities, but the form of this memory is unclear in research literature. Early efforts assume one could consider memory as though it were a single, monolithic repository of some sort for the entire organization" (Ackerman and Halverson, 2000). Many see this term as meaning both a process of collecting and using information as well as a repository. So what do we mean by knowledge management? We think that this term includes issues from all the terms discussed. Some goals of knowledge management can be (Wiig, 1997):

1. To make the enterprise act as intelligently as possible to secure its viability and overall success and
2. To otherwise realize the best value of its knowledge assets.

Thomas Davenport has defined it as "a method that simplifies the process of sharing, distributing, creating, capturing and understanding of a company's knowledge" (Davenport et al., 1998a). If we look a bit more into knowledge management, we find that some important aspects are to (Wiig, 1995):

- Survey, develop, maintain and secure the intellectual and knowledge resources of the enterprise
- Determine the knowledge and expertise required to perform work tasks, organize it, make the requisite knowledge available, "package it" and distribute it to the relevant points of action
- Provide (...) knowledge architecture so that the enterprise's facilities, procedures, guidelines, standards, examples, and practices facilitate and support active knowledge management as part of the organization's practices and culture

This seems to be in line with what people from two different software companies that we will introduce later in this thesis see as knowledge management. We interviewed 19 managers and developers about what they meant by "knowledge management" and got answers like "manage, plan, deploy, collect and spread knowledge in an organisation, and do it in a planned manner", and "to create, store, survey, use and revise knowledge".

Knowledge and knowledge management for ETO companies is connected with the concept of effective business processes. Many companies have developed efficient business processes, which they have deployed across functions (Cameron and Braiden, 1999). Indeed, the activity of developing business processes it itself is a matter of knowledge and knowledge management. However some companies, particularly those involved in major project- type activities, create business processes to suit the particular projects (Ridley and Braiden, 1997). Business processes in companies thus lie on a continuum from those that are fully mapped and supported throughout the organisation, to those created on ad hoc basis. Most business processes may be mapped in a serial fashion, but they have connections with other processes forming a multi-layered structure. For example, ETO companies have processes associated with tendering, product design, manufacturing, installation, and commissioning. However, decisions made within a process are strongly influenced by the availability and the quality of knowledge and information obtained from other processes. Furthermore, early stage decisions have an impact on subsequent processes, their solution space and constraints. These interactions between knowledge, decisions and multilevel process significantly increase the complexity of knowledge management activities.

2.11.2.2 Why is Knowledge Management a Good Approach?

After having seen some different possible solutions to some of the common problems in software engineering, why would we suggest another one like knowledge management? Let us first discuss why this approach is relevant for capital goods manufacturers, and why it is interesting as a research topic. Our main argument why knowledge management is a good solution to common problems in MTO/ETO product development is that MTO/ETO product development is knowledge-intensive work, and knowledge-intensive work can be improved by managing knowledge better. We claim that MTO/ETO product development is knowledge-intensive because:

1. To develop MTO/ETO manufacturers require deep technical knowledge in many specific domains. Design Development; Problems and Remedies

2. The required knowledge is changing because of technological changes, and because the market wants new solutions. So, it requires knowledge both to do a good job, and also to cope with rapid changes in both technology and needs in an contract specification. Then we reach our second step in the argument: Knowledge intensive-work can be improved by managing knowledge better, because:

   (i) Work that requires knowledge can be done better if you know that the knowledge is relevant and up to date, which requires learning.

   (ii) To ensure that you learn relevant knowledge, it is best to learn from you own environment, which is the essence of knowledge management. This also means that you "try to make the best out of the resources you have available already".

   (iii) To improve knowledge work, we need a holistic approach with both technical and organisational aspects. People learn better when they are motivated to do so.

   (iv) Focusing on managing knowledge will activate local knowledge that exists in a company.

Some knowledge is easier to transfer to others if it is written down, like in a (possibly) formal document. Frederik Brooks writes about this in his book The Mythical Man-Month about software development, where he recommends that "no matter how small the project, however, the manager is wise to begin immediately to formalize at least mini-documents to serve as his database" (Brooks, 1995). Of course, many companies are interested in having knowledge from employees written down - to make it easier to replace the employees if they leave for another company, or another position internally. This is an issue that can make normal employees sceptic to knowledge management, as this can reduce their "value" in the company. However, we can also expect the contrary to be the case: that employees that are good at sharing knowledge with others become even more valuable for a company than before.

Hicks 2002 acknowledged that knowledge management has a promising set of methods and tools, that could help knowledge workers in performing their job better, and that will probably be used in many different occupations in the future. It seems that the last years' focus on knowledge management has made a business climate for learning, and even learning "on the job". The field of knowledge management is also a truly interdisciplinary arena, where many communities including artificial intelligence, organisational development, software engineering, pedagogy and psychology meet.

Knowledge management is a field dominated by a lot of hype and a mixture of theory and technology from different research fields. It can be difficult to understand the different knowledge management initiatives.

2.11.3 Success Factors in Knowledge Management Initiatives

Davenport, Long and Beers (Davenport et al., 1998b) studied 31 knowledge management projects in 24 companies - by interviewing people in the companies. They identified eight "success factors" in these projects, which were:

- Link to economic performance or industry value
- Technical and organizational infrastructure
- Standard, flexible knowledge structure
- Knowledge-friendly culture
- Clear purpose and language
- Multiple channels for knowledge transfer
- Senior management support

Another study about a knowledge management initiative in the Buckham laboratories (Pan and Scarbrough, 1999) also conclude that "specifically, the task for the organization is to continuously create and maintain a knowledge-enterprising culture and community whereby associated feel comfortable with knowledge and are motivated, rewarded and entrepreneurial". They further find that knowledge management systems "involve more than technology but rather a culture in which new roles and constructs are created". The importance of organisational factors is also stressed in a study from an American Consulting company. The introduction of a groupware system for sharing experience was unsuccessful, because of a very little collaborative culture, and few structural incentives for cooperation (Orlikowski, 1992).

A fourth study that we have found, is McKinsey's survey (Kluge et al., 2001) on knowledge management in 40 companies in Europe, the US and Japan. They tried to find success in knowledge management initiatives by looking at companies "process performance" and financial success. The findings of this survey was that companies that are more "successful" focus more on the following factors (non-extensive list) in knowledge management: development efficiency, process efficiency, quality standards, product innovation. We also find factors such as "active involvement of employees in process improvement decisions" and "financial incentives for cooperation, information flow in production".

2.11.4 Project Learning

We now describe two ways of capturing knowledge from projects: writing experience reports (usually written by a project manager), and a more structured method which involves as many people as possible from a project team, namely postmortem reviews. In recent years the number of tasks and the amount of work within a company, which is being managed in the form of projects, is growing very fast. There is no end of this trend to be seen, because key characteristics of project organizations address success factors of companies: high flexibility, interdisciplinary work, promoting innovation.

Additionally, the need for better project efficiency increases and the length of projects becomes more and more important. Development projects are made urgent by the influence of "time-to-market", internal projects should show their benefits as soon as possible. Time pressures can result in some short term optimisation. The phrase "reinventing the wheel" stands for such tactics, where existing knowledge and experiences cannot be accessed and used, because these are not stored and disseminated.

Increasing complexity of project work caused by a growing number of technical and social relationships and interfaces to be considered gives higher value to existing knowledge in order to deal with complexity and to increase efficiency. For that reason projects have to adapt knowledge and experiences from the daily work of a company within the routine organization and from former projects.

Project team members can be the main carriers for knowledge and experiences from daily work, they bring this input into a project team, e.g. for application development projects the future users of an application system. The terms "user participation" and "user involvement" stand for ways to transfer knowledge and experiences from users and functional experts to developers. Also internal documentation, standard operating procedures (sop) etc. contains knowledge, which can be reused in projects. Additional, experienced users and experts can be interviewed during requirements analysis. So the transfer of knowledge from routine organizations to projects is regarded as well established.

The transfer of knowledge and experiences from projects to the routine organization is explicitly assigned and addressed within the project management: product documentation takes this role, for example in the form of a technical drawing, which is given to the production department as a part of a technical solution worked out in a project, or in the form of users' manual and operating instructions for an application software, where knowledge about usage and handling of the application is documented for users and system administrators. Training courses and materials have similar functions to transfer knowledge about an application from the developer to the user. However, with these tools and techniques only knowledge and experiences with regards to the working results of projects can be stored and disseminated. Prospective readers are users of project results working in the routine organisation, e.g. users and administrators of an application system.

In contrast to this, knowledge about methods and tools used in the project, which might be useful to other workers in the routine organization or – even more – useful for members of following projects cannot be transferred with these methods. In parallel, the transfer of knowledge and experiences from preceding projects about methods and tools used should be passed on to following projects.

2.11.5 Two Strategies for Managing Knowledge

We can divide between two different usages, or strategies for knowledge management (Hansen et al., 1999):

- Codification - to systematize and store information that represents the knowledge of the company and make this available for the people in the company. If we look at the models for learning we presented earlier, this is what Nonaka and Takeuchi calls "exter-nalisation" - to make tacit knowledge explicit. In Kolb's model, this is when you reason with symbolic representation, and make abstract ideas of your experience, what he refers to as intention
- Personalization - to support the flow of information in a company by storing information about knowledge sources, like a "yellow pages" of who knows about what in a company. Referring again to the previous subchapters on learning, we can think of a community of practise as an environment that focuses very much on person to person communication, what Nonaka and Takeuchi calls socialization. In Kolb's model, this could include both modes of the grasping and transforming dimensions

Hansen et al. argues that companies should focus on just one of these strategies.

We should add here that the codification strategy does not fit all types of knowledge. In situations where knowledge is very context dependent, and where the context is difficult to transfer, it can be directly dangerous to reuse knowledge without analysing it critically. For some more examples of problems with this strategy see (Jørgensen and Sjøberg, 2000). Another strategy than the two mentioned above could be to support the growth of knowledge - the creation of new knowledge by arranging for innovation through special learning environments or expert networks, but that is beyond the scope of this thesis. When we go on to discuss product knowledge in ETO and associated processes that support project-based learning, we will restrict the scope to systems supporting the first two strategies. Note that some have referred to these strategies by other names: Codification can also be called "exploitation", and personalization "exploration" (Mathiassen et al., 2002).

2.11.5.1 Processes for Knowledge Management

What activities can an organisation perform to promote knowledge management? If we return to our three models of learning, we can say that to improve working conditions for different "communities of practise" can be one activity. This would be similar to knowledge transfer in different arenas through socialization. If we turn to Kolb, we should try to make room for reflection on experience in order to improve learning processes in a company; and understand that different people have different learning modes that they prefer. No learning recipe will suit all people. If we turn to Nonaka and Takeuchi, codifying (externalising) tacit knowledge and writing it down can be one activity, having a group of people to combine explicit knowledge a second, and finally making such externalised knowledge available for people to learn from.

As an example of a knowledge management process, we will now describe varieties of processes for "externalising" tacit knowledge, and making it explicit, what we can call "harvesting knowledge" or "knowledge acquisition".

2.12 Systems Modelling Techniques

2.12.1 System Analysis and modelling

Systems analysis and modelling techniques are commonly used by engineers seeking to understand complex systems. They are particularly applied in identifying and defining information technology requirements. Bravoco and Yadav (1985) reviewed a number of methodologies that may be used in modelling systems. They distinguished three types of model.

1. Functional Models which decompose complex systems using a hierarchical, top-down approach. They provide a means of understanding processes and their interrelationships. Example include: the structural Analysis and Design Technique (SADT) which produces graphical representation of the hierarchical structure of the system. Diagrams contain boxes, with represent processes, and narrow arrows represent interface between subsystems. Each box has four sides corresponding to inputs, outputs, controls and mechanisms. The processes transform inputs into outputs using mechanism, within the constraints defined by controls (Ross 1977). The Checkland

Method is a "soft" systems modelling approach which aims to provide a way of seeing the pattern in diffuse, ill structured problems which takes into account that there may be many different views of any particular system (Checkland 1972).

2. Information Models may be used for describing and analysis the information used within a system. They commonly used for defining the data structures used in computer database applications. They consist of graphical notations which show entities and their interrelations, together with attributes, primarily and secondary keys and relationship types (1:1, 1:n or n:1). Howe, 1993, considers the development of entity relationship diagrams in detail.
3. Dynamic models describe the dynamic characteristics of systems using graphical notions. Examples include Activity, of Life Cycle Diagram (Hutchinson 1975) which symbolises states as circles and activities by boxes. Petri-Nets have also found wide application (Peterson 1975).

The structured systems Analysis and Design methodology (SSADM) is a framework for system analysis and the development of information systems that includes functional, information and dynamic modelling techniques (Cutts 1991). McGovern et al 1999 describes the use of the SSADM methodology for analysing knowledge based processes in ETO/MTO companies. The Integrated Computer Aided Definition (IDEF) also aimed to support functional modelling (IDEF0) information (IDEF1) and dynamic modelling (IDEF2). These methods are reviewed by (Braiden, et al 1996). A common limitation of these models is that they neglect the significance of tacit knowledge, information systems and personal routines and knowledge workers.

The identification of the appropriate performance criteria for the various business processes is also an important consideration. Profile analysis is commonly used technique that relate to achieved performance and market requirements and to identify appropriate changes that can lead to improved competitiveness (DTI undated). This approach was applied by (Braiden et al 1996) to ETO companies in the capital goods industry. It was identified that product performance and functionality were hygiene functions with price, delivery performance were key competitive factors. The need to reduce lead-times has increased the use of concurrent engineering and modelling and analysis software. In the ETO sector, the duration of product development activities influences delivery performance. This contrasts with companies that produce products in high volume on the MTS basis. In this case NPD times determine the time to market.

Systems analysis and modelling techniques are commonly used by engineers seeking to understand complex systems. They particularly applied in identifying and defining in formation technology requirements. (Bravoco et al 1985) reviewed a number of methodologies that may be used for modelling systems.

2.12.1.1 SSADM

The structured systems Analysis and Design Methodology (SSADM) is a framework for systems analysis and the development of information systems that include functionality, information and dynamic modelling techniques (Cutts 1991). (McGovern, et al 1999) described the use of SSADM methodology for analysis knowledge based processes in ETO/MTO companies. The Integrated Computer Aided Manufacturing Definition (IDEF). These methods are reviewed by Bravoco and Yadav (1985). A common limitation of these models is that they neglect the significance of tacit knowledge, information systems and the personal routines of knowledge workers.

The identification of appropriate performance criteria for the various business processes is also an important consideration.

2.12.1.2 IDEF

In ETO companies, the sequence of processes and the procedure relations for the various business processes is an important issue. This also applies to the generation, use and reuse of knowledge and information. The literature on the NPD/Design management includes some of the tools and techniques that may be used to identify the process and the procedural relationship and group activities together in a systematic way to facilitate integral team building. The approach involved mapping the process into an array the relationship of activities between the task. There are three situations: a) serial, or dependent tasks; b) independent tasks that can be performed in parallel and (c) independent or coupled tasks. The management of these task of (a) and (b) are relatively straight forward, however, task (c) may prove more difficult due to interaction causing iteration problems.

A variety of methods and tools can be used to promote enterprise information system development. The work of Shena, Wall, Zarembab, Chena, and Browneb, (2004) classified the modelling methods and techniques most frequently used which is summarised in Figure 2.13.

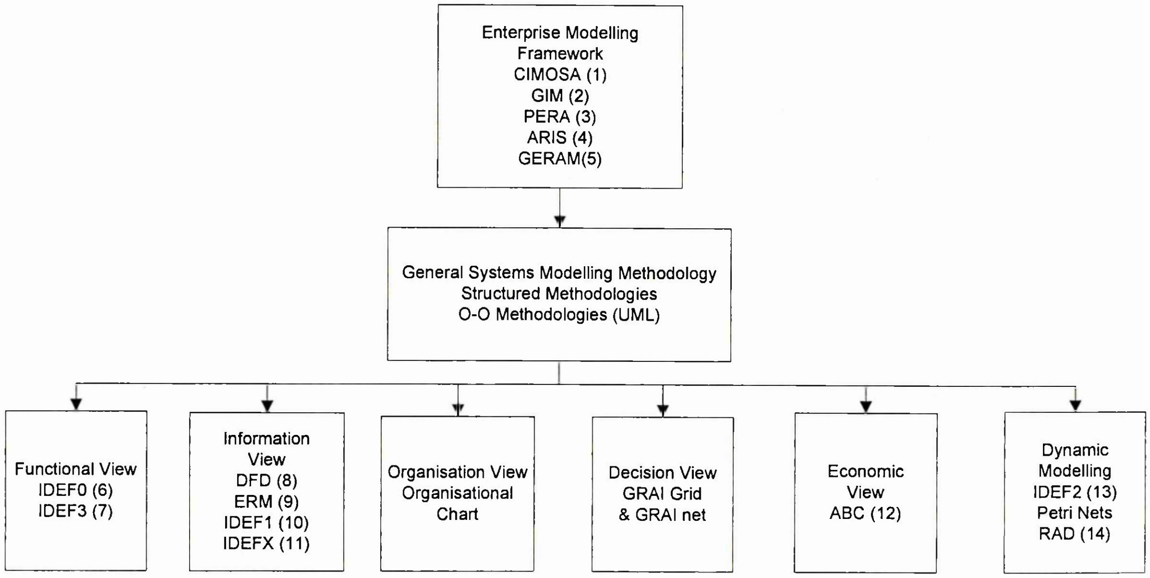

Figure 2-13; A classification of modelling methods and techniques (Shena, H., Wall, B., Zarembab, B., Chena, Y., and Browneb, J., (2004).

IDEF0 is a standard modelling method used to establish function models, which has already been accepted by most experts and end-users in this field. It was derived from a well-established graphical language, the Structured Analysis and Design Technique (SADT), and has only two types of graphic notation, the activity box and boundary/interface arrow. Diagrams are formed based on the Inputs-Controls-Outputs-Mechanisms (ICOM) Code and there are strict syntax and semantic rules, which ensure that the model is described precisely. Because of its rigor, it can be integrated seamlessly with other types of models such as IDEF1X (Cheng 2000) and is explained in more detail in section 6.4.1 below.

The deficiency of IDEF0 models is that they only describe the functions, the information connection (ICOM) between them and the precedence. The logical and sequential relations among different activity units cannot be described clearly. In order to combine the advantages of the modelling method and make NPD-ETO tasks easier to grasp, thus maximise the effect of knowledge sharing, the implementation guideline for a staged modelling method using IDEF0 will be presented in chapter 6.

2.13 ETO 'Good Practice' Summary

The section has shown how NPD practices have caused severe problems for such as MTO and ETO manufacturers had they been left unchecked. However, these changes are unlikely to be sufficient to cope with future challenges caused by changes in the NPD context, such as increased outsourcing, globalisation and the advances in highly specialised areas of science and technology. The need for MTO/ETO firms to change, and to continue to change, is as real as ever, which begs the questions, what might NPD-ETO manufacturing projects look like in the future?

The next generation of MTO/ETO manufacturing organisations should be in a position to make use of information and extract knowledge from information system and the business environment to maximize their return (Davenport and Prusak, 1998) and reuse knowledge for innovation (Hung et al., 2005). This approach converts data to information and transforms information to knowledge so that business intelligence can be devised and used in the decision-making process. Muda & Hendry (2002) Summarised some of the main aspects of the ETO/MTO operation that are not addressed by the general world class manufacturing techniques but are included in the MTO literature:

- The first issue, the need for integration of the production and marketing functions when bidding for customer orders, has been recognised by many researchers. Bidding is an extremely important part of the MTO customer enquiry process, as they tend to compete with other companies on the basis of price and delivery date to win new orders.
- The second issue relates to the distinct nature of the design process. MTO companies should aim to have an efficient and versatile means of developing drawings, designs and specifications for new products. This often entails having a database of products previously produced that can be modified as required.

- The third issue is regarding `repeat business a. MTO companies can be grouped into two types on the basis of customisation by individual order or customisation by contract. For the latter group, labelled as supply chain repeat business (RBC) producers, they usually aim to have contracts running over a period of time that is long enough to be able to operate under some of the efficiency regimes achieved by some MTS companies. However, they still require the flexibility to change as new contracts are constantly being negotiated. The firms that tend to customise by individual order try to gain repeat business by developing long term relationships with their customers, though each order may require quite different products. Where companies are able to gain some repeat business, efficiencies are gained and this enables them to reduce costs and therefore become more competitive on other orders for which they are bidding. Thus a characteristic of a 'best practice' would be to have achieved some success in obtaining both repeat business and the consequent efficiency gains.

- The flexibility of process referred to in the fourth issue relates to the need for many MTO companies to make a strategic decision to retain a functional layout rather than changing to cellular. The option of changing to a cellular layout may still be possible if product families can be identified and should always be considered, however it can not be assumed that this is an essential characteristic for an ETO best practice.

- Instead, more efficient methods of operating under a job shop setting need to be investigated as stated under the fifth issue scheduling and workload control. The latter concept can be used to control the total amount of work on the shop floor in such away that firms can more consistently meet promised delivery dates, an important objective for MTO firms.

- The sixth and final issue relates to one of the most basic distinctions between MTO and MTS, the inherent flexibility of their workforce. The employment of well trained, highly skilled employees has been a traditional strength, often described as craftsmanship, in the MTO sector. However, MTO workers often still need to attain higher standards in several areas including motivation, enthusiasm, housekeeping, quality assurance, preventive maintenance, and machine repair.

The section has shown how the nature of MTO and ETO manufacturing practices impact the very nature of the NPD process, due to the high levels of risk and uncertainty had they been left unchecked. However, these changes are unlikely to be sufficient to cope with future challenges caused by changes in the NPD context, such as increased outsourcing, globalisation and the advances in highly specialised areas of science and technology. The need for MTO/ETO firms to change, and to continue to change, is as real as ever, which begs the questions, what might NPD-ETO manufacturing projects look like in the future?

2.14 Conclusions

Each individual literature summary sections 2.4 to 2.13 and subsections have their own set of conclusions. The main overlapping conclusions are listed below.

1. The review of current 'good practice' within NPD presents a very different picture to the traditional approach. NPD 'best practice' implies major changes in the conduct of NPD. Changes are necessary at a strategic level, at an operational level, at a group level, and at an individual level. Table 2.3 summaries the difference between 'Traditional' and 'Best' practice in NPD. However, the way in wide successful NPD for effective manufacturing is achieved is dependent on the volume and types of products to be manufactured. It was concluded that there are a number of reasons why manufacturing should be involved in the NPD process. For example, innovation is a form of learning (Argyris and Schon, 1996) and Pisano and Wheelright (1995), explained that if manufacturing was involved earlier on in the NPD process can speed significantly.

2. Manufacturing strategies can range from completely make-to-stock (MTS) to completely make-to-order (MTO). Table 2.6 presents the core differences MTS and MTO manufacturing organisations. MTS products are based on forecasts of overall customer demand while MTO waits until customer orders are received. Generally, MTO strategies are considered more flexible. The manufacturing enterprises of MTO and ETO suppliers of capital goods are an important sector of the world economy. However despite the importance of this sectors contribution to the UK economy, it has been neglected to some extent by academic research. So far NPD frameworks for ETO are not

adequately addressed as the process is most likely derived from an MTS framework.

3. The different bodies of knowledge reviewed provide different perspectives of Knowledge Management and Knowledge Sharing with NPD and ETO, the work of Hick (2000) provided the following. First, the effective sharing of knowledge and information requires the use of common systems that support tendering, design, procurement, and project management. This requires records of previous designs, standard components and subsystems together with costing, planning, vendor performance and sourcing information. This knowledge is a key source of competitive advantage for ETO companies. The goal of this methodology and framework is to develop knowledge sharing within the NPD-ETO process.

4. The complex nature of NPD-ETO provokes the need for an analytical model for project assessment, from macro to micro levels of the organisation, in a structured process manner, the ETO issues, such as uncertainty and risk, as well as learning from 'one-off' projects. From the point of view of assessment, systems analysis and modelling techniques are commonly used by engineers seeking to understand complex systems. These methods are reviewed by Bravoco and Yadav (1985). A common limitation of these models is that they neglect the significance of tacit knowledge, information systems and the personal routines of knowledge workers. The later chapters will show how the application of process modelling in this research which enables the description of the events as they happen, as well as the robustness of the process. This assessed will be shared within the NPD-ETO process, as well as providing a case history for future projects.

Future work will attempt to develop a framework that is suitable and applicable to an ETO company that will include the features mentioned above. The framework to be developed could be modified by an ETO company to suit different requirements for each individual project and apply suitable tools for product design and development.

Chapter 3 - RESEARCH METHODOLOGY

3.1 Introduction

This chapter begins with an explanation of the research philosophy, it then outlines the strategy followed, describing the original methodical design and explanation how this has evolved with the adoption of a multi-methods approach. Section 3.1.3 also provides an overview of the research methods used, covering their objectives, sequencing and timing. The practical details of each method and the main research tools are given in section 3.4. This is followed by a critical review of the methodologies applied.

The steps taken to test and validate the research are described in Chapter 7, after the research findings have been presented and discussed in Chapters 4, 6, and Appendix A (postal survey). This reflects the sequencing of the validation process, which was designed and implemented afterwards after the research findings had been analysed.

3.1.1 Research Approach

Early on in the research process two developments occurred which led to the re-evaluation of the research strategy. First it became increasingly clear from the literature and the preliminary questionnaires, that although there was of interest in the NPD topic, little was known about the NPD process within certain manufacturing enterprises and as a result influenced the researcher to be open the area as broadly as possible. No single method, case studies included is perfect. There was a strong argument for adopting a variety of methods which would approach the research problem from different directions and help create a consolidated picture of the issues involved. Secondly, several opportunities arose which enabled the researcher to adopt a multi-methods approach and in doing so strengthened the research argument. Lewis (1998) noted that researchers should employ field-based research methods in order to cope with the growing frequency and magnitude of changes in technology and managerial methods. Case study analysis is an example of field-based research. Based on in-depth examinations of real-world operations, process and systems conditions, case study analysis can potentially improve the relevance and workability of resulting management theory (Yin, 1993 and McCutcheon and Meredith, 1993). Case research is lauded to be particularly useful in studying the product innovation process (Workman, 1993 and Dougherty, 1992). With this in mind, extensive interviews were undertaken with a number of MTO and ETO manufacturing enterprises. However it was only when the researcher was able to source a collaborating ETO manufacturer which resulted in a longitudinal case study and more of an action research approach was adopted. The framework was developed on the back of the longitudinal case study, as shown in the diagram below. However the diagram also shows other research methods that played a crucial part in the development process. Framework Design and develop took place with the industrial end user very much at the centre of the research/development from beginning to end.

3.1.2 Overview of the methods used

The main methods used fall into three categories: mailed questionnaire, mini case studies based on detailed questionnaire and a longitudinal case study. A summary of these methods is given in Table 3.1. In addition to an overall purpose (e.g. to explore the issue, to generate hypotheses) each method had distinct objectives:

3.1.3 Rationale behind the research approach

Management research is quite different from experimentally based science projects which are focused around a series of laboratory tests. True experimentation cannot be used because it is almost impossible for management research not to affect a subject's responses in some way.

Recognised literature in the field of research questioning, such as the work of Yin 1994 and Rowley 2002, states that all investigational questions can generally categorised into to main distinction types:

1. the 'How' type of questions (e.g. who, when, what and where, etc) and
2. the 'Why' type of question

Strategy	Form of research questions
Experiment	How, Why
Survey	Who, What, where, how many, how much
Archival Analysis	Who, What, where, how many, how much
History	How, Why
Case study	How, Why

Table 3-1; Classification of research strategy type (based on Yin 1994 and Rawley 2002)

Table 3.1 categorises the different strategy and suggests the type of research questions (i.e. the how, why, who, when and where etc.) they are best suited to answering effectively. It can be seen from the table that the questions falling into 'who' what and why category, are moat effectively answered in the form of documentation, surveys and interviews (e.g. 'surveys' and 'archival analysis').

The research questions asked in this thesis rely on more rigorous study, and not merely asking what a particular outcome will be, rather *can* this be done, and if so *why* is there a demand for this case and *how* can it be satisfied. This mode of questioning therefore, fits naturally into the implied 'how/why' categories, and consequent demands support in the form of history, experiments and/or case studies.

The *history* section for the field of study has been examined and presented, via an extensive literature review (Chapter 2), and has been further supported with the findings derived from a series of strategic case study (Chapter 4 interview case studies and Chapter 6, the longitudinal case studies). The case study research method allows the questions of why, what and how, to be answered with a relatively full understanding of the nature of complexity of the complete phenomenon (Meredith, 1998).

3.1.4 Research Types

Many different, and varied, types of research are available, designed for many different research areas and applications (Saunders et al 2003) and Hussey & Hussey (1997) have developed a classification model that divides them into four distinct categories:

1. The purpose of the research: exploratory, descriptive, analytical/explanatory and predictive
2. The process of the research: quantitative and qualitative research
3. The logic of the research: deductive or inductive research
4. The outcome of the research: applied or basic/pure research

Definitions of all the types of research, found to be under these four different categories, are offered being:

3.1.5 Pure and Applied Research

Pure research is a term for the type of research that contributes only to a specific area of enquiry and has no relevance or practical implications anywhere else beyond that. It is carried out with no specific application in mind other than to contribute to the knowledge pool of a particular field.

Applied research, however, is directed towards solving a particular problem that does have practical implications from the offset, and can commonly be sponsored or funded by external sources and industrial organisations.

Both pure and applied can lead to the creation or new knowledge and discovery of new facts about the phenomenon or phenomena under study. This thesis has an outcome based in the applied research field, one that is directed towards solving a particular problem(s), i.e. learning from 'one-off project', within ETO manufacturing environment.

3.1.6 Primarily and Secondary Research

Primarily research can usually described s that research involving a collection of totally new and original data via a means of an observation research methodology, data that is generally collected specifically in the pursuit of a particular research goal.

Secondary research can be generalised as that which involves no original data, instead of drawing upon only existing sources. This is usually collected as a means to establish that work has been carried out in a particular field before commencement of a programme of primary research. This can often take the form of data obtained fro books, statistics, government reports, documents etc.

The course of study utilises a combination of both primarily and secondary sources of research. For example, the experimental approach utilised in Appendix A was designed to generate primary data, on the trends and NPD practices with engineering and manufacturing companies within the UK, where as the literature review (Chapter 2) analysis established knowledge in the field of NPD 'good practice' and uses it as a basis of creating insights.

3.1.7 Qualitative and Quantitative Research

Collated research data can be divided into two categories; qualitative and quantitative data. Qualitative data is that concerned with solely associated qualities, and not with any numerical characteristics, whereas quantitative data is simply that which can be collected and expressed in a quantifiable numerical format.

Strauss and Corbin (1998) suggest that qualitative research is the most effective in gaining a better understanding of a phenomenon about which little is known yet, or in gaining new perspectives on matters about which is known already.

Quantitative research, on the other hand, has its emphasis on the measurement and analysis of causal relationships between variables (Kerssen-van Drongelen and Cook, (1997) and principally involves collecting and analysing numerical data and applying statistical testing methods.

Again, in this current course of research, a combination of both methods has been utilised. Overall, more qualitative evidence has been presented in the exploratory study than quantitative, but a level of quantitative evidence has been incorporated in order to achieve the claims. Much qualitative data was secured from the literature review in Chapter 2, and through the mini case studies in Chapter 4, with some supporting quantitative data being generated and collected through the two longitudinal case studies in Chapter 6.

The manner, by which the two types of information can be combined, so as to complement each other, is later discussed in this chapter in section 3.2 below.

3.1.8 Case Research

Case research is that which uses the findings of case studies as its basis. A case study is a unit of analysis in case research (Voss, Tsikriktsis & Frohlich, 2002). Bewerston and Millward (2002) advocate the use of case study research in an applicable research environment, and Meredith (1998) cites three outstanding strengths of case research, originally put forward by Benbasat et al. (1987), that can be used to effectively answer the research questions raised in this work:

1. The phenomenon can be studied in its natural setting and meaningful, relevant theory generated from the understanding gained through observing and actual practice
2. The case study method allows the questions of why, what and how, to be answered with a relatively full understanding of the nature and complexity of the complete phenomenon
3. The case method lends itself to early exploratory investigations where the variables are still unknown and the phenomenon not all understood

This thesis can be described as that of a modular study, brining together a series of separate components to test out and support theories drawn from the literature findings. The separate case studies, though linked via a common theme, could be equally considered as standalone studies in their own right.

Case studies were particular suited to new research areas or research areas of which existing theory seems inadequate (Eisenhardt, 1989), which is indicative of this work, and act as a perfect response to the matters raised as being the reason for this study in the opening chapter. Furthermore, the use of more than one case study to support the research findings, and to test out derived approaches, is believed to strengthen the results and increase the confidence in the theory (Amaratunga & Baldry, 2001)

3.2 Research Design

Trochim (2002) describes the research design as being an important step to be used towards structuring the overall research. It should consist of a series of flexible guidelines that connect the research paradigms to the strategies of the inquiry, assist in data collection and interpretation, and act as a roadmap towards successfully meeting the research objectives.

As discussed in Chapter 1 section 1.4 the objective of the particular research was to develop an effective tool for assisting in the knowledge sharing across NPD-ETO manufacturing projects. A definitive gap in the market for this research was identified with a subsequent business need for the development of some kind of approach tool or guidelines. The objective was therefore to satisfy this need, filling the gap in the available literature, and to impart support for the decision-making process within such NPD-ETO manufacturing projects, and to assist them in the development of knowledge exchanges being built around business processes. A basic approach was initially designed, establishing a framework and guidelines for achieving the primary objectives, which was inherent to for the most part, but for the occasional digression into unforeseen areas. The research method designed for the work is illustrated in Figure 3.1.

The model depicts the proposed stages and process flow of the project, starting with identifying the need for the research, initiating a thorough literature review, and examining the current ETO manufacturing practices, plotting its NPD process right through to the final stages of the analysis of the case study findings, drawing on the conclusions, and the making of recommendations for future work.

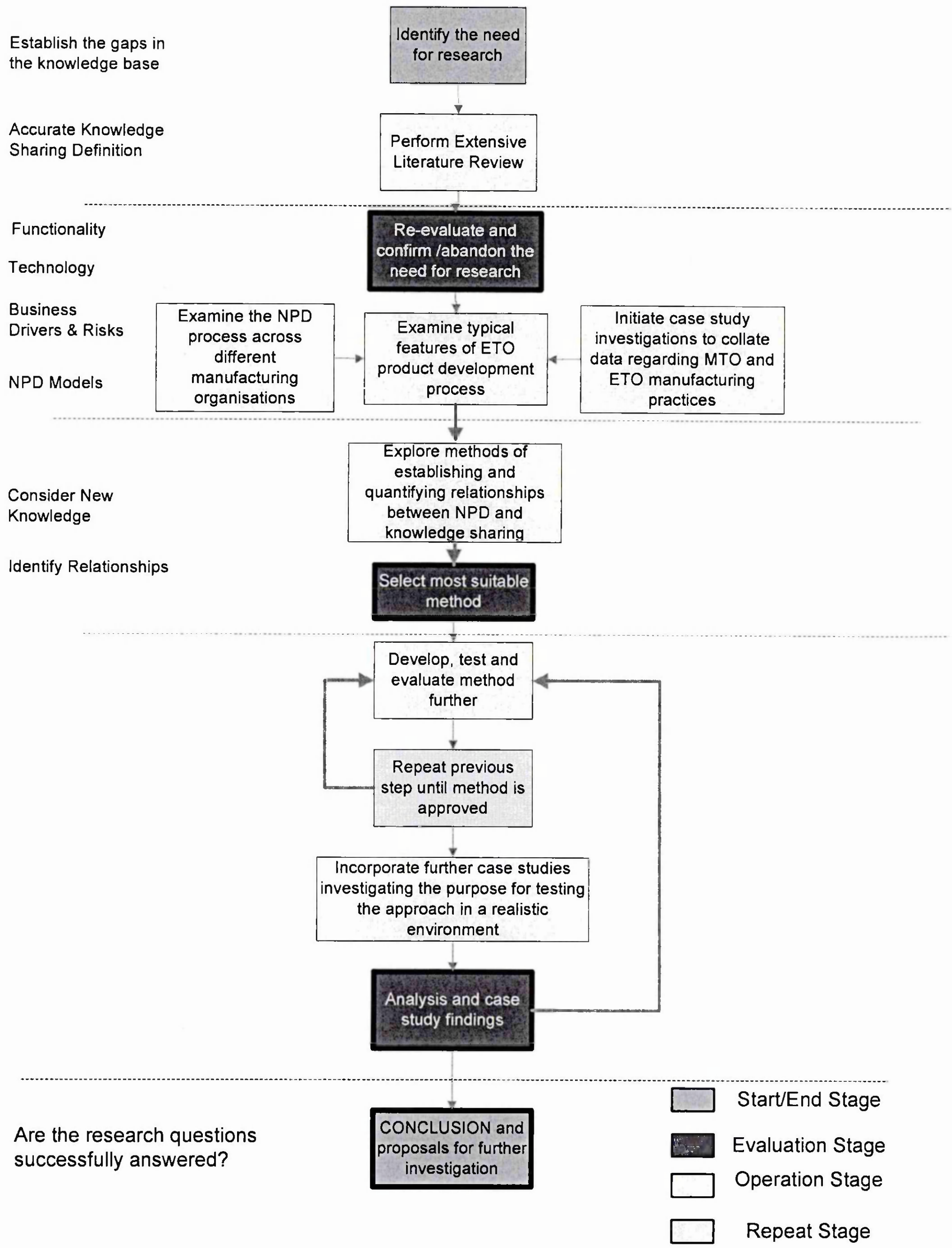

Figure 3-1; Research Approach

As discussed previously, a combination of both qualitative and quantitative, primary and secondary, research methods were eventually incorporated throughout the life cycle of this study, one which was geared towards the outcome based in the filed of applied research, and was designed to solve a particular problem with an identified practical implication from its inception.

3.2.1 Implementation of the Research Design

This section describes in detail the research program in phases. Essentially the research was divided into six phases:

- **Phase 1. Preliminaries NPD Survey & Literature Review** – through, a mailed questionnaire, literature review and academic publications.
- **Phase 2. Interview Case Studies: MTO & ETO Perspective -** through, mini case studies; detailed interviews and questionnaires; literature review; academic publications, fact finding and document analysis.
- **Phase 3. Development of the NPD-ETO Model and the Methodology**: Dev industrial analysis and review of the MTO/ETO manufacturing process and literature, and synthesis of results for formulation of the conceptual framework and methodology.
- **Phase 4. Establishing the Framework**
- **Phase 5. Longitudinal Study 'Methodology Refinement':** Longitudinal testing and refinement of the conceptual framework and methodology within the collaborating ETO organisation via industrial analysis and synthesis of results for structure of the framework.
- **Phase 6. Validation within ETO manufacture:** Longitudinal testing and modification of the conceptual framework and methodology.

The diagram below presents a summary of the research programme and gives an indication of the relative time scales of the chapters of this PhD which cover the relevant issues. Following on from the diagram is a detailed review of the research programme phases in terms of the timer scales, aims and purpose; data collection techniques and outputs or results of data analysis.

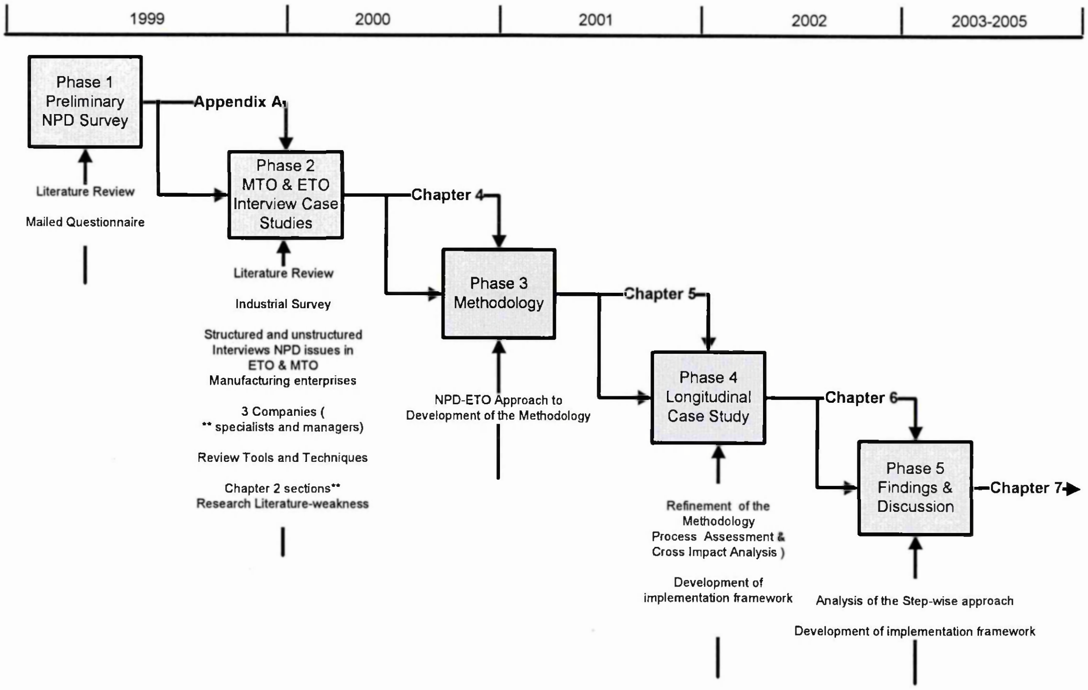

Figure 3-2; Summary of Methods Used in Research

3.3 Data Collection Methods

3.3.1 Phase 1 Preliminaries: Literature Review

Throughout the course of this research a continuous literature review has been in operation, taking in material from many different sources, including: journals, papers, white papers, books, conference proceedings, industrial publications, news groups and websites. It is important to document the valuable role of industry white papers and web based articles played in construction of the literature review. As the subject matter in this area is still regarded to be in its infancy, and rapidly changing, and with the time it takes from one academic paper being written to its receiving approval and then being published being such a lengthy one, there is a definite shortage of quality research material in this field. Industry papers and articles go some way to filling that void, and whilst one must be careful not to be drawn into using material that may be biased towards systems, however a lot of valuable information, insights and opinions can be gathered via this medium that may not yet be in press in an academic article.

Research began in the August 1999 with a literature review. Even in the early stages the research literature reveal gaps in the scope of NPD practices were being applied across different manufacturing enterprises. It became quite clear that to get a clearer understanding of NPD best practices within both engineering and manufacturing companies participating was required, particularly during assessment of the design tools and techniques. This defined the research methodology (and means of data collection). In order to get an idea of the companies the researcher carried mailed questionnaire with a number of UK engineering based and manufacturing companies.

3.3.2 Questionnaires

It was obviously of great importance to the design of the questionnaires, described in Appendix A, in such a way as to enable the extraction of data in as useful a format as possible, and in as easy manner as possible, without the need for any/much adjustment to be made after its collection. The questionnaires are probably best described as being that of a self-completion category of questionnaires, containing detailed questions, with the need for detailed responses and explanations, looking at the behaviours, attitudes and beliefs of those questioned. The intentions of the questionnaires' design was to offer a mixture of both open and closed questions, extracting both qualitative and quantitative data, and to ensure this is a rigorous piloting process was undertaken before entering the questionnaires into a full scale programme.

A certain amount of checkbox style multiple choice questions were designed into the questionnaire, such as asking the participants whether they felt that their own views best matched certain supplied statements, particularly associated with their predictions fro future activities. Checklists help to easily, quickly, and more accurately collate the data.

3.3.3 Case studies

Case studies, as well as presenting a viable means of testing out research findings in their natural environment, also off a channel by which to collect further pilot data. Case studies have been used throughout this course of work, for collecting valuable information about the current climate of MTO/ETO manufacturing organisations. Chapter 4, in studying the experiences of the company highlighting their ongoing issues and frustration (section 4.3) and in the testing out derived theories and practices associated with knowledge sharing (sections 6.3 - 6.5).

3.3.4 Phase 2 NPD Survey and Literature Review

The time scale for this phase was roughly 10 months from August 1999 to June 2000. The purpose of the survey was built on existing NPD research. The researcher carried out a survey of 150 UK-based engineering and manufacturing companies. The aim was to establish the broad goals of the research and to develop a research strategy. Two pieces of data were required:

1. Current nature and the state of the organisation issues in terms of product development, and how Design process was being managed. It was supported by literature reviews (carrying on from phase 1)
2. Tools and Techniques available for the management of NPD including the design process - research literature and software market review

A pilot study was carried out with five local engineering manufactures and enabled the researcher to gain a much clearer perspective of the research survey, and also to correct any faults in the initial design of the questionnaire. Some of these factors that were tested during the this stage included: (a) the clarity of the language used in the NPD survey; (b) the likelihood that any one person could reasonably hope to answer the issues raised in the survey instrument.; (c) it was hope that the pilot test could provide some validity of the test instrument; (d) the relevance of the questions to manufacturing industries, and finally (e) what might be the likely response rates to the survey. It provided the researcher with a good opportunity to generate some quantitative data of the NPD tools and techniques being applied within UK manufactures. The results of this survey are shown in the Appendix A.

3.3.5 Phase 2 Interview Case Studies and Literature Review

The objectives of the mini industrial survey or mini case studies intended to help in establishing the structure of, and the problems in both MTO and ETO manufacturing companies, with particular focus on the NPD process. This would help enable the researcher in defining the needs and requirements of a new framework for modelling and analysing the NPD process within such manufacturing enterprises. Essentially the questions were designed to answer the things of what to model and analyse?

The study was spread over an 18 month period and overlapped with the methodology and framework development (Phase 3) i.e. was done concurrently. The development of the framework was phased in when Phase 2 was at its half way stage. This was possible because an idea of what was required was becoming clearer at the half way stage of Phase 2, so work on the development of the framework could proceed. The study was carried out using structured interviews in a form of questionnaires and semi structured interviews targeting specific areas of interest. A survey form (see Appendix B) was developed to achieve this so that a structured analysis could take place. The form was split in three parts to gather information and data. The questionnaires were developed through interview sessions with key members of the organisation. The information was gathered from a wide audience i.e. different hierarchical levels and also different functional backgrounds. Senior managers e.g. Projects manager, functional managers and team leaders

This research used a multiple case study design to explore the similarities and the differences between MTO and ETO practices across radical projects within a sample of firms. The study of NPD practices in MTO/ETO firms has relatively little theoretical background. Case study research is especially appropriate for exploratory research, with a focus on (1) documenting a phenomenon within its organizational context, (2) exploring the boundaries of a phenomenon, and (3) integrating information from multiple sources (Eisenhardt, 1989; Meredith et al., 1989; McCutcheon and Meredith, 1993). McCutcheon and Meredith (1993) argue that case studies are a powerful tool for gathering information and understanding the real conditions that are occurring in manufacturing organizations. To understand each case, the researcher interviewed senior management, project managers, and individual team members. Using multiple interviewees reduced the risk of undue influence that an individual interview may have on the case study, and brought a richer portrait of each case (Yin, 1989; Eisenhardt, 1989; Flynn et al., 1990).

It became quite clear that to get an understanding of the problem and to develop a better solution, significant involvement with participating MTO/ETO manufacturers was required, particularly during the development stages of the conceptual framework and methodology. This defined the research methodology (and means of data collection). In order to get an idea of the companies the researcher carried out semi structured interviews with key people in the participating companies, briefly observed and recorded how NPD-ETO was generally carried out and analysed the associated documentation used when developing new products. Observations were compared among the research team at the conclusion of each visit. Convergence of opinions from the various researchers involved enhanced confidence in the findings: as conflicting views keep the research from premature closure (Eisenhardt, 1989). To uncover and examine the key themes in the data, the researcher used the approach outlined by Miles and Huberman (1984), Yin (1989), and McCutcheon and Meredith (1993). In particular, we used a cross case or multi-case method used for exploring and describing themes. This approach allowed the researcher to understand the phenomena beyond each individual firm's context and increased the generalisation of our observations (Eisenhardt, 1989).

The interview data were transcribed and a representative set of the interviews was used to establish common themes emerging from the data. From the themes, eight general categories emerged to classify the data. Each interview was then reduced, analyzed, and coded separately by the author and a doctoral student. The results of each independent analysis were then compared. This pattern of coding and data reduction was repeated twice following the procedure suggested by Miles and Huberman (1984, p. 57). These codes were then used to retrieve and organize the data groupings of data for each project. In addition, observations and emerging themes were cross-checked with other researchers involved in the innovation study. This analysis narrowed the data into five main categories: competence, alliances, the NPD process, risk, and finding a divisional home.

3.3.6 Phase 3 NPD-ETO Model and the Methodology

Based on the conclusions and knowledge gained from the literature review and interview case studies it was possible to integrate and develop the requirements for the methodology and model which addressed the weaknesses in the existing approaches; purpose of these interviews was to establish:

- a map of the ETO-NPD process via 4 interview companies

- to highlight the critical decision-making points within the NPD-ETO process

This was the second most important data phase with the aim of establishing the NPD-ETO model and what should go into the methodology and how the company highlights the critical issues with the NPD-ETO project which is defined as the Points of Commitment[4] within NPD-ETO projects, and how it shares this knowledge and experience across other ETO projects both past and present.

The time scale for phase 3 was roughly 12 months.

3.3.7 Phase 4 Longitudinal Study 'Methodology Refinement'

The objectives of the longitudinal survey followed on from the previous phases. The longitudinal study was intended to further develop the proposed methodology into the support framework for modelling and analysing the NPD process within such manufacturing enterprises.

Altogether this activity lasted 18 months from September 2000 to 2002. The first phase of this was carried out Sulzer Pumps (UK) Ltd over a 12 month period. The implementation took place during live (ETO-NPD) projects. The senior management team at Sulzer gave me the task of using and implementing the system. The quality manager himself took responsibility of implementing the methodology and tool. Lessons learned were used further to develop the framework to be tried out on key stages of the ETO-NPD process. The second and final stage of the testing was phased in as the first approach to its conclusion. The second phase Chapter 6 describes the results of testing and subsequent developments in detail.

- the extent to which knowledge sharing which is or is not being applied to the NPD-ETO projects
- the extent to which knowledge sharing / organisational learning could or could not be applied to the NPD-ETO process

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[4] A Point of Commitment refers to when an individual makes a decision on behalf of the company that will take a significant amount of resource and cost to change.

This was the third most important data phase with the aim of establishing the framework and what should go into the methodology.

In addition to the normal methods of testing frameworks (self testing and interviewing end users etc). Ethnographic methods were employed. The researcher would attend project meetings, monitor how the design engineers carried out their day to day duties and liaise with other members of the project team to see how they viewed the use of the system by the project engineers. He would then modify and improve the analysis methodologies accordingly. Various typed of processes within the six-stage ETO-NPD were modelled and analysed.

3.3.8 Phase 5 Establishing the Framework

Based on the conclusions and knowledge gained from the literature reviews, interview case studies and longitudinal survey it was possible to investigate and develop the requirements for the framework, which addressed the weaknesses identified in the existing approaches; provided the necessary knowledge management tool for supporting knowledge sharing or addressing real life 'Hot Spots' of uncertainty in NPD-ETO process and project management issues. The requirements were characterised in terms of where, when and how.

The aim was to develop a process modelling approach as a foundation upon to analyse and hence model the NPD-ETO process. The earlier field studies and literature identified that the process modelling approach method should be highly structured allowing for detailed analysis, of inputs, controls, outputs, methods and communication links. A corresponding approach was required, which clearly defined the critical decision-making points or vulnerabilities and the use of weightings to get accurate answers, which identified the level of robustness of the activity. The outputs should be in the form of:

- IDEF0 NPD-ETO process
- Resource Quality
- Resource Usage and Cross Impact Analysis
- Process Performance

- Knowledge Sharing / Project Learning

3.3.9 Phase 6 Validation within ETO manufacture

In an attempt to increase the validity of research findings, by using multiple supporting methods instead of just one, Jick (1979) developed the technique of "multiple operationalism" or triangulation. Triangulation is believed to help overcome the potential bias and weakness suffered through using a single method to support the research findings (Denzin & Lincoln, 1998; Erzberger and Prein, 1997) and is the combination of both qualitative and quantitative methods.

Various forms of triangulation have been identified, commonly in the use in many research fields, and some of which have been used in validating the research. Easterby-Smith et al (1996) support triangulation but war that "it is not an end it itself, but in an imaginary way of maximising the amount of data collected". In general, researchers advocating triangulation (Richardson, 1996) would tend to see it as a way of strengthening the claims they make in an attempt of getting a richer fuller story.

Triangulation has been incorporated in this thesis as an effective means by which to maximise the diverse nature of the types of data that have been collected. Two main types of triangulation have been used:

- Methodological Triangulation: in combining qualitative and quantitative research approaches
- Data Triangulation: where the data collection is from different times and sources (Easterby-Smith et al, 1996). For example, this approach applies to the literature (Chapter 2), where many different sources from different periods were brought together in order to establish the background of the research, and in the interview case studies (Chapter 5) where the data was collected from the participants over a period of sessions. In testing the assessment matrix (Section 6.5), additional data from an external source, the Sulzer surveys and workshops, was also incorporated into this thesis.

The fact that the research was initiated on the basis of a thorough literature review having been performed, with the developed process assessment approach then being applied in the two test case study environments (sections 6.3 and & 6.5), exhibits further evidence of the validation of this work. The researcher, in order to maintain external validity [5] of the work been carried out, remained in contact with the other companies involved in earlier stages. Additional one other ETO manufacturer was contacted who acted as a reviewer of the methodology and framework. This company was Laker Vent Engineering. From this research supplementary validation has been achieved with the publication of five conference papers, based on the work. They have been presented and published, for review amongst piers, and more additional material is still being developed.

3.4 Evaluation of the research approach

To simplify, the research can essentially be divided three phases, one involved collecting data to enable building of the methodology and the second for collecting data to refine the methodology and to develop the support framework. To build the basic structure literature reviews, documentation analysis, and mini case studies using questionnaires and interviews were used. For the development of the support framework and refinement of the methodology literature reviews, on site over a long period, along with action research was carried out. This, the author believes this gave a balanced approach to the research question.

Each of the main methods used in this research has its strengths and weaknesses, as detailed above. An advantage of using multiple methods is that particular limitation of one method may be compensated by the strength of another of the methods used. For example, whilst there are many doubts about the accuracy of the survey responses, the data generated by the interviews in the case firms appear to have high internal validity. The relative strengths and weakness of the methods reviewed above are summarised in Table 3.2

[5] This term refers to the extent to which the theory behind the research findings can be generalised beyond the immediate research sample or setting.

	Internal Validity	External Validity	Reliability
Survey	-	(+)	
Company Cases	+	(-)	+
Longitudinal Study	+	(-)	+

Table 3-2; Relative Strengths (+) and Weaknesses (-) of the Research Methods Used

Research validation, and specifically the method of triangulation, with its suitability to a field of study that utilises a variety of research approaches, that combine both qualitative and quantitative methods, has also been briefly presented and described. However it remains true that there is no single method of research that is suitable for generating and assessing information in management related research projects. Any method used on its own is subject to bias. For example, postal questionnaires carry with them a risk of subjective interpretation of responses and snap shot interviews are restricted to the views of the interviewee. Case studies when used along have limited use, as then cannot be generalised to a wider application. For this reason, data collection was based triangulation of information described earlier.

As mentioned the longitudinal case study followed an action research approach, which acknowledges the effect of the researcher on the subject or situation. In general, action research is appropriate when the research question relates to describing an unfolding series of actions over time in a given group, community or organisation; understanding as a member of a group how and why their action can change or improve the working of some aspects of a system; and understanding the process of change or improvement in order to learn from it (Coghlan and Brannick, 2001). In fact, the researcher's intervention was an intrinsic part of the research design, with intervention being analogous to the independent variable. Action research depends largely on qualitative methods, although the use of quantitative methods also makes an important contribution. This research is very much a collaborative in that the synthesis contributions from the researcher and the industrial participants to solve problems. One day a week (on average) was spent in the company over a period of 18 months. The researcher's role was to introduce academic knowledge and theories about the process of product development, enterprise modelling and organisational learning and knowledge management into the company, discuss how the principles suit their needs and apply the results.

An effective action research project involves mutual learning (and the dissemination of learning) by the company and the researcher. Karlsson and Åhlström (1996) examined the implementation process when implementing lean product development. Lean product development offers the potential for faster product development with fewer engineering hours, improved manufacturability of products, higher quality products, fewer production start-up problems, and faster time to market, so improving the likelihood of market success. Over two years observing and facilitating one company's efforts to make this transition, Karlsson and Åhlström (1996) were able to identify various factors that either hindered or supported the implementation of lean product development. In this particular case the problem owners are both the practitioner and the researcher. Typically, the former will wish to understand the impact of changes and the process of change with a view to replication at another time or in another setting. As importantly, the researcher will wish to contribute to the understanding in the academic world of the issues under investigation.

It could be argued that the researcher acted as a catalyst within the company. However this is not strictly true, as personal development of the abilities and an understanding and appreciation of the processes within in the company are gained. An effective research methodology involves mutual learning (and dissemination of that learning) by the company and the researcher.

Reviewing the research project methodologies revealed that several criteria have been identified to ensure that quality applied research is carried out.

1. A research project should be conducted in a manner that allows the researcher to draw on his own conclusions.
2. Researchers should be present their paradigm i.e. values of the Framework under analysis and personal values together with the clarification of these have been developed or changed through the duration of the research.

3. The researcher should possess credibility i.e. correct data with any interpretation being supported by data. In addition, the researcher should select methods that are appropriate to the problem.
4. The researcher should have adequate access to the process under study.
5. A statement should be made regarding the validity of the research – to whom the results apply and does the research confirm the findings of the research's study.
6. The research should make a contribution to increased knowledge and be of value to both the company participant and under the academic community
7. The researcher should have commitment and integrity – to be deeply involved in the project but at the same time remain objective.

Ensuring validity of the data is very important aspect of the research. As stated by Easterby –Smith et al; 'validity is a question of how far we can be sure that a test or instrument measured the attribute which it I supposed to measure. This is not too easy to ascertain, because if one already had a better way of measuring the attribute, there would be no need for a new instrument', in other words, validity is the capacity of a test to us what we already know. Reliability is also important. For example, is the instrument (in this case a questionnaire) stable? Will it yield the same or similar results when used on different occasions with new responses?

It could be argued that the research results almost inevitably had a situation-bias built into them. With the increased popularity of questionnaires and case studies over the last decade, there is a danger that conditioned answers that often reflect how respondents would normally react or manage are recorded. This can be very difficult (if not impossible) to filter out the bias this may cause. The researcher can, however, be ware of this occurring when carrying out the in-depth analysis. Although steps were taken to balance data collected, as with any approaches, the data collection techniques adopted also has its own pros and cons. These are discussed below, by first describing and how these weaknesses were addressed and counterbalanced.

The problem with document study analysis is that:

- A document study cannot contain all the facts and is open to interpretation

However a documentation Study provides:

- A relatively unbiased account of factual information (assuming that the facts are recorded the use of interviews will allow for enriched information from expansion on the questionnaire responses.

With Questionnaires the conventional problems are:

- Lack of understanding of the questions are not always detected – fear of ignorance;
- Questionnaire respondents give answers that they want you to think;
- Those who respond may not be the representative of the sample frame- who motivated them to respond and others to ignore the questionnaire?[6]
- Respondents may take the opportunity to enhance the impression of the company;
- Time constraints: brief answers are given with no (or inadequate information) explanation
- Testing validity of results is difficult, especially if only response is received per company
- Owing to space constraints, questions can be phrased in an unnatural way compared with face-to-face situations- this can lead to misinterpretation; and questionnaires do not reveal the root causes- e.g. NPD projects may not run smoothly due to low morale, due to recent redundancy resulting in poor communication etc, even if the systems and processes are in place.

- *However these can be counterbalanced by:*
  - Implementing the questionnaires personally through lengthy interview sessions leading into in-depth case studies, and carry out ethnographic studies, hence seeing whether what was said in the interviews is actually what is happening.

This was done whilst retaining the advantages of the questionnaire, which are:

- Questionnaires are quick to administer and replicate

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[6] This problem was addressed by contacting the non-respondents, to determine their reason for non response

    - They are useful in that they allow a large number of people to be surveyed and reduce influence of any researcher bias (compared to interview method)
    - They are relatively easy to code and therefore interpret
    - Tick boxes often reduce potential bias from the researcher

Case Studies have the following weaknesses:

- The possibility of interviewee bias and the ability to interpret a particular set of events in realistic manner, this bias can be reduced by speaking to as many people as possible across the company.
- There can be a danger of drawing general conclusions from a case study; generalisations cannot easily be made on this basis
- Case studies can be used to generate hypotheses but not to test them
- Lack of objectivity of the researcher
- The whole truth may not be reported owning to fears of exposure of the company's (and employees) identify.
- Given the large volume of data typically involved in the case study, there is a danger of losing focus in the final interpretation and building a theory that tries to capture everything.

However on the positive side case studies provide the following advantages:

- A holistic view of the process under the study can be gained
- Historical roots to problems e.g. processes that have led up to the company's present situation, can be identified through document searches
- The longitudinal nature of the case study allows for the effects of change (including behaviour and attitudes) to the experience over a period of time
- Multiple visits to the company allowed clarification on previously discussed issues
- Results from the case study research is likely to have important strengths such as novelty, testability and empirical validation which arise from the intimate linkage with evidence

- case studies are useful for testing theory and hypothesis in areas where little or no work has previously been done before
- cases are good for reporting and presenting current practices to mangers (from an impartial point of view) who can then choose to implement findings
- issues are explored more deeply than with questionnaires alone
- the interviewer can follow up unexplained answers
- Reasons of difference in opinions can be established and validity of answers checked (where clarification is required).
- It is easier to telephone the contact when ever clarification is needed
- Fuller explanation of questions can be given than with other methods

So, the limitations of different research techniques have been overcome by then use of multiple methods of data collection techniques which avoids over-reliance on one data source and helps present the most realistic, balanced picture possible.

3.5 Chapter Summary

This chapter presents a comprehensive account of the methodology used in developing a framework for study for this multidisciplinary research, establishing overall objectives and end goals, identifying constraints, drawing upon the relevant previously pieces of work and existing literature, and highlighting the philosophical positioning of the research. It discusses in detail all the research questions, and *how's* and *why's*, the *what's* and *where's* etc., explaining the different methods in which the different types of questions were approached, and why they were best suitably answered in a particular manner.

The various types of research methods utilised in this research, such as primary and secondary, pure and applied, quantitative and qualitative, the case research, were also highlighted, along with the numerous data collection techniques employed. Data was collected from a combination of comprehensive literature reviews, a questionnaire survey, and number of case study interviews, including two longitudinal studies including a set of specifically designed experimental questionnaires, and from strategic interviews. In developing the process models and activity assessment matrix (section 5.6) and knowledge sharing framework, all these sets of data are considered, both inputs into its design, and in the testing out of its appropriateness.

Chapter 4 - RESEARCH FINDINGS: MTO/ETO INDUSTRIAL SURVEY – MINI CASE STUDIES

The previous chapter described the research strategy the thesis and explained the reasons for adopting a multi-methods approach which included postal questionnaire, interview case studies and longitudinal case study. It gave a practical insight into how the research activities were carried out and critically reviewed the main methods in terms of validity and reliability. Appendix A presents the findings first part of the research methodology, the postal questionnaire survey and explained the findings and gave the researcher a practical insight into NPD awareness being applied in engineering and manufacturing organisations within the UK.

This chapter continues with the report findings of each of the second part of the research activities, the preliminary case studies within a number of MTO/ETO (customer-driven) manufacturers. Presentation is in the form of a straight forward commentary and each section also concludes the implications the research activity had for (a) the research process and (b) the research content. Presentation is in the form of a straight forward commentary and each section concludes by highlighting the implications of the research activity had for (a) the research process and (b) the research content. The results of these activities, together with the contribution made by the literature, and the postal questionnaire survey (Appendix A) will be consolidated, analysed and discussed in chapter 7 in order to address the research question and related themes. The steps taken to validate the conclusions reached are also reported in Chapter 6, finally the implications that the findings and their interpretation have for future research will be discussed in Chapter 7 (Figure 4.1).

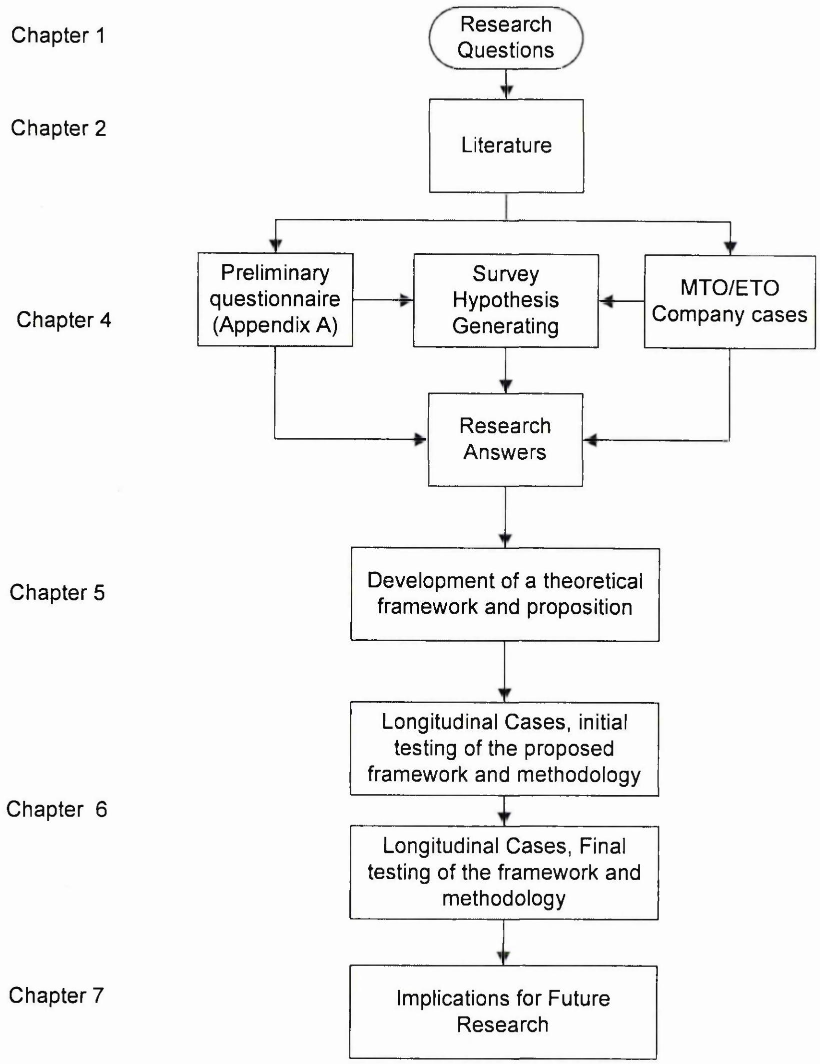


Figure 4-1; The research activities and their role in the development of the thesis

4.1 Introduction

To develop an analysis framework for knowledge sharing, one needs to establish three things; (a) what to measure (b) when and were to analyse (c) how to analyse which includes the modelling approaches. The survey presented below, using questionnaires and interviews, addressed the above questions and contributes towards the understanding of the requirement needs. The industrial survey attempted to establish the structure, issues and problems in capital goods NPD within particular focus on the use of knowledge management techniques, thus the researcher in defining the needs and requirements for the NPD-ETO model and a framework for analysing the NPD process within an ETO manufacturing environment. Four companies and one management consultancy across the UK took part in this study. The study was carried out over a two period from autumn 2000, to 2002 with some follow up interviews and data collection in spring 2004. A total of 31 managers and engineers/specialists involved in the NPD-ETO/MTO process were involved. A brief description of the participating companies is given below.

Participating Companies	Prime Function	Number Employed	Typical Project Value	Number of People involved in the Survey
Morris (Loughborough) (A)	Design, Development and Manufacture of gantry cranes & material handling equipment	100	£450K	6
Alstom Power (B)	Design, Development and Manufacture of Industrial Gas Turbines	500	£2m	4
Sulzer Pumps (Leeds) (C)	Design, Development and Manufacture of material handling equipment	150	£750K	12
Laker Vent Engineering (D)	Design and Manufacture of pipework systems and fabrications	120	£20-50K	8
The Bowman Group (E)	Management Consultancy	7	N/A	1

Table 4-1; MTO/ETO Company descriptions

For the sake of brevity the companies will be referred to as using their assigned letters A, B, C, D and E.

4.2 The Approach Taken

The survey was divided into two phases:

4.2.1 Phase 1- Establishing Boundaries and Context of research

This involved semi-structured interviews with key people at the four manufacturing companies (A, B, C, D, and E) a review of all relevant company documentation was carried out too. This enabled an initial description of the companies and their problems relating to NPD-ETO projects and knowledge sharing. The interview survey is presented in Appendix B.

At Sulzer, however, because of the close geographical proximity compared to the other sites it was possible to carryout a far more detailed analysis. The aim was to get additional information about the company in terms of knowledge sharing and more importantly a feel of the issues in NPD-ETO, early on the research process. The initial survey/assessment questionnaire within Sulzer & Laker Vent Engineering is shown in Appendix C.

The knowledge gained in the above survey was also used to develop more structured questions and approaches for a more detailed second survey described below. Experience was also gained in how to conduct such surveys.

4.2.2 Phase 2- The main survey

As described in Chapter 3 the main survey was carried out using both structural interviews in the form of questionnaires and semi-structure interviews targeting specific areas of interest. A three-part form was used to achieve this (Appendix B). So, following the structure of the form in Appendix B, the results of the main survey are presented below. Note that the factual information in Part 1 is not presented as most of the relevant information is present in the company description provided below in Appendix B.

4.3 PART II ORGANISATION & MANAGEMENT ISSUES

4.3.1 Results of Q1 –Semi Structured Interview

The results of the four companies can be seen in Figures 1, 2, and 3 respectively. The percentages show how many respondents think that the particular process is a problem in their organisation. The results show each company has its own peculiar way of describing its problems. However, as shall be discussed later the basic underlying problems and frustrations are the same. The results of the individual companies are explained first. The management consultant was interviewed to provide a more holistic view of present day issues based on his consultancy experience. His view is also summarised.

4.3.1.1 Company A:

Some terms used in the chart require explanation since these represent a collection of related problems grouped under one heading.

The term functional organisation related was used to summarise a variety of issues connected to the strong functional organisational structure. These are:

- Conflicts of interest between product managers and project managers:
- Conflicts of interest between product orientated workers and functional orientated workers:
- Functional heads not releasing enough resources upfront:
- Lack of empowerment to project teams:
- NPD documentation has a functional bias:

'Weak Collocation/Integration' implies that not all the functions involved fully committed to the concepts of collocation. For example was the project department were not always represented at important tendering meetings. The other summarised or abbreviated terms were:

'Market Specific related' issues are incomplete or in sufficient specifications and specifications are late either from the customer or from internal sources.

'Lead Time related' issues such as taking too long or deadlines not always met.

'Matrix Structure related' issues as too many people to report to.

'Top Management commitment' issues such as problems with operational issues.

The key issue for company A was that the multi-functional team project members once having got a taste for the benefits of single collocated project they wanted more of it! However for the company that manage contracts on average around £2m every year, requires some careful planning and project managing. A process model is a good start. The results also show that even within a company there are many different types of issue, which are individualistic, or function related and not found in the organisation as a whole. The spread of issues is quite specific broad with only a few issues showing over 50% agreement amongst representatives. The others roughly 75% of the issues where related to specific departments or functions. Also the issues and frustrations at different levels some were very operational, some middle management and some strategic. This indicates the requirement for an analysis methodology, which would detect these various issues. Focusing on a few issues mentioned in the list are important. For example the issue of 'resources for communication between project teams' is a serious issue, and was a prime concern for the management team. It did not register highly with the project team members (designers engineers etc), because they were either unaware of it or did not appreciate the real significance. Actually this highlights the problem of simple aggregated analysis. A more structured analysis differentiating between organisational levels and also adding some kind of weighting factor would provide a more accurate picture.

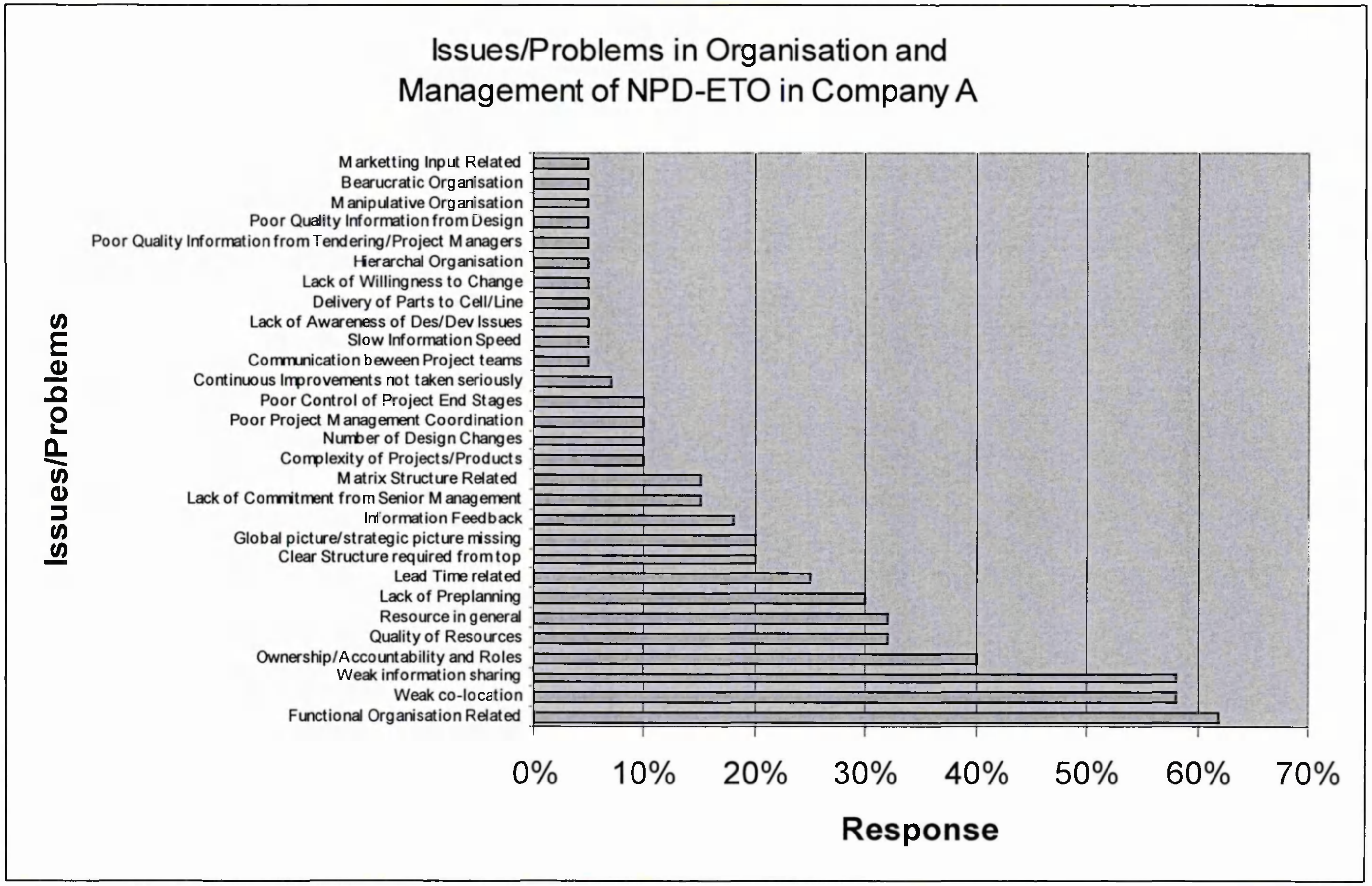


Figure 4-2; Interviews Results (Part II–Q1) for Company A

4.3.1.2 Company B

Company B is a global manufacturer, has a turnover of around €400 million euros and employs around 2300 staff at its sites at Lincoln and Aberdeen. The results focus on the Lincoln site and the key findings are represented in Figure 4.3. The main issues for company B were global coordination, collaboration communication, and supply chain management. Discussions with managers and engineers revealed that individual behavioural characteristics played a major part in the issues. Having the right mix of people in a project team was even more important at this level.

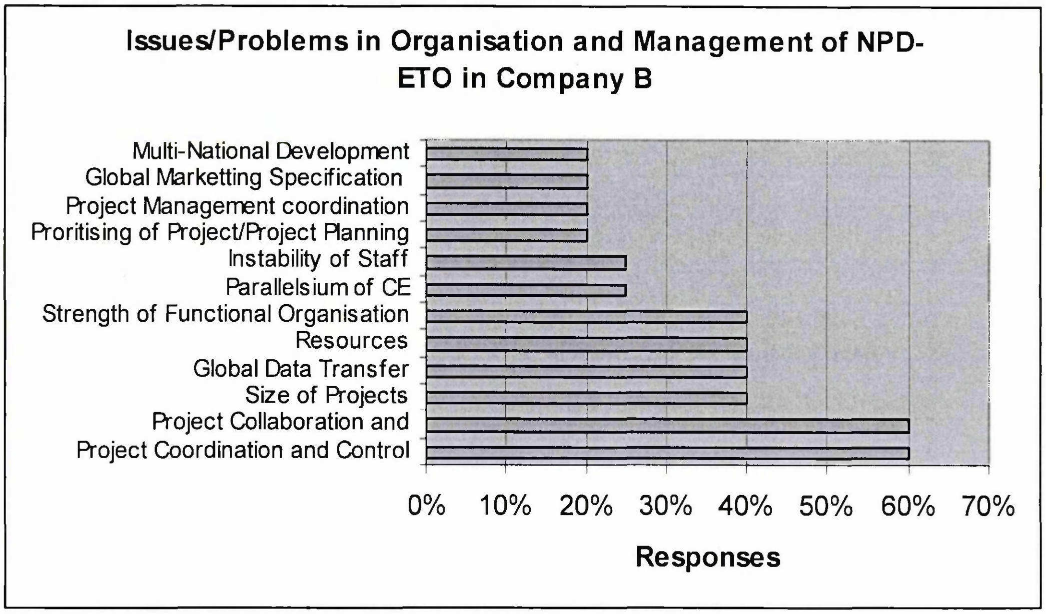


Figure 4-3; Interviews Results (Part II–Q1) for Company B

4.3.1.3 Company C

Company C is also a global manufacturer with manufacturing and packaging facilities in 15 countries with sales offices, service centres and representatives in more than 150 countries around the world. The company received orders totalling some €697 million euros and employed 4983 people worldwide in 2004. The results focus on the Leeds manufacturing site and the key findings are represented in Figure 4.4. The main issues for company C were collaboration, coordination, and communication. Discussions with managers and engineers revealed that individual cultural and behavioural characteristics played a major part in the issues. Having the right support at the 'front end' of the business was even more important when developing new products.

Some of the issues need more clarification. On the chart from the bottom most popular up:

Under the heading 'project management' the following were grouped:

- Project coordination and control
- Stage Gates or Milestones within the project
- Lack of customer involvement especially in the early stages, weak integration.
- Movement from procedures, lack of continuous improvement initiatives

Under the Heading 'Team human resources': estimating / planning etc.' the following implied:

- Knowledge sharing opportunities were not in place
- The lack of accessible information from previous projects
- No database of skills and project experience
- Estimating

The **'Requirements Specification'** is referring to that whole phase problems associated with it.

'Training' referred to both product and team effectiveness etc.

'Matrix Structure related' issues refers to weak matrix weak project managers lacking control over the functional resource. This issue provided conflicting views since some people thought that the balance was ok, when in fact the project manager had power.

Cultural related issues were mostly:

- Functional thinking, people find it difficult to integrate in teams
- Attitude problems –only to fix problems and working on one-off projects.

The other issues are self explanatory.

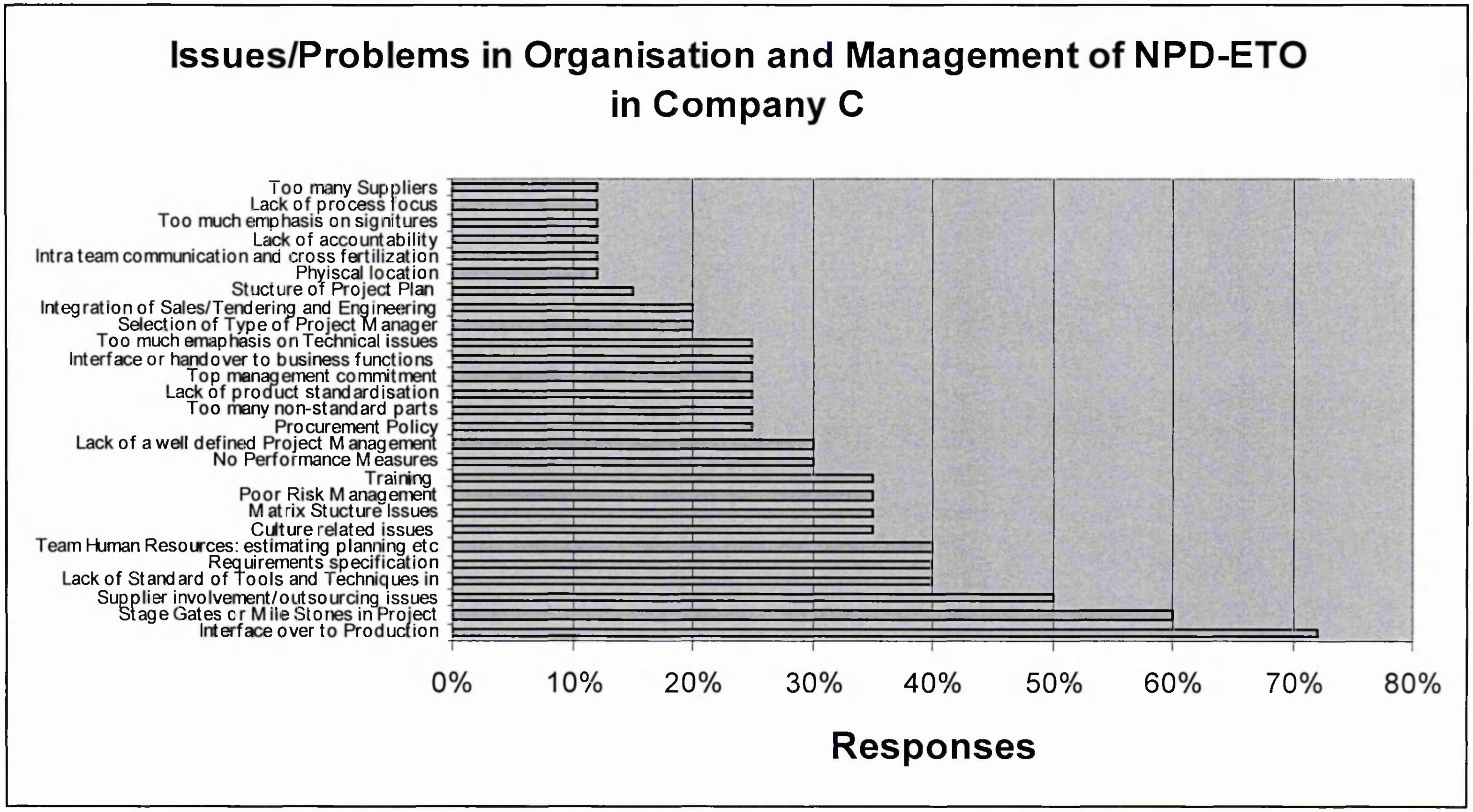


Figure 4-4; Interviews Results (Part II–Q1) for Company C

4.3.1.4 Company D

Company D was different from A, B, and C in two ways. Firstly the company is a small to medium enterprises (SME). Whilst larger organisations by their nature can afford the risk of making mistakes, SME's are typically more vulnerable, and hence need a structured low risk approach. Secondly the company also operates on a MTO basis manufacturing pipe-work systems as the designs predetermined by the customer.

They also had a matrix structure and hence in that respect had similar problems to companies A, B, and C but with different emphasis due to the factors described above.

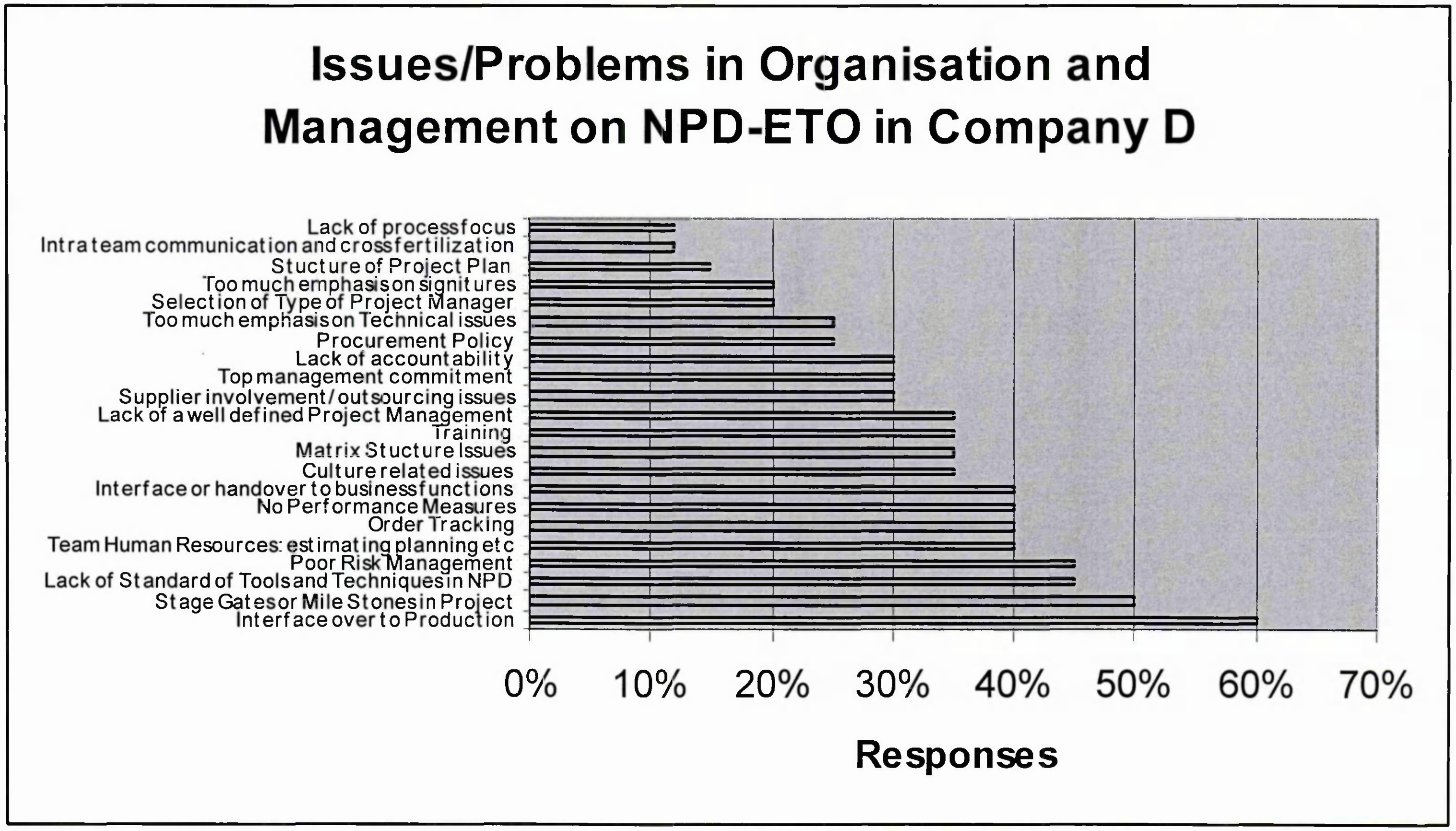


Figure 4-5; Interviews Results (Part II–Q1) for Company D

4.3.2 Management Consultants View

Rather than focusing on the problems he described how most 'good' companies are reacting to improve NPD and accommodate continuous improvement. The comments can be used to benchmark with the three cases above. Below is the detailed description of the consultant's views.

4.3.2.1 On the NPD Management

The projects themselves are having an impact of the need for introduction of new resources and new technology at different levels in the organisation, but no real impact on the capabilities of knowledge sharing and organisational learning.

The key issues:

- Training and implementing organisational learning and knowledge management practices in existing environment
- Minor changes to obtain process improvement

The change in the way of developing a product sometimes spurred on by the ability in NPD management, has caused restructuring of departments, enlargements or reduction of tasks assigned to a given department and minor changes in cooperation and coordination NPD projects.

4.3.2.2 Organisational Structure and Design

Organisational Design textbooks provide generalised knowledge about organisations, which is widely accepted. For the manager, there is additionally the experiences gained from earlier organisational changes in the company and their effects, which can be used.

The companies working in accordance or partly in accordance with CE and organisation learning principles have traditionally had a **mixture of structures** in their organisation. The relation between the main business processes and NPD has been based on the interaction between different departments as functions.

Development processes, either product or manufacturing have been initiated and controlled by the business functions closet to the identification of the problem. Interaction with other departments through the development process has mainly been passing on results for further development or asking specific questions to functional specialists,

The development of a **matrix organisation** for the product development projects, within an existing structure has generally been to answer the problems. Using 'Resource Pools' taken from the existing functional resort, forming intermediate structure and delivered back when their task was done, is a common approach in most companies. Basically this change, creating project groups and perhaps introducing resource managers has caused little changes to the rest of the organisation as a whole, but has improved the management of the NPD process and the way NPD projects are run generally.

The major changes in the wider organisation have been based on the major changes in the process leading:

- Virtual factories
- Establishing product cells
- Establishment of collocated teams with full time assignments on development projects
- Increased interdepartmental co-operation on the more structured basis than known
- Top down involvement and commitment to cultural changes
- Improved utilisation of technology, resources, process, people, products and organisation

The existing structures have basically been (in NPD) Project Group Matrix or Functional Work Groups within a Project Matrix. Primarily, *"a structure that would improve the quality, (customer point of view) project coordination, and reduce development lead time"*.

However, the basic problems that led to the change in NPD with such still exist in most MTO and ETO manufacturing organisations. These problems are

- The empowerment of project managers versus the manager of departmental function
- The uncertainty of the project members, whether or not they are improving their status in the organisation by participating in a project group.
    - The dissemination and utilisation of achieved knowledge
    - The conflicts of loyalties
    - The prioritisation between day to day business and the project
    - The information and workflow:
        - Who needs to be informed
        - Control information to and from
        - The quality and completeness of the information being received
            - Received acceptance from the right authority

In order that the requirements of KM and project-based learning can be implemented successfully requires a change in the NPD-ETO process and also the project management of the process.

On the Process Focus

The introduction of CE means a change in the development process and in some cases a change in the manufacturing processes as well. Based on the wishes for a change in process, the process view is or should be introduced as shown see Table 4.2. All organisational functions are expected to focus on more team goals rather than functional goals.

Traditional View	Process View
• Functional	• Value Chain
• Task orientation	• Process
• Departmental	• Project Group
• Local	• Network
• Individuals	• Team
• Narrow Specialisum	• Multi-skilling

Table 4-2; Organisation characteristics of a traditional and process view

The major changes in the wider organisation have been based on the major goals in the process leading to:

- Establishment of the process based organisation
- Building of process teams across traditional functional boundaries
- Creation of Core process owners/managers
- Establishment of focused, supporting teams to enact
- Enabling processes

4.3.2.3 On Knowledge Sharing

To develop KM practices a change in the NPD process and some cases a change in the project management as well. Based on the wishes for a process improvement a 'stage-gate' approach is or should be introduced. All project-driven organisations are expected to place more focus on the "Hot Spots" of the NPD process rather than functional constraints of the organisation.

The development of the knowledge management approach within an organisation, the takes place on the following **established platform**:

√ Complete detailed descriptions of the process (both 'as-is' and 'should-be')

√ Establish a working information structure

√ Adaptation of effective control systems:- as regards to quality and progress

The MTO/ETO organisational demands are primarily a ***change in the foundation*** of what created the original organisation.

- X Delegation of power in a way suited to the tasks to be carried out
- X Strict vertical and horizontal lines of communication
- X An embedded reward system through recognition and promotion

On Cost versus benefits of KM:

KM provides two major benefits to an organisation:

- Improving the organisation's performance through increased effectiveness, productivity, quality, and innovation.
- Increasing the financial value of the organization by treating people's knowledge as an asset similar to traditional assets like inventory and capital facilities.

Looking at the benefits and cost of KM if the change takes place from different organisations, for

A. Hierarchal Organisation (could be a functional or line staff, could be a division or could be a product division)

Benefits of KM

- Highly Improved process capability
- Highly improved resource utilisation
- Savings or improvement in organisational quality and efficiency
- Improved employee satisfaction
- Reduced cost of training
- Reduced learning curve for new employees

Cost of KM

- More complex lines of communication
- Scattering of existing power and decision making
- Major changes in managerial behaviour

- Major cultural changes

And,

B. Matrix Organisation

Benefits of KM

- Highly Improved process capability
- Highly improved resource utilisation
- Savings or improvement in organisational quality and efficiency
- Improved employee satisfaction
- Reduced cost of training
- Reduced learning curve for new employees

Cost of KM

- More complex lines of communication
- Upgrading of power delegation
- Major cultural changes

This implies that the

- Introduction of KM into the organisation will give identical benefits:
- Extent of the benefit will vary depending on the 'as-is' situation
- Costs varying depending on the 'as-is' situation

But it also means that, the focus points and the prerequisites are the same whatever organisation structure KM is introduced into. The differences in the potential benefits and the costs are dependant on the three areas and the degree to which the manufacturing organisation handles the following:

- Controlling and changes processes
- Utilisation and quality of resources
- Managerial behaviour

4.3.2.4 Discussion of Results

The top two issues for company A were 'functional organisation requirements' Alstom Power (A) Morris (B) (Loughborough) (C) Sulzer Pumps (Leeds) (D) Laker Vent Engineering The Bowman Group (E).

The top two issues for company A were 'functional Organisational related' and weak collocation (integration). Whereas company B they were 'Global Coordination, Collaboration, and communication and Multi-site teams' Company C was similar to company B, and even company D as they operated in the same market sectors, but was a 2nd tier supplier.

Though they had different names and common for all four companies is of course integration, communication and collaboration between different functional groups to enable proper functioning knowledge sharing and organisational/project-based learning, whether the function is an internal department or an external party. The difference between the companies is strength of the functional organisation. Though for company

Company B was found to be more process focused, especially with regards to NPD-ETO projects. Company B also had a well defined NPD process model, whilst the other companies did not. The researcher regards the development of a process map or model crucial for the implementation of a KM system in an ETO manufacturing environment. It helps in creating better process and product knowledge of an ETO manufacturing environment.

4.3.3 Results of the Structured Questionnaire (Q2)

ETO manufactures experience high uncertainty in terms of specification, demand, process duration and lead-time. They are dynamic organisations in which the internal structures and the boundary of the firm are often reconfigured to match external requirements (Hick, 2000). Hick's work was used as a basis for structuring this question. This survey too showed the complex nature of the ETO product development process and risks associated knowledge sharing. The results for all the four companies have been combined into one output.

With regards to the development of a new analysis methodology for NPD-ETO the researcher concluded that a methodology, which identified all issues relating to the project's performance; had to be developed and the focusing of certain issues would suffice. According to Harreld (1998), Knowledge Management (KM) systems provide access to the desired information and knowledge to support innovation, responsiveness, productivity and competency of all employees, and consequently leveraging the enterprise's intellectual capital.

4.3.4 Implications on Modelling & Analysis Methodology (Q's 1 & Q2)

The above results have identified the diversity of the problems in ETO and MTO manufacturing organisations. This calls for the structured analysis approach to NPD phases and critical stages in different levels of ETO product development. The focus should be on the 'softer' NPD-ETO issues, including the use of technology supporting knowledge sharing and organisational learning, rather than the 'harder' financial measures of performance.

4.4 PART II ANALYSIS OF THE ETO PRODUCT DEVELOPMENT PROCESS PHASES (Q3)

The aim was to establish the bottlenecks or problem steps, at what stage they occurred and for what reasons. This would establish which stages or phases of the NPD-ETO process have most problems and what they were. Only people who directly involved understood the NPD procedure were interviewed such as project managers, design and development engineers and management and other functional managers and specialists. The interviewing was semi structured.

4.4.1 Analysis Approach and Results for Company A

Company A had an eight stage process `Inquiry, Bid, Order, Engineering Design, Procurement, Manufacture, Installation Support, 12 month management review.

In absence of a process map a model at Company B, their ISO9000 documentation on their management procedures was used to conduct the analysis. The interviews were presented with a copy of the procedures manual and were asked to identify which steps in their view were the problems.

The ISO document detailed the NPD process in 74 steps. Out of those steps 30 i.e. 41% were identified as problem areas or with the potential for improvement. The table below shows the general structure of the NPD-ETO process as identified by the ISO9000 documentation.

Stages	Total Number of Stages	% of NPD	No of Steps with problems	% contribution to overall problems	% of stage with problems
Inquiry/Tender	12	16%	7	23%	58%
Bid	8	11%	5	17%	63%
Order Review	1	1%	1	3%	100%
Engineering Design,	20	27%	6	20%	30%
Procurement,	5	7%	2	7%	40%
Manufacture,	18	24%	8	27%	44%
Installation Support	4	5%	1	3%	25%
12 month review	6	8%	0	0%	0%
TOTALS	74	100%	30	100%	41%

Table 4-3; Summary of NPD Analysis for Company A (Survey Part II Q3)

We can see that the Inquiry/Tendering contributes to the problems found in Company B's NPD-ETO process and also has one of the highest percentages of problems. The order review stage only has one step which is a problem. So though the percentage of stage with problems is 100%, they only contribute to 3% of the total problem. The table below looks at the main steps that contributed to the problems and discuss the reasons stated by the interviewees.

Stages	Brief Description	% of respondents identifying this step as a problem
Inquiry /Tender	Customer Specification	60%
Bid	Product Specification & Costings	40%
Inquiry & Order Review	Standards	40%
Engineering Design	Incomplete and insufficient Engineered End date, No project milestones	40%
Order Review	Forward Load Invisibility of current manufacturing production schedule	35%

Table 4-4; Steps with the most problems NPD process in Company A (Survey Part II Q3)

The reasons for the problems, described in the interviews are discussed below:

Inquiry /Tender: Specification:

- Customer Specification is not stable and too many changes and this stage

Need more activities targeting the identification in customer specification errors and identification of corrective actions. The Crane 'Solve' software I.T. software is described badly and is unclear in the documentation.

Bid: Product Specification:

- Link between Tendering Engineers and Project Engineers needs to be improved
- Large amount of information required for the Contract Plan & G.A drawing

Inquiry & Order Review:

- No full use of standards e.g. BS466 (mechanism structure)
- Incomplete Contract Control Sheets

Engineering Design:

- Incomplete customer data
- No Project Milestones
- Budgetary requirements needs to be improved
- Reliability of the information from estimating and previous case histories
- Communications problems with technical specification

Order Review:

- Not enough information between Sales Engineer and Design Engineers
- Overload on Manufacturing Functions
- Processes between us and suppliers unclear

4.4.2 Analysis Approach and Results for Company B

Company B had nine stage process Quotation, Order Entry, Engineering Design, Production Planning, Manufacturing Production, Assembly, Testing Systems, Installation Phase, Project Management Reviews. 6-12 Month Reviews.

Company A had a very well documented process map or model of their NPD-ETO process, showing also the overlapping stages and sub-stages and steps. The process flow charts and associated documentation were used to identify the problem areas. The ISO documentation detailed the process in 68 steps. Out of those steps 31 i.e. 46% were identified as a problem areas or were identified for potential improvement. The table below shows the general structure of the NPD-ETO process as defined in the ISO9000 documentation. The table below shows the general stages of the NPD-ETO process:

Stages	Total Number of steps	% of NPD	No of Steps and Problems	% contribution to the overall NPD-ETO process	% of Stage problems
Quotation	5	7%	4	13%	80%
Order Entry	2	3%	1	3%	50%
Engineering Design	14	21%	10	32%	71%
Quality Control	5	7%	3	10%	60%
Manufacturing Production	12	18%	4	13%	33%
Assembly	6	9%	2	6%	33%
Testing Systems	3	4%	1	3%	33%
Installation phase	12	18%	3	10%	25%
Project Management Reviews	5	7%	3	10%	60%
6-12 Month Reviews	4	6%	0	0%	0%
Totals	68	100%	31		

Table 4-5; Summary of NPD Analysis for Company B (Survey Part II Q3)

Based purely on the number of steps identified as the problem or bottleneck, regardless of how many people actually agreed or identified it, the table above shows that the Engineering Design, which is the largest stage, contributes most towards the problems, even though on 71% of the stage is a problem, compared to 80% of Quotation. However that is not the complete picture. Looking at the results from the view of how many people actually agreed that a particular step in a stage was a problem reveals a different picture. First we looked at each stage individually to find which were the most commonly agreed upon problems. The table in Appendix I shows the results. For our research the reasons cited the occurrence of the problems or bottlenecks are of prime interest. We shall examine the top most problems i.e., the ones with over 50% agreement (the percentages indicate the number of respondents which identified the problem step).

Stages	Stage or Milestone	% of respondents identifying this step as a problem
Group 1.1 Level	Quotation: • Investigation of project proposal • Create Bid for potential client point of sale tool (POST) • Create Bid for potential client (non-POST) • Develop with client	80%
Group 1.4 Level	Order Entry: • Sales Handover	50%
Group 3.1 Level	Project Management: • Form a project Team and nominate team coordinator • Review letter of intent and purchase order • Documentation control	60%
Group 2.1 Level	Engineering Design: • Design Review • Design Study • Revision Control	88%
Group 4.1 Level	Quality Control • Supplier Approval • Material control • Performance indicators	60%

Table 4-6; Key NPD-ETO issues in Company B (Survey Part II Q3)

Below is a description of the reasons presented by various managers and engineers for the above problems and subsequent evaluations and analysis by the author.

Group 1.1 Level Quotation typical problems were:

Level 1.1 and 1.4 Quotation (Tendering)

- The initial request for quotation (RFQ) were worth responding to was a key decision since the number of (RFQ) received significantly greater than the tendering capacity in order to deal with. However, there was no formalised system to support the decision making process. The knowledge requires includes explicit information, such as historical data on success rates, as well as tacit knowledge obtained through informal contact. An example of good practice of this was the "Corporate Risk Management (CRM)", which provided information for identifying commercial risk that were likely to new product development projects. This allowed anticipation of the RFQ. And throughout the development of the relationships with potential customers, more knowledge of the requirements to be obtained.

- The company's competitiveness was often based on a detailed knowledge of the individual's customers operations which has been gained during the installation and commissioning process.
- Tendering within extreme time constraints sometimes resulted in new and untested suppliers being included in the tender. This lack of knowledge led to considerable risks being taken since up to 90% of product and project costs are determined during the tendering and particular designs are dependant upon particular suppliers at this stage.
- A database was used as a source of approved suppliers/product information in the tendering development process. It was assembled from information collated from previous bids, buyer guides, faxes and telephone enquiries. It also included unapproved that had not been vetted, as there was no common database with Purchasing and Quality, much of the data was out-of-date causing uncertainty in contract pricing, this lack of sharing knowledge with procurement resulted in increased risk and decision making uncertainty.
- The company received functional, performance, and technical customer specifications. Some customers provided highly detailed specifications that weakened the company's negotiating position, because of the limitations that it imposed on supplier selection. In some cases, suppliers were specified, further weakening the company's position. In these situations, customers were able to strengthen their negotiating stance by minimising the level of tacit knowledge

Level 3.1 Project Management

- Projects were effectively excluded from the key decisions which contributed to the cost and lead time since they only became involved after the contract had been awarded and the contract information had been handed over from Tendering. The Project Manager, therefore, had little prior knowledge of the project requirements and the decisions made during the bidding process within tendering. The analysis of the process maps revealed that projects acted as a "post office" for the business, with data entering the department being diverted to other departments, causing complicated lines of communication. Weekly meetings only allowed Projects a brief overview of the progress and did facilitate effective control of any project.

- Projects believe that it influence over design was limited because most of the internal activities related to a project were the domain of design. In effect, Projects was viewed as the department that monitored progress, rather than being responsible for control

Level 2.1 Engineering Design

Design engineering had only limited contract with the customer, and this way was restricted to clarifying the specification. Consequently, the department did not use formal NPD tools such as QFD to fully comprehend customer requirements

1. Design Engineering recommended those suppliers that may be used, often based upon engineering rather than commercial knowledge. This could directly influence the choice of suppliers by designing-in proprietary components.
2. Information communication channels existing Purchasing and Design Engineering in post tender stage. Design sometimes informally issued drawings directly to Purchasing to circumvent delays in Projects. On many occasions Purchasing requests were seldom compiled with Designer's reluctance to change drawings and incur additional design and re-issue (rework) costs. The formal system for any changes was through Projects
3. The reuse of previous design/data was limited since, for example the CAD system retains the information and parametric programming was not widely used. The reuse of detailed design knowledge of previous contracts was thus limited
4. The re-use of previous design/date was limited since, for example the CAD system retain information and parametric programming with not widely used. The re-use of detailed knowledge of previous contracts was thus limited.

Level 4.1 Quality

- Supplier vetting and approval was the responsibility of Quality. However, it was possible, as shown earlier, for an order to be sent to an unapproved supplier before Quality was informed. In addition, supplier-vetting information was not made available to other departments, which reduced the potential influence it may have had on supplier selection decision. However, this was being addressed by the development of an intranet supplier approval register.

- Supplier section and approval were the responsibilities of Quality. However, it was possible, as shown earlier, for an order to be sent to an unapproved supplier.

4.4.3 Analysis Approach and Results for Company C

Company C also was in absence of a process map, and so similar to company B and D the researcher used their ISO9000 documentation was used to conduct the analysis on the NPD-ETO procedure. The interviews were presented with a copy of the procedures manual and were asked to identify which steps in their view were the problems. The ISO document detailed the NPD-ETO in 57steps. Out of those steps 32 i.e. 56% were identified as problem areas or with the potential for improvement. The table below shows the general structure of the NPD-ETO process as identified by the ISO9000 documentation.

Stages	**Total Number of Stages**	**% of NPD**	**No of Steps with problems**	**% contribution to overall problems**	**% of stage with problems**
Tendering	9	16%	7	22%	78%
Projects	8	14%	5	16%	63%
Pre-Manufacturing	12	21%	7	22%	58%
Procurement	6	11%	3	9%	50%
ODC Scheduling	3	5%	1	3%	33%
Core Operations	11	19%	6	19%	55%
Production Technologies	4	7%	1	3%	25%
Engineering Services	4	7%	2	6%	50%
Totals	57	100%	32	100%	56%

Table 4-7; Summary of NPD Analysis for Company C (Survey Part II Q3)

The reasons for the problems, described in the interviews are discussed below:

Tendering:

- **Customer Specification** - is not stable and too many iterations are occurring

Projects:

- **Misleading milestone achievement** - stages are marked as complete while items remain outstanding
- **Performance Monitoring** - at least on key performance milestone is missing (when all orders have been raised) and there are no embedded procedures for logging process failures and initiating corrective action.

Pre-Manufacturing:

- **Pattern management** - there is no formal pattern register and patterns are only checked prior to use. This can cause unnecessary delays and there is no general lack of clarity around the pattern status and location.
- **ECN control** - engineering changes are poorly managed in particular relating to the control and issue of drawings and outside suppliers.

General Overview:

- **No process owner** - for each of the process identified there was no clear process owner with recognised and the active responsibility to operate the process effectively. Indeed, there was little sense of what a process was or understanding of what needed to be done to improve process performance.
- **Management** - the level of management intervention is variable and not always appropriate, sometimes too hand-off and other times to hands-on. Many managers prefer to work in a specialist rather than a managerial mode.
- **Often more than process** – where there exists more than one practitioner of a process, while the core activities carried out where much the same, each individual tendered to have their own version of the process. The quality of the process therefore varied between individuals. In the case did there seem to be a collective view of best practice and how this can e achieved.
- **Process Partition** - what exist are really more sets of activities than the designed process and these activities are partitioned out among sixteen specialised groups or functions.

- **Poor Systems integration** - many of the systems are stand alone or poorly integrated as a result that the data has to be entered into more than one system, which is frustrating and the time consuming and has the attendant risks of error and omission. Many of the systems (the Order Set and the Business Order Book) are not user friendly and require time consuming administration.
- **Poor visibility of priorities** - many of the systems do not really provide a clear view to either status or priority across the projects being undertaken. Such a view can only be obtained by manual interaction and analysis.
- **Functional orientation and cultures** - the individual functions along the process tend to have a parochial view of priorities and requirements and tend to work first support their own interests. The results in sub-optimisation of the overall process.
- **Too little sense of collective obligation** - there is a general feeling that provided 'I've done my bit' then that is all that is required. While there are exceptions, too many individuals do not feel a collective responsibility for ensuring that customer deadlines are met.
- **Process loading and performance degradation** - once the process becomes the overloaded the level of performance deteriorates disproportionately. An overload, particularly in what can be a resource bottlenecks like engineering, can soon bring about the major slippage against deadlines.

4.4.4 Analysis Approach and Results for Company D

Due to the time constraints analysis of each of the phases (and steps) of company D, as done for companies A, B and C could not be carried out. However, a slightly less detailed analysis of the NPD process and its phases was carried out through interviews during a 4-day visit to the company, and also telephone interviews (for the entire case study) later on. The results have been provided as part of the analysis described in section 6.3.3.

In summary, the main problem with the product development process was resource management. This included the allocation of resources to given projects and the quality of tools available for managing the project. The process was under constant development with introduction of new methods, new systems, new procedures and that tended to take a great deal of resource capacity. The other key problem was the lack of process overlapping or cross-functional integration during the early phases of product development. This would leave gaps in requirements specification.

4.4.5 Implications for the new modelling and analysis methodology

The above study shows that analysing the NPD-ETO at an operational level provides an abundance of information, critical to the improvement, management and reengineering of the process as well as the organisation. An analytical approach has to be well structured to capture and retrace all issues.

The approach used can be made more structured by differentiating between the different levels within the process and highlighting the downstream consequences through the process flow modelling. Additionally structured questions will provide the ability to carry out quantitative analysis on the reasons for weakness and risks.

4.5 PART II DRIVERS AND CHANGE ENABLERS FOR GIVEN REQUIREMENTS (Q4)

In this section we examine how the organisation creates value in terms of NPD-ETO. We do this by thinking of the NPD process as a 'system' which given a certain input or driver, delivers value (output) using transformation processes (enablers).

4.5.1 Company A

At company A the following outs and Hot Spots were examined:

1- Improved Product, 2- Quality Reduced Lead Time, 3-Reduced Product Cost and Price, 4- Improved Tendering/Design, 5-Improved Flow of information, 6-Improved Quality of Work. For a given requirement the main enablers, drivers and hot spots identified were:

For a given requirement the main enablers, drivers and Hot Spots were:

Requirement	Enabler	Driver
Improved Product Quality	(1) Upgraded or changed technology. Or Manf. And any office. (2) Introduced Multi-functional Project Teams. (3) Establishment of a continuous Improvement Team	Market Demands it
Reduced Lead Time	Introduction of Collocated Teams	To capture new customers and new markets
Improved Design (Sales Support)	Tendering (Commitment to Bid) and Tendering (Job Costing/ Margin)	To improve departmental operational efficiency in terms of cost and quality of work (including optimisation of the information and workflow)
Improved Human Resource Utilisation	Changed a process (reengineer)/ continuous improvement initiatives	To improve departmental operational efficiency in terms of cost and quality of work (including optimisation of the information and workflow)
Improved Flow of information	(1) Upgraded or changed technology. Or Manf. And any office. (2) Introduced Multi-functional Project Teams. (3) Establishment of a continuous Improvement Team	To improve departmental operational efficiency in terms of cost and quality of work (including optimisation of the information and workflow)
Improved Quality of Work	Introduced Collocated Teams	(1) To solve inter or cross departmental conflicts. (2) To improve departmental operational efficiency in terms of cost and quality of work. (inc. optimisation of information flow. (Workflow and information)
Improved Product Manufacture	(1) Upgraded or changed technology. Or Manf. And any office. (2) Introduced Multi-functional Project Teams. (3) Establishment of a continuous Improvement Team	(1) To solve inter or cross departmental conflicts. (2) To improve departmental operational efficiency in terms of cost and quality of work. (inc. optimisation of information flow. (Workflow
Improved Inter and cross departmental relationships	Introduced Collocated Teams	(1) To solve inter or cross departmental conflicts. (2) To improve departmental operational efficiency in terms of cost and quality of work. (inc. optimisation of information flow. (Workflow and information)

Table 4-9; Change Enablers, Drivers Hotspots at Company B(Survey Part II Q4)

Overall the main enabler or facilitator for change was the introduction of Collocated Teams and the upgrading of change of technology. The main driver was to solve inter or cross departmental conflicts and problems.

4.5.3 Company C

The following outputs or requirements were investigated for company C:

2. Improved Product Quality, 2- Reduced Lead Time, 3- Improved Design (Sales Support), 4- Improved Human Resource Utilisation, 5- Improved Flow of

information, 6- Improved Quality of Work, 7-Improved Product Manufacture, 8- Improved Inter and Cross departmental Relationships

For a given requirement the main enablers and drivers were:

Requirement	Enabler	Driver
Improved Product Quality	(1) Upgraded or changed technology. Or Manf. And any office. (2) Introduced Multi-functional Project Teams. (3) Establishment of a continuous Improvement Team	Market Demands it
Reduced Lead Time	Introduction of Conversion Team	To capture new customers and new markets
Improved Design (Sales Support)	Tendering (Commitment to Bid) and Tendering (Job Costing/ Margin)	To improve departmental operational efficiency in terms of cost and quality of work (including optimisation of the information and workflow)
Improved Human Resource Utilisation	Changed a process (reengineer)/ continuous improvement initiatives	(1) Because the technological environment has change in which the products supply has changed. (2) To improve departmental operational efficiency in terms of cost and quality of work (including optimisation of the information and workflow)
Improved Flow of information	(1) Upgraded or changed technology. Or Manf. And any office. (2) Introduced Multi-functional Project Teams. (3) Establishment of a continuous Improvement Team	(1) Because the technological environment has change in which the products supply has changed. (2) To solve inter or cross departmental conflicts. (3) To improve departmental operational efficiency in terms of cost and quality of work. (inc. optimisation of information flow. (Workflow and information)
Improved Quality of Work	(1) Introduced Conversion Team, Accreditation of ISO9001	(1) To solve inter or cross departmental conflicts. (2) To improve departmental operational efficiency in terms of cost and quality of work. (inc. optimisation of information flow. (Workflow and information)
Improved Product Manufacture	(1) Upgraded or changed technology. Or Manf. And any office. (2) Introduced Multi-functional Project Teams. (3) Establishment of a Conversion Team	(1) To solve inter or cross departmental conflicts. (2) To improve departmental operational efficiency in terms of cost and quality of work. (inc. optimisation of information flow. (Workflow
Improved Inter and cross departmental relationships	Introduced 'Conversion' Team	(1) To solve inter or cross departmental conflicts. (2) To improve departmental operational efficiency in terms of cost and quality of work. (inc. optimisation of information flow. (Workflow and information)

Table 4-10; Change Enablers, Drivers at Company C (Survey Part II Q4)

So depending on requirement the key drivers are Market Demands and Competition and the key enablers are upgrading ISO9001, changing processes, upgrading I.T. systems, and a Conversion Team/Continuous Improvement Team.

4.5.4 Implications on Modelling and Analysis Methodology

The above results indicate the importance of multi-functional teams and improved technology in enabling change. Changing the process was also a key enabler for different requirements. So the modelling methodology should enable analysis of not only process task and process flow but also the quality of the resource information particularly that of individuals, teams and technology.

The main drivers for change vary from company to company, Company A was driven by the external factors, where as companies B and C were driven mostly by internal improvements. The main drivers are to improve the department efficiency, improve the interdepartmental relationships and market demands. So this means that any analysis structure whilst focusing on teams, collaboration and technology and resources, can not ignore the functional or departmental requirements in terms of improved performance and management. All have an ultimate bearing on the company's market position and strength.

4.6 PART II Critical Phases or 'Hot Spots' in NPD (Q5)

In this section we examine the critical phases of NPD-ETO in terms of risk and reliability of information and resources. We do this by thinking of the NPD process as a 'system' which given a certain input or driving force delivers value (output) using transformation processes (enablers), these are the critical drivers which are critical to the outcome of the process and therefore we called these 'Hot Spots'.

A summary of 'Hotspots' across the four companies is given below:

Critical Phases or Hotspots	Company A	Company B	Company C	Company D
Requirement Identification and Management	Requirements Capture at Bid stage Customer Feedback loops and User involvement Changes in Scope and new requirements from customer Negotiation Skills Product Standardisation	Requirements Capture at Bid stage Learning from Customers Changes in Scope and new requirements from customer	Requirements Capture at Bid stage Learning from Customers Changes in Scope and new requirements from customer Staffing pressures at Bid Stage Poor Risk assessment Issue Product Standardisation Negotiation Skills	Changes in Scope and new requirements from customer Requirements Capture at Bid stage Changes in Scope and new requirements from customer
Coordination of Information	Task Definition Project Feedback Loops Bid and Project Team continuity Technical Uncertainty and Difficulty	Technical uncertainties and Difficulties Bid and Project Team continuity Collocation of Project and Tendering departments	Technical uncertainties and Difficulties Project Structure Supplier Management Negotiation Skills Bid and Project Team continuity Technical uncertainties and Difficulties	Bid and Project Team continuity Negotiation Skills
Process Issues	Inattention to procedure Staffing Levels Supplier Management Organisation Structure	Project Structure Transfer of organisation culture to new employees Compatibility between new product and previous generations of technology Technical Uncertainty and Difficulty	Project Structure Organisation Structure Compatibility between new product and previous generations of technology Technical Uncertainty and Difficulty Management of suppliers	Project Structure Staffing Levels Management of suppliers

Table 4-11; Critical Phases of Hotspots in the four case companies (Survey Part II Q4)

The main drivers for change vary from company to company, Company A was driven by the external factors, where as companies B and C were driven mostly by internal improvements. The main drivers are to improve the department efficiency, improve the interdepartmental relationships and market demands. So this means that any analysis structure whilst focusing on teams, collaboration and technology and resources, can not ignore the functional or departmental requirements in terms of improved performance and management. All have an ultimate bearing on the company's market position and strength.

4.6.1 Implications on Modelling and Analysis Methodology

The above results indicate the there are four general areas (each of which contribute to a number related to 'Hotspots' or "Points of Vulnerability") which kept coming up include those that relate to:

- Commercial uncertainty/difficulties and risk
- Organisation and project structure
- Management of requirements capture
- Technical uncertainty/difficulties

By signalling out those problem areas which are experienced time and time again across ETO manufacturers is not to suggest that they should be ranked as most important to those that appear less frequent. The research is not currently in the position to rank the "hotspots" in descending order of importance. However, some of these identified will have short term significance, often influencing whether a ETO-NPD project is completed on time and within budget; an example might be the difficulties experienced in moving from the bid stage to the development and production. Other will have more significant and long terms impacts on the overall efficiency and productivity of the company; for example the inattention to project management procedures.

The above results indicate the importance of managing the NPD-ETO at is most critical phases. Monitoring the risk and uncertainty of the process was also a key driver for the creation of a learning organisation. So the modelling methodology should enable analysis of not only process task and process flow but also the critical phases of the NPD-ETO process particularly that of people product process and organisation.

4.6.2 Part II - Use of Performance Measures (Q6)

Use of performance measures or Key Performance Indicators for organisational aspects of NPD-ETO did exist but they were the standard (such as product cost, supplier costs of factored items, quality rework costs and time related metrics. Organisational issues are looked at by directors and the senior management teams during some kind of management reviews. For example company C they have something called 'Conversion Process' where they discuss the contribution of the success or failure of projects to, amongst other factors, the organisation structure.

One should note that performance measures or KPIs are however used in other areas such as manufacturing processes, material flow and other inventory related issues, and the flow of information flow etc.

In company A, for NPD productivity improvements in terms of budgeted and actual spend are measured as a well as time/speed of doing things.

One key person in Company B's productivity improvements commented that improvements in productivity without a change of organisation structure can only yield so many benefits, where as changing organisation structures if done carefully can immensely increase those improvements.

One key middle manager stated that for organisational structure analysis the one thing one should look at is training given to people to enhance their skills and monitor if they actually being utilised to the best.

4.7 PART III Application Requirements for Decision Support Tools (Q1)

On the survey relating to the use of tools for knowledge sharing and organisational learning aspects of NPD-ETO we discovered that the concept of using process modelling and analysing the process models particular for knowledge sharing and organisational learning issues using knowledge management theories, was still alien to most companies. The most common approach to identify such problems was through emails, meetings and discussions.

Various aspects of knowledge sharing were studied. They were:

- Type of Decision Support Techniques most frequently used (Q1)

- ❖ Knowledge Sharing (Q2)
- ❖ Most Preferred Application of Modelling and Analysis (Q3)
- ❖ Preferred Type of Knowledge Sharing Output (Q4)
- ❖ Potential Users of Decision Support & Project-Based Analysis (Q5)
- ❖ Structure of Modelling and Analysis Tool (Q6)

The results of each question are presented in the sections below. For each question/section a summary (or conclusion) is presented in the opening paragraph followed by the results of the individual, participating companies.

4.7.1 Type of Decision Support Techniques most frequently used (Q1)

Through the literature research and earlier interviews key improvement areas and applications for decision support were identified. A sample of key improvements was selected and the staff questioned on what decision support mechanism they use to achieve these aims. Overall it was found the people (managers and engineers) used a variety of decision support aides to relate to problems associated NPD-ETO/MTO operational and organisational issues. The study identified a market gap for a suitable decision support product as well genuine need for the use of process modelling and analysis on the models for NPD-ETO project-based learning. The main issue given for not using process modelling and analysis extensively was the lack of appropriate, low cost tools and associated methodologies which dealt with issues important to KM and OL. The results of the individual companies are as follows.

4.7.1.1 Company A

The table below reveal that the use of modelling tools is lacking. Process Modelling does exist however, only in terms of the requirements set out in the procedures required under the ISO9000:2001 standard. The decision support mechanisms are reviews and meetings or discussions.

Application	Various Decision Support Mechanisms used by Managers and Engineers interviewed											
	Tendering Engineer		Project Manager		Contract Engineer		Design Engineer		Planning Engineer		Production Manager	
	Decision Support Mechanism	NPD time & frequency of use	Decision Support Mechanism	NPD time & frequency of use	Decision Support Mechanism	NPD time & frequency of use	Decision Support Mechanism	NPD time & frequency of use	Decision Support Mechanism	NPD time & frequency of use	Decision Support Mechanism	NPD time & frequency of use
Optimisation of information flow	Sometimes use of process mapping & Team based discussions	Continuous Improvement and frequently	Meetings with Teams, Brainstorming Meetings which review	Occasionally	discussions and programme compliance with clients	N/A	N/A	N/A	Using computer networks, LAN, email,	Continuous Improvement and frequently	Using computer networks, LAN, email,	Continuous Improvement and frequently
Improvement to the ETO process	Management Reviews and quality audits	Continuous Improvement and frequently	Discussions and Meetings,	Occasionally	Using Gantt Charts Brainstorming sessions, basic flow charts	N/A	Discussions and meetings Design Reviews/ Brainstorming sessions	Only when problems arise which happens frequently	Discussions and meetings	Quality Audit (ISO9000), general meetings twice s year with issues raised	Discussions and meetings	Only whe problems aris which happer frequently
Improvement to the manufacturing process	N/A	N/A	N/A	Occasionally	N/A	N/A	N/A	N/A	Discussions and meetings	Only when problems arise which happens frequently	Discussions and meetings on a weekly basis	Only when problems arise which happens frequently
Organisational Change and Continuous Improvement	Produce an Organisational Review Report which	Continuous Improvement and frequently	Paper Based methods and discussions Experience and Training	Occasionally	Paper Based methods and discussions Experience and Training	Only when problems arise which happens frequently	Experience and Training	Only when problems arise which happens frequently	Discussions and Meetings	Occasionally	Discussions and Meetings	Occasionally
Investments costs Vs benefits	Pre and Post investment review, utilisation, margin, turnover is predicted and checked	Occasionally	Departmental budgets once a year using excel spreadsheets	Only when problems arise which happens frequently	Measure payback time frame	Continuous Improvement and frequently	Paper based system to decide	Only when problems arise which happens frequently	Route cards and	Only when problems arise which happens frequently	Discussions and Meetings	Only whe problems aris which happer frequently

Table 4-12; Use of Decision Support Tools at Company A (Survey Part III Q1)

4.7.1.2 Company B

Six people from this gas turbine manufacturer were interviewed. The full results are shown in the table below. We can see the use of software tools, as decision support aides is more prevalent than in company A, in particular the use of process modelling, Alstom are a world class MTO/ETO manufacturing company so this shows the acceptability of process modelling as a viable decision support / knowledge sharing mechanism in NPD-ETO project analysis and analysis of KM in ETO manufacturing environment.

Application	Various Decision Support Mechanisms used by Managers and Engineers interviewed					
	1	2	3	4	5	6
Optimisation of information flow	Use of process mapping	Meetings with Teams, Brainstorming Meetings which review PMs compliance with programme	Paper based flowcharting discussions	On a one –to-one basis		
Improvement to the ETO/MTO process	Continuous Improvement Team Key Performance Indicators Business Development Team	Discussions and Meetings, Project Review Meetings, Highlighting project and process issues, Brain storming meetings	Measure milestones/ stage-gates against estimate Measure and Review Key Performance Indicators (KPIs)	Quality Audit (ISO9000), general meetings twice s year with issues raised	Discussions	
Organisational Change and Continuous Improvement	Senior Management Team Monthly Reports	PM look at Budgets and Actual spends				
Investments costs Vs benefits	Pre and Post investment review, utilisation, margin, turnover is predicted and checked Staged Process	Measure payback time frame	Departmental budgets once a year using excel spreadsheets	Paper based system to decide	Route cards and ERP System	Project review meetings
Design Change System	Flow Charting, brain storming, audit and control process from ISO9001:2000					
Project Management System	Flow Charting, brain storming, Project Monitor meetings (weekly)					

Table 4-13; Use of Decision Support Tools at Company B (Survey Part III Q1)

4.7.1.3 Company C

6 people from this pump manufacturer were interviewed. The full results are shown in the table below. We can see the use of software tools, as decision support aides is more prevalent than in company A, in particular the use of process modelling, Sulzer Pumps is also a world class MTO/ETO manufacturing company so this shows the acceptability of process modelling as a viable decision support / knowledge sharing mechanism in NPD-ETO project analysis and analysis of KM in ETO manufacturing environment.

Application	Various Decision Support Mechanisms used by Managers and Engineers interviewed					
	1	2	3	4	5	6
Optimisation of information flow	Management Procedures & Internal Quality Audits	Meetings with Project Managers, Brainstorming Sessions which review PMs compliance with programme	Quality Manual and management and operational procedures	On a one –to-one basis		
Improvement to the ETO/MTO process	Conversion Team New KPIs Cap Ex.	Discussions and Meetings, Project Review Meetings, Highlighting project and process issues, Brain storming meetings	Measure milestones/ stage-gates against estimate Measure and Review Key Performance Indicators (KPIs)	Quality Audit (ISO9000), general meetings twice s year with issues raised	Discussions & Team Briefs	
Organisational Change and Continuous Improvement	Produce an Organisational Review Report which Budgets and Training programmes	PM look at Budgets and Actual spends	Commercial Reviews			
Investments costs Vs benefits	(1) Pre and Post investment review, utilisation, margin, turnover is predicted and checked (2) Staged Process	Measure payback time frame Estimation and Actual Costing Matrix	Departmental budgets once a year using excel spreadsheets	Paper based system to decide	ERP System	Production review meetings Activity Planning Meetings
Design Change System	Design Review, Design Control audit and control process from ISO9001:2000	Design Review Meetings				
Project Management System	]brain storming, Project Monitor meetings (weekly)	MS Project				

Table 4-14; Use of Decision Support Tools at Company C(Survey Part III Q1)

Company D

There were few tools used internally in the planning of change except for process tool and descriptions of the existing information flow and control systems. The "tools" and decision support came mostly from outside consultancies and their analysts. This was combined with the internal knowledge throughout the levels of the organisation. The same goes for the knowledge and understanding of process optimisation. The internal knowledge comes from the use of text books and process improvement and NPD management.

4.7.2 Knowledge Sharing (Q2)

In this question the aim was to find what the critical activities within NPD-ETO process were the main considerations when making such decisions in terms of management and coordination of such NPD-ETO projects. Through the earlier discussions and literature 'Hot Spots' were identified as elements as critical decision. These were:

> 1) The information feedback of previous projects, 2) Knowledge sharing across the organisation, 3) Capturing tacit knowledge (resides in people's heads), 4) Accessibility of previous projects, 5) The ability of repeating previous ETO Projects, 6) Predictability of future forecasts, 7) Supplier knowledge and understanding, and 8) Organisational learning (learning from experiences).

This research is about KM and Project-Based Learning in NPD-ETO manufacturing projects with the focus on the 'softer issues' elements of process uncertainty and project risk and vulnerability and definition of appropriate metrics. One can say that all are equally important issues, but the aim to identify which comes first when making decisions in NPD-ETO. This would identify the relative importance, currently placed in industry on the analysis of the 'softer' issues compared to the 'harder' cost and time related issues or metrics. The results of the study were not surprising as all the companies involved in the analysis were biased towards financial considerations when making decisions. This in fact is a good reason why a tool is required to look at the softer aspect of human (as well as technical) resources issues, under the umbrella of knowledge sharing. The results for companies A, B, C and are given below.

4.7.2.1 Company A

Six people from all levels were interviewed and asked to rate the eight characteristics, with position one getting the highest score and three the lowest. The following result was drawn:

1) The information feedback of previous projects, 2) Knowledge sharing across the organisation, 3) Capturing tacit knowledge (resides in people's heads), 4) Accessibility of previous projects, 5) The ability of repeating previous ETO Projects, 6) Predictability of future forecasts, 7) Supplier knowledge and understanding, and 8) Organisational learning (learning from experiences).

		Respondents								
	Knowledge Management Capabilities	Tendering Engineer	Project Manager	Contract Engineer	Design Engineer	Planning Engineer	Production Manager	**Totals**	**Percentage Max**	**Ranked Position**
		Highest (1=30; 2=20 3=10) Lowest								
1	The information feedback of previous projects	10	20	23	10	10	10	**83**	**46%**	**5**
2	Knowledge sharing across the organisation	20	30	30	20	20	20	**140**	**78%**	**2**
3	Capturing tacit knowledge (resides in people's heads)	20	20	20	20	10	20	**110**	**61%**	**4**
4	Accessibility of previous projects	30	30	30	30	20	10	**150**	**83%**	**1**
5	The ability of repeating previous ETO Projects	20	30	20	20	20	20	**130**	**72%**	**3**
6	Predictability of future forecasts	10	20	10	10	10	10	**70**	**39%**	**6**
7	Supplier knowledge and understanding	20	30	20	10	20	20	**120**	**67%**	**4**
8	Organisational learning (learning from experiences)	20	20	30	20	10	20	**120**	**67%**	**4**

Table 4-15; Comparison of Knowledge Management Characteristics for Company A

The six people were then asked to rate the mechanism that support knowledge sharing in order of importance (if that was possible) the 14 knowledge sharing mechanisms. Following are the results.

Knowledge Sharing Mechanisms	Respondents: Tendering Engineer	Project Manager	Contract Engineer	Design Engineer	Totals	Percentage Max	Ranked Position
	Highest (1=30; 2=20 3=10) Lowest						
Informal Meeting	30	30	30	30	120	100%	1
Expert System	30	30	30	30	120	100%	1
Database	30	30	20	20	100	83%	2
Social Gathering	20	30	30	20	100	83%	2
Email	20	30	30	20	100	83%	2
Hard Copy Document/Report	20	30	20	20	90	75%	3
Formal Meeting	20	30	20	20	90	75%	3
Minutes/Memo	20	30	20	20	90	75%	3
Phone call	20	30	20	20	90	75%	3
Internet/Intranet	30	20	20	20	90	75%	3
Knowledge Based System	20	20	30	20	90	75%	3
Spreadsheet	20	20	20	20	80	67%	4
Library Archive	20	20	20	20	80	67%	4
Word Doc.	10	10	20	10	50	42%	5

Table 4-16; Knowledge Sharing Mechanisms for Company A

4.7.2.2 Company B

Four people were interviewed to express their views by rating in order of importance (if it was possible) the eight knowledge management 'ability' statements

	Knowledge Management Capabilities	Respondents: Business Development Manager	Respondents: Project Manager	Respondents: Contract Engineer	Respondents: Design Engineer	Totals	Percentage Max	Ranked Position
		Highest (1=30; 2=20 3=10) Lowest						
1	The information feedback of previous projects	10	20	23	10	**63**	**53%**	**5**
2	Knowledge sharing across the organisation	20	30	30	20	**100**	**83%**	**2**
3	Capturing tacit knowledge (resides in people's heads)	20	20	20	20	**80**	**67%**	**4**
4	Accessibility of previous projects	30	30	30	30	**120**	**100%**	**1**
5	The ability of repeating previous ETO Projects	20	30	20	20	**90**	**75%**	**3**
6	Predictability of future forecasts	10	20	10	10	**50**	**42%**	**6**
7	Supplier knowledge and understanding	20	30	20	10	**80**	**67%**	**4**
8	Organisational learning (learning from experiences)	20	20	30	20	**90**	**75%**	**4**

Table 4-17; Comparison of Knowledge Management Characteristics for Company B

For company B Predictability was the lowest ranking followed by the information feedback of other projects and then knowledge that resides from individual's personal knowledge and experience. However we can also see the differences of opinion between the other categories.

The six people were then asked to rate the mechanism that support knowledge sharing in order of importance (if that was possible) the 14 knowledge sharing mechanisms. Following are the results.

	Knowledge Sharing Mechanisms	Business Development Manager	Project Manager	Contract Engineer	Design Engineer	Planning Engineer	Production Manager	Totals	Percentage Max	Ranked Position
		Respondents								
1	Informal Meeting	30	30	30	20	30	30	170	94%	1
2	Expert System	30	30	20	30	30	30	170	94%	1
3	Database	30	30	30	30	20	20	160	89%	2
4	Social Gathering	20	30	30	20	30	20	150	83%	3
5	Email	30	30	20	20	30	20	150	83%	3
11	Knowledge Based System	20	20	30	20	30	20	140	78%	4
6	Hard Copy Document/Report	20	30	20	20	20	20	130	72%	5
7	Formal Meeting	20	30	20	20	20	20	130	72%	5
8	Minutes/Memo	20	30	20	20	20	20	130	72%	5
9	Phone call	20	30	20	20	20	20	130	72%	5
10	Internet/Intranet	30	20	30	10	20	20	130	72%	5
12	Spreadsheet	20	20	20	20	20	20	120	67%	6
13	Library Archive	20	20	20	10	20	20	110	61%	7
14	Word Doc.	10	10	10	10	20	10	70	39%	8

Table 4-18; Comparison of Knowledge Management Characteristics for Company B

4.7.2.3 Company C

6 people from the organisation were asked to express their views by rating in order of importance and benefits (if that was possible) of sharing experiences and personal knowledge and organisational learning.

	Knowledge Management Practice	Respondents 1	2	3	4	5	6	Totals	Percentage Max	Ranked Position
		Highest (1=30; 2=20 3=10) Lowest								
1	The information feedback of previous projects	10	20	23	10	10	10	**83**	**46%**	**5**
2	Knowledge sharing across the organisation	20	30	30	20	20	20	**140**	**78%**	**2**
3	Capturing tacit knowledge (resides in people's heads)	20	20	20	20	10	20	**110**	**61%**	**4**
4	Accessibility of previous projects	30	30	30	30	20	10	**150**	**83%**	**1**
5	The ability of repeating previous ETO Projects	20	30	20	20	20	20	**130**	**72%**	**3**
6	Predictability of future forecasts	10	20	10	10	10	10	**70**	**39%**	**6**
7	Supplier knowledge and understanding	20	30	20	10	20	20	**120**	**67%**	**4**
8	Organisational learning (learning from experiences)	20	20	30	20	10	20	**120**	**67%**	**4**

Table 4-19; Comparison of Knowledge Management Characteristics for Company C

The six people were then asked to rate the mechanism that support knowledge sharing in order of importance (if that was possible) the 14 knowledge sharing mechanisms. Following are the results.

	Knowledge Sharing Mechanisms	Business Development Manager	Project Manager	Contract Engineer	Design Engineer	Planning Engineer	Production Manager	Totals	Percentage Max	Ranked Position
		Respondents								
1	Informal Meeting	30	30	30	20	30	30	170	94%	1
2	Expert System	30	30	20	30	30	30	170	94%	1
3	Database	30	30	30	30	20	20	160	89%	2
4	Social Gathering	20	30	30	20	30	20	150	83%	3
5	Email	30	30	20	20	30	20	150	83%	3
11	Knowledge Based System	20	20	30	20	30	20	140	78%	4
6	Hard Copy Document/Report	20	30	20	20	20	20	130	72%	5
7	Formal Meeting	20	30	20	20	20	20	130	72%	5
8	Minutes/Memo	20	30	20	20	20	20	130	72%	5
9	Phone call	20	30	20	20	20	20	130	72%	5
10	Internet/Intranet	30	20	30	10	20	20	130	72%	5
12	Spreadsheet	20	20	20	20	20	20	120	67%	6
13	Library Archive	20	20	20	10	20	20	110	61%	7
14	Word Doc.	10	10	10	10	20	10	70	39%	8

Table 4-20; Knowledge Sharing Mechanisms for Company C

The results of this study were not surprising as the companies involved in the study were biased towards financial considerations when making decisions. This in fact is a good reason why a tool is required to look at the softer characteristics of human (as well as technological) resources, under the umbrella of project performance. The results for companies A, B, and C are given below. Company D did not take part in this question due to the time constraints on the amount of interview time provided by the people provided.

4.7.3 Most Preferred Application of Modelling and Analysis (Q3)

Six applications were presented and interviewees were asked to rate the need of modelling and analysis for each. The applications were: NPD processes, Manufacturing Processes, Resource Allocation, Information Flow optimisation and Project Management. The results were quite varied amongst the four companies. This showed the different needs of each company. However modelling and analysis of the NPD process scored highly for all four companies as shown in the sections below.

4.7.3.1 Company A

10 people representing a cross section of the business involved in NPD-ETO or those who were familiar with the use of decision support tools were interviewed. They were (note some members had dual roles):

From Tendering & Sales

Sales Manager, Procurement Manager, Projects Managers, Project Engineers.

From Engineering Design

Projects Managers, Project Engineers Design Engineer, Chief Designer.

From Production Planning

Projects Managers, Project Engineers.

From Manufacturing

Production Manager, Production engineer, Logistics Manager.

Other Functions

Marketing Manager.

The results, in descending order of need, are given below showing the %age of points to each application as most preferred application (rating 1-5) The relative positions allocated were given appropriate scores (1=25 2=20... and 5=5). The respective totals were divided by the maximum possible scores to get the percentages.

Most Preferred Application	% of the Votes Given
1. NPD Process	90%
2. Manufacturing Processes	68%
3. Resource Allocation	51&
4. Human Resource Management	42%
5. Information Flow Optimisation	40%
6. Organisation Structure	32%

Table 4-21; Most Preferred Application for Modelling & Analysis of Company A

So based on company A's results the focus of the methodology should be on processes and focus on issues relating to the resource allocation

4.7.3.2 Company B

Four people were interviewed. The results are as follows:

Most Preferred Application	% of the Votes Given
1. Resource Allocation	90%
2. NPD Processes	68%
3. Information Flow Optimisation	51%
4. Human Resource Management	42%
5. Organisation Structure	40%
6. Manufacturing Processes	32%

Table 4-22; Most Preferred Application for Modelling & Analysis of Company B

So based on company A's results the focus of the methodology should be on processes and focus on issues relating to the resource allocation

4.7.3.3 Company C

Six people were interviewed. The results are as follows:

Most Preferred Application	% of the Votes Given
1. Resource Allocation	90%
2. NPD Project Management	70%
3. Project Management Processes	56%
4. Information Flow Optimisation	42%
5. Organisation Structure	40%
6. Human Resource Management	32%

Table 4-23; Most Preferred Application for Modelling & Analysis of Company C

4.7.3.4 Company D

Six people were interviewed. The results are as follows:

Most Preferred Application	% of the Votes Given
1. Resource Allocation	90%
2. Information Flow Optimisation	68%
3. Manufacturing Processes	62%
4. Human Resource Management	42%

Table 4-24; Most Preferred Application for Modelling & Analysis of Company D

4.7.4 Preferred Type of Output for Knowledge Sharing (Q4)

Three choices were given to the persons were asked to rate them (1 to 3) in order of preference. If an option was not preferred then the rating of zero would be given. The ratings were translated into the appropriate scores. Summarising the results, the main functionality in types of output should be used:

- Index Values/Benchmarks/Performance Measures (Scores) Rating System
- Process Variables (the process maps, number of activities, quality of resources, value added activities, identification of risk or uncertainty etc); and
- Representation of change in score due to a change in process improvement, case-base histories

The tables below show the individual company results:

4.7.4.1 Company A

Rating	Output Type	Total Score	Percentage of Max
1	Index Values / Benchmarks / Performance Measures (Scores) Rating System	230	64%
2	Checklists	200	56%
3	Actual Cost Saving to Benefits	160	44%

Table 4-25; Preferred Type of Output for Company A

4.7.4.2 Company B

Rating	Output Type	Percentage of Max
1	Process Values / Benchmarks / process loops, project risk, value added activities	100%
2	Checklists	64%
3	Actual Cost Saving to Estimated	52%
4	Resource Profiles	20%

Table 4-26; Preferred Type of Output for Company B

4.7.4.3 Company C

Rating	Output Type	Percentage of Max
1	Index Values / Benchmarks / Performance Measures (Scores) Rating System	100%
2	Checklists	60%
3	Actual Cost Saving to Estimated (Tendering)	52%

Table 4-27; Preferred Type of Output for Company C

4.7.4.4 Company D

Company D had a slightly more open view regarding the type of output they would like to see. Below is the synthesis of different people's comments. From a model one would expect data representation of the result of change. This would be best if some sort of graphical representation could ease the communication of the results. A model should give sufficient data in the critical areas with which the efficiency of the modelled subject normally is measured. Project-Based Learning or Knowledge Sharing can be any value as long as its clear what value stands for and how it is changing.

4.7.5 Implications on Modelling and Analysis Methodology

The above results indicate the performance outputs should be designed and implemented to reflect organisational goals and objectives. Managing the knowledge is a not only a strategic process that enables other critical business processes such as NPD. Therefore, it is important to focus measures (and the entire initiative) on factors that affect the ability to achieve.

Knowledge Sharing measures have several objectives:

- To help make a business case for implementation
- To help guide and tune the implementation process by providing feedback
- To provide a target or goal
- To measure, retrospectively, the value of the initial investment decision and the lessons learned
- To develop benchmarks for future comparisons and for others to use
- To aid learning from the effort and develop lessons learned

By capturing these outputs which are occur during the entirety of the NPD-ETO process will support the strategic goal for creating organisational learning So the modelling methodology should enable analysis critical phases of the NPD-ETO process also the mechanisms for project-based learning as well as organisational learning.

4.7.6 Potential Users of Decision Support & Project-Based Analysis (Q5)

Project Managers, Resource Managers and other senior managers in front line activities such as Tendering, Design or other technical roles. In addition to this team leaders of collocated or multifunctional teams.

4.7.7 Structure of Modelling and Analysis Tool (Q6)

Most people at company A envisioned the final tool to be a collection of tools to support the decision making process in NPD-ETO at different levels. Companies B, D and D also shared the same view.

4.8 Discussion and Conclusions

4.8.1 Overview of the Survey Results

The results of the survey despite the introduction of such techniques as CE, organisational structure related issues in terms of integration of functions and processes were still a main problem or bottlenecks. There are various reasons for these problems such as weak matrix structures i.e. functional divisions still driving projects, confusion over command and control in matrix structures, lack of supplier integration and involvement (supply chain issues), multi-site teams communication and collaboration problems etc. Where collocated teams were introduced these problems were considerably reduced, however, new problems relating to group dynamics emerged especially with regards to human resource utilisation and sharing resources. Human resource estimating, planning, management and coordination were general problems across all MTO & ETO projects. Other issues relating to specifically to NPD management was training, rewards, project control systems and administration resources and external pressures from customers, suppliers and competition. Overall, inter-functional communication and collaboration, use of new technology and training were the key issues in NPD-ETO management and knowledge sharing.

Regarding the use of computerised decision support for management analysis of such problems, it varied depending on the culture within the company. Only one company used limited process modelling. Using process models for knowledge sharing was an alien concept for most people. It was found that informal meetings and discussions predominated and Key Performance Measures for NPD management did not exist. Only manufacturing and quality functions used simulation tools or performance measures for decision support and knowledge sharing.

The observations made in these mini case studies agree with what was confirmed in literature that organisational, cultural and technological issues are key barriers to knowledge sharing and organisational learning.

4.8.1.1 Impact of Changes to be introduced:

Most manufacturing organisations exist with different types of organisation structures. Only a few have clear identical structure in every department or function. This is true for the companies that have invested. The impact of changes on the manufacturing organisation will depend on the ratio between the main processes and supporting processes and how changes in the main process affect the supporting processes.

One can have major changes within the NPD-ETO (process teams, etc.) with only a few noticeable changes elsewhere except for communication standards and resource management. For example at Sulzer Pumps though the tendering and advance engineering departments had been modified to enable knowledge sharing due to the changes in NPD-ETO practices, the rest of the organisation was still quite hierarchical and functional thinking. As soon as a task went downstream it entered the old and slow organisation, hence affecting the effectiveness of the project team.

So in order to introduce a change (the proposed analysis method for MTO and ETO manufacturing environments) the following issues will have a bearing on the level of impact:

- The ideal ETO/MTO organisation is that one the can control its processes and utilise its resources to the optimum, as well as learning and share from those experiences
- The structure will vary from one company to another with vast number of mixtures proving to be ideal

4.8.1.2 Implications on Methodology and Tool:

From the investigations carried out, in order to tackle the issues of improving the NPD-ETO process the following specifications need to be satisfied in terms of 'what' to model and analyse: the knowledge sharing and project-based learning 'context' of analysis (the where and when); and 'how' to model and analyse:

What to model and analyse (Questions 1, 3, and 5 of part II of survey)

Analysis of knowledge sharing and project-based learning issues, as defined in sections 1.5.6 in particular the performance of teams, individuals, and communication links, in terms of value adding activities and the ability to add value). A focus on the 'softer' issues i.e. human resource behaviour and quality of tools and other resources is required. This will lead to the evaluation of the process and will in turn verify the project risk and quality of the commitment.

Knowledge Sharing and Project-Based Learning context of analysis (Questions 1 and 2 of part II of the survey)

Dis-aggregation of the analysis is required. Different levels of process hierarchy require different views and forms of analysis.

How to model and analyse (Q4 pf part II and all questions in part III)

Develop a process modelling approach as the main knowledge sharing tool, a highly structured approach is required, with the use of 'weightings' to get accurate answers, results and measures which highlight the issue for the right level.

The output should be in the form of:

- Process values / Benchmarks / Rating Scoring system (the activity, quality of the input, quality of the tools, and quality of the human resource)
- Process variables (the output, number of activities, value added, feedback loops, cross impact, identification of risk and uncertainty) and;
- Representation of a change in score due to the change an the process quality metric assessment criteria

Process modelling and analysis will focus on the thinking towards knowledge sharing and not the functional constraints in NPD-ETO. The tool should be within budget allowed for such investments.

Chapter 5 - THE FRAMEWORK PROPOSAL & ANALYSIS METHODOLOGY

5.1 Introduction

In Chapter 2 (Literature Review) discussed the application NPD practices, the manufacturing characteristics of ETO and knowledge management methods and process modelling in NPD, with regards to developing a framework for modelling the NPD-ETO process and analysing the knowledge sharing issues – i.e. developing a analytical model for NPD-ETO. A 'company survey' was carried out to investigate the practical requirements from the end users point of view. The conclusions drawn have resulted in the following are described:

The proposed Sharing-ETO-Knowledge 'SETOK' framework is presented in Figure 5.1 and consists of four development phases:

1. Levels of modelling and Analysis
2. Modelling Approach
3. Analysis Approach
4. Implementation Approach – involving the application and appropriate computerised tools and software for implementing the methodology and a step wise implementation procedure for applying the methodology and tools in industry.

Section 5.2 describes briefly the focus of each level. Sections 5.3 to 5.6 explain the modelling and analysis methods and tools for the process quality analysis. Section 5.7 describes the practical implementation steps or methodology for application within such ETO manufacturing enterprises. The framework developed tackles pertinent issues for both the academic and industrial communities. Business processes and organisation structures, whether they are Matrix, Product or Project types are made of specialist functions or departments. Though the framework developed has been designed based on the researcher's analysis of primarily ETO manufacturing organisations of the participating companies and companies found in the literature reviews. MTO organisations can also use this.

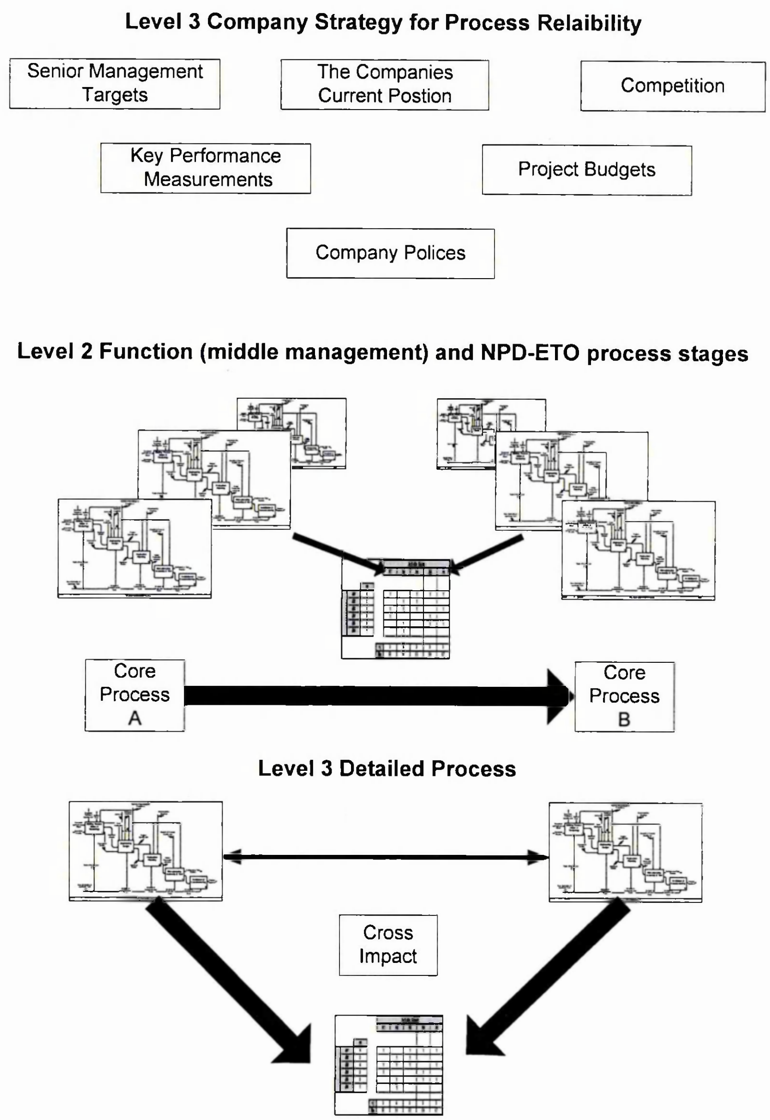


Figure 5-1; 'SETOK' Framework Proposal

5.2 Levels of Modelling & Analysis- Overview

The aim was to develop an analysis mechanism to enable comprehensive analysis of the NPD-ETO process. Knowledge within traditional process mapping approaches including to decomposition, in particular IDEF0 was adapted to suit the manufacturing environments to ETO. The result was two view points:

- an NPD-ETO process viewpoint
- a Knowledge Sharing viewpoint

For each there are three further views: a modelling viewpoint, an analysis of the model viewpoint, and knowledge sharing viewpoint.

Three generic levels of analysis were developed. These were based on or contingent upon the analysis focus and the modelling approach used. Each level was then partitioned further to deal with the different perspectives or viewpoints. Note that as opposed to the traditional levels of the organisational analysis the new model adopts the "process hierarchy" into the framework as well. The analysis levels developed were:

- Level 3- Company Strategic Level- Company Strategy for process improvement (company wide assessment)
- Level 2 – Functional and NPD-ETO Projects level– Middle management level, focusing on Department or Functional performance of the main phases, as well as learning across projects
- Level 1 –Detailed Process Level – Focusing on the operational activities at an operational level, and inter functional levels process activity level

The diagram below illustrates the constituents both process and organisation for the 3 levels.

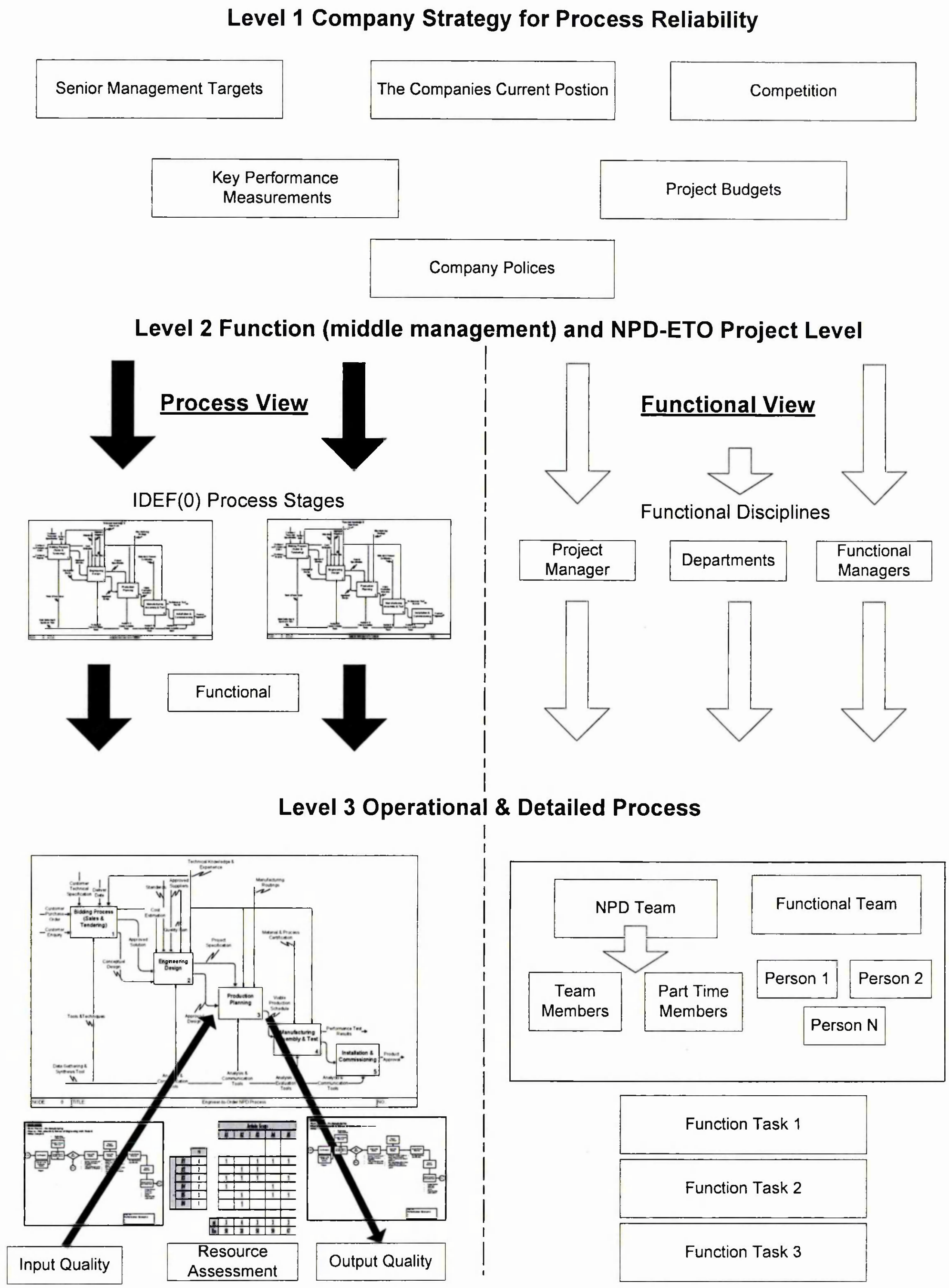


Figure 5-2 Organisation Hierarchy versus Process Hierarchy

A brief explanation or 'focus of each level is given below. Details and explanations are given in sections 5.3 onwards.

5.2.1.1 Level 3 –Company Strategic Level

The focus here is to assess the strengths and weaknesses of the company at an aggregated level in terms of issues important to ETO manufacturing principles. The analysis is for the group of people who are charged with ensuring that the organisation implements practices in an effective way.

5.2.1.2 Level 2 –Functional and Project Learning Level

The focus at this level is the functional departments and the key NPD-ETO phase. The phases define what needs to be done in terms of requirements and contributions.

Here we analyse the level of difficulty in the information exchange between departments whether due to poor 'efficiency' or low 'effectiveness'. The data gathered through a quantitative analysis of:

I. The contributions made by each department or function to a NPD-ETO phase (i.e. the outputs of the phase);
II. The requirements (from other functions or departments) of each department or function for the contributions.

It concerns primarily the people (or system) concerned with managing and directing the ETO project and process in terms of tasks and resources. Such people are Project Managers, Department Managers. Examples of departments are, sales, tendering, design, procurements, contracts or projects, quality and manufacturing production etc.

There is also the aspect to do with knowledge sharing and project-based learning. Here we analyse project's performance against previous case histories which is drawn up through the level one analysis which assesses the level of reliability whether due to poor 'information sharing' or low 'project-based learning'. The data gathered through a quantitative analysis of:

I. The contributions made by previous projects to a NPD-ETO phase (i.e. the outputs of the phase);

II. The level 1 process outcomes of each operational activity and process for the contributions.

The process model of the key NPD-ETO stages has been labelled as the primary level process in Figure 6.1. This is the NPD-ETO process in its most aggregated form. For example at Sulzer Pumps (UK), the stages (or phases) were (1) Tendering, (2) Projects, (3) Pre-Manufacturing, (4) Procurement, (5) ODC Scheduling, (6) Core Operations, (7) Production Technologies, (8) Engineering Services

5.2.2 Level 1 - Operational Level and Detailed Process Level

The management of the NPD-ETO process is key focus and hence main output of the PhD. The focus of risk and uncertainty defined under those 'points of vulnerability and commitment' focus. At this level the process involves a combination of workflow, from one process activity to another, and communication. Here in this context workflow is defined as: *the flow of work from on activity to another without any change in function (individual or team).* The term function is defined more accurately later in the section 6.3. This focus of cross impact on process-based activities is what distinguishes this activity from others. Our interest is in the modelling and analysis of quality of the resources within the process.

5.3 Framework Summary

The analysis methodology has to cope with the characteristics of each type of NPD-ETO project at organisational level as well as process level. How this is achieved is summarised in the framework shown in Figure 5.1. One will notice that the NPD-ETO process has been decomposed into three levels of processes, primarily, secondary, and tertiary. This composition style is drawn upon the IDEF(0) and is explained earlier in Chapter 2 and Section 5.5.1 below in more detail. These analysis levels are presented in a schema below:

5.3.1 Level 3- Company Strategic Level

The model is a static type of model depicting the key elements, which affect the manufacturing project in terms of knowledge sharing. The criteria making up this performance or assessment model are:

1. Customer Feedback
2. Risk Assessment
3. Goal Sharing
4. Activities and Processes
5. Quality of Resources
6. Organisation and Management
7. Key Performance Indicators
8. Implementation, and
9. Knowledge and Information

5.3.2 Analysis

The PoC assessment model focuses on the identification of critical phases with respect to NPD-ETO in terms of information flow and workflow and mechanisms available. Bottlenecks, project uncertainty can be identified as a gap between 'as-is' model and 'ideal' model of a particular 'best practice' criteria defined by the company.

The assessment must be performed in a number of steps. The first step is to identify the current 'as-is' profile, and this is done through the **'Knowledge Sharing'** questionnaire. Finally the results are compared in a radar graph showing the gaps of the departmental profiles. The gap analysis will then form the basis for the change in implementation processes in the company. Additionally, there is another aspect of the **'Knowledge Sharing'** questionnaire form, Which is called The '**Points of Commitment',** its asks the user to identify the critical decision making points on certain key criteria, as well as the mechanisms that support those critical decisions. The full questionnaire is provided in Appendix C.

5.3.3 Knowledge Sharing Questionnaire

The questionnaire is used to identify the current profile of the company. The targets are relative to KM principles. The company must define which KM practices are the most important for the organisation. For every area a target profile is defined by asking management levels where they want to see the company in the future in terms of being a learning organisation. The target profiles can be presented in a bar chart format. With this result the company can study their target profile and evaluate it against their current situation. The questions in the questionnaire are support the mapping process and assessment model.

The management team and persons working in or with the company fill in the use of the questionnaire. The individuals are asked how they rank the current company performance. A large number of persons from different levels and functions in the organisation will be asked the opinion on the current company performance.

5.3.3.1 Results

The aggregated current profile can be graphically represented in a radar diagram, with the results of study, the company can study their current situation and evaluate it against the company's current performance profile:

The calculation of the results will be performed in the following way:

- These values are translated into percentage values representing the current situation
- The user questionnaire defines the current profile from the ideal profile

5.3.4 The computer based tool

Analysis is carried out using an MS Excel spread sheet/form

5.4 Level 2- Functional and Process Phase Level

5.4.1 Modelling

This consists of two elements:

1. a top process model (primarily) showing the key phases an NPD-ETO project goes through, an indication of the phase and the interrelationships in terms of outputs across projects
2. a spreadsheet modelling listing the key inputs, controls, methods, and outputs for each activity involved in the process.

5.4.2 Analysis

Analysis is primarily carried out on the data of the spreadsheet. One could also review at the top level the process based on the analysis.

As shown in Figure 5.1 this level is divided (and consequently the lower levels too).

The primary focus (as defined earlier) is analysed buy the functional and project managers. To analyse the process at this level an input-output type of analysis is proposed. A two part table is been developed which filled out for each primary activity by each contributing department /functional head or manager.

Each Functional/Process Manager lists the following:

- **Inputs**: requirements or 'Inputs' to their function; the information provider, and the quality of input from the previous activity,
- **Activity Assessment:** a combination of three internal characteristics:
    - Explicit Knowledge (score between 1-10),
    - Tool Quality (score between 1-10)
    - Tacit Knowledge of the individual or group (score between 1-10)
- **Output:** Outputs or contribution from their department and the quality of output

This type of analysis provides a top level view of the problems as seen from functional manager's point of view. This view can help us in establishing which secondary or lower level process needs to be modelled and analysed, Additionally comparison could be made of the results of this level with the results from level 1 detailed process activity analysis, to find the if the problem activities at this level also appears as problem issues at a more specific level.

5.4.3 The computer based tool

Data collection and analysis was carried out using an MS Excel spread sheet format

5.5 Level 1- Operations and Process Phase Level

In section 6.2.3 two main levels of decomposition and hence analysis were described –Secondary and Tertiary Levels. Both use the same basic modelling and analysis method, which is described below.

5.5.1 The IDEF(0) Modelling Methodology

5.5.1.1 The Approach

Modelling was carried out using Integration Definition for Function Modelling (IDEF) modelling technique. It was developed to facilitate process understanding, analysis, improvement, or reengineering processes (Hunt 1996). An IDEFO process map is composed of a hierarchical series of diagrams in gradually increasing levels of detail of functions and their interfaces. It is a graphical modelling technique that represents activities with their inputs, outputs, controls, and mechanisms. Boxes represent activities and arrows represent relationships and other entities. Inputs are entities that the system transforms them to outputs. Controls are constraints on the system and mechanisms define how and by what mean (s) the activities are carried out.

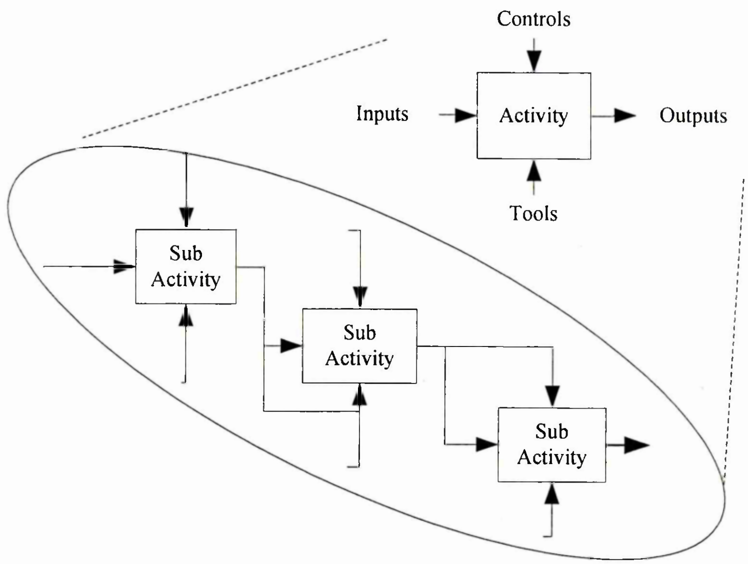


Figure 5-3; IDEF0 task structure

The IDEF0 definition of a function is a set of activities that takes certain inputs and, using some mechanisms, and subject to certain controls, transforms those inputs into outputs. Such inputs, controls, outputs and mechanisms can be used to model relationships among various activities as illustrated in Figure 5.3. Activity boxes represent the process activities and each activity box receives "inputs" which is transformed into "outputs" by applying the "tools" or "methods" and constrained or guided by "controls". The representation provides a good structure for categorising the characteristics of the activity.

In a product development context, the activity characteristics are assigned as follows:

a. **Inputs:** represents information or objects that describe the state of the product which are added to or transformed by the activity. For example, ideas, proposals, specifications, concept sketches, detailed drawings, models, prototypes, launched products .The input may also include material data, performance data, cost data and manufacturing process data.

b. **Controls:** describe the objectives, instructions, conditions, circumstances, influences, information and monitoring factors that govern the activity and show why, when, to what standards, etc. the activity is to be executed. Every activity will have at least one control.

c. **Methods:** are the people, skills, facilities, equipment and materials that are necessary to carry out the activity. The characteristics relate to the identification, availability, quality and management of these resources.

d. **Outputs:** are the consequences of the activity. The output of one activity will often form part of the input to subsequent activities. The view is taken that high quality output will result when the other characteristics, on which the output is dependent, are such as to promote effective execution of the activity (Muller and Fairlie-Clarke, 2003).

IDEF0 supports functional decomposition, which is essential for the complex systems such as the design process. The description of the activities of the system can be easily refined into greater and greater detail until the model is as descriptive as necessary for decision-making. This enables the process to be broken down into detailed and manageable activities and their relationships. The information and resources that are needed for each activity in any stage can also be clarified. The hierarchical nature of IDEF0 facilitates the ability to construct models that have a top-down representation, while they are based on a bottom-up analysis process. Therefore an IDEF0 approach is used to develop and represent the proposed NPD-ETO process.

An IDEF0 model begins with a single box, which represents the boundary of the system under study. This is called context diagram. The context diagram for the generic model of the NPD-ETO process is shown in Figure 5.4. In this diagram the overall design process with the assumed inputs, outputs, controls (constraints), and mechanisms (the supporting tools and personnel) determines the whole process and its boundaries. Starting from targets and goals a company needs to search for the opportunities to achieve them through an approved strategy for NPD. With the predetermined goals and strategies as the inputs to the design process the main source of opportunities and new ideas is the marketplace, which needs to be searched and studied beforehand. Design process then proceeds from ideas based on the customer needs towards an approved design ready for production.

The success of NPD-ETO depends on a wide variety of methods, control, influencing factors, uncertainties, fuzziness have different effects on the product development process stages and activities. Therefore the framework is desirable to organise, identify and measure the effect of the uncertainties, ambiguities and fuzziness on the process at any given stage in the process. This requirement highlights the need for a tool that is, universally applicable to all activities identified under the generic product development process, which can model the entire process and yet provide the opportunity to focus on specific detailed activity if required.

The ability of IDEF to describe a process using a hierarchical approach (Figures 6.3) is one of its key strengths of using it to describe the NPD process. At the top of level of the IDEF0 model (Figures 5.4) is the most general description of the system. This is decomposed into a number of sub-activities (Figures 5.5) which in turn can be further decomposed hence detailed information about the process is exposed along the decomposition path. Strict rules for maintaining the integrity of the inputs, tool, controls and outputs during the decomposition process are critical to the technique so that low level detailed sub-activities is traced backed to top level activities strategic activities. However IDEF0 is limited by its inability to quantitatively assess the effectiveness of the process.

The modified approach is aimed at overcoming this limitation and introduces means for measuring and assessing the vulnerabilities and uncertainties of the process at any specific stage as well as proposing means for improving the reliability of the process.

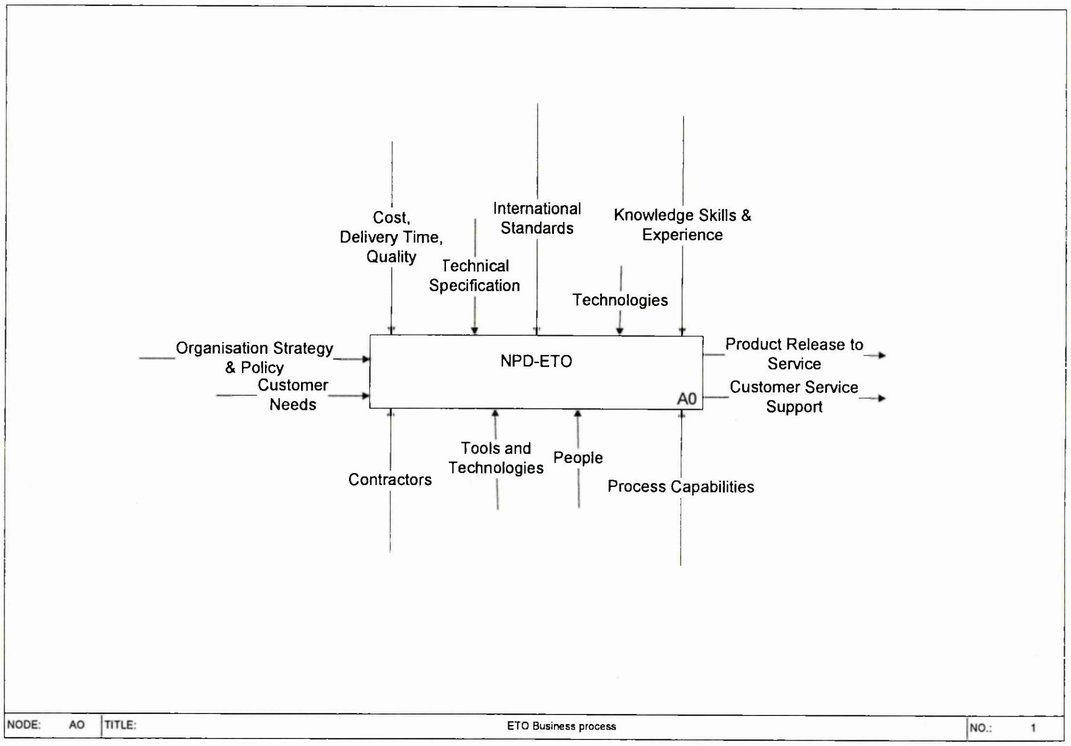


Figure 5-4; The Top Level processes of the NPD-ETO

The main constraints and limitations on the ETO process revolve around cost and time, quality, knowledge and skills, available technology, standards, rules and regulations. These constraints are mainly driven from both external and internal environments in which the company operates (Poolton 1999).

The context diagram is extended to the zero level (A0) diagram that represents the first level activities of the NPD-ETO process and their corresponding arrows. These highest-level activities determine the general structure of the process. Here the main activities of the NPD-ETO process and their supporting tools are considered as follow:

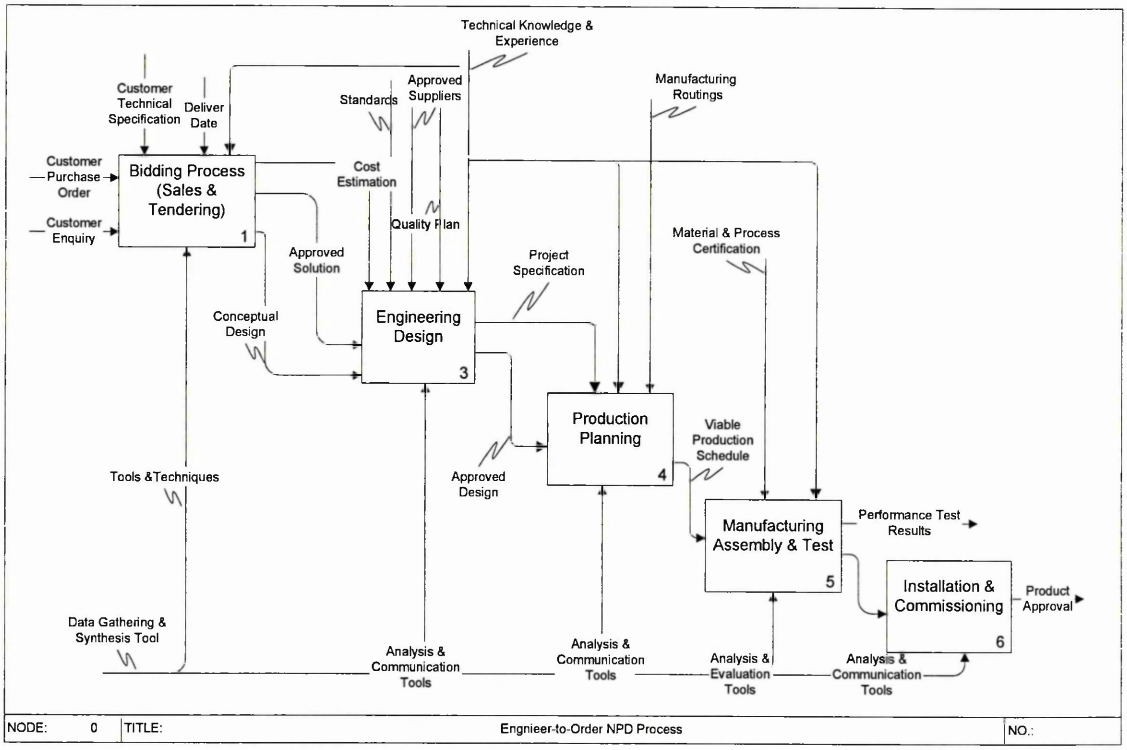


Figure 5-5 A0 diagram of the IDEF0 model

Therefore a technique is needed to represent the overall NPD-ETO process, including the activities, methods, constraints, inputs and outputs and ETO project teams and personnel. By investigating the NPD-ETO processes from both the technical and commercial viewpoint, each of the activities can be viewed as a process of converting specific input(s) into output(s) subject to a series of constraints. These necessities along with the hierarchical nature of the proposed NPD-ETO process are well suited to IDEF0 methods.

5.6 The Process Assessment Approach

As mentioned already the hierarchal decomposition IDEF0 is used. However the modified approach is aimed at overcoming this limitation and introduces means for measuring and assessing the vulnerabilities and uncertainties of the process at any specific stage as well as proposing means for improving the reliability of the process. The approach was then extended by adding quantitative measures indicating the process quality of each of the input entities (Input, Controls, Methods/Tools) and the impact they have on the quality of the input on the next process activity as shown in Figure 5.6 below.

The application and use of the IDEF Assessment Matrix method requires a detailed analysis of the output (new Input) quality of the NPD-ETO activities by assessing the quality of the inputs, controls, methods/resources and in order to measure the quality of the output. This necessitates the use of formal methodology, systematic and probing approach for capturing the characteristics of the activity throughout the process of NPD-ETO. This allows for continuous updating of the process quality as new evidence is available at any stage of the process. The defined framework for process quality of the IDEF model can be used to develop a tool that will enable customer-driven manufacturing companies such as MTO and ETO, to understand the impact of uncertainty due to the quality of the process. This section introduces and first step of the IDEF assessment, the activity assessment matrix. The flowcharted activities were categorised as the following:

a. **Resource Quality:** The technique is a valuable tool to assess the sensitivity of the activity to changes in the quality of inputs, controls, resources and tools. The developed model can be used as a performance assessment tool whereby various scenarios are tested and the reliability of the process is evaluated. Preventative action can then be identified and implemented.

b. **Process Robustness:** The technique can also be used to monitor the level of uncertainty made within the activity process to which there maybe a point of no return. Frequent evaluation of the process model throughout key phases of the project can be carried out using current data to assess whether the certain decisions or outcomes are retrievable or not. Potential risks can be identified and contingency plans can be recommended or implemented. This avoids the ad hoc approach to project management when the numbers of factors to consider make it difficult to understand their impacts on the process.

c. **Process improvement:** The technique can also be used to monitor and control the process. Regular evaluation of the process model throughout the project life can be carried out using current data to assess whether the quality of the outputs are achievable or not. Remedial actions can be identified and implemented. This also avoids the ad hoc approach to process improvement when the numbers of factors to consider make it difficult to understand their interdependency.

5.6.1 Resource Quality

In order to meet process reliability calculation, the reliability analysis must contain both activity resources and process operations. Based on a popular tool for reliability Failure Mode and Effects Analysis (FMEA) technique in which the researcher identified as a possible source for assessing process quality and reliability. FMEA covers both design and manufacturing stages. It is common and critical to conduct reliability analysis at the earliest stage of the product life cycle. The tool is used to identify the potential quality and reliability failures in the design process. Hence, the problems can be eliminated as early as possible to avoid complicated and costly correction processes. Through known probabilities of each potential failure state at the sub-assemblies, the final assembly, and the manufacturing system operations, one can calculate system reliability by using. FMEA is a technique that identifies, first, the potential failure modes of a product during its life cycle; second, the effects of these failures; and, third, the criticality of these failure effects in product functionality. FMEA enables engineers find potential problems in the product earlier and thus avoids costly changes or reworks at later stages, such as at the manufacturing stage. This analysis process provides a thorough analysis at each detailed functional design element. It allows FMEA to be a very useful tool in quality planning and reliability prediction. The tool was therefore modified in order to address the levels of uncertainty in ETO product development.

PART I: Activity Analysis

5.7 The Activity Assessment

As shown in Figure 5.6, in a single IDEF activity box, the transformation of input to output is carried out by the tool(s), which are also referred to as means or mechanism, following certain instructions or operating within certain conditions and monitors referred to as "Controls". This section introduces how the 'IDEF Activity Assessment Matrix' is calculated.

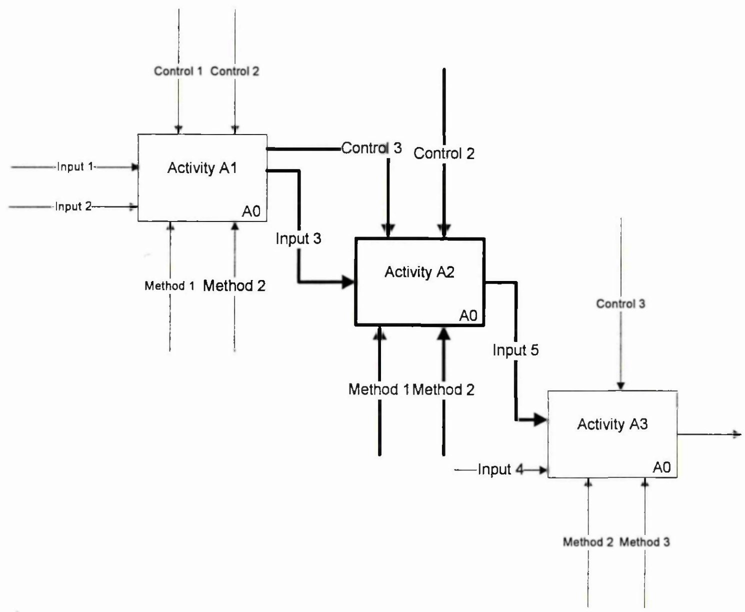
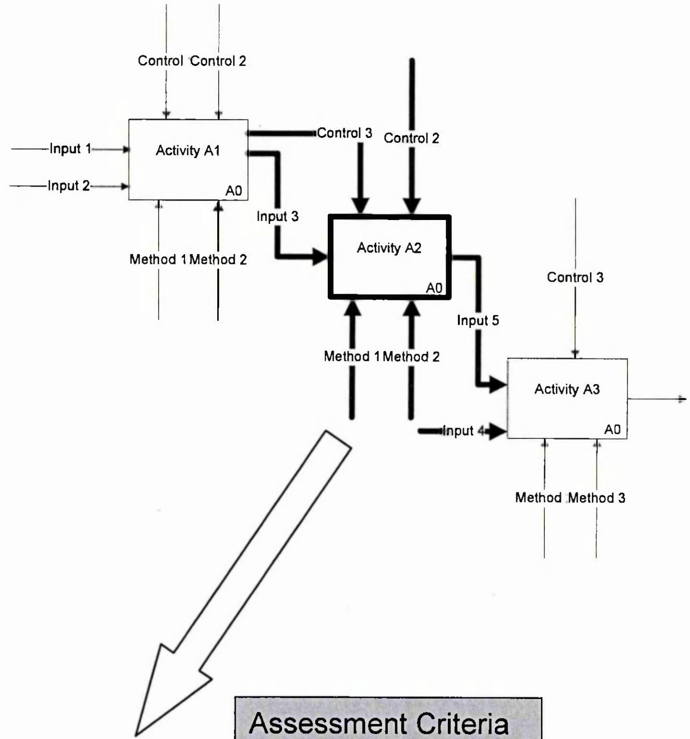


Figure 5-6; IDEF0 Activity A2 Structure

The IDEF Activity Assessment Matrix' is shown in Figure 5.7 above is designed to assess the reliability of the activity. The quality of each ICOM is derived from the product of the ICOM assessment function and the Activity Assessment Matrix (AAM). The matrix enables a company to assess the quality and reliability of the process and identifies the confidence of the methods controls within the activity.



		Assessment Criteria			
	A2	Explicit Knowledge	Tool Quality	Tacit Knowledge of Individual /Team	Output Quality
Activity Characteristics	Input 3				
	Method 1				
	Method 2				
	Control 3				
	Control 3				
	Quality				Total

Figure 5-7; Activity Assessment Matrix

The 'Activity Assessment Matrix is shown in Figure 5.7 above, it is designed to analyse the output quality of the activity. The main features include:

- A list of the NPD-ETO IDEF Activities
- The Quality of the Input
- The Confidence of the Control
- The Effectiveness of Method
- The Quality of the Resources

The matrix enables the company to assess how reliable the process is as well as highlight the output quality of each activity within the process. The results of the exercise will provide possible insights into how the activity within the process, can be improved as well as highlight the critical phases or potential risks of the NPD process. To be most effective, the exercise should be performed in a collaborative multidisciplinary environment.

5.7.1 Sections of the IDEF Activity Assessment Matrix

The 'IDEF Assessment Matrix' is divided into sections (see Figure 5.8 below).

- Section A: Activity Characteristics
- Section B: Explicit Knowledge
- Section C: Tool Quality
- Section D: Tacit Knowledge of Individual/Team
- Section E: Output Quality
- Section F: Resource Reliability

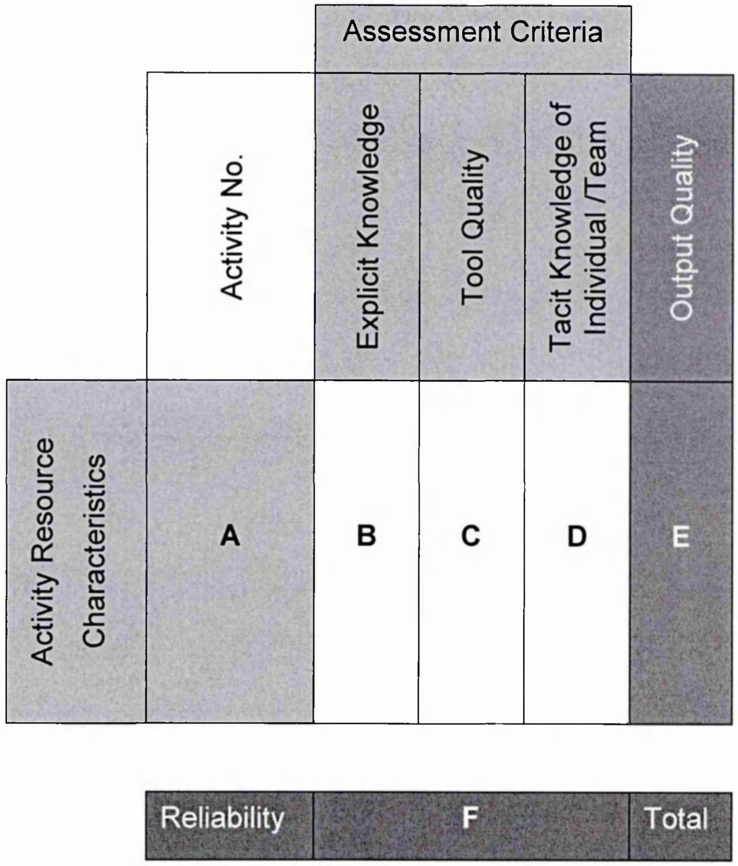


Figure 5-8; IDEF Activity Assessment Matrix (AAM)

5.7.2 Output Robustness Calculation

The output robustness calculation can be performed to identify the level of reliability for the project process. The Output Quality (OQ) score method then requires the analysis team to use past experience and engineering judgment surrounding the following sections:

Section A: Activity Characteristics – considers the approach to process reliability at each activity in the NPD-ETO stages (A1Tender, A2 Engineering Design, A3 Production Planning, A4 Manufacturing & Test, A5 Installation & Commissioning). The activity characteristics within each activity:

- Inputs
- Methods (Tools/Resources)
- Controls
- Output

Section B: Explicit Knowledge – which rates the completeness of the data and information received in order to fulfil the output requirements for the individual activity. These are typically based on data and supporting information available within and outside the company.

Section C: Tool Quality– rates the quality and effectiveness of the tool/resources in order to cope with the turbulent activities defined with each individual activity.

Section D: Tacit Knowledge– which rates the skill of the human resource in supporting each individual activity. These are typically based on knowledge, experience, 'know-how', available within the process or function.

Section E: Output Quality Score – is the result of the resource assessment (Explicit Knowledge, Tool Effectiveness and Tacit Knowledge of Individual or Team) with the combined resource characteristics (inputs, methods and controls) in each individual process activity).

Section F: Reliability Score – is the result of the resource assessment of the combined Knowledge, Tool Effectiveness and Tacit Knowledge across the resource characteristics (inputs, methods and controls) in each individual activity).

Rating scales usually range from 1 to 5 or from 1 to 10, with the higher number representing the higher levels of process reliability. For example, on a ten point occurrence scale, 10 indicates that the activity is very likely to be reliable and is worse than 1, which indicates that the reliability is low, Table 5.1 shows a generic five point scale for reliability.

Rating	Description	Criteria
1-2	High of potential Risk	Loss of control high levels of concern
3-4	Vulnerable	Concerns must be raised
5-6	Satisfactory, but not ideal	Caution, Cause for Concern
7-8	Moderate Confidence in Reliability	Minor Concerns
9-10	High level of Reliability	Comfortable with

Table 5-1; OQS Assessment Description

After the ratings have been assigned, the Output Quality (OQ) for each issue is calculated by multiplying Explicit Knowledge Score x Tool Quality Score x Tacit Knowledge Score.

$$Oq = Ek * Tq * Tk \qquad [5.1]$$

The Process Quality Score (PQS) which is the total Oq scores in the activity can then be used to compare the issues identified within the activity process. Typically, if the PQS falls within a pre-determined range, corrective action may be recommended or required to reduce the risk and improve the level of uncertainty or vulnerability of the process if possible and therefore increase the confidence levels of the process. When using this activity assessment, it is important to remember that PQS are relative to a particular analysis (performed with a common set of rating scales and an analysis team that strives to make consistent rating assignments for all activities identified within the process activity). Therefore, a PQS in one analysis is comparable to other PQSs in the similar NPD-ETO projects, but it may not be comparable to PQSs in dissimilar NPD-ETO projects.

5.7.3 Aggregated Output Robustness

The '*Output Quality coefficient*' O_n identifies the aggregate output quality of an activity against the maximum target value within the activity group (i.e. aggregation score of resources). It is only based on the resources used in the activity group and defined as follows:

- The aggregated Output Quality score in the activity, O_{ag}.
- The number of OQ scores in the activity group, N, therefore.

$$O_{ag} = \frac{\sum Oq}{N \quad x \quad 1000} \qquad [5.2]$$

5.7.4 Illustrated Example

To illustrate how the activity assessment matrix can be used as an example matrix for a simplified NPD-ETO project, an engineered pump is shown in Figure 5.9 below.

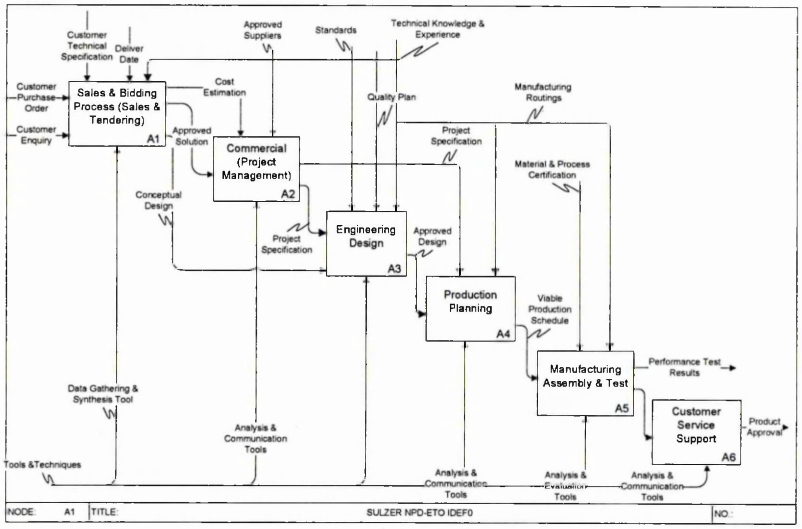


Figure 5-9; IDEF model representing Engineered Pump

The IDEF model starts by a customer requesting a response from a contractor to a project specification (varying in detail from a detailed design through to a functional or cardinal point specification). In accordance with the customer requirements, the sales & tendering department produces a quotation defining the time, costs and specification for the product or service delivered. This quotation is submitted to the customer via a bidding process and if successful with the bid, the sales and tendering function issues the specifications to the engineering function via the projects function. Engineering then provides the production division with the specifications and the suppliers with the specifications for the required materials and parts. Once these parts and materials have been supplied, the production function carries out the manufacturing process.

By considering each of the activities individually, and analysing the approach to the level of reliability for each of the NPD-ETO activities, it can be seen that the customer enquiry for the bidding process attribute. Therefore the NPD-ETO strategy is tailored to the customer's requirements. The simplified activity groups needed to manufacture the "pump" are shown in the Table 5.2 below.

Activity Groups	Main characteristics
A1Tender	• Order enquiry • Job Costing • Commercial Terms & Conditions
A2 Engineering Design	• Order / Design Review • Rota-dynamic Calculations • G.A. Drawings • Quality Plan
A3 Production Planning	• Routings • Procurement
A4 Manufacturing & Test	• Manufacturing Assembly • Test Results • Material Certification
A5 Installation & Commissioning	• Site Instructions • Technical data & Manuals

Table 5-2; NPD-ETO Activity Groups for n Engineered Pump

To illustrate how the activity assessment matrix can be used, an example for a engineering design activity is shown below in Figure 5.10

		Assessment Criteria			
	A2	Explicit Knowledge	Tool Quality	Tacit Knowledge of Individual /Team	**Output Quality**
Attributes	Input 3				
	Method 1	6	7	10	420
	Method 2				
	Control 3	7	7	4	496
	Control 3				
	Reliability	Total	Total	Total	Total

Figure 5-10; AMM for the Engineering Design Activity

Method 1

$$Oq = Ek \quad x \quad Tq \quad x \quad Tk$$

$$Oq\,1 = 6\,x\,7\,x10$$

$$Oq\,1 = 420$$

Control 3

$$Oq = Ek * Tq * Tk$$

$$Oq = 7\,x\,7\,x\,4$$

$$Oq = 496$$

Aggregated Output Quality

$$O_{ag} = \frac{\sum Oq}{N \quad x \quad 1000}$$

$$O_{ag} = \frac{\sum (420 + 496)}{2 \quad x \quad 1000} =$$

$$O_{ag} = \frac{916}{2000} = 0.46$$

By considering each process characteristics individually, and analysing the level of explicit knowledge, effectiveness of the tool and the tacit knowledge of each activity, it can be seen that the output quality of the process is affected by the level of reliability of explicit knowledge, effectiveness of the tool and the tacit knowledge in the process. The matrix enables a company to assess the quality of the outputs within the activities of the product development processes. The matrix is designed to be as simple as possible to use. To be most effective, the exercise should be performed in a collaborative multidisciplinary environment.

PART II: Project Quality and Utilisation Coefficients

5.8 The Level of Uncertainty in NPD-ETO Projects

This section examines how resources can affect the quality of the project or process. It identifies the need to measure the utilisation of the output quality within a NPD project to identify the level of risk, as well as highlight critical phases in the process.

5.8.1 Uncertainty & Risk

To successfully manage potential risk and uncertainty by assessing the quality of the process and what lessons learned can new knowledge be captured, managed, embedded and disseminated to support future projects. The measurements should be used to assess the level of uncertainty and potential risks of the resources currently available and to then transfer those lessons learned and set the boundaries within which new projects will have to operate. The measurements should be also used to identify the cross impact and contribution across the project processes and project milestones.

> **Uncertainty** *adj.* suitable or fit to be relied on; dependable. -Reliability *n.*"
>
> The New Penguin English Dictionary (2000)
>
> **Risk***adj.* suitable or fit to be relied on; dependable. -Reliability *n.*"
>
> The New Penguin English Dictionary (2000)

This section examines how uncertainty and risk can be classified in IDEF. It identifies the need to measure the utilisation of activities within an NPD-ETO project in order to highlight the potential risks within the process inputs, methods/tools and controls.

5.8.1.1 The Need for a Measurement of Project Performance

To enable companies to be confident in the processes required to support product development whilst optimising the resources available within the NPD-ETO activity, a measurement of risk between the NPD-ETO activities is needed. A more accurate measurement for stability should also consider factors such as:

- The budgeted cost for the ETO project
- The output quality of the resources used in the activities within the project
- The reliability of the resources and tools available to perform the task
- The benchmark measure that the project is set against whether its project expectations or previous projects

Table 5.2 shows the typical information to an example of an IDEF utilisation model. The IDEF function model has five process activities (A1 to A5), to fulfil these activities the activities use six resources (B1 to B6) consisting of Inputs (I), methods (M) and, controls (C). The table includes each activity 'process cost/budget' and 'process time' a matrix is used to show were each resource is used in the IDEF processes. To be most effective, the exercise should be performed in a collaborative multidisciplinary environment

					IDEF Process (A0)				
					A1	A2	A3	A4	A5
				Quality Benchmark	66.7	41.67	52.50	42.78	20.00
			Cross Impact	Occurrence					
Resources	Input 1	B1	0.80	3	x		x		x
	Input 2	B2	0.45	2		x	x		
	Method1	B3	0.90	5	x	x	x	x	x
	Method 2	B4	0.25	2	x			x	
	Control 1	B5	0.75	2		x			x
	Control 2	B6	0.50	1		x			

Table 5-2; Example IDEF Utilisation Matrix

5.8.1.2 Process Risk

At a basic level, the stability from process to another within an ETO project should be measured. This 'utilisation coefficient' is based on resources within activities. The following should be measured:

- The number of process in the 'IDEF process group' (i.e. the number of resources involved in every activity involved in the process
- The number of distinct resources that contribute to the output in the particular activity
- The number of other processes in the IDEF process group using the same resources

An 'utilisation coefficient' should be calculated for each activity with respect to every other activity in the process group. This should indicate those processes with 'high impact' and 'low impact' to others in the process group. This should indicate those resources with 'crucial to the ETO-NPD process.

In the example IDEF process group shown in Table 6.2 above, process A1 (uses resources B1 and B3) is considered to have a high utilisation value. All of the resources utilised in process A1 are also shared with at least three other processes in the IDEF activity/process group (i.e. resource B1 is also applied in processes A1, A3, A5). In contrast, Process A4 (uses resources B3 and B4) is considered to have a lower utilisation value. This is because resource B4 is not applied to any other activity/process. In the example above, it can be seen that resource B3 has a maximum occurrence (i.e. it is has high utilisation output and occurs in every process in the process group.

5.8.1.3 The Output Quality Factor

The resource output involved in the NPD process should be considered when utilisation is measured. In an ideal world processes would be use trustworthy resources. In practice most individuals use resources that more trustworthy due to the criticality of the process. Where possible resources should be as reliable as possible, it is undesirable to have activities that utilise when the confidence level in the resource is low. Any measure of utilisation should consider this.

The effect of the output of the resource can be seen by the simple example above. Activity A4 (using resources B3 and B4) is considered to have a poor robustness output score. As already discussed B4 is not being utilised by any other process. In addition, resource B4 is the most unreliable resource in the process group. Therefore the reliable of process A4 is further reduced.

5.8.1.4 The Benchmark factor

The benchmark of each activity in a project also has an impact on robustness. Most NPD-ETO projects will contain some activities that have low utilisation values. This may be for a number of reasons that might include the completeness of a NPD-ETO process, and process constraints. If a process is specialised and is in high demand, the utilisation value becomes less important. In this circumstance the benchmark should negate the effects of low cross-impact. Any measure of utilisation should consider this. The effect of target benchmark can be seen in the example above. Process A2 is compiled from resources B2, B3, B5 and B6. The utilisation value of process A2 is lowered by resource B6 (because B6 is not common to any other process). However, process A1 has the highest benchmark target in the process group. Therefore, the cross-impact value should reflect this high target benchmark, and negate the effects of low utilisation on resources

5.9 Resource Usage

This section presents Resource Usage

- Activity cross impact coefficient (R_n)
- Cross Impact Coefficient (R_{ci})
- Key Performance Indicator coefficient (K_{pi})

5.9.1 The Resource Usage Matrix

A process family is defined with *N* distinct resources (B_1 to B_i) needed to complete *M* finished process (A_1 to A_j) within the process group.

i.e.

N: number of resources needed to complete the process or project activity
B_i: resources ($i = 1 \rightarrow N$)
M: number of resource in the process
A_j: Activities ($j = 1 \rightarrow M$)

The cross impact (process-activity) matrix U_{ij} is used to represent the process group is defined as follows:

$$U_{ij} = 1 \rightarrow B_i \in A_j \quad [5.3]$$

$$U_{ij} = 0 \rightarrow B_i \notin A_j \quad [5.4]$$

An example activity - resources matrix is shown in Figure 5.11 to represent a activity group that uses several resources (B1 - B6), to support five activities (A1 – A5).

			Activities				
			A1	A2	A3	A4	A5
Resources	Input 1	B1	x		x		x
	Input 2	B2		x	x		
	Method1	B3	x	x	x	x	x
	Method 2	B4	x			x	
	Control 1	B5		x			x
	Control 2	B6		x			

Figure 5-11; Activity – Resource Matrix U_{ij}

5.9.2 Resource Usage coefficient' R

The '*Resource Usage Coefficient*' R_n identifies the resources within an activity with respect to the resources within the activity group (i.e. utilisation of resources). It is only based on the resources used in the activity group and defined as follows:

- The number of resources required to complete every activity in the process or project activity , N
- The number of activities in the process, M
- The number of resources used in the activity of the process n_j
- The number of the activities in the project or process group using each particular resource, m_i

The number of unique resources used in the activity *Aj* is defined as:

$$n_j = \sum_{i=1}^{N} U_{ij} \qquad [5.5]$$

The number of activities using resources B_i is defined as:

$$m_i = \sum_{j=1}^{M} U_{ij} \qquad [5.6]$$

The 'Resource Usage Coefficient' (R_n): for process A_j is defined as:

$$R_{nj} = \frac{\sum_{i=1}^{N} U_{ij}(m_i - 1)}{(M-1)n_j} \qquad [5.7]$$

To understand how the 'resource usage coefficient' was derived, the maximum and minimum values of R_n must be considered. The maximum R_n for a process A_j is '1'. This would occur when every activity in the activity group uses every resource used to in the process A_j, (i.e. m_i =M). for example

$$R_{nj} = \frac{(M-1)+(M-1)+(M-1)}{(M-1).3_j} = 1$$

The minimum R_n for Activity A_j =0. This would occur when no other activity in the activity group uses any resources used to process the activity A_j, (i.e.m_i=1). For example:

$$R_{nj} = \frac{(1-1)+(1-1)+(1-1)}{(M-1).3_j} = 0$$

Worked Example

An example activity-resource matrix is shown in Figure 5.12

Resources	mi	Activity Group A1	A2	A3	A4	A5
B1	4	1		1	1	1
B2	2		1	1		
B3	4	1	1	1		1
B4	2	1			1	
B5	3		1		1	1
B6	1		1			
nj		3	4	3	3	3
Rn		58	38	58	50	67

Figure 5-12; Cross Impact (Activity – Resource) Matrix U_{ij}

The number of resources used within the activity group is six, (i.e. N=6). The total number of activities, in the activity group is five, (i.e. M = 5). Consider Activity 4, the number of distinct resources used in the activity A4 is two, (i.e. n_j = 2 therefore:

$$R_{n4} = \frac{(m_1-1)+(m_4-1)+(m_5-1)}{(5-1).2_j} = 0$$

$$R_{n4} = \frac{(4-1)+(2-1)+(3-1)}{(4).3_j} = 0$$

$$R_{n4} = \frac{3+1+2}{12} = \frac{6}{12}$$

$$R_{n4} = 0.50 \, or \, 50\%$$

This value for R_{n4} indicates that activity A4 uses 50% of the resource available in the activity group.

The example activity –resource matrix shows the Rn values for each activity in the process group/IDEF model. A company should therefore, establish a minimum level for their own process models.

5.9.3 Cross Impact Coefficient

The 'cross impact coefficient' R_c identifies the cross impact of activity quality with respect to the other activities within the process, based on the output quality and robustness of the resources used in the process group. Where:

c_i is the quality of resource B_i

c_{max} is the maximum quality of resource usage of all resources used in the process group

The 'weighted' output quality of resource B_i and 'quality cross impact coefficient' R_c, are defined as:

$$w_{ci} = \frac{c_i}{c_{\max}} \qquad [5.8]$$

$$R_{cj} = \frac{\sum_{i=1}^{N} U_{ij}(m_i - 1)w_{ci}}{(M-1)\sum_{i=1}^{N} U_{ij} w_{ci}} \qquad [5.9]$$

Worked Example

					Activity Group				
					A1	A2	A3	A4	A5
					140	210	180	105	130
Resources	mi	Ci	Wn	Wci					
B1	4	45	80%	0.60	1		1	1	1
B2	2	75	40%	1.00		1	1		
B3	4	60	80%	0.80	1	1	1		1
B4	2	35	40%	0.47	1			1	
B5	3	25	60%	0.33		1		1	1
B6	1	50	20%	0.67		1			
nj					3	4	3	3	3
Rn					58.3	37.5	58.3	50.0	66.7
Rc					62.5	36.3	54.2	52.4	70.2

Figure 5-13; Cross Impact Matrix Rc

The matrix shows the output quality of each resource ci, the weighted quality of each resource Wci and Rn values for each activity in the group.

Consider process A4:

$$R_{c4} = \frac{(m1-1)w_{c1} + (m4-1)w_{c4} + (m5-1)w_{c5}}{(M-1)(w_{c1} + w_{c4} + w_{c5})} = 0$$

$$R_{c4} = \frac{(4-1)_{45} + (2-1)_{47} + (3-1)_{33}}{(5-1)(_{60} + _{47} + _{33})} = 0$$

$$R_{c4} = \frac{180+47+66}{4(_{60} + _{47} + _{33})} = \frac{293}{560}$$

$$R_{c4} = 0.5238 \; or \; 52.4\%$$

This value for Rc4 indicates that activity Ac4 indicates that the activity A4 is 52.4% cross impacted by the rest of the activities in the activity group, based on the reliability of the resources used in the process activities. To demonstrate the effect of the resource quality on Rc, consider the example below (see Figure 5.14).

	mi	Ci	Wn	Wci
B1	4	45	80%	0.45
B2	2	75	40%	0.75
B3	4	60	80%	0.60
B4	2	100	40%	1.00
B5	3	25	60%	0.25
B6	1	50	20%	0.50

The output quality of resource B4 is increased from '35' to '100'. Now:

$$R_{c4} = \frac{(4-1)_{45} + (2-1)_{100} + (3-1)_{25}}{(5-1)(45 + 100 + 25)} = 0$$

$$R_{c4} = \frac{180 + 47 + 266}{4(45 + 100 + 25)} = \frac{285}{680}$$

$$R_{c4} = 0.415 \; or \; 41.9\%$$

It can be seen that Rc4 has decreased from 52.4% to 49.1% this drop is mainly due to B4 is only 'cross impacting' on one other activity in the process/project group.

The quality 'cross impact coefficient' Rc is an improved measurement of cross impact analysis because it introduces the factor of resource quality. The coefficient highlights the effect of expensive resources that do not impact widely with the activities in the process.

The cross impact matrix enables a company to assess the quality prior to the next activity and how reliable the resources are within the activity. The results of this exercise provided possible insights in how the NPD-ETO process can highlight in terms of reliability and utilisation of resources.

5.9.4 Key Performance Indicator Coefficient

The 'cross impact coefficient' K_{pi} identifies the cross impact of activity quality with respect to the maximum quality score attainable within the process, based on the output quality and robustness of the resources used in the process group. Where:

K_{pi} is the performance of activity A_i

$$K_{pi} = \sum_{Kpi=1}^{N} U_{ij} \qquad [5.10]$$

5.9.5 A Complex Systems Approach

Finally, the quality of the resource such as inputs/controls/resources (e.g. CAD Tool Designer) of each activity in the process is considered when cross impact is measured. As discussed, most processes will contain resources that have low quality output value. If a resource has a low quality output but has a high cross impact value to the NPD-ETO project or process, the project has a higher level of risk. In this circumstance the contribution should highlight the project risk and vulnerability. Likewise, any measure of high quality and low cross impact should consider this as a major point of commitment within the project.

Worked Example

An example IDEF – activity matrix is shown in Figure 5.14 below

	Resource Description	Explicit K	Tool Effectiveness	Tacit K	Input ID	Ci	mi	Wni	Wci
Inputs	Input 1	6	8	7	I1	336	5	100%	0.58
	Input 2	8	7	8	I2	448	1	20%	0.78
	Input 3	7	7	7	I3	343	2	40%	0.60
	Input 4	10	6	6	I4	360	4	80%	0.63
	Input 5	9	7	8	I5	504	2	40%	0.88
	Input 6	8	8	9	I6	576	2	40%	1.00

	IDEF Process Group					
Target	3000	3000	4000	3000	3000	
	A1	A2	A3	A4	A5	
Bm	1255	1272	1648	1039	1200	
I1	1	1	1	1	1	
I2			1			
I3	1			1		
I4		1	1	1	1	
I5			1		1	
I6	1	1				
nj	3	3	4	3	3	
KPI	42%	42%	41%	35%	40%	
Rn	50.0	66.7	50.0	66.7	66.7	Win
Rci	45.1	59.0	44.4	66.6	61.0	1

	Resource Description	Explicit K	Tool Effectiveness	Tacit K	Control ID	Ci	mi	Wnc	Wci
Controls	Control 1	5	5	7	C1	175	4	80%	0.31
	Control 2	6	6	6	C2	216	2	40%	0.39
	Control 3	10	8	7	C3	560	4	80%	1.00
	Control 4	9	6	8	C4	432	1	20%	0.77
	Control 5	5	6	7	C5	210	3	60%	0.38
	Control 6	6	5	5	C6	150	2	40%	0.27

	IDEF Process Group					
Target	3000	3000	4000	3000	3000	
Node	A1	A2	A3	A4	A5	
Bm	817	926	1161	945	885	
C1	1		1	1	1	
C2		1	1			
C3		1	1	1	1	
C4	1					
C5	1		1	1		
C6		1			1	
nj	3	3	4	3	3	
KPI	27%	31%	29%	32%	30%	
Rn	41.7	41.7	56.3	66.7	58.3	Wco
Rcc	28.9	55.2	61.2	69.4	66.5	1

	Resource Description	Explicit K	Tool Effectiveness	Tacit K	Resource ID	Ci	mi	Wnr	Wci
Methods & Tools	Tools / Methods 1	7	7	7	B5	343	4	80%	0.48
	Tools / Methods 2	7	6	6	B6	252	4	80%	0.35
	Tools / Methods 3	8	6	5	B7	240	3	60%	0.33
	Tools / Methods 4	8	7	6	B8	336	4	80%	0.47
	Tools / Methods 5	9	8	8	B9	576	4	80%	0.80
	Tools / Methods 6	10	8	9	B10	720	4	80%	1.00

	IDEF Process Group					
Target	5000	5000	3000	5000	5000	
	A1	A2	A3	A4	A5	
Bm	1891	2124	1639	2227	1747	
B5	1		1	1	1	
B6	1	1		1	1	
B7	1	1			1	
B8	1	1		1	1	
B9		1	1	1	1	
B10	1	1	1	1		
nj	5	5	3	5	5	
KPI	38%	42%	55%	45%	35%	
Rn	70.0	70.0	75.0	75.0	70.0	Wmt
Rcr	71.8	72.2	75.0	75.0	71.6	1

	Resource Description	Explicit K	Tool Effectiveness	Tacit K	ID	Ci	mi	Wno	Wci
Outputs	Output 1	4	8	4	B5	128	5	100%	0.18
	Output 2	3	8	6	B6	144	0	0%	0.20
	Output 3	8	5	8	B7	320	4	80%	0.44
	Output 4	8	9	7	B8	504	5	100%	0.70
	Output 5	8	7	7	B9	392	2	40%	0.54

	IDEF Process Group					
Target	2000	4000	3000	4000	3000	
	A1	A2	A3	A4	A5	
Bm	632	1344	952	1344	952	
B5	1	1	1	1	1	
B6						
B7		1	1	1	1	
B8	1	1	1	1	1	
B9		1		1		
nj	2	4	3	4	3	
KPI	32%	34%	32%	34%	32%	
Rn	100.0	75.0	91.7	75.0	91.7	Wop
Rco	100.0	72.2	91.6	72.2	91.6	1
R	61.5	64.6	68.0	70.8	72.7	67.5
Kpi	46.2%	49.1%	52.2%	47.4%	60.2%	51.0%

Mean	67.5
Max	72.7
Min	61.5

Figure 5-14; Cross Impact Matrix of a Complex Arrangement

The effect of the quality of the resource can be seen in the example above. Activity A4 is made from Inputs I1, I3 I4, Control C1, C3, C4, Resource R1, R2, R3, R5 and Outputs O1, O3, O4, O5. Activity A4 has the highest resource quality in the process group. Therefore, the cross impact value should reflect this, and negate the effects of low cross impact based on deployment of resources.

The 'cross impact analysis' can be performed on a number of levels in the process group. At the lowest level, this would be for every activity in a project. However, for most process groups this analysis would be over complex. Therefore it is often necessary to rationalise the process groups. Typically, this would usually limit the analysis to those processes that collectively contribute to the NPD-ETO process itself.

The Cross Impact Coefficients Rn identifies the input, methods and control resources in terms of cross impact within the activity group, based on quality coefficients of the activities involved in the process. Where:

The resources factor on each activity in a process also has an impact on project reliability.

5.9.5.1 Aggregated Cross Impact Coefficient (R)

The 'aggregate cross impact R combines of the three cross impact coefficients: $R_{n,}$ R_c $R_{i,}$ and $R_{r,.}$ Each coefficient is assigned a 'weight' that corresponds to the influence it has of the measure of Reliability. Where

$W_{Ci,}$ is the weight assigned to the cross impact input coefficient' R_{ii}

$W_{Cc,}$ is the weight assigned to the cross impact control coefficient' R_{ic}

$W_{Cr,}$ is the weight assigned to the cross impact resource coefficient' R_{ir}

$W_{Cr,}$ is the weight assigned to the cross impact output coefficient' R_{io}

There can be no fixed rules to determine the 'weights' that should be applied to the cross impact coefficients $R_{i,}$ $R_{c,}$ $R_{r,}$ and R_o. They depend on the properties of the project processes, skills base, quality of resources, company policy etc. for the initial measurements of reliability the 'weights' should be equally balanced, each with a value of '1.00' (i.e. $W_{Ci,} = W_{rc,} = W_{rr} = W_{ro} = 1.00$).

The 'cross impact control coefficient' C for a Process A2 is defined as:

$$R_j = \frac{R_{ci}w_{ni} + R_{cc}w_{nc} + R_{cr}w_{nr} + R_{co}w_{no}}{w_{in} + w_{co} + w_{tm} + w_{op}}$$

The completed project-process 'reliability matrix' is shown in Figure 5.15. The cross impact coefficients C_i, C_c, and C_r values for each process in the project are shown.

Inputs	Resource	Explicit K	Effectiveness	Tacit K
	Input 1	6	8	7
	Input 2	8	7	8
	Input 3	7	7	7
	Input 4	10	6	6
	Input 5	9	7	8
	Input 6	8	8	9

Input ID	CI	mi	Wnl	Wci
I1	336	5	100%	0.58
I2	448	1	20%	0.78
I3	343	2	40%	0.60
I4	360	4	80%	0.63
I5	504	2	40%	0.88
I6	576	2	40%	1.00

	IDEF Process Group				
Target	3000	3000	4000	3000	3000
	A1	A2	A3	A4	A5
Bm	1255	1272	1648	1039	1200
	1	1	1	1	1
			1		
	1			1	
		1	1	1	1
			1		1
	1	1			
nj	3	3	4	3	3
KPI	42%	42%	41%	35%	40%
Rn	50.0	66.7	50.0	66.7	66.7
Rci	45.1	59.0	44.4	66.6	61.0

Win
1

Controls	Resource	Explicit K	Effectiveness	Tacit K
	Control 1	5	5	7
	Control 2	6	6	6
	Control 3	10	8	7
	Control 4	9	6	8
	Control 5	5	6	7
	Control 6	6	5	5

Control ID	CI	mi	Wnc	Wci
C1	175	4	80%	0.31
C2	216	2	40%	0.39
C3	560	4	80%	1.00
C4	432	1	20%	0.77
C5	210	3	60%	0.38
C6	150	2	40%	0.27

	IDEF Process Group				
Target	3000	3000	4000	3000	3000
Node	A1	A2	A3	A4	A5
Bm	817	926	1161	945	885
	1		1	1	1
		1	1		
		1	1	1	1
	1				
	1		1	1	
		1			1
nj	3	3	4	3	3
KPI	27%	31%	29%	32%	30%
Rn	41.7	41.7	56.3	66.7	58.3
Rcc	28.9	55.2	61.2	69.4	66.5

Wco
1

Methods & Tools	Resource	Explicit K	Effectiveness	Tacit K
	Tools / Methods 1	7	7	7
	Tools / Methods 2	7	6	6
	Tools / Methods 3	8	6	5
	Tools / Methods 4	8	7	6
	Tools / Methods 5	9	8	8
	Tools / Methods 6	10	8	9

Resource ID	CI	mi	Wnr	Wci
B5	343	4	80%	0.48
B6	252	4	80%	0.35
B7	240	3	60%	0.33
B8	336	4	80%	0.47
B9	576	4	80%	0.80
B10	720	4	80%	1.00

	IDEF Process Group				
Target	5000	5000	3000	5000	5000
	A1	A2	A3	A4	A5
Bm	1891	2124	1639	2227	1747
	1		1	1	1
	1	1		1	1
	1	1			1
	1	1		1	1
		1	1	1	1
	1	1	1	1	
nj	5	5	3	5	5
KPI	38%	42%	55%	45%	35%
Rn	70.0	70.0	75.0	75.0	70.0
Rcr	71.8	72.2	75.0	75.0	71.6

Wmt
1

Outputs	Resource	Explicit K	Effectiveness	Tacit K
	Output 1	4	8	4
	Output 2	3	8	6
	Output 3	8	5	8
	Output 4	8	9	7
	Output 5	8	7	7

ID	CI	mi	Wno	Wci
B5	128	5	100%	0.18
B6	144	0	0%	0.20
B7	320	4	80%	0.44
B8	504	5	100%	0.70
B9	392	2	40%	0.54

	IDEF Process Group				
Target	2000	4000	3000	4000	3000
	A1	A2	A3	A4	A5
Bm	632	1344	952	1344	952
	1	1	1	1	1
		1	1	1	1
	1	1	1	1	1
		1		1	
nj	2	4	3	4	3
KPI	32%	34%	32%	34%	32%
Rn	100.0	75.0	91.7	75.0	91.7
Rco	100.0	72.2	91.6	72.2	91.6
R	61.5	64.6	68.0	71	72.7
Kpi	46.2%	49.1%	52.2%	47.4%	60.2%

Wop
1
67.5
51.0%

Mean	67.5
Max	72.7
Min	61.5

Figure 5-15: The Cross Impact Matrix 'R

Worked Example

Consider the process A4:

For the example, the assigned weightings for R_{ci} R_{cc} R_{cr} R_{co} are all set to equal (i.e.. W rm = W rm =, W in, W , W rm = 1.00

$$R_j = \frac{R_{ci}w_{ni} + R_{cc}w_{nc} + R_{cr}w_{nr} + R_{co}w_{no}}{w_{in} + w_{co} + w_{tm} + w_{op}}$$

$$R_4 = \frac{(0.66)1.00 + (69.4)1.00 + (0.75)1.00 + (0.72)1.00}{1.00 + 1.00 + 1.00 + .100}$$

$$R_4 = \frac{0.66 + 0.69 + 0.75 + 0.72}{4} = \frac{2.82}{4}$$

$$R_4 = \frac{0.66 + 0.69 + 0.75 + 0.72}{4} = \frac{2.82}{4}$$

R4 = 0.705 or 71%

5.10 Summary

Chapter Five presented a detailed look at the proposed 'SETOK' Framework and the concept of 'Activity Assessment Matrix' and 'Cross Impact Matrix' to determine the quality of resources within the NPD-ETO project processes. The chapter was divided into four main parts.

The first part proposed the 'SETOK' framework and explained the four development phases. The framework for NPD-ETO in part one constituted to the work undertaken to meet the first research objective. The measures of reliability presented in part two constituted to the work undertaken to meet the second research objective. Both form new contributions to the field of knowledge on the area of ETO product development and enterprise modelling.

The second part of the chapter proposed an IDEF0 assessment model that is more detailed than that found in the literature. The framework was based on the activities in IDEF process model and the potential approaches to risk and uncertainty within an activity or business process. An activity assessment matrix is introduced to assist companies to assess the output quality of resources. This should enable them to optimise or identify areas for continuous improvement initiatives, as well as opportunities for knowledge sharing. The framework also presented a cross impact matrices that identifies how the output quality within the overall project performance in terms of explicit knowledge, effectiveness of the tool and the tacit knowledge across the NPD-ETO activities. To test the framework two case studies were conducted in companies known to design and manufacture ETO products. This took the form of structured interviews. The analysis established that ETO companies were true to the proposed framework. Based on this, confidence was gained to test the framework in further detail.

The final part examined how true the output quality of resources can improve the reliability of the process. The development of two coefficients to measure reliability of processes was presented. These considered factors of:

- Resource Usage coefficient (R_n)
- Cross Impact coefficient (R_c)
- Key Performance Indicator (K_{pi})

An 'aggregate cross impact coefficient' was defined to assess the input, controls, methods/tools cross-impact resources coefficients. A weight was assigned to each coefficient to represent the influence it has on the aggregated measure of reliability.

The activity-resource matrix was introduced to represent process groups and calculate the coefficients. By measuring the quality of resources in a process structure or group it is possible to identify activities (of low robustness) that result in excessive attention or rework. This should enable companies to assess their NPD process to identify critical phases or 'points of commitment' within the process.

Chapter 6 - VALIDATION AND REFINEMENT OF THE 'SETOK' FRAMEWORK

This chapter discusses the evolutionary development and longitudinal testing and evaluation of the 'SETOK' Framework. The initial development of the framework, methodology and tool was carried out with Sulzer Pumps. The testing was carried out in two phases. The initial phase was part of the 'conversion' project at Sulzer Pumps and Laker Vent. Subsequent developments and longitudinal evaluation and was carried out by the author in collaboration with Sulzer Pumps and refined for Laker Vent as a comparative study.

This chapter is structured in the following way. Firstly the state of the methodology at the time of the initial testing is described. Account is given of the initial testing and the resulting conclusions. Secondly, the subsequent evolution of the framework is detailed. Thirdly a description of the final testing of the full methodology, using the implementation steps described in chapter 5 is given and finally conclusions are drawn from the entire exercise.

6.1 Modelling Methodology and Tool at Initial Testing

Chapter 5 described the SETOK framework, assessment methodology and tool at the end of the research programme. This section describes the state of the development prior to the initial testing.

6.1.1 The modelling methodology

The approach used to building models of the NPD-ETO process was a 'bottom-up' i.e., to develop a modelling syntax which represents the operational levels of the organisation. Also the aim was to capture the status of the resources and to differentiate the flow of information in terms of taking actions or acting upon, decisions being made and resources available in terms of systems, tools and techniques available to the individual or team. So we started at 'Level 1', modelling the individual activities.

Also the definition of the Activity at that time was as follows:

An activity was made up of:

- Activity- the particular task performed within the activity;
- Controls- the particular resources that the activity has to comply to;
- Resources- the particular human resource available to perform the task, individual or group;
- Tools- the particular resources available to perform the task; and
- Node identification (ID) – a number indicating the sequence of operation.

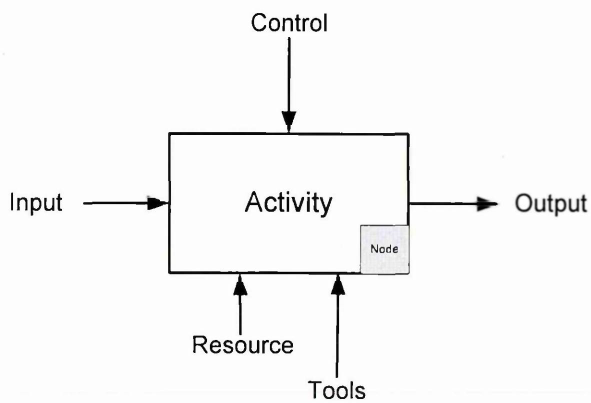


Figure 6-1; Definition of Activity

The methodology differentiated between resources and tasks, but did not take into account the flow of information along the links was limited to forward feed only, i.e. no feedback loops.

6.1.2 Analysis Methodology and Criteria

The analysis criteria were:

- For Activities
- Skills- ability to retrieve information, aptitude, education, training
- Resources- amount of resources, the quality of the tools and time allocation
- Knowledge for taking actions- relevant experience and exposure
- Information for taking actions- importance, frequency of completeness, correctness, timelines and correctness

For Links:

- Robustness- the quality of the decision or action.

The tools used were, as described in Chapter 6, MS Visio and for process modelling and the MS Access database for the analysis.

6.1.3 Initial Testing

Sulzer Pumps (UK) and Laker Vent Engineering were chosen to test the methodology and tool.

6.2 Initial Testing at Sulzer Pumps (UK)

6.2.1 Company Background

Sulzer Pumps (UK) Ltd is one of ten Sulzer Pump Division factories across the world. Their product range consists of engineered pumps with a focus on the oil and gas, HPI and the power generation industries. The dedicated design and manufacture of centrifugal pumps, some of the world's largest and most powerful pumps have been designed, manufactured, packaged and tested at this particular facility for customers all over the world. A background to the company's profile is also presented in Appendix D.

6.2.2 NPD-ETO at Sulzer and Pilot Study

Though Sulzer had a well documented set of procedures (ISO9001) for their NPD-ETO system, to allow them to control the quality of the process, it had never been mapped out, however the process included 28 project milestones and for the project management purposes as see in Table 6.2 below.

Project Milestones	
1. Order Receive	15. Base-Plate Release
2. Quality Plan	16. Pipe-Work Release
3. Kick off Meeting	17. Final Release
4. Order Set (Post Kick Off Meeting)	18. Instrumentation Release 1
5. Milestone Issue Release	19. Instrumentation Release 2
6. Hydraulic Data Sheet	20. Pattern Issued
7. Pattern Release	21. Assembly Programme
8. Pre-Order (Material)	22. Hydra Test
9. Suppliers' Drawings	23. Last Witness Test
10. Customer Drawings	24. Clear Final Inspection
11. Coupling Release	25. Dossier Release
12. Seal Release	26. Manual Release
13. BRG Release	27. Despatch (Leeds)
14. Pump Release Tools/Hydro/Test	28. INCO Delivery

Table 6-1; Sulzer NPD-ETO Project Milestones

The testing and refinement of the methodology took place as part of a larger continuous improvement project within the organisation. This was only the second time the company had run a collocation team as part of their NPD-ETO process.

6.2.2.1 Familiarisation and Application of the Modelling Tool to the NPD-ETO process:

This section discusses how Sulzer approached the mapping of the NPD-ETO process. The discussion and analysis applies to the development of both the robustness and output qualities of the NPD-ETO processes.

At the initial stages of the development of process maps, the company's senior management team attended an extra-ordinary meeting. The purpose of this meeting was specifically to establish the initial modelling approach and phases for mapping out the business processes. It took the form of 'presentation and workshop type activity. The analysis presented here is based on the results of this initial meeting.

The further development and refinement of the modelling tool continued through a multidisciplinary team of senior managers that met on a regular basis.

The modelling tool was used to analyse the levels of uncertainty of the NPD- ETO process, and how matrix was used to analyse how the product development of the HPcp 150-300-22 6St pump for Mobile North Sea Ltd relates to the modelling tool and 'knowledge sharing framework'. In particular it was used to:

- Capture the activity structures of the NPD-ETO process
- Analyse the resource attributes of the NPD-ETO process
- Identify the uncertainties on each activity structure
- Identify the 'Points of Vulnerability' within the NPD-ETO manufacturing project
- Analyse the approach to improve the dissemination of knowledge

6.2.2.2 Pilot Project

The project selected by Sulzer was an HPcp 150-300-22 6St pump for Mobile North Sea Ltd, see Figure 6.2 below. The requirement was to reduce the cost of the HpCp packages, as well as the number of quality non-conformances (NCRs) within the NPD-ETO projects.

For each type of pump the activities along the critical path are the same. The standard lead-time, depending on the pump type and the major factored equipment content varies from 28-40 weeks. Many projects actually have a longer delivery lead-time and, therefore, in the theory there should be slack in process. While the external elements represent a large part of the lead-time, the effective control of the internal element is critical in both achieving commitments and reducing the time on the critical path. With this in mind, the company decided that this project and the supporting business processes should support the principles of knowledge sharing.

The design criteria established by Mobile North Sea Ltd were:

- "The water injection pumps are critical to the timing of the Project and the platform's overall uptime

- It is a requirement that the water injection pumps be highly reliable and safe
- Efficiency is important due to the horsepower required, however, a small sacrifice in efficiency would be preferred over ANY sacrifice in reliability
- Therefore the pump design must consider reliability and the ability to operate the pumps safely as the two highest priorities."

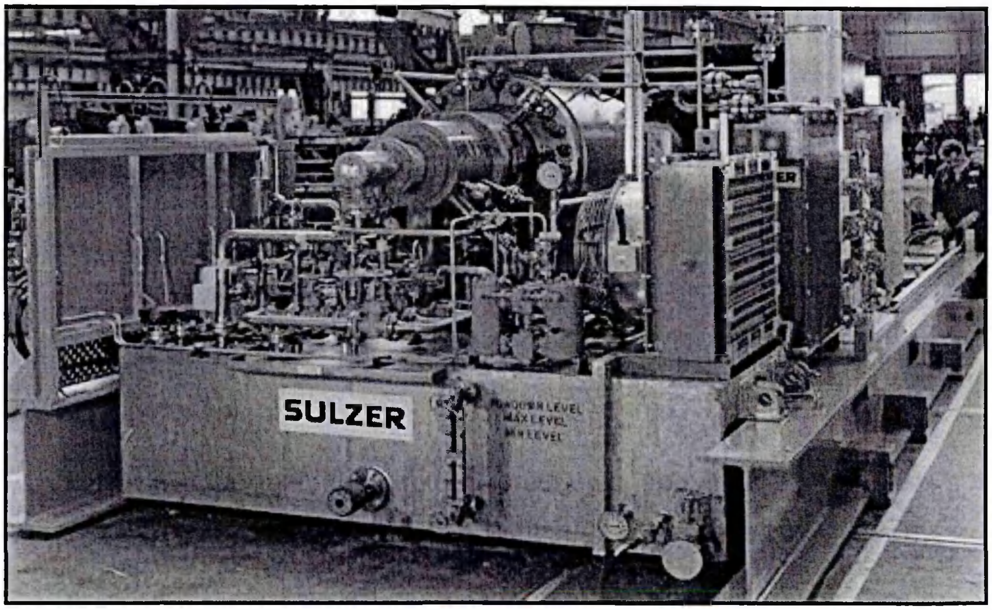


Figure 6-2; HPcp Barrel casing Pump

The current design of this pump type is approximately 20 years old and although excellent from an engineering standpoint, has not been optimised to incorporate cost saving features, which is possible as experience is gained. In addition, production and casting expertise has also improved and it is proper to re-visit the design and manufacture process of the pumps. The customisable attributes table is presented in Table 6.2 below.

Technical Requirements	Product Features	Additions
• Design Pressure • Pump Size ('6' stages) • Barrel Design • Rotodynamic Design (shaft size) • Speed 2840rpm • Bearing Loads • Impeller life • Balance Piston • dia 176.6mm) • Specific Speed (5800rpm) • Balance Required g2.5) • Quality Plan • Material Selection	• Injection Pump • Barrel • Suction cover • Delivery Cover • Casing Element • Suction Impeller • Series impeller • Shaft • Balance Piston • Balance Piston Brush • Bearing Housing • Rings • External Bolting • Internal Bolting	• Base Frame • Auxiliary framework • Pump Assembly • String Test • Equipment

Table 6-2; Sulzer's HpCp Customisable Attributes

6.2.3 Modelling the Process

Initially the aim was for the users to get acquainted with the process modelling methodology and understanding the NPD-ETO process. An attempt to model the NPD-ETO process was made. The experience is described below.

The first step was to select the people who would lead the use of the methodology and tool. The operations manager delegated this task to the researcher and was supported by the senior management team. The process modelling was lead by the researcher and supported by the systems and audit manager. Using MS Visio, they mapped out the existing or 'as-is' process. This represented the process followed by non-collocated multi-functional teams, with a bias towards functional priorities i.e. functionally driven as opposed to process/project driven organisational structure as see in Table 6.3. The author used ISO 9000 documentation plus their own personal knowledge about projects. They then modified this 'as-is' model process to the 'to-be' situation.

The 'to-be' situation represented changes the changes that would take place because of:

Collocation- meaning that functions contributing to NPD-ETO project must be physically located close to each other to encourage collocation and team work, and

1. A stronger process focus- by setting up a matrix line for functional/specialist reporting see Table 6.4 below.

For example one of the main changes made was that, hitherto, two sequential processes/activities would be tried in parallel to support the 'front-end' Tendering process ('Advance Engineering' and 'Advance Procurement').

The modelling methodology enforced a well defined process representation, i.e. one of that would capture all the important elements. Though the operations manager led the mapping process, collaboration with the other functions was crucial to defining the amount of parallelism and early involvement activities and definition of the project-driven tasks. Workshops and team meetings were key to getting the right models and improving the understanding amongst different function. However, all was not 'rosy' as it might sound. Not all functions felt the need to participate and the models were not exactly perfect. However, the level of cooperation was much better than what they had in the past. The use of process modelling aided by the new collocated culture hence contributed towards the achievement of the creation of a culture of 'concordance'.

	Functional Reporting				
Process Reporting	Sales	Commercial	Conversion	Eng. Services	Quailty
Sales	Tendering	Adv, Procurement ODC- Tendering		Adv. Eng Estimating	
Commercial		ODC- Scheduling Project Handeling Commercial Partnership Dev			Quality Planning
Conversion		Order Placing	Bill of Materials Prod. Technology Progressing Goods inwards Machining Assembly & Test Packaging	Ops. Eng Packaging Eng	Quailty Eng
Eng. Services				Specialist Engineering	
Quality				Retrofits/Upgrades	Quality Audit
CSS				Technical Services	

Table 6-3; Sulzer's Process Matrix

Analysis of the entire NPD-ETO process using our analysis methodology could not be carried out because:

a) the process was too long and complex and hence beyond the capability of the analysis tool;

b) the analysis criteria had not accounted to team based activities

c) though quite detail detailed process mapped was far from complete and each stage needed further more accurate modelling for the analysis too have any valid meaning

Modifications to the modelling and analysis had to be made. However the modelling and analysis methodology was capable of handling a smaller process as follows,

6.2.3.1 Modelling of Smaller Sub-process: Quotation Process

The 'Quotation Process' (Figure 6.3) process was a sub process or input process within the early part of the NPD-ETO core process. The Quotation process involves documentation of incoming pump enquiries from a potential customer, identification of standard and non-standard pump and selection and submission of bids. It provides a link between customers and design engineering as it acknowledges the receipt of inquiry as well identify all technical and commercial details. It also proposes a pump type and changes, if required, to customer's specification based upon decisions taken by the sales and tendering team if the customer's specifications cannot be strictly met.

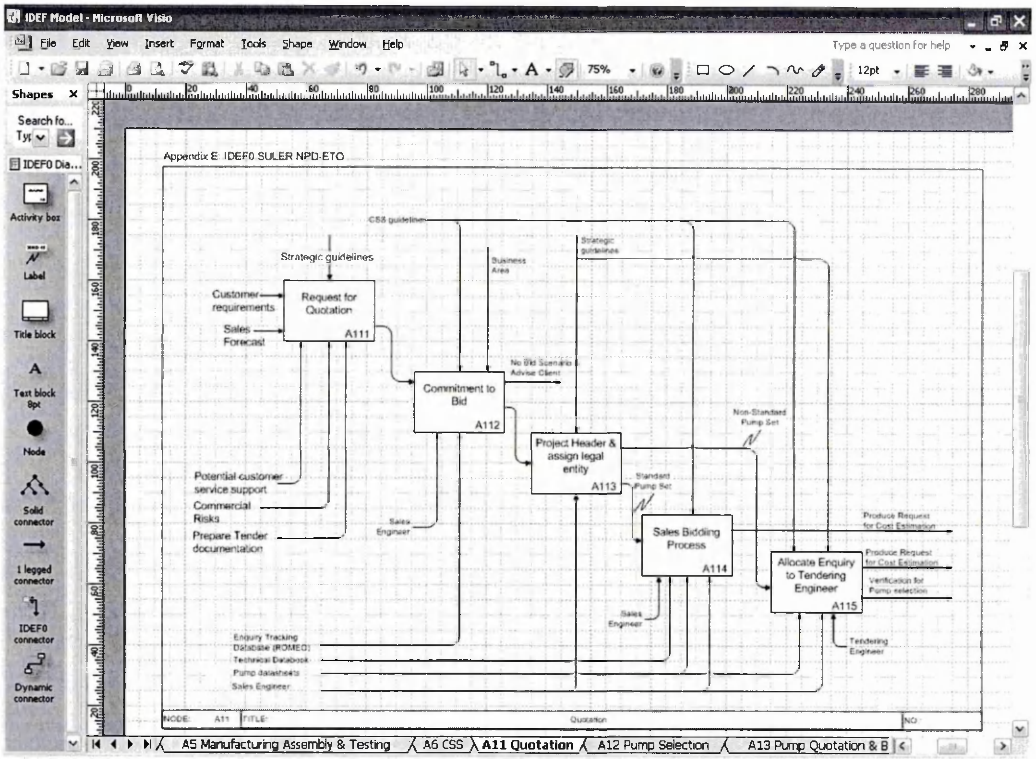


Figure 6-3; IDEF0 Quotation Process in 'MS Visio'

6.2.3.2 Phase One: IDEF Model

In order to carry out a more specific analysis of the above process was simplified in order to look at one particular strand of the process. This strand involved the customer and also involved the engineering design department. This was done because it was found during the initial modelling of the process, that the Tendering department is divided into specialist teams, Advanced Engineering and Advanced Procurement and not all units shared the same regard to knowledge sharing. This simplified and slightly extended process model is shown below and has been named as 'Pump Selection'. The process attributes for the first phase development for the NPD-ETO knowledge sharing assessment can be represented in the IDEF0 model. See Figure 6.4.

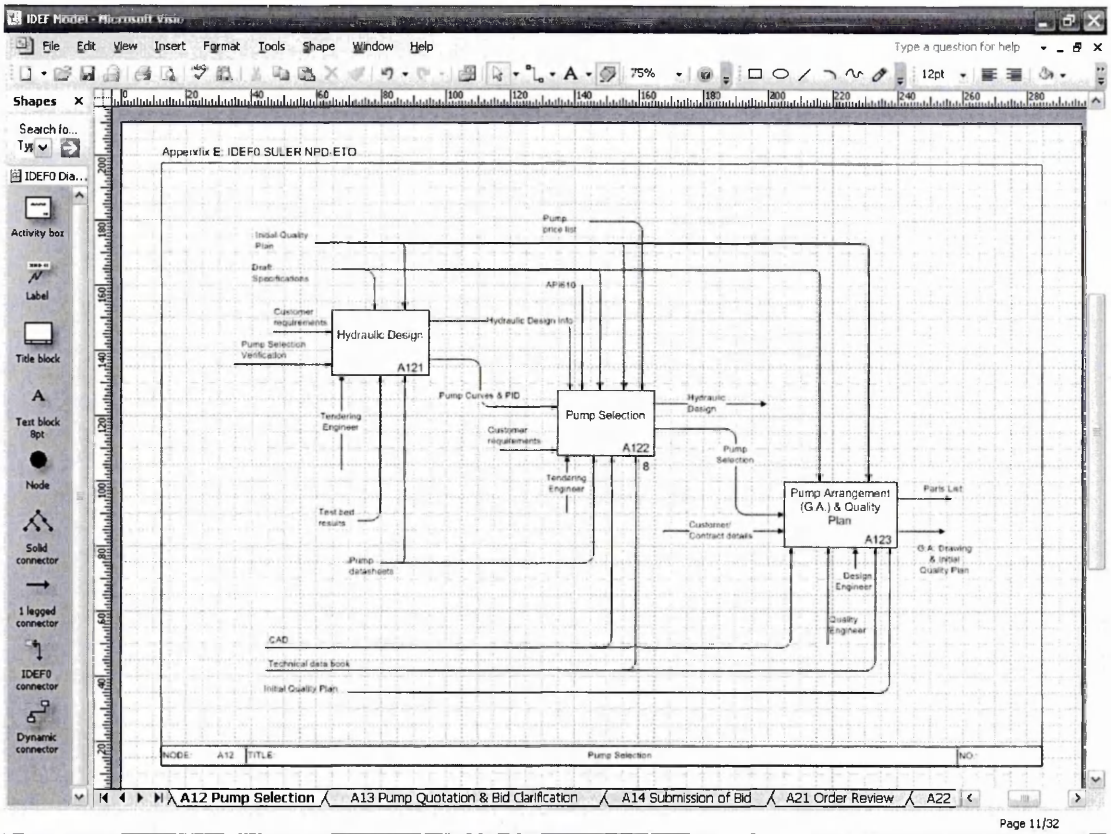


Figure 6-4; Pump Selection Process in 'MS Visio'

By considering each activity individually, and analysing the approach for assessing the quality of the process, it can be seen that the hydraulic design info output becomes one of the controlling resources on the pump selection activity and the client input is a contact key input in the decision making process. Each activity represents an application of a set of resources to manipulate the inputs in order to generate the output, whether physical or in the form of information or data, to produce a set of outputs. These resources are physical will also require a set of knowledge skills required to carry out the activity. The performance of each activity is affected by the quality of the tool or resources (e.g. level of skill of the individual or group or reliability of the tool) and the controls required to support and control the processes within that activity.

Therefore, the ability of the individual or group to carry out its role is affected by his or hers knowledge and experience as well as the quality and availability of the resources. Therefore a method is desirable to assess the level of the robustness on the process at any given stage in the activity. This requirement highlights the need for a tool that is, universally applicable to all activities identified under the NPD-ETO process, which can model the entire NPD-ETO process and yet provide the opportunity to focus on specific detailed activity if required.

6.2.3.3 Phase Two: Quality Assessment

The quality assessment on activities was completed in order to support the modelling process, which was then entered into the data analysis tool. See Figure 6.5 for the sample view of the 'Knowledge Sharing' tool (Access Database).

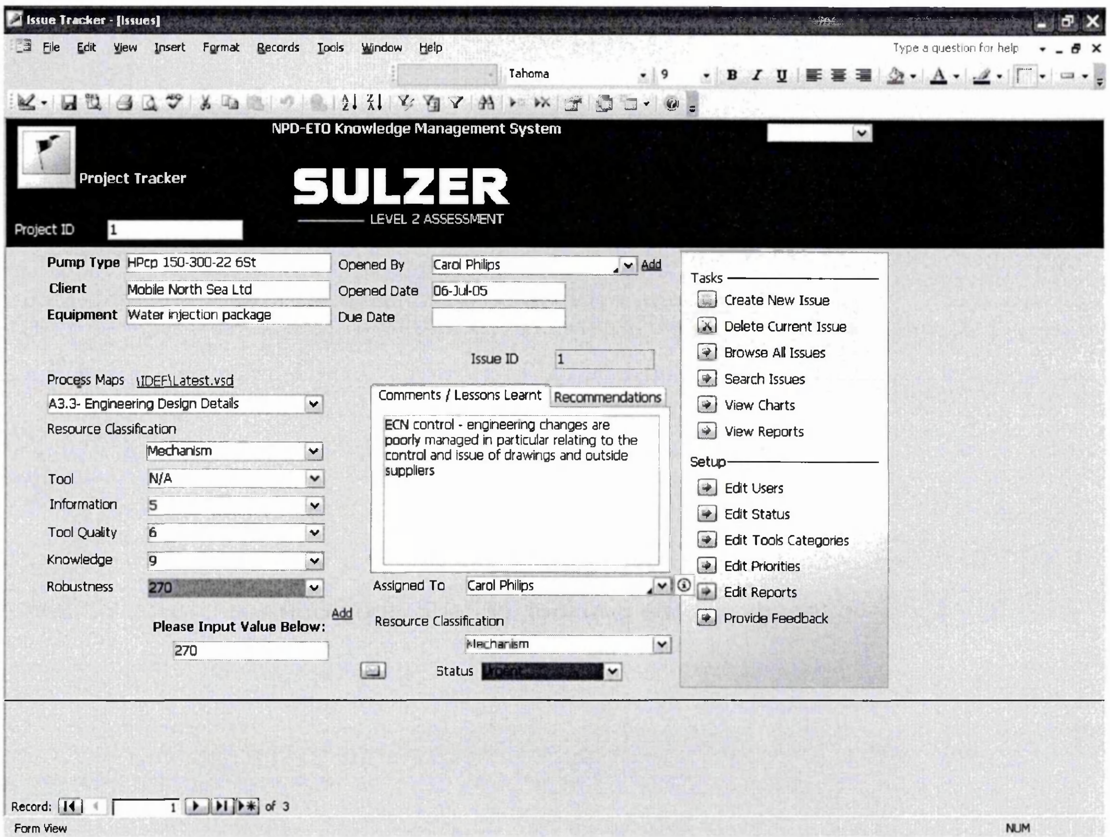


Figure 6-5; A screen shot of the 'Activity Assessment' with data

IDEF A12 Pump Selection Process:

The tool then produced an overall score for the activity as well as detailed view to indicate where specific attention needed to be focused in order to improve knowledge sharing as well as process performance. The activity assessment and robustness scores can been see in Table 6.4 below.

	Inputs	Assessment Criteria: Explicit Knowledge	Tool Quality	Tacit Knowledge	
I1	Customer Requirements	5	6	9	270
I2	Customer Contracts	8	8	8	512
I3	Pump Verification	8	7	8	448

	Resources/Tools	Assessment Criteria: Explicit Knowledge	Tool Quality	Tacit Knowledge	
R1	CAD	9	8	7	504
R2	Pump Data Sheets	7	8	8	448
R3	Technical Data Book	3	4	9	108
R4	Quality Plan	4	8	6	192
R5	Test Bed Results	8	8	7	448

	Controls	Assessment Criteria: Explicit Knowledge	Tool Quality	Tacit Knowledge	
C1	Draft Specifications	8	5	7	280
C2	Initial Quality Plan	6	7	8	336
C3	Pump Price List	7	8	5	280
C4	AP610 standard	9	8	5	360
C5	Hydraulic Design Info	10	8	9	720

	Outputs	Assessment Criteria: Explicit Knowledge	Tool Quality	Tacit Knowledge	
O1	Pumps Curves & P&ID	5	5	7	175
O2	Parts List	6	8	8	384
O3	GA Drawing & Initial Quality Plan	8	8	9	576
O4	Hydraulic Design	6	6	6	216
O5	Pump Selection	7	7	8	392

Table 6-4; Activity Assessment for Pump Selection: IDEF A12

This qualitative performance evaluation was complemented by qualitative data gathered during the interview process and recorded separately. The weakness in the process are discussed and illustrated in the following paragraphs.

The Activity Assessment Matrix (see Table 6.4) illustrates the output quality of the activity, using the assessment criteria for output quality in terms of explicit knowledge level, effectiveness of the tool and the tacit knowledge (skill and knowledge of the individual or group).

The IDEF Model and Activity Assessment Matrix also identified that the 'Pump Selection' activity carried by the Tendering Engineer has problems. It was found out that the problem was in the incompleteness of customer requirements. The task impacted on the quality of the draft specification for the job. This is despite the fact that the Tendering Engineer scored highly in the tacit knowledge criteria. The problem was tracked down to additional requirements from 'Advance Engineering' during the conceptual design stage due to delay in correct information from the customer. Lessons were learnt from this analysis and future projects would take these into account, especially allowing for unexpected problems with the use of this resource.

The technical data book 'Resource R3' had a low performance as it was a new initiative and was still being generated during this particular project, however the individual who was coordinating the new 'Advance Engineering 'collocated team department had over 20 years of experience. The correct low scores were not a surprise as it was one of the reasons for targeting this process.

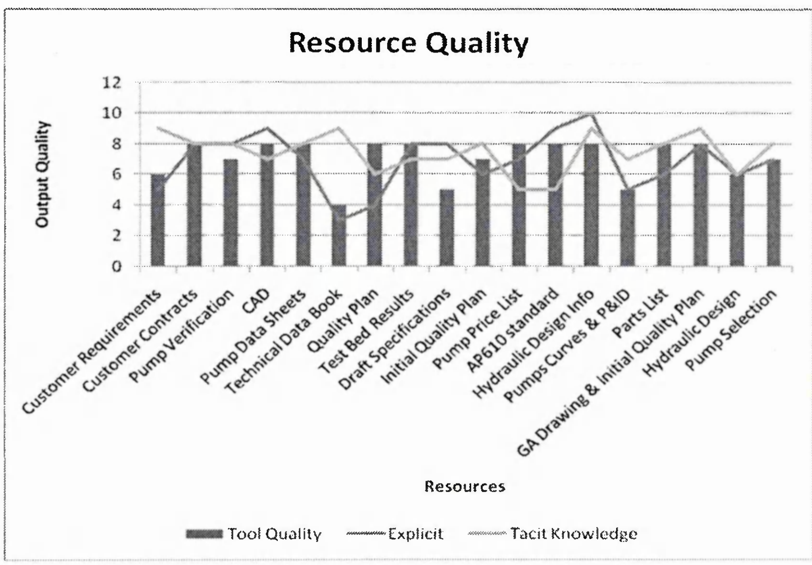


Figure 6-6; Resource Quality

IDEF A12 Resource Quality:

Figure 6.6 illustrates the overall resource quality of the pump selection process and the quality of the explicit and tacit knowledge scores based on the performance in the activity processes. It shows a rather overall average tool quality performance of 6.8. From the average scores analysis of the three criteria of explicit knowledge, tacit knowledge and tool quality the tool quality scored the lowest. This was because of the technology was underdevelopment e.g. the Orderset database was being redeveloped. The exercise also revealed that low value adding explicit knowledge was being balanced tacit knowledge of individuals e.g. Pump Curves and P&ID with a 5 and 7 accordingly.

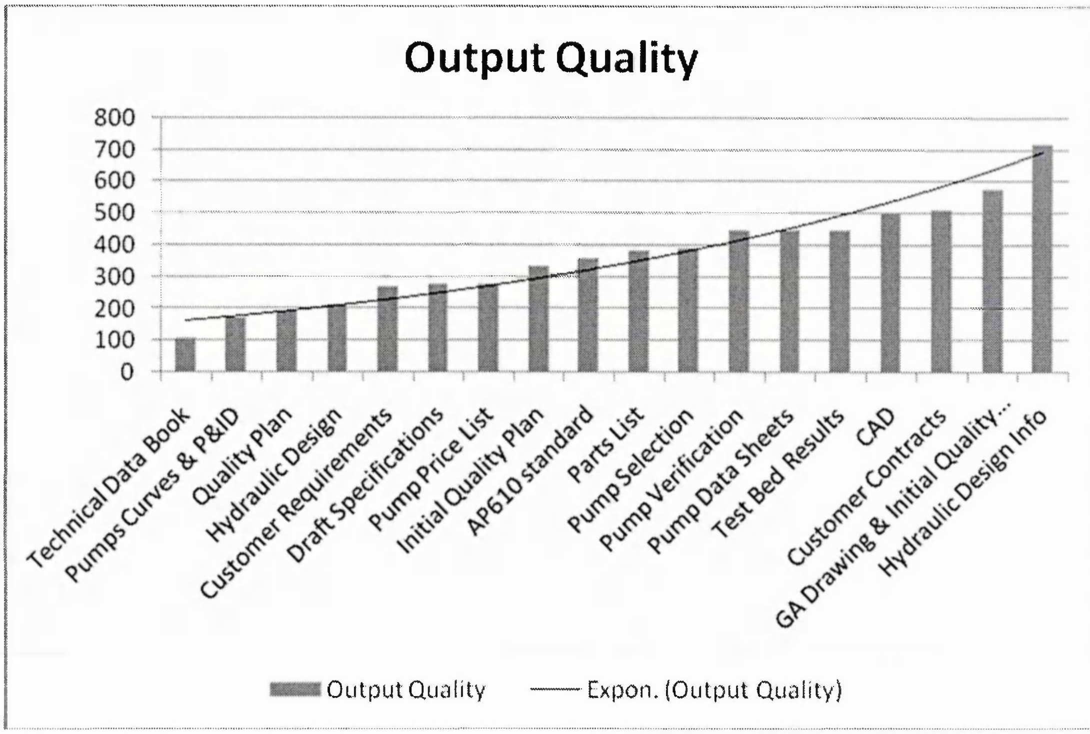


Figure 6-7; Resource Quality

IDEF A12 Process Robustness:

Figure 6.7 illustrates the output quality of the Pump Selection process and the ranking of low to high in accordance to resource quality. The pump selection process was modelled and analysed for Mobile North Sea Ltd project, Described below is additional findings within the process, which revealed interesting information, and involved a senior design engineer views:

"Specifications, our design engineers make notes, but they don't know whether they should read all the design specs fully or take it for granted that it they're correct. You also don't necessarily know if things where good or bad on the previous design"

The analysis indicated that the process had a weakness in the Customer's feedback. Two reasons were cited (a) centralised decision making with the tendering engineer and (b) inadequate communication between customer service support and tendering, resulting in poor and inadequate decision making on pump data. This prompted managers to consider further studying the process to resolve some of the feedback problems.

6.2.3.4 Three: Cross Impact Matrix

To identify if the knowledge sharing process was beneficial, the cross impact coefficients presented in Chapter 5 were used. The two coefficients are as follows:

6.2.3.5 Process Quality

This section presents Process Quality:

- Resource Usage coefficient (R_n)
- Cross Impact coefficient (R_c)
- Key Performance Indicator (K_{pi})

The cross impact coefficients were used to measure the robustness of the resources in the process group. Only three coefficients were applied ($R_{n,}$, R_{ci} and $K_{pi)}$. Sulzer's process robustness for it pump selection process was analysed against the maximum performance benchmark (B_n) which is calculated from the number of resources occurrence within the activity and achieved robustness score against the process target

Sulzer's existing Pump selection process, and equivalent HpCp NPD-ETO process was analysed. The following sections compare the results. In total there were 20 resources analysed. The following sections compare the results. In total there are 69 attributes within the Tender Preparation Process. However a number of the resources evolve during the downstream NPD-ETO process.

A full cross impact analysis of Sulzer's existing NPD-ETO process can be found in Appendix H. With the number of 426 attributes and 98 process activities, the size and complexity of the cross impact matrix was considerable. Therefore the initial study focused on the cross impact Pump Selection IDEF map which consisted of 3 process activities and 20 process attributes.

Table 6.5 shows the resource usage coefficients for the process structure (R_n) cross impact coefficient (R_n) and cross impact robustness coefficient (R_{ci}):

											Pump Selection		
										Target	8000	12000	11000
										NODE	A121	A122	A123
										Bm	2399	4076	3870
		Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge	Input ID	Ci	mi	Wni	Wci			
Inputs	I1	Customer Requirements	5	6	9	I1	270	2	67%	0.42	1	1	
	I2	Sales Forecast	8	5	8	I2	320	1	33%	0.49	1		
	I3	Customer Contracts	8	8	8	I3	512	1	33%	0.79			1
	I4	Pump Verification	8	7	8	I4	448	1	33%	0.69	1		
Controls	C1	Draft Specifications	5	5	7	C1	175	2	67%	0.27		1	1
	C2	Initial Quality Plan	6	6	6	C6	216	2	67%	0.33		1	1
	C3	Pump Price List	10	8	7	C7	560	2	67%	0.86		1	1
	C4	AP610 standard	9	6	8	C8	432	1	33%	0.67			1
	C5	Hydraulic Design Info	5	6	7	C9	210	1	33%	0.32	1		
Resources & Tools	R1	CAD	8	5	7	R1	280	3	100%	0.43	1	1	1
	R2	Pump Data Sheets	6	7	8	R5	336	3	100%	0.52	1	1	1
	R3	Technical Data Book	7	8	5	R6	280	1	33%	0.43		1	
	R4	Quality Plan	9	8	5	R7	360	2	67%	0.56	1	1	
	R5	Test Bed Results	9	8	9	R8	648	1	33%	1.00		1	
Outputs	O1	Pumps Curves & P&ID	5	5	7	O1	175	3	100%	0.27	1	1	1
	O2	Parts List	6	8	8	O5	384	1	33%	0.59		1	
	O3	GA Drawing & Initial Quality Plan	8	8	9	O6	576	1	33%	0.89			1
	O4	Hydraulic Design	6	6	6	O7	216	1	33%	0.33			1
	O5	Pump Selection	7	7	8	O8	392	1	33%	0.60			1
	O6	Bid Docs (GA, Ordeset & QP)	7	7	8	O14	392	1	33%	0.60		1	

Mean	359.1
Max	648.0
Min	175.0

Mean	39.2
Max	46.1
Min	32.7

nj	8	12	11
Performance	30%	34%	35%
Rn	10.0	6.5	6.3
Rco	46.1	38.8	32.7

Table 6-5; Cross Impact Assessment

Table 6.6 shows the process vulnerabilities, which are highlighted in red and the higher level process quality, which are highlighted in green within the cross impact coefficients for the process.

Group	ID	Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge	Input ID	Ci	mi	Wni	Wci	Pump Selection A121 (Target 8000, Bm 2399)	Pump Selection A122 (Target 12000, Bm 4076)	Pump Selection A123 (Target 11000, Bm 3870)
Inputs	I1	Customer Requirements	5	6	9	I1	270	2	67%	0.42	1	1	
	I2	Sales Forecast	8	5	8	I2	320	1	33%	0.49	1		
	I3	Customer Contracts	8	8	8	I3	512	1	33%	0.79			1
	I4	Pump Verification	8	7	8	I4	448	1	33%	0.69	1		
Controls	C1	Draft Specifications	5	5	7	C1	175	2	67%	0.27		1	1
	C2	Initial Quality Plan	6	6	6	C6	216	2	67%	0.33		1	1
	C3	Pump Price List	10	8	7	C7	560	2	67%	0.86		1	1
	C4	AP610 standard	9	6	8	C8	432	1	33%	0.67			1
	C5	Hydraulic Design Info	5	6	7	C9	210	1	33%	0.32	1		
Resources & Tools	R1	CAD	8	5	7	R1	280	3	100%	0.43	1	1	1
	R2	Pump Data Sheets	6	7	8	R5	336	3	100%	0.52	1	1	1
	R3	Technical Data Book	7	8	5	R6	280	1	33%	0.43		1	
	R4	Quality Plan	9	8	5	R7	360	2	67%	0.56	1	1	
	R5	Test Bed Results	9	8	9	R8	648	1	33%	1.00		1	
Outputs	O1	Pumps Curves & P&ID	5	5	7	O1	175	3	100%	0.27	1	1	1
	O2	Parts List	6	8	8	O5	384	1	33%	0.59		1	
	O3	GA Drawing & Initial Quality Plan	8	8	9	O6	576	1	33%	0.89			1
	O4	Hydraulic Design	6	6	6	O7	216	1	33%	0.33			1
	O5	Pump Selection	7	7	8	O8	392	1	33%	0.60			1
	O6	Bid Docs (GA, Ordeset & QP)	7	7	8	O14	392	1	33%	0.60		1	

	Pump Selection		
Target	8000	12000	11000
NODE	A121	A122	A123
Bm	2399	4076	3870

	Ci
Mean	359.1
Max	648.0
Min	175.0

	Wci
Mean	39.2
Max	46.1
Min	32.7

nj	8	12	11
Performance	30%	34%	35%

Rn	10.0	6.5	6.3
Rco	46.1	38.8	32.7

Table 6-6; Analysis of the Cross Impact Assessment

- The variation of R_c is due the level of insufficient and incomplete customer information, which was also highlight in the questionnaire analysis (Appendix D) in the initial knowledge sharing questionnaire assessment.
- The effect of introducing new technology for pump data generation within the Pump selection process as it supports the decision making process in all three activities.

The plateaus in process attributes identify quality of the attribute in terms of explicit knowledge level, effectiveness of the tool and the tacit knowledge (skill and knowledge of the individual or group) against the number of times the resource contributes to activity process.

Figure 6.8 shows the weight cross impact coefficient for the pump selection process. The important attributes to notice are:

- Draft specifications and initial quality plans are being compiled with insufficient data being supplied by the client

- The pump data is based on the historical data from the test bed results, the aim is to supply additional field data during the commissioning process.

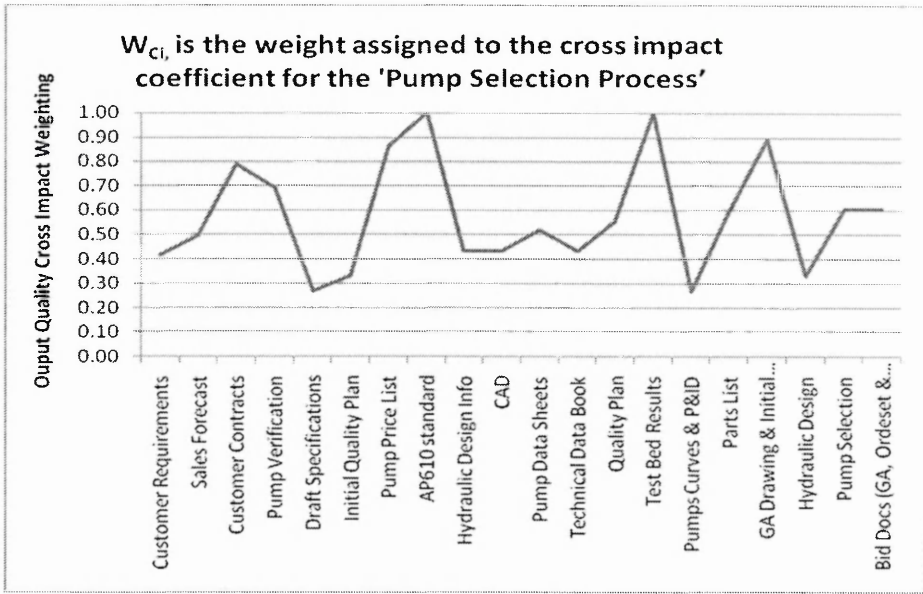


Figure 6-8; Output Quality of within the Pump Selection Process

6.2.3.6 Process Improvement

To demonstrate the effect of colocated team within in the cross function analysis, a second analysis was conducted for the pump selection process. Table 6.7 shows the increase in output quality by the colocated team of 'Advance Engineering' which resulted in a higher level of knowledge in the requirements of the API610 standard.

Group	ID	Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge	Input ID	CI	mi	Wni	Wci	Pump Selection A121	Pump Selection A122	Pump Selection A123
Inputs	I1	Customer Requirements	5	6	9	I1	270	2	67%	0.42	1	1	
Inputs	I2	Sales Forecast	8	5	8	I2	320	1	33%	0.49	1		
Inputs	I3	Customer Contracts	8	8	8	I3	512	1	33%	0.79			1
Inputs	I4	Pump Verification	8	7	8	I4	448	1	33%	0.69	1		
Controls	C1	Draft Specifications	5	5	7	C1	175	2	67%	0.27		1	1
Controls	C2	Initial Quality Plan	6	6	6	C6	216	2	67%	0.33		1	1
Controls	C3	Pump Price List	10	8	7	C7	560	2	67%	0.86		1	1
Controls	C4	AP610 standard	9	8	9	C8	648	1	33%	1.00			1
Controls	C5	Hydraulic Design Info	5	8	7	C9	280	1	33%	0.43	1		
Resources & Tools	R1	CAD	8	5	7	R1	280	3	100%	0.43	1	1	1
Resources & Tools	R2	Pump Data Sheets	6	7	8	R5	336	3	100%	0.52	1	1	1
Resources & Tools	R3	Technical Data Book	7	8	5	R6	280	1	33%	0.43		1	
Resources & Tools	R4	Quality Plan	9	8	5	R7	360	2	67%	0.56	1	1	
Resources & Tools	R5	Test Bed Results	9	8	9	R8	648	1	33%	1.00		1	
Outputs	O1	Pumps Curves & P&ID	5	5	7	O1	175	3	100%	0.27	1	1	1
Outputs	O2	Parts List	6	8	8	O5	384	1	33%	0.59		1	
Outputs	O3	GA Drawing & Initial Quality Plan	8	8	9	O6	576	1	33%	0.89			1
Outputs	O4	Hydraulic Design	6	6	6	O7	216	1	33%	0.33			1
Outputs	O5	Pump Selection	7	7	8	O8	392	1	33%	0.60			1
Outputs	O6	Bid Docs (GA, Ordeset & QP)	7	7	8	O14	392	1	33%	0.60		1	

	Pump Selection		
Target	8000	12000	11000
NODE	A121	A122	A123
Bm	2469	4076	4086

	CI
Mean	373.4
Max	648.0
Min	175.0

	Wci
Mean	38.2
Max	44.8
Min	31.0

	A121	A122	A123
nj	8	12	11
Performance	31%	34%	37%
Rn	10.0	6.5	6.3
Rco	44.8	38.8	31.0

Table 6-7; Analysis of the Cross Impact Assessment

Figure 6.9 represents the 'cross impact' coefficient for the collocated 'Advance Engineering' function for the pump selection process.

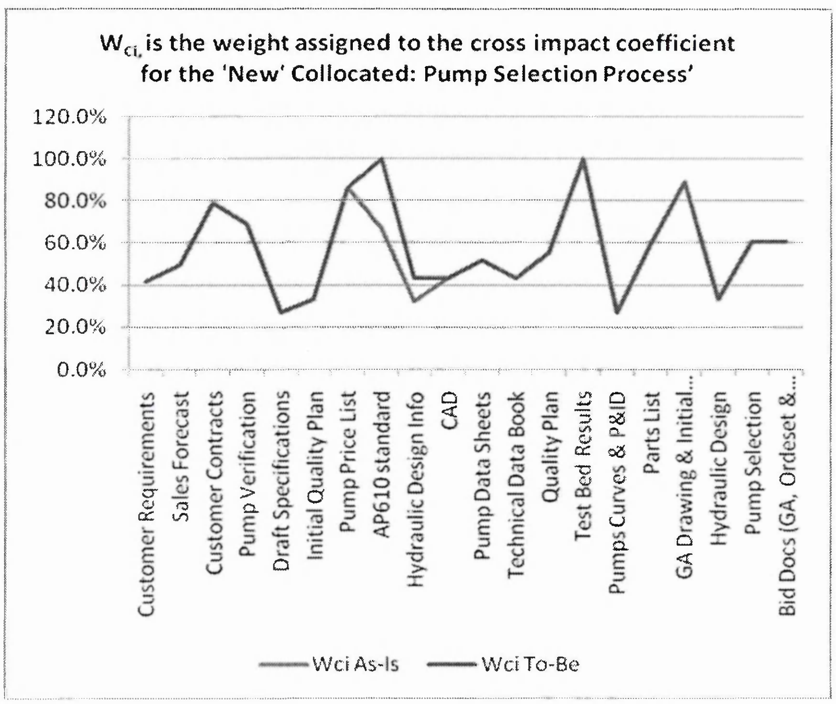


Figure 6-9; Output Quality of the Attributes against the Cross Impact of within the new 'Collocated' Pump Selection Process

6.2.3.7 Evaluation by the Project Manager

Following the comments, of the Senior Project Manager at Sulzer Pumps regarding the use of the methodology and tool:

> *The scoring aspect of the tool is one which expects to show highs and low, but the process of talking to individuals about their experiences was a great benefit to provide qualitative data and factual information upon which to base decisions for improvement.*
>
> *The other information provided by the tool is an overall reliability score, it is not very useful on its own but when changes are made to the process or when it is highlighted of point of concern during a previous project can be used again to check if the process has improved.*
>
> *One observation of the tool that was the detailed questions for activities required that individual staff members to assess themselves about their job and their managers were asked for details about their skills, this brought out a confidentiality issue. This needs to be considered in connection with who is given the task of analysing the data. As some personal data is collected the person who will assess the activity needs to understand the sensitivity of the data, but also the person will need to be accepted by those being assessed.*

The interview not only produced the quantitative scores of entry into the process reliability tool, but also provided qualitative information to base improvements upon.

6.2.4 At Laker Vent

6.2.4.1 Background

The business process of Laker Vent Engineering is provided in Appendix H. The methodology and tool are used on two real projects. After the analysis of the first project's NPD process, changes were made based on the first set of results. The second project used the new set and was analysed to identify the benefits. Before the start of the pilot project, Laker Vent defined such goals as

- Maintain or not compromise the quality of Laker Vent Engineering service

- Reduce costs, specifically in rework
- simplify processes, and
- keep or improve the customer focus perspective of the company

Project 1 Slurry oil backwash system

This MTO project involved product engineering and construction of Slurry oil backwash system for a client's particular design.

Project 2 Pipework System for Food and Brewing Industry

This second project was used to compliment the conclusions about the utilisation of the tool and methodology. The necessary changes made in the NPD process of this MTO manufacturing project were the results obtained through the analysis of the process performance in project 1.

6.2.4.2 Modelling and analysis of the NPD-MTO process

Compared with Sulzer's NPD-ETO Laker Vent product development process was relatively less complex as the engineering design aspect was dictated by the customer.

The results of the obtained for the 'As-Is' model process (as per project 1) were as follows.

6.2.4.3 Phase One: Cross Functional Model

Similar to Sulzer Pumps, Laker Vent Engineering had a well documented set of procedures (ISO9001) for their NPD-ETO system, to allow them to control the quality of the process, it had never been mapped out, however after the initial questionnaire analysis the workshop the company requested that their NPD-ETO was mapped out using the cross functional analysis methodology rather than adopting the IDEF Model has Senior Management Team (SMT) wanted to capture the decision making as seen in Figure 6.10 'Cross Functional Diagram' below.

6.2.4.4 Modelling of Smaller Sub-process: Project Management Planning

The 'Project Management Planning' process was a sub process or project management process within the management part of the NPD-ETO core process. The Project Management process involves reviewing the incoming customer order, the contract review, the scope of supply and commercial and contractual requirements. It provides the mechanism between customers and manufacturing organisation as it project manages the process as well coordinate all technical and commercial details. It also manages both the technical and commercial information flow surrounding the project, including budgets, labour absorption and coordinating with suppliers.

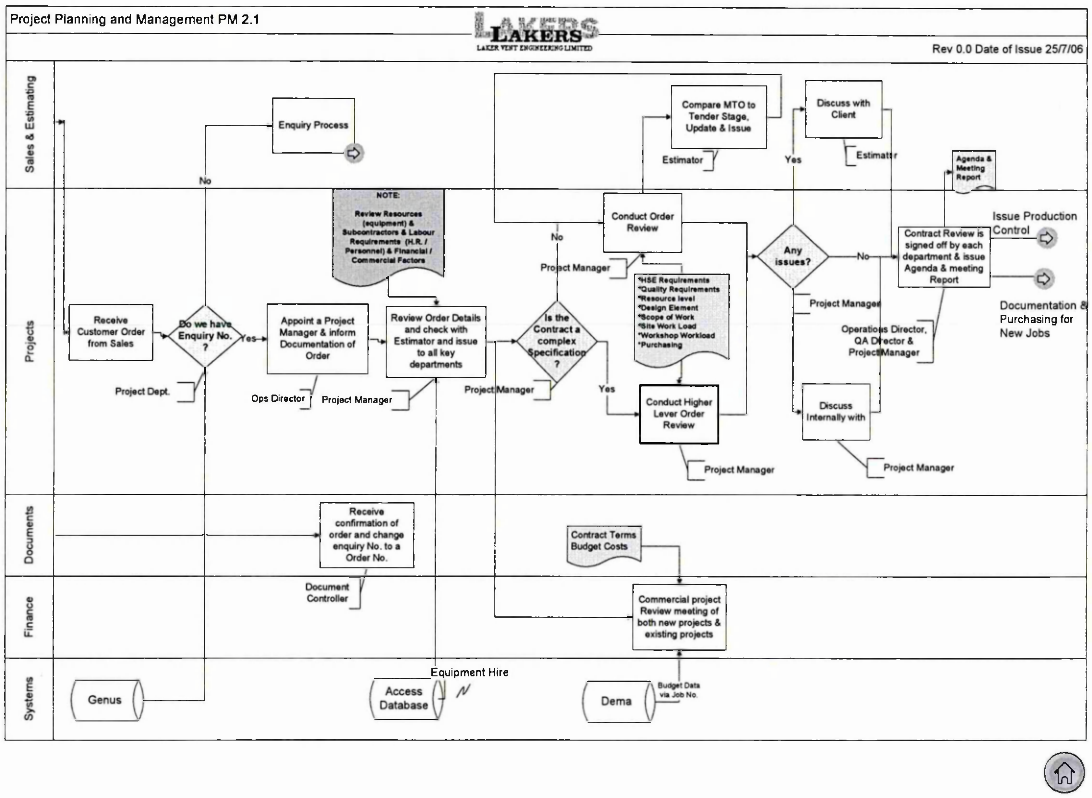


Figure 6-10; Cross Functional diagram of the Project Management Planning Process

The results (Output Quality Assessment) obtained for the 'as-is' model (as per Project 1 was as follows in Figure 6.11 below.

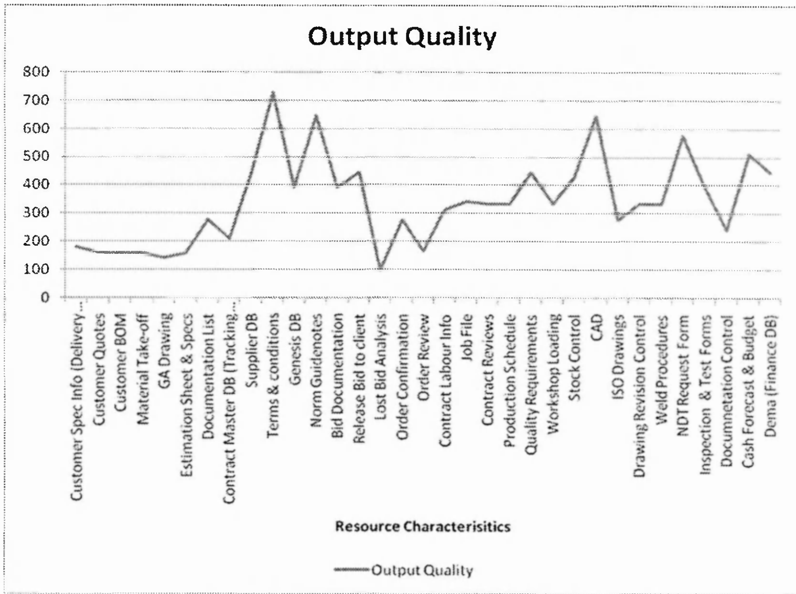


Figure 6-11; Output Quality for the Project Management Planning Process

The results highlighted the fact that the customer details regarding the general assembly drawings were incomplete in order to generate a production BOM. It was raised by one of the project managers that this was an ongoing issue.

The results (Process Reliability Assessment) obtained for the 'as-is' model (as per Project 1 was as follows in Table 6.8 below.

Resources	Resource Description Resources	Explicit Knowledge	Tool Quality	Tacit Knowledge
R1	Customer Spec Info (Delivery Date)	6	5	6
R2	Customer Quotes	6	3	9
R3	Customer BOM	5	4	8
R4	Material Take-off	4	5	8
R5	GA Drawing	6	3	8
R6	Estimation Sheet & Specs	5	4	8
R7	Documentation List	8	5	7
R8	Contract Master DB (Tracking Database)	5	7	6
R9	Supplier DB	7	8	8
R10	Terms & conditions	9	9	9
R11	Genesis DB	7	8	7
R12	Norm Guidenotes	9	8	9
R13	Bid Documentation	7	8	7
R14	Release Bid to client	7	8	8
R15	Lost Bid Analysis	5	5	4
R16	Order Confirmation	8	5	7
R17	Order Review	6	4	7
R18	Contract Labour Info	7	5	9
R19	Job File	7	7	7
R20	Contract Reviews	6	7	8
R21	Production Schedule	7	6	8
R22	Quality Requirements	8	7	8
R23	Workshop Loading	7	6	8
R24	Stock Control	9	6	8
R25	CAD	8	9	9
R26	ISO Drawings	8	7	5
R27	Drawing Revision Control	7	8	6
R28	Weld Procedures	6	7	8
R29	NDT Request Form	9	8	8
R30	Inspection & Test Forms	8	7	7
R31	Documnetation Control	5	7	7
R32	Cash Forecast & Budget	8	8	8
R33	Dema (Finance DB)	7	8	8

Process ID	Ci	mi	Wni	Wci
R1	180	6	50%	0.25
R2	162	3	25%	0.22
R3	160	3	25%	0.22
R4	160	2	17%	0.22
R5	144	2	17%	0.20
R6	160	3	25%	0.22
R7	280	1	8%	0.38
R8	210	3	25%	0.29
R9	448	4	33%	0.61
R10	729	3	25%	1.00
R11	392	2	17%	0.54
R12	648	2	17%	0.89
R13	392	3	25%	0.54
R14	448	1	8%	0.61
R15	100	1	8%	0.14
R16	280	1	8%	0.38
R17	168	1	8%	0.23
R18	315	1	8%	0.43
R19	343	3	25%	0.47
R20	336	4	33%	0.46
R21	336	4	33%	0.46
R22	448	3	25%	0.61
R23	336	4	33%	0.46
R24	432	5	42%	0.59
R25	648	1	8%	0.89
R26	280	5	42%	0.38
R27	336	2	17%	0.46
R28	336	4	33%	0.46
R29	576	5	42%	0.79
R30	392	5	42%	0.54
R31	245	4	33%	0.34
R32	512	6	50%	0.70
R33	448	6	50%	0.61

Mean	344.8
Max	729.0
Min	100.0

Table 6-8; Resource Assessment (Project 1)

The scores, activity performance were analysed and improvements were made to achieve the 'the 'to-be' situation and to improve upon the lower scores. The improvements made particularly in the 'Non Compliance Reporting' generated the following results in Table 6.9.

Resources	Resource Description: Resources	Explicit Knowledge	Tool Quality	Tacit Knowledge
R1	Customer Spec Info (Delivery Date)	6	5	6
R2	Customer Quotes	6	7	9
R3	Customer BOM	5	4	8
R4	Material Take-off	4	5	8
R5	GA Drawing	6	3	8
R6	Estimation Sheet & Specs	5	4	8
R7	Documentation List	8	5	7
R8	Contract Master DB (Tracking Database)	5	7	6
R9	Supplier DB	7	8	8
R10	Terms & conditions	9	9	9
R11	Genesis DB	7	8	7
R12	Norm Guidenotes	9	8	9
R13	Bid Documentation	7	8	7
R14	Release Bid to client	7	8	8
R15	Lost Bid Analysis	9	5	[illegible]
R16	Order Confirmation	8	[illegible]	7
R17	Order Review	6	9	7
R18	Contract Labour Info	7	5	9
R19	Job File	7	7	7
R20	Contract Reviews	9	7	10
R21	Production Schedule	7	6	8
R22	Quality Requirements	8	7	8
R23	Workshop Loading	7	6	8
R24	Stock Control	9	6	8
R25	CAD	8	9	9
R26	ISO Drawings	8	7	5
R27	Drawing Revision Control	7	8	6
R28	Weld Procedures	6	7	8
R29	NDT Request Form	9	8	8
R30	Inspection & Test Forms	8	7	7
R31	Documnetation Control	8	7	7
R32	Cash Forecast & Budget	8	8	8
R33	Dema (Finance DB)	7	8	8

Process ID	Ci	mi	Wni	Wci
R1	180	6	50%	0.25
R2	378	3	25%	0.52
R3	160	3	25%	0.22
R4	160	2	17%	0.22
R5	144	2	17%	0.20
R6	160	3	25%	0.22
R7	280	1	8%	0.38
R8	210	3	25%	0.29
R9	448	4	33%	0.61
R10	729	3	25%	1.00
R11	392	2	17%	0.54
R12	648	2	17%	0.89
R13	392	3	25%	0.54
R14	448	1	8%	0.61
R15	315	1	8%	0.43
R16	448	1	8%	0.61
R17	378	1	8%	0.52
R18	315	1	8%	0.43
R19	343	3	25%	0.47
R20	630	4	33%	0.86
R21	336	4	33%	0.46
R22	448	3	25%	0.61
R23	336	4	33%	0.46
R24	432	5	42%	0.59
R25	648	1	8%	0.89
R26	280	5	42%	0.38
R27	336	2	17%	0.46
R28	336	4	33%	0.46
R29	576	5	42%	0.79
R30	392	5	42%	0.54
R31	392	4	33%	0.54
R32	512	6	50%	0.70
R33	448	6	50%	0.61

Mean	382.7
Max	729.0
Min	144.0

Table 6-9; Resource Assessment (Project 2)

The results obtained for the cross impact quality significantly improved, this means that improvements made in the second project were correct. The full cross impact assessment of Laker Vent Engineering is provided in Appendix I.

6.2.4.5 Evaluation by Project Manager

The project had the following to say:

"The process maps and database tool helped us capture the dynamics of project management and product development process. The information provided was quite helpful for the organisation in terms of project risk and process performance and will

assist us in the post project reviews and process improvement initiatives from both a functional and process point of view".

6.2.4.6 Conclusions of initial testing

As a result of the testing the following conclusions were drawn:

Improvements to the modelling syntax/methodology and analysis questionnaires had to be made. In particular:

- Process visibility had been improved especially within the scope of Project Management
- Front-end decision-making needs to be more robust
- Provision of Feedback loops or stage-gates decision analysis needed improving
- Need for describing the modelling analysis in clearer terms and to 'pitch' to the right audience such as senior managers to engineers
- Need for the development of new level of analysis for project and middle managers i.e. knowledge sharing and project-based learning point of view

These and other developments made are described below.

6.3 Post Initial Testing Evaluation

6.3.1.1 Modelling Representation

Modelling was initially carried using the 'IDEF0 methodology'. However the IDEF0 representation has been revised to accommodate the 'Output Quality' measures. The nodes represent the actual scores for the 'Output Quality' of the activity assessment matrix. An example of the 'IDEF0 model with performance indicators is shown below Appendix E. Below is the Activity Model (Figure 6.12) as well as a screen shot of the process in the MS Visio Modelling tool in Figure 6.13.

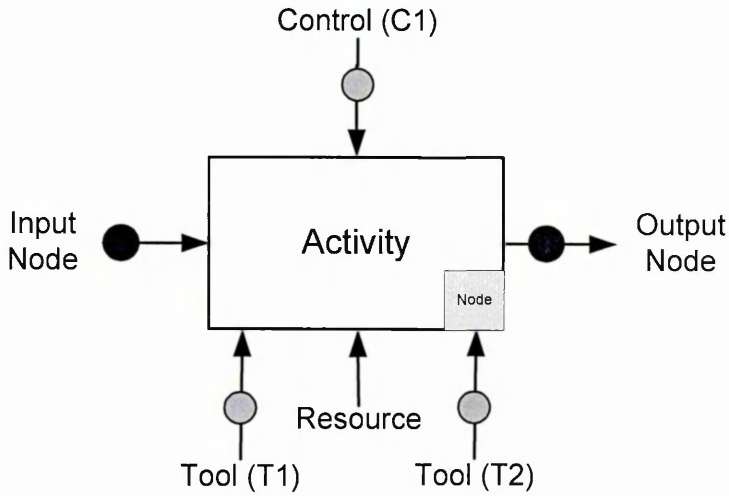


Figure 6-12; New IDEF0 'Knowledge Transfer' Activity Model

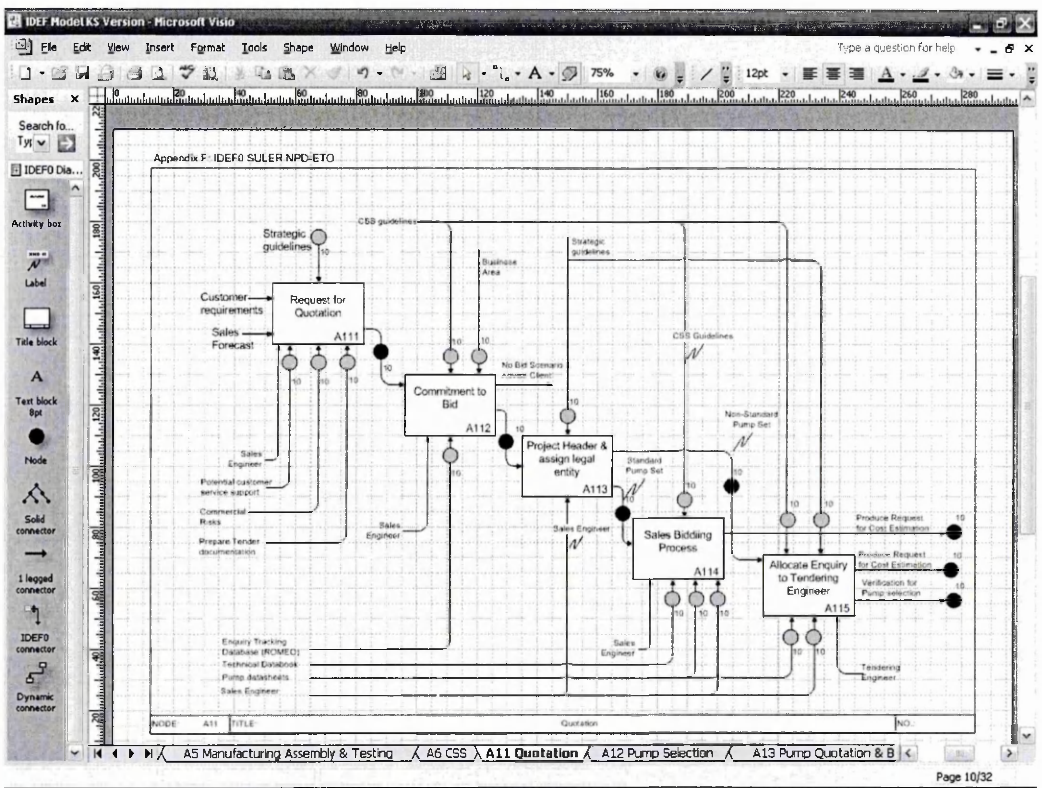


Figure 6-13; IDEF-Knowledge Transfer Quotation Process in 'MS Visio'

6.4 Refinement of the Framework

There was an aspect to do with project-based learning. Here we analyse project's performance against previous case histories which is drawn up through the level one analysis which assesses the level of reliability whether due to poor 'information sharing' or low 'project-based learning'. The data gathered through a quantitative analysis of:

I. The contributions made by previous projects to a NPD-ETO phase (i.e. the outputs of the phase);

II. The level 1 process outcomes of each operational activity and process for the contributions.

Modelling of the NPD-ETO primary stages:

This arose as a request from Sulzer in the implementation methodology to include a more structured analysis of the Project Management Phases of the NPD-ETO process at a primary level.

6.4.1 The need for a modification to the 'SETOK' Framework

Due to the introduction of teams and stages that there existed different levels of modelling and analysis which required differ objectives. Consequently a modelling hierarchy and SETOK Framework was therefore modified to reflect the IDEF-Knowledge Transfer (KT) in Figure 6.14. This was also important because of the project managers information flow was quite diverse because of the iterations taking place during primary stages of the project.

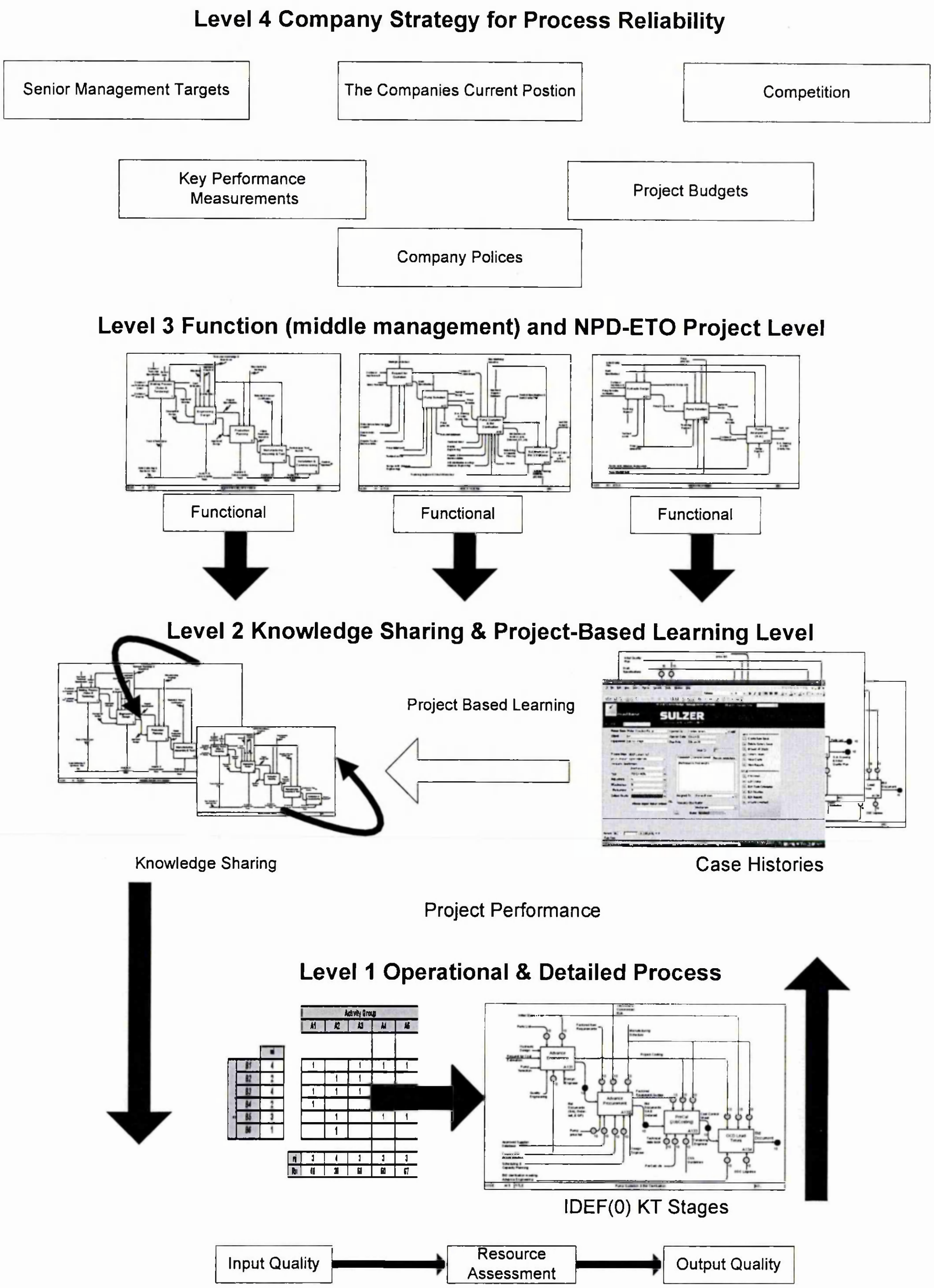


Figure 6-14; SETOK Framework Refinement

6.5 Final Testing at Sulzer Pumps (UK)

Sulzer being in the Leeds, UK, were a natural choice for a detailed final evaluation of the final methodology. The database application or process analysis tool, developed for the first prototype was not further developed in MS Access. Instead it was replaced by MS Excel, which provided a quicker solution. This was done because the aim was not to develop a sophisticated tool but to evaluate the methodology and the outputs of the analysis. Below is a brief description of the final testing using the implementation steps described in chapter five.

6.5.1.1 Step 1 Perform Company Level Assessment (Level 4)

All the departments and functions were involved NPD-ETO completed the assessment questions for analysis. For each of the six sections (KS and KM criteria) bar charts were produced to illustrate which areas to further examine for improvements. For example one section on ongoing issues is illustrated in Figure 6.15 below.

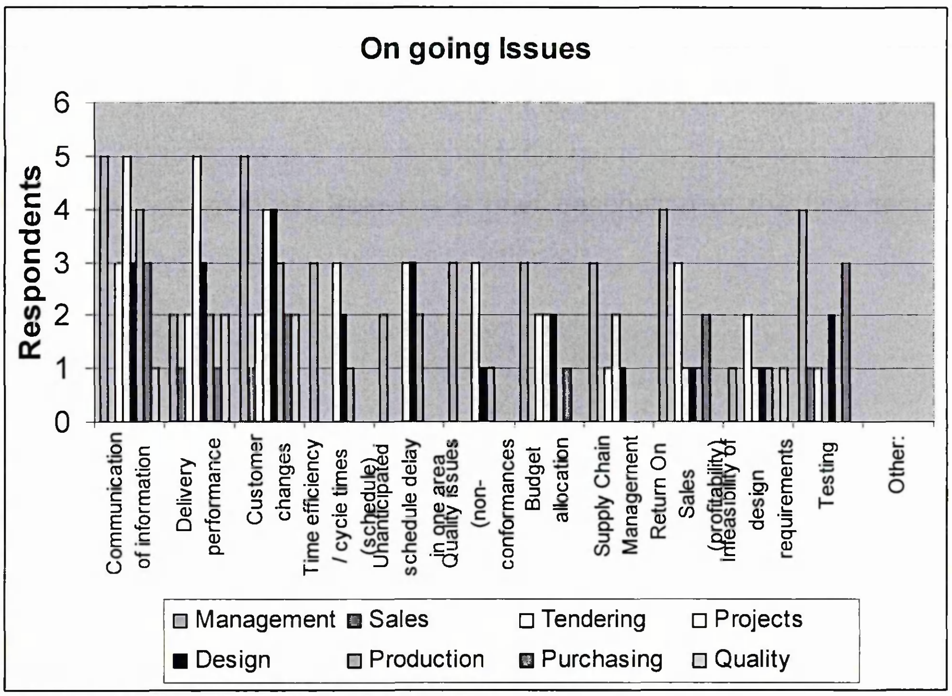


Figure 6-15; On-going Issues from the Assessment Questionnaires

The bar chart represents the views of Sales/Tendering, Projects, Engineering Design, Quality, Procurement and Manufacturing. The initial process characteristics identified by Sulzer Pumps can be seen in Table 6.3.

The questionnaire interview findings were up and a summary radar diagram was produced (Figure 6.16 and 6.17) to show an overall picture. This illustrated that Sulzer achieved high scores in product technology, product reliability, Sulzer brand, test abilities and tender quality, but low in price, customer relations, fast response project management, short lead time, on time delivery and on time documentation experience.

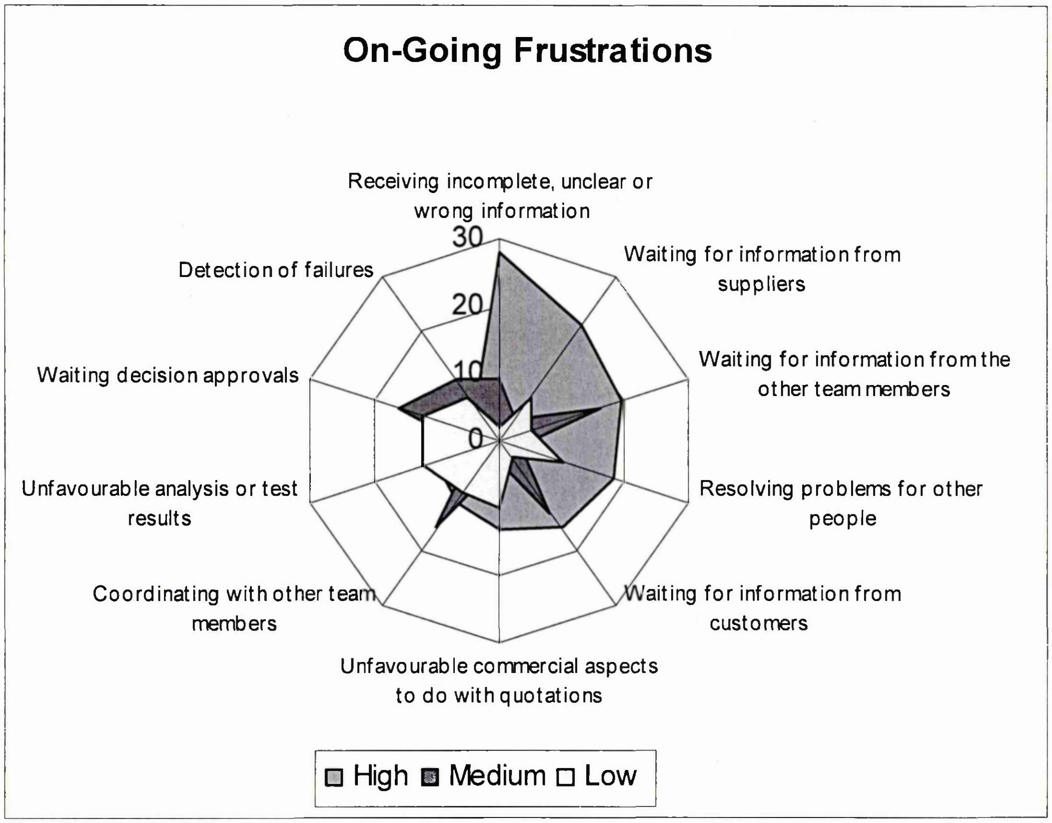


Figure 6-16; Q6b On-going Frustrations from the Assessment Questionnaires

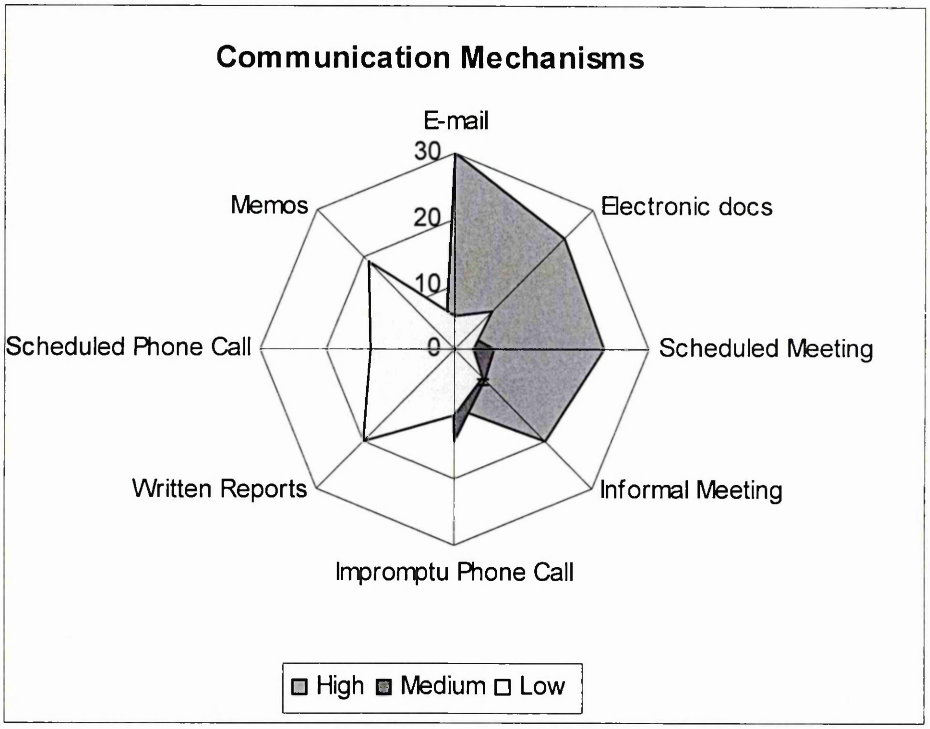


Figure 6-17; Q13 Communication Mechanisms

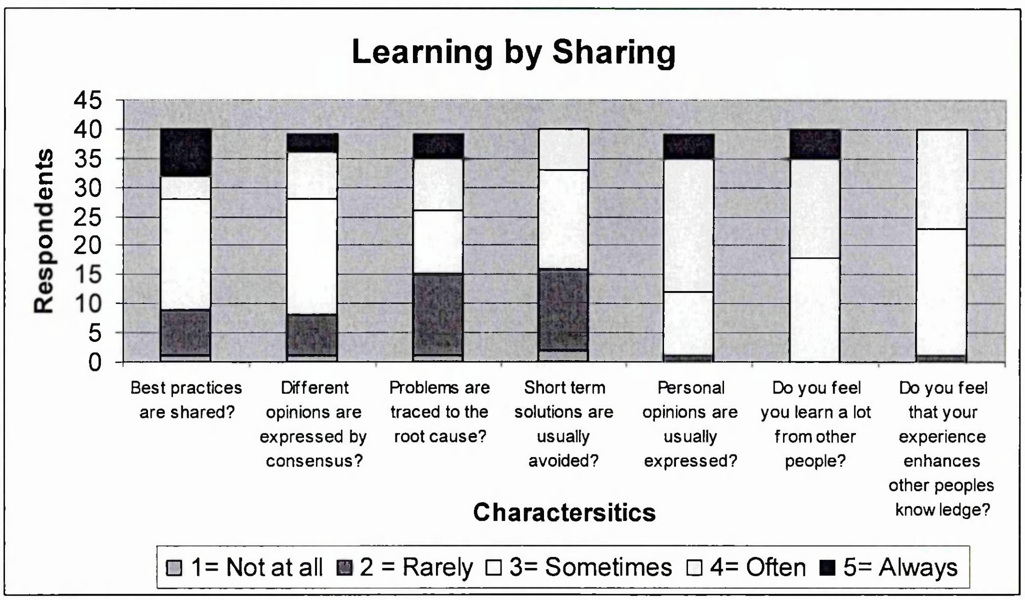


Figure 6-18; Q14 On-going Frustrations from the Assessment Questionnaires

On the basis of these results Sulzer actually responded by putting in place several detailed reviews to start improvements. They included key performance indicators (KPIs) to use during the course of live projects these were structured analysis of the particular strategic targets. The other structured reviews were order reviews, design reviews, shop floor loading, outsourcing overload resolution and a database for supplier assessments to aid procurement with scope of supplier and prevent supplier information errors being repeated on new projects.

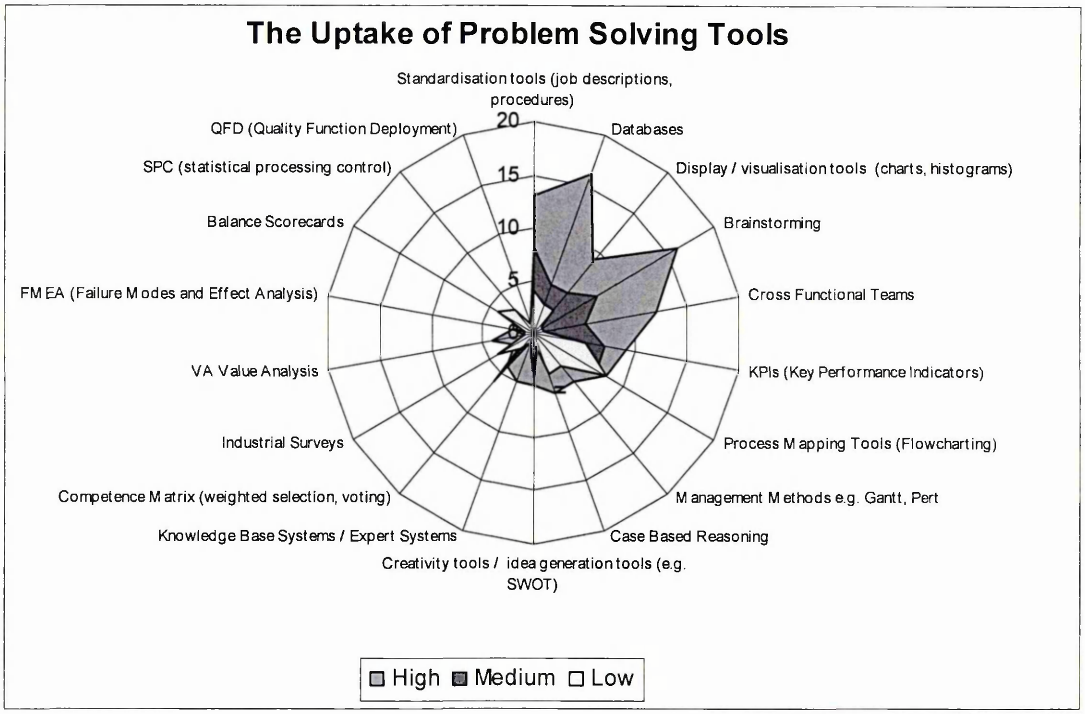


Figure 6-19; Q19 Uptake of Tools & Techniques from the Assessment Questionnaires

These issues were too addressed, especially the use of tool and technology and multi-functional teams. More mechanistic tools and training in project management were introduced (MS project) and more (flesh blood) were recruited into project administration to make it stronger and more effective as seen in Figure 6.19 above.

Note that a lot more information was gathered in this exercise but as the information contained confidential data about the company full access was not allowed, hence not published here. However these issues were being further examined with respect to other improvements that could be made in Sulzer Pumps manufacturing operations.

6.5.1.2 As-Is Model of NPD-ETO

The modelling of the entire 'NPD-ETO had been carried out in the initial testing (section 6.3.1.2) and the modifications to the methodology had only a minor effect on the model itself.

6.5.1.3 Step 2- Define the 'to-be' model of NPD-ETO

This too had been modified in the earlier testing phase. See section 6.3.1.2 for the discussion about the outcomes. The IDEF(0) model has been put together in appendix E.

6.5.1.4 Step 3- analysis of the NPD-ETO phases (as-is) at Primary Level (Level 2 modelling analysis)

Level 2 in the analysis framework looks at NPD-ETO from a departmental manager's and project manager's point of view, as already described in Chapter 5. Scoring of the problems associated with the project milestones (Table 6.1) within the NPD-ETO process enabled its assessment at this level. The full set of results is given in Appendix F.

Overall it was found that the phases of the process, i.e. tender design and project management and design reviews had more difficulties associated with their respective requirements and contributions. On close analysis of the tables it was found that those problems were primarily caused, by or were a consequence of, the potential vulnerabilities identified in the earlier phases of the bid clarification, order review and design & procurement process (see Figure 6.20). For example in the bid clarification review one of the major problems was preparation of the pump selection due to delayed customer feedback on incomplete and insufficient client specifications. This caused problems in the implementation phase especially with regards to purchasing and quality activities. These and many other issues can be investigated in further detail by using the analysis methodology developed for the detailed process at Levels 1 in the analysis framework.

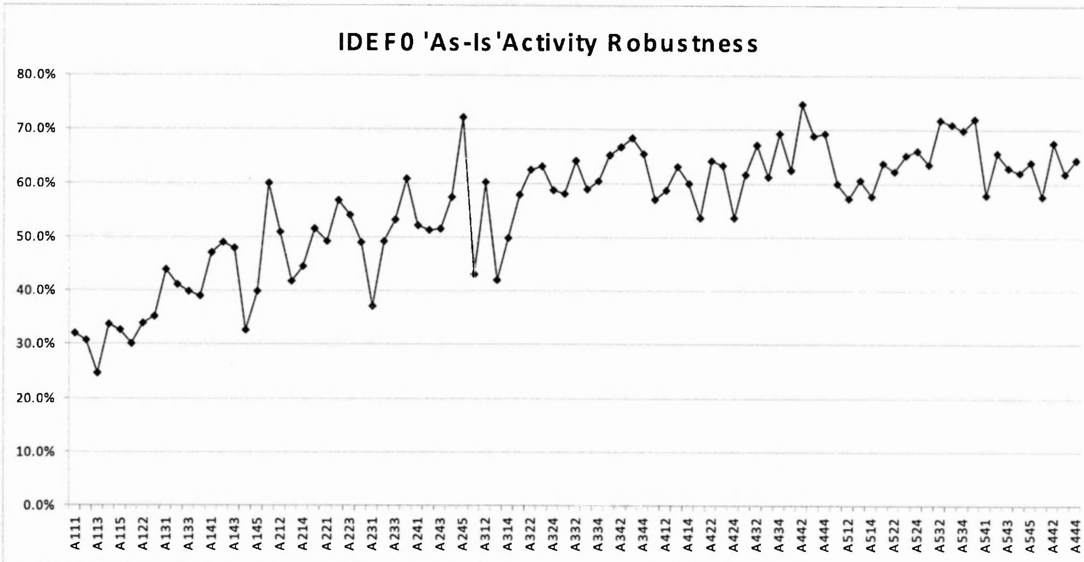


Figure 6-20; NPD-ETO Phases and Associated Activity Robustness

The other deduction from this analysis was that the robustness levels increased as the process moved downstream. Order Review and Project Planning and Design Reviews had the lowest levels of robustness compared with the production planning and control, as seen in Table 6.10 below.

Low Levels of Robustness	**High Levels of Robustness**
Order Review	Production Planning
Design Reviews	Production Control
Project Planning	

Table 6-10; Level Two Analysis Summary

Below is a summary of the key issues, i.e. the ones that highlighted as problem requirements and contributions, emerging from the tabulated data for the pre-manufacturing phases of the NPD-ETO process. The table should be read from left to right. Note that the 'problem requirement and contributions, could be seen as a 'cause' and effect' relationship respectively.

We can see the advantage of this type of analysis as it homes in on the actual issues and relates it to the functions involved and the process phase. However this approach does not go into the reasons why these problems might occur or give a clearer indication of the associated processes and process flows that are affected. The activity robustness assessment is missing. This is covered in the next phase level down, i.e. knowledge sharing level, level 3.

6.5.1.5 Step 4- analysis of the NPD-ETO phases (as-is) at Primary Level (Level 1 modelling analysis)

As a result of the above step the commercial stage was identified as the root cause of further downstream activities risk and uncertainty. It was consequently decided to apply level 1 analysis to this phase. Firstly the process had to be remodelled 'as-they happened' and then analysed using the analysis mechanism developed.

As described in chapter 5, level 1 has two classes of analysis

1. at a aggregate level, for the core NPD-ETO processes
2. at a detailed level for the process, the level of explicit and tacit knowledge contributing to the activity
3. at a detailed level, for the tool quality

The full set of results is given in Appendix F.

A collocated Advance Engineering and Advance Procurement team, as it was composed in the initial stages of the NPD-ETO process were analysed. A total of five functions/people were involved with the project at this stage. The analysis revealed five critical points to the team were:

- Lack of rewards or recognition of a good job
- Difficulty in allocation of time
- Dissatisfaction with a number of tasks performed in the project
- Cultural and interpersonal differences were tested at times
- Slow and incomplete flows of information

Again these results showed additional information which has not been picked up in earlier levels of the analysis (see Figure 6.21). A detailed process model of 'Sales & Tendering to Engineering Design is shown in Appendix E. We can see that there are essentially three steps of analysis and representation of the primarily level of the NPD-ETO process. The three steps were represented and analysed separately using the IDEF Model, Output Quality Assessment Resource Usage and Cross Impact Analysis, as already described in section 6.2.3.1

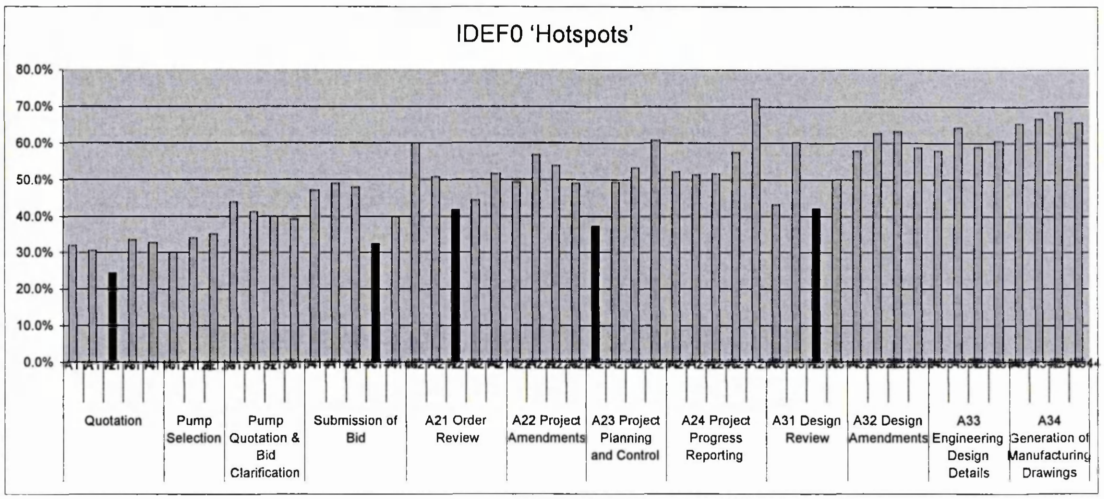


Figure 6-21; NPD-ETO Activity 'Hot Spots' (Sales-Tendering-Projects-Engineering Design)

6.5.1.6 Robustness Assessment of the 'Inputs', 'Control', 'Tools/Resources', and 'Outputs'

The detailed process assessment (core processes) of NPD-ETO IDEF0 Model is shown in Appendix E. We can see that there are essentially four characteristics of resources attributes, inputs, control, resources/tools and outputs. These were analysed separately using the activity assessment matrix, as already described in section 5.7. One should also note that as the resource has evolved and grown the ID number automatically be revised with a new resource ID number.

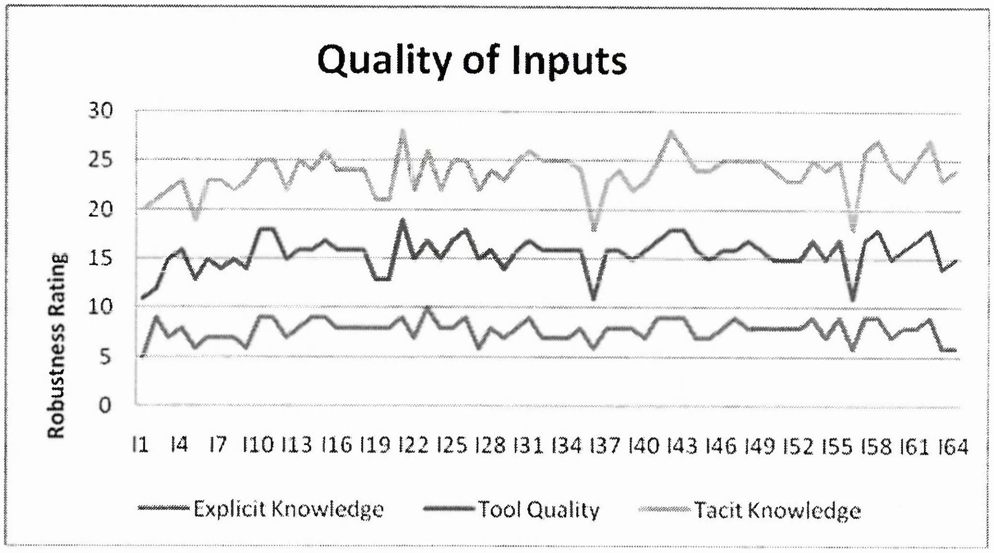


Figure 6-22; Phase 1 Analysis: Robustness of Inputs

INPUT	**Mean**	**Max**	**Min**
Robustness	50.1%	81.0%	21.0%

Table 6-11; Robustness of Inputs: mean, maximum and minimum values

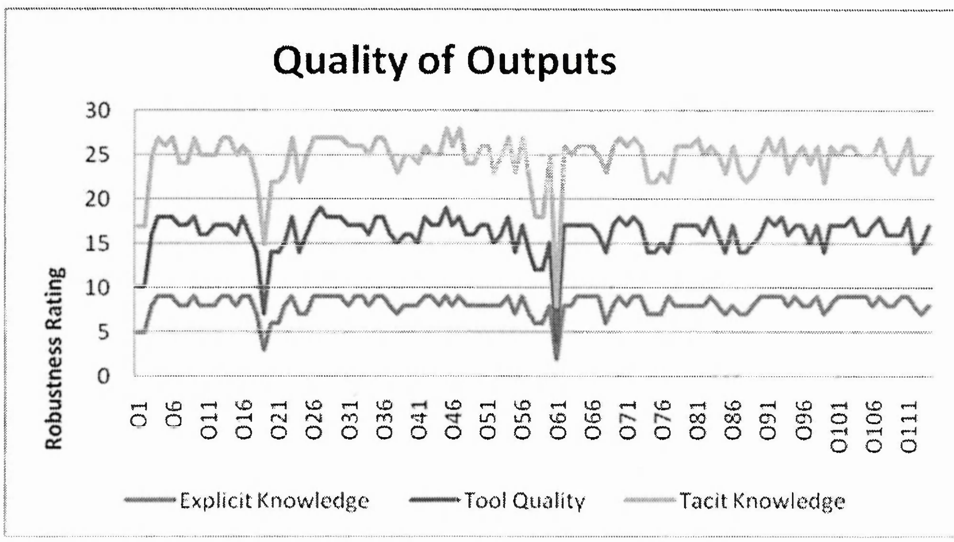


Figure 6-23; Phase 1 Analysis: Robustness of Output

OUTPUT	**Mean**	**Max**	**Min**
Robustness	56.7%	81.0%	1.6%

Table 6-12; Robustness of Outputs: mean, maximum and minimum values

The results showed that control C61 Project Closeout' score was excessively low. For the last two years prior to this research the senior management team identified this activity as major weakness within the realms of knowledge sharing and organisational learning and was therefore not easily initiate over a period of time because of resource constraints and no systems in place. Other problems with the lost bid analysis also highlighted the need for sharing and discussing previous case histories and lessons learnt.

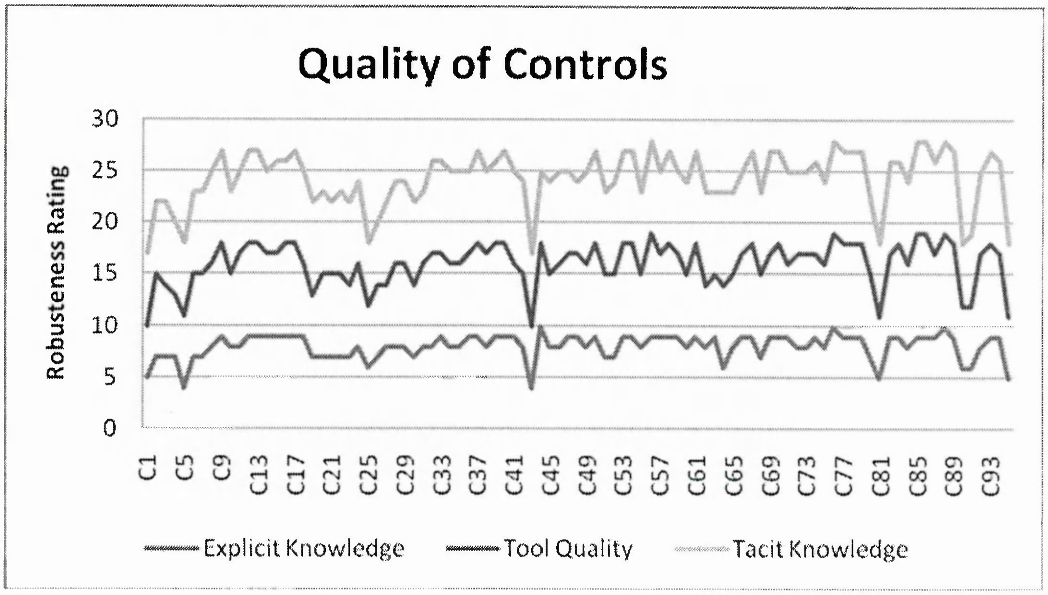


Figure 6-24; Phase 1 Analysis: Robustness of Controls

CONTROL	Mean	Max	Min
Robustness	54.8%	81.0%	16.8%

Table 6-13 Robustness of Controls: mean, maximum and minimum values

The results showed that control C43 'Customer Service Support Guidelines' scores was low. The main reason identified that field service data was archived in a remote location within the organisation and was therefore not easily accessible which resulted on past case filed data being unavailable to supporting the tendering engineers in the quotation process. Other problems with the office layout and environment, was that Design Engineers did not have the commercial understanding and by their very nature focused on the technical considerations whilst relying on the project managers to disseminate the commercial implications to the project.

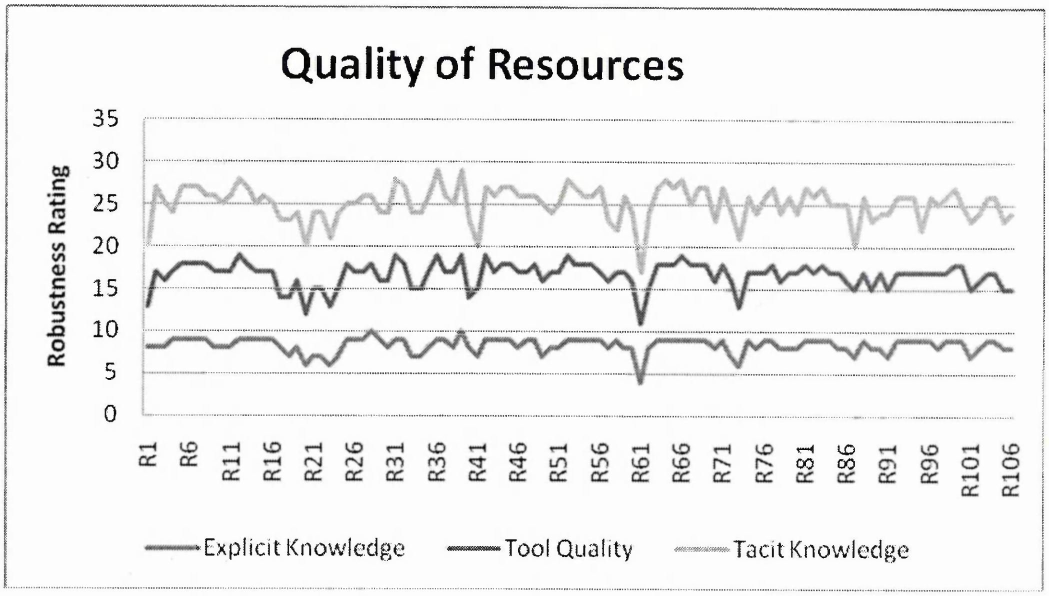


Figure 6-25; Phase 1 Analysis: Robustness of Resources

Resource	Mean	Max	Min
Robustness	59.3%	90.0%	16.8%

Table 6-14 Robustness of Resources/Tools: mean, maximum and minimum values

The sections were summarised in Table 6.15 below to show any vulnerabilities within the process as well as activities highest levels of robustness.

Level of High Uncertainty	Level of High Robustness
Project Header & Legal Entity 25% Bid Clarification 33% Review Scope of Supply 42% Issue Project Programme 37% Design Review Level 42%	Invitation to Order Review 61% Shop Floor Routings 64.7%

Table 6-15; Level 2 Analysis –Summary

6.5.2 Cross Impact Analysis of Projects

The full cross impact analysis of Sulzer's NPD-ETO process can be found in appendix H. With the number of resources being very high (380 resources and 89 activities) the size and complexity of the cross impact matrix was considerable. Therefore, this section summaries the results and highlights the important characteristics.

Figure 6.26 shows the cross impact coefficients for resource usage coefficient (R_n) and the cross impact coefficient (R_c). The important featured to notice:

The variation in (R_c) is due to the specialisation of certain resources such as certain tools are specific within certain departments such as CAD, whilst there are other such as the company's ERP system 'Jobscope' which tracks the order from order to despatch.

The order review activity (Node: A21) has 10 resources/tools across 5 activities and as a result achieves a higher cross impact score compared to Pump Selection Process only uses 5 resources/tools across 5 activities as the activity requires a higher level of expertise.

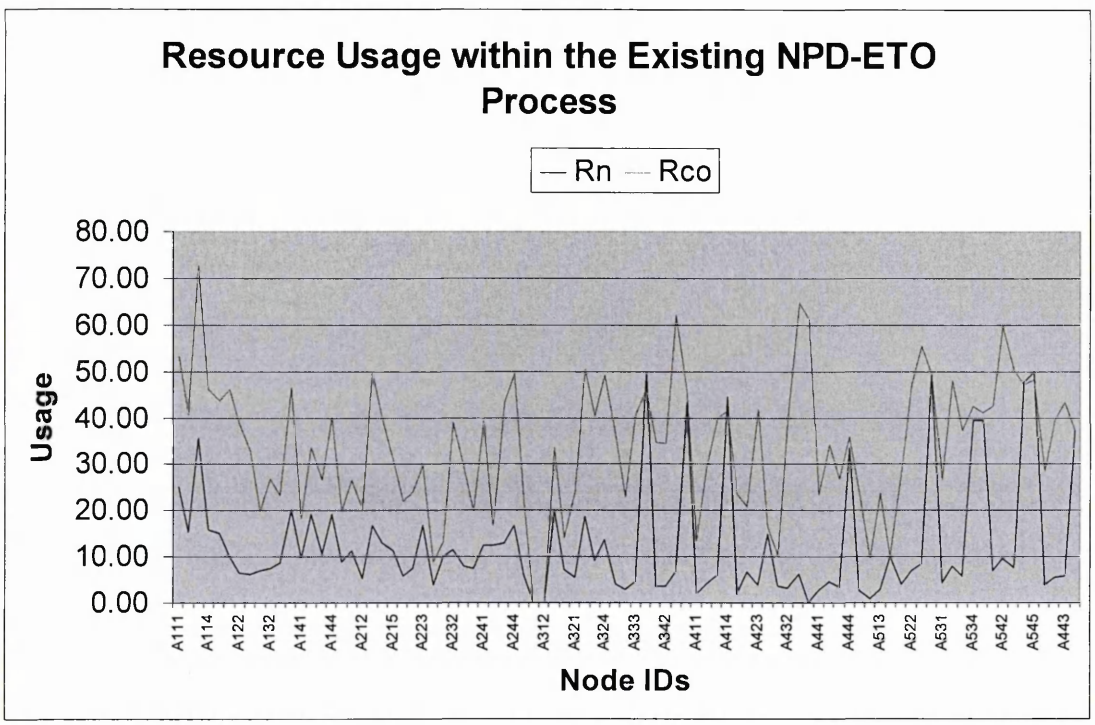


Figure 6-26; Resource Usage within the Existing NPD-ETO

The mean, maximum and minimum values R_n and R_c can be seen in Table 6.16 below:

	Mean	Maximum	Minimum
Rn	12.5%	50.0%	0.0%
Rc	34.2%	72.6%	0.0%

Table 6-16; Existing Resource Usage NPD-ETO: mean, maximum and minimum values

6.5.2.1 At the NPD-ETO Project Level

The matrix was used to analyse the process attributes for both the as-is and to-be modelling analysis. This showed how the attributes relate to the 'SETOK' framework, and identified the potential vulnerabilities by assessing the robustness of the resources within the NPD-ETO process. Secondly it showed what impact the activity attributes had on the 'core' NPD-ETO processes phases. This enabled the company to identify the attributes that have the highest level knowledge and resource quality with the NPD-ETO activities, shown below in Figure 6.27 in Appendix F.

Therefore the IDEF methodology acted as the mechanism to encourage knowledge sharing. Following on from this, the result of this the cross impact analysis helped Sulzer to identify weaknesses in their existing processes and identify the areas for improved process performance of 'one-off projects'.

6.5.3 Observations

Resource issues (Figure 6.27 in Appendix F) showed a steady performance across all activities, except for Resource 61, the Project Review. The main problem bringing the score up, here was the available resources as well as the level of quality and robustness. This means that project managers have limited resources in capturing or disseminating the learning experience. This actually verifies the earlier results of limited tools and techniques to capture the review process. Furthermore, the researcher investigated a variety of tools for building knowledge sharing at those under the following headings:

- Manuals & Procedures

- Post Project Reviews
- Storytelling
- Information System Tools
- Knowledge Management Practices

6.5.4 Modelling of the Project Management Process

Project Management is the key process in terms managing the information and workflow activity. It also provides the ideal mechanism for sharing knowledge due to the very nature of the process. The role of the Project Manager provides guidance, support to a team of projects & engineer in order to satisfying the customers requirements profitably, taking to different functions of the organisation to lobby support from mangers within the company, as well coordinate all technical and commercial details side of the contract.

Table 6.17 in Appendix F shows Activity Assessment including the scores of the output Quality Assessment and Cross Impact Matrix for Project Programme Reporting:

- IDEF Map A242 has a KPI score of 61%
- The variation in (R_c) is due to the limited use of tools to support the project management process of certain resources such as certain tools are specific within certain departments such as CAD with engineering design

As a result of developing the 'knowledge sharing tool' depicted in Figure 6.5 and its cross impact within the NDP-ETO process is represented in Table 6.18 in Appendix F. The variation in (R_c) improved from 21.3% to 31%, despite scoring only 6 on the Tacit knowledge characteristic, because of its recent introduction into the company and it current prototype state.

6.5.5 Step 5 Compare and Contrast results from the different levels of analysis

It has been found that the perspectives gained from the different levels of analysis differ as well as similarity and trends. However, there was a clear cause and effect relationship both vertically and horizontally across the business processes.

Analysis at Level identified the broader issues in the organisation relation to NPD-ETO, which could be traced to managerial level such as key performance indicators, elements showed up as issues at Level 2 analysis. However is was found that Level 3 analysis was not always an accurate state of affairs, because Level 1 and Level 2 analysis revealed the most beneficial and interesting, and presented them in a way would enable managers to solve the real problem.

The senior management team has since resolved the issues above. As an example the issue of high level project management checklists at the following project critical decision-making points:

- Project Header & Commercial Details (Non-physical)
- Project Launch (Non-physical)
- Order/ Review (Non-physical)
- Design & Procurement (Non-Physical)
- Manufacturing & Test (Physical)
- Project Closeout (Physical)

The interface between management and the project team is also very important based on these case histories. Management's responsibilities for new product development must be executed in a disciplined, consistent, and focused manner. These responsibilities include the alignment of projects with enterprise strategy, the selection of project team membership to get pertinent functional representation, and disciplined decisions (or Gate reviews). Problems in these areas tended to be more serious, and can be mitigated by a good NPD process design. Previously agreed gate milestones, another form of checklist, are of considerable benefit to improving the discipline and consistency of gate reviews.

Resulting from the case study findings, these activities appear to be loaded towards the 'front-end' compared to the more traditional NPD process within MTS (Soman Donk and Gaalman 2004). Table 6.19 compares these six critical decision-making points and referred to as 'Points of Commitment' (PoCs) between ETO and MTS industry sectors, within MTS process the PoCs seemed to occur further downstream, thus allowing MTS organisations more flexibility within their critical decision making in terms of price, delivery, quality and specification.

Manufacturing Strategy	Sales	Design Engineering	Manufacturing & Assembly	Despatch
Make-to-Stock	——————————————→			PoC
Engineer-to-Order	——→	PoC		

Table 6-17; Comparison of PoCs between MTS and ETO Manufacturing Companies

6.6 Project Management Process

From the initial findings there was an apparent need to support future projects in terms of uncertainties with lessons learning during previous projects. Bartezzaghi et al (1996) suggested that project reviews provide knowledge and information that can be shared across projects, however, they also note firms where more forthcoming with the information when the project was complete. However, Kransdorff (1996) suggests that key decision makers record their actions on a regular basis during the event or projects life cycle. Therefore there is a need for a framework and methodology for knowledge sharing to address those critical decision making points within the NPD-ETO process. The framework also needs address the variations between what has been sold and what has been designed and manufactured.

6.7 Improvements Made at Sulzer

Analysis at different levels of the organisation will lead to significant process improvement of the NPD-ETO process. The weaknesses identified were taken up by the senior management team which lead to the following changes:

- Changes in project management KPIs – introduction of checklists and six PoCs or Project KPIs with improved reviews at regular interval
- A more well defined NPD-ETO system, with hotspot capabilities
- The early phases of the NPD-ETO process were made clearer by the addition of a pre-contract review stage called 'scope'
- The NPD-ETO system focuses more on the quality of the resource, which will lead to better planning and control.

The traditional process modelling techniques have been developed for relatively structured and stable processes, hence, focus exclusively on structure and static (i.e. "as is") objects and disregard the information, interaction and dynamic state of the product development processes. Their analyses are simplified representations of processes at a particular point in time. As such, they ignore the dynamic state of the system, which may change over time as a result of resource competition, interactions, or other sources of internal or external uncertainty that can only be revealed by sampling data, information and results through time.

Although the proposed approach or extension is of a static nature, it can transform the static process into dynamic (e.g. "what if") model. This hybrid modelling methodology can be integrated into businesses processes and management systems, and used as a tool to support continuous business and manufacturing decisions at any point of time. The approach is holistic, stressing the state of a process model as a whole rather than its parts, supporting Hammer (1996) argument that a sensible view of a business process 'sees not individual tasks in isolation, but the entire collection of tasks that contribute to a desired outcome'. A discrete event analysis and simulation of a typical process is concerned with modelling discrete state changes and individual entities, where as our method and extension adopts features of system dynamics process models and operates at a more aggregated level in which flow rates can be modelled as continuous variables. Furthermore the process dynamics can be applied in a quantitative mode by transforming the diagrams into a set of equations, so that a measurable assessment and simulation of the process can be conducted. This allows a modeller to provide quantitative estimates of the process effectiveness and reliability at each stage of the process together with insight into their potential stability.

The proper application and use of the 'Activity Assessment' and 'Cross Impact Matrix' requires a detailed analysis of the process activities; identifying inputs, resources, methods/tools and assessing impacts of each on the quality of the output. The technique encourages the use of a methodical and probing approach, which helps validate the integrity of the process and helps improve the understanding of the impact of key factors on the successful implementation of the process. The technique is applicable as a process quality-based assessment as well as a risk assessment tool enabling practitioners to test for various scenarios.

6.8 Evaluation and Conclusions to the Methodology and Tool

Chapter six proposed a framework for process reliability and presented measures of output quality and cross impact analysis. The purpose of the case study was to test the validity of these, focusing on the 'core' business processes by the company to support the ETO product development, denoted as NPD-ETO.

This approach of using 'lightweight' technology (static process mapping tools, databases and spreadsheets) combined with group discussions and workshop provide a much richer and analytical approach to the management and improvement of ETO manufacturing projects.

At Sulzer the application of the methodology and tool was tied in with the use of collocated teams, which in itself has many benefits. It was believed that the two approaches complimented each other. These were seen at a macro level in the project performance. The main benefits were a reduction in the development time by improved project performance and the reduction in quality issues, resulting in the reduction of overall project cost.

There were 'intangible benefits too. These were found mainly at a micro level or operations level and one could argue were drivers behind the success achieved at a macro level. The benefits were a generalised better understanding, less conflict and improved morale amongst the project teams. This was achieved through the re-design of the process using process modelling and analysis, which encouraged earlier involved and a more controlled project managed process. The collaboration between the members of the project team i.e. sales, tendering, design, projects, procurement, production, manufacturing engineers, who produced the process models were totally committed to collocation, was considered "a major improvement" by the senior project manager in charge of projects. However the lack of involvement from some other departments caused problems and overshadowed some of the successes. According to the senior project manager though collocated projects had their benefits were some major issues and problems that had to be resolved at the outset before further collocation projects could continue. These issues described below are also relevant to implementing NPD-ETO project analysis methodology and tool.

Chapter 5 proposed a framework for Knowledge Sharing within NPD-ETO (SETOK) and presented measures of process quality. The purpose of the case study was to test the validity of these focusing on the NPD activities undertaken by and ETO and MTO companies in order to support the management and coordination of NPD-ETO manufacturing projects. The analysis and results presented in this chapter clearly demonstrated the validity of the proposed SETOK framework and the process performance and knowledge sharing measures (i.e. the research undertaken to meet the research objectives (1) and (2), Furthermore, it is believed that this concurs with and thus reinforces the supporting hypothesis to this research, namely:

1. By undertaking the strategies and approaches to managing and sharing knowledge, mangers can assess their resource capabilities and 'know-how' in order to satisfy the need to supply a customised solution

2. By measuring the cross impact of the process within NPD-ETO manufacturing projects (based on the activity structures and the quality of resources), the management of NPD projects can be optimised to reduce the uncertainty and improve the dissemination of knowledge on future projects

Chapter 7 - DISCUSSION & CONCLUSION

7.1 Introduction

This chapter presents the overall conclusions derived from the research. The research theme was to develop the concepts, techniques and tools to support knowledge sharing in NPD-ETO manufacturing projects. The research objectives have been met through detailed review of the literature, survey by questionnaire, and structured case study interviews with practitioners and two longitudinal case studies. The research focused on three objectives. The first was to propose a detailed framework for process and project reliability, to help ETO manufacturing companies understand the risk and uncertainties in the NPD-ETO activity. The second objective was to develop a measure of the process quality across NPD-ETO manufacturing projects. The third objective was to develop a structured approach and a framework for a tool, to support and manage effective knowledge sharing for the management process of NPD in ETO manufacturing projects.

This research satisfies not only the original aims and objectives defined in Chapter 1, but also deals with other issues which are not considered at the start of the research, but have emerged during the course of this work. Though the discussions below are drawn upon the literature review and the industrial survey described in Chapters 2 and 4 respectively, additional literature was reviewed during the writing of this section to identify the latest thinking and addresses the issues not discussed earlier. The chapter is divided into three sections.

Section 7.2 summaries how the research method was developed to address the objectives defined to meet the research aim. The section 7.4 reviews the original hypothesis and the research objectives. Conclusions are drawn from the work undertaken to meet the defined objectives, and the research elements that contribute original knowledge to the field of ETO and the knowledge sharing support are identified. To finish the limitations of the research are discussed.

7.2 The Research Method

In chapter one, three objectives were defined to meet the overall research aim. The research method and deliverables are presented in Chapter 1 to address these objectives and are shown diagrammatically in Figure 1.1 and Section 3.2 above.

The research method consists of seven stages, namely:

1. Review of Literature
2. Survey of NPD practices
3. Interview Case Studies of ETO and MTO manufacturers
4. Development of the knowledge sharing framework for NPD-ETO process quality, 'cross impact' matrix and mechanism for knowledge sharing
5. Development of the measures for process quality and cross impact coefficients
6. Case studies to test and develop the framework and quality measures

7.3 Research Summary

7.3.1 Overall Approach

The dissertation began to set the scene of the investigation, The current context of ETO manufacturer was discussed in terms of the need for firms to improve their NPD process in terms of uncertainty and risk, with examples of certain NPD-ETO characteristics, and need for research into the area. Chapter 2 reviews the most significant NPD process models presented over the years and described what are currently considered 'good practice' approaches to organising and managing product development activities.

This review demonstrated also the multi-faceted nature of the NPD and the types of manufacturing methods inherent with NPD. Though general models for NPD exist, such as Pugh (1991), Boothroyd (1994) and Peters (1999) focused mainly on MTS manufacturing models. This in turn increased the importance of MTO and ETO manufacturing organisations. The second part of the literature review was to identify manufacturing characteristics with regards to NPD within MTO and ETO manufacturing organisations. With respect to NPD-ETO Rahem (2003) and Hick (2002) gave some ideas as to what problems exist in ETO product development, but did not go into explicit details that this research required. In order to make up this gap and to get the detailed answers required to understand the NPD characteristics industrial questionnaires and surveys (in form of multi-methods approach was carried out). However additional information was revealed and there was a lack of understanding of the process of NPD-ETO and use of process modelling for analysis of resource issues, communication, collaboration knowledge sharing, team, and process integration. The last part of the literature review was to identify supporting knowledge management tools and techniques that are available and process modelling was suggested as a good approach to understanding these issues, especially amongst project managers, engineers and specialists within a project team (Hick 2002).

Chapter 3 began by stating the rationale for following an applied research approach for this research. It then described the research strategy and showed how the preliminary investigation pragmatism and opportunism led to the application of a multiple methods approach: a descriptive postal survey, case study interviews and longitudinal case studies. A critical review of the methodology concluded that although the methods all had certain limitations, their degree of validity and reliability was such that, taken together, it should be possible to build a fairly accurate picture of the for the application of knowledge sharing to the process of NPD-ETO. The findings of the case study and descriptive postal survey interviews were reported in Chapter 4 and Appendix A, which also highlighted the implications each activity had for both research process and research content. Chapter 5 drew on the sources used in the research to examine the characteristics of such NPD-ETO manufacturing projects. Chapter 6 presented the SETOK Framework and the application of the modelling and assessment tool via two longitudinal case studies and finally Chapter 7 brings the research to a close by discussing the findings and conclusions.

7.3.2 Survey of NPD practices

The survey of companies by questionnaires reported in Appendix A found that companies increasingly acknowledge the positive role that a structured and formal NPD process can play in their new product development activities. Many of the surveyed companies had general new product development process and believed that these are effective in their success rates. Nevertheless most of these models were not an exact application of the suggested methods available in the literature. Companies change these models in the way that can suit their specific needs. The importance of the different NPD stages for each company as related to its own specific situations was examined. The utilisation of NPD methods by each company and also the importance of each method in supporting different stages and activities of the NPD process were identified. It was found that companies still have more emphasis on the engineering and technical stages of the design process than front-end stages such as idea generation and conceptual phases. The barriers to the uptake of NPD tools and techniques by practitioners were also considered. The most prominent barriers were:

- Lack of expertise of NPD tools and techniques, only 38% of the respondents declared they were experts
- Lack of project reviews, only 23% of respondents carryout project post mortems

These observations highlighted the importance of a framework for customising the design processes and design methods to suit the specific needs of various companies. It was also recognised that the use of the more structured and sophisticated NPD methods such as QFD, Taguchi, DFM and DFA, is highly dependent on individual skills within the companies and not part of a company's formal procedures. In some companies the use of these methods has been stopped after the related expert has left the company, while other companies have tried these methods and found difficulties in their application. The most important problems identified were:

- 42% of the respondents usually make between 5-10 design modifications
- Lack of task clarifications was highlighted by 73% of the respondents
- 31% of respondents felt distant with the NPD process

Like the stages of the NPD process in the application of design methods the focus of companies was found to be on the engineering and computer-based methods such as parametric design methods, CAD, CAM, finite element analysis (FEA), and so on. Most of the concept generation and selection methods (for example Pugh's method), decision-making methods and even economic models were unknown by designers and new product development managers.

7.3.3 Interview Case Studies

The initial conclusions of the 4 interview case studies in Chapter 4 indicated that the NPD process of MTO and ETO firms' is sequential, has incomplete knowledge of customer requirements, a functional structure, commits to products and costs at an early stage and utilises few of the wide range of design tools and methodologies available. An examination of current NPD model within the interview case studies revealed weaknesses in certain areas, such as sequencing, monitoring, controlling, and displaying the process. To create a NPD-ETO process based upon the integration of natural assets and technology within the organisation via a knowledge sharing support system will require the adoption of a human-centred approach to the NPD-ETO process, rather than focus upon 'hard' technologies.

The importance of the different NPD stages for each company as related to its own specific situations was examined. The utilisation of NPD methods by each company and also the importance of each method in supporting different stages and activities of the NPD process were identified. The above results indicate the there are four general areas (each of which contribute to a number of 'Hotspots' or "Points of Vulnerability" which rose regularly including those that relate to:

- Commercial uncertainty/difficulties and risk
- Organisation and project structure
- Management of requirements capture
- Technical uncertainty/difficulties

Additional information was revealed which was that there was a lack of understanding of the process of NPD-ETO process and use of process modelling for analysis of resource issues, risk, uncertainty, team communication and collaboration within the process. Process modelling was accepted as a good approach to understanding these issues, especially amongst project managers, engineers and specialists within a project team. The knowledge management context of the problem was quite wide spread, covering strategic issues, technical issues, commercial issues, administration issues and operational and project management issues. From a hierarchal context, all levels were interviewed i.e. director level, senior management, middle management, and operations level staff. Their results showed similarity in terms of causes of problem (as mentioned above) as well as some commonality in its actual issues themselves.

7.3.4 Longitudinal Case Study

The main site development and testing of the 'SETOK' Framework was at Sulzer Pumps (UK) Ltd. The development of the methodology and supporting computer-based tools was evolutionary. The longitudinal case study approach, lasting over an 18 month period, was used in Sulzer. It considered pf developing a basic prototype version of the framework, methodology and tool from the results of the interview case studies and literature search. Then through a process of 'test–record-improve-refine', the final framework was arrived at. The first prototype was tested at two companies and the subsequent improvements were made at one company. In terms of the framework and methodology approach could be labelled as 'Concurrent Ethnography' as defined by Hughes (1999). Therefore the research led to the development of the methodology and tool (Chapter 6), which considered two elements:

1. Modelling Approach
2. Analysis Approach

The implementation methodology enabled a systematic and structured analysis of the organisational, operational and project management issues of their NPD-ETO process. Level 3 of the methodology, the company strategy level, gave an overall pointer as to what issues to focus on during the detailed analysis to be carried out in later levels. The 'functional-process stage' Level (Level 2), whilst providing a picture of the state of workflow between functions, allowed the user (project manager) to choose a particular NPD-ETO phase for further analysis, if so desired. The operational detailed process' level can be implemented in different ways. The resource assessment can be used to asses an ongoing project by carrying out a detailed analysis of what is actually happening at the resource level. Or based on the results of previous project assessments, one could carry out a comparative analysis in order to highlight the potential risk and implement the recommendations based on previous case histories. Analysis in such explicit detail eliminates the previous mistakes or ambiguities introduced by aggregated or one sided views. At Sulzer, the tendering phase of their NPD-ETO process was analysed in detail. In the Level 3 analysis of the operational level do not seem to be an issue. In fact on the contrary a rather positive picture was portrayed. However detailed analysis at Level 1 revealed otherwise for the NPD-ETO phase under analysis. This shows the benefit a more explicit and phase or activity focused analysis as opposed to overall general assessment.

One of the novel features of the 'SETOK' framework is the methodology of the scoring system for the process or resource quality elements that provides a quantitative picture for soft issues in NPD-ETO. The scores in isolation have limited potential, but when a series of scores for a number of activities within the same process or when the same process is compared to other ETO-NPD projects over a period of time. This scoring mechanism combined with the qualitative information gathered by the analyst during the data gathering stage phase provides a comprehensive approach to knowledge management diagnosis and hence improvement. The benefits are long term in nature. The main beneficiaries or end users of this project would be senior manager, team leaders/supervisors and project managers who have to make important resource decisions during the product development process as well as business process reengineering activities and other process improvement initiatives. The individuals taking part in the modelling and analysis also benefits in terms of better understanding of the various issues in NPD-ETO and the process itself.

The final analysis revealed key issues for Sulzer about its NPD-ETO activity, which enabled them to make improvements. Both tangible and intangible benefits were accrued. Tangible benefits were the identification of weaknesses within the process and organisation, which needed attention. The fact that Sulzer managers had quantitative data to back up their claims or their requests for improvement was the main benefit of this tool. Intangible benefits came from mutual trust and collaboration. This was achieved because all levels from senior management to engineering specialists were some how involved in the process of assessment. This brought collaboration not only within levels but also across levels of the organisation and authority. The biggest advantages were at level 1 analysis, whereby various team members got together to produce process models and clarification of the inter-functional relationships. As a result of the implementation, Sulzer made some changes in their NPD-ETO process, in particular the introduction of 'project closeout review', which focuses on project performance and learning experiences. Additional challenges emerged with regards to an organisational learning as a result of this analysis process. The challenges were to incorporate six project assessments or critical decision-making points within the following project phases or stages and incorporated them to in the company's key performance indicators (KPIs) system:

- Project Header & Commercial Details (Non-physical)
- Project Launch (Non-physical)
- Order/ Review (Non-physical)
- Design & Procurement (Non-Physical)
- Manufacturing & Test (Physical)
- Project Closeout (Physical)

The other challenges were the selection of strong project managers; improvement of participation and commitment of non-core project members. The author believes that no matter what tools and methods are applied the full benefits of managing knowledge and the proposed analytical methodology to the NPD-ETO will not be realised until these issues are resolved.

7.3.5 Activity Summary

Summarising, above it has been argued that ETO manufacturing organisations implementing knowledge sharing practices face problems within a project-based environment such as communication, collaboration, knowledge sharing, resistance to change, empowerment, conflicts of interest and effectiveness analysis of the NPD-ETO process. It has been shown that these can be overcome systematically and logically through the application and benefits of a structured, process based project management diagnosis methodology and tool. The main barriers to the success of knowledge sharing as well as the application of a detailed diagnosis through process modelling are weak project management, poor commitment and inadequate support for 'virtual' or 'non-physically collocated team members. Figure 7.1 below illustrates the main concepts of this research.

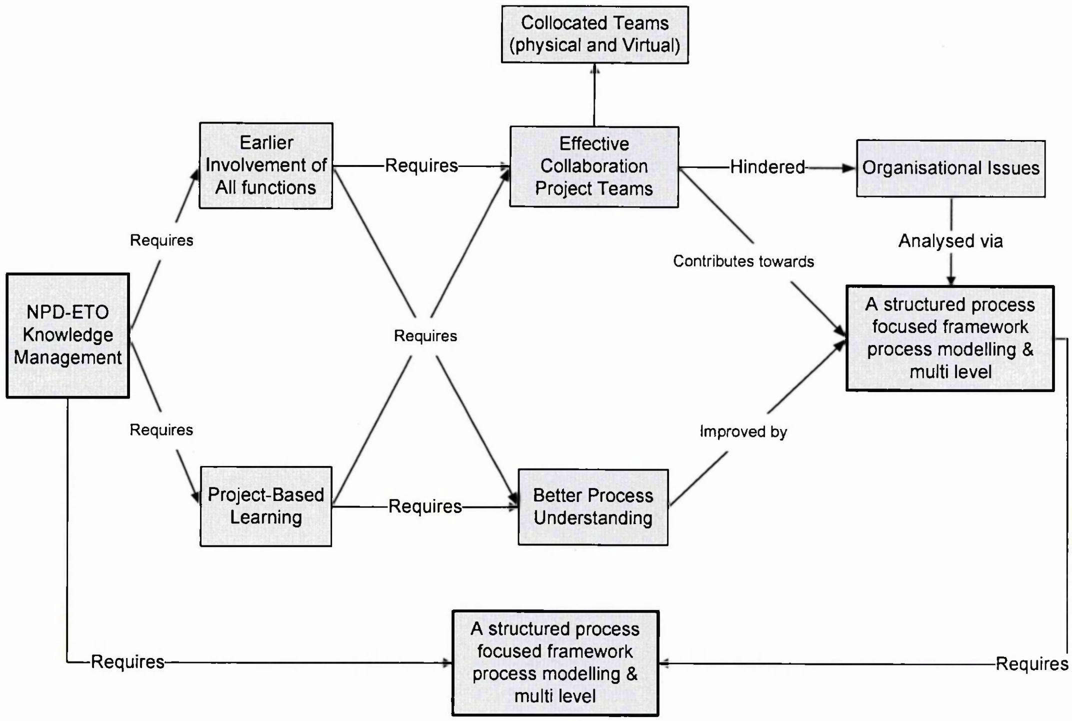


Figure 7-1 Main activities of this Research

On reflection, it is believed that the research method proved successful for the following reasons:

- The review of literature and subsequent survey of NPD practices enabled the researcher to develop a thorough understanding of the subsequent subject area as well as highlight the differences between the NPD characteristics of make-to-stock to engineer-to-order manufacturing organisations
- The knowledge gained from the literature review, the NPD survey and the subsequent MTO and ETO interview case studies formed the basis for the development of the modelling and analysis framework for assessing the output quality and resource usage across the NPD-ETO processes and impact via the cross impact coefficients

- The two case studies undertaken and presented in chapter seven supported the validity of the developed framework, activity assessment and the cross impact matrix and coefficients
- The knowledge gained from the literature review, NPD survey, MTO/ETO interview case studies formed the basis of the developed framework for the SETOK framework/project tracking support system
- Although a prototype project tracking system was developed within the research period, sufficient to define the framework and modelled system semantics for further development. This could be expanded to provide commercial benefits as well

7.4 The Research Hypothesis & Objectives

The hypothesis underpinning this research was that:

- The effective management of NPD-ETO manufacturing projects requires a structured approach and supporting tools to manage the process effectively.

This was further supported by the hypothesis that:

I. By understanding the issues and problems of ETO manufacturing projects, managers can identify the potential risks and uncertainties are suited to the knowledge sharing opportunities within their company.

II. By highlighting the process vulnerabilities in an ETO manufacturing project, the process can be optimised to reduce the project risk and uncertainty within the NPD-ETO process and improve knowledge transfer on future projects.

The aim of the research was to develop the concepts, techniques and tools to support the underpinning and upholding of the hypothesis to achieve this aim, a number of research objectives were established and developed. It is believed that within the limitations of the research all the three objectives were met. Therefore, it is further believed that the underpinning and supporting hypothesis held true.

The results of this research in this thesis can be characterised as being process-orientated. A great deal of attention has been focused on following a specific approach for completing the NPD-ETO knowledge sharing research presented in this thesis. The structure and scope for completing the NPD-ETO knowledge sharing research see (Chapter 2) and further developed of the various topics in Chapter 4 through Chapter 7 could serve as an example for future NPD management research. The approach used for structuring and developing knowledge sharing within NPD-ETO project based environments can be seen as a contribution to the approach in modelling management research to the field of business process modelling.

7.5 Research Objective (1)

Having investigated the problems within NPD and ETO manufacturing, the next phase was to explore the developments currently undertaken in the UK to address issues in NPD-ETO, and what are the main methods and tools, both research and commercially based, were being adopted. Based on the conclusions and knowledge gained from the literature reviews and industrial survey it was possible to investigate the develop the requirements for a framework, methodology and tool, which addressed the weaknesses identified in existing approaches; and provided the necessary decision support for solving or sharing real life industrial problems in NPD-ETO manufacturing projects. The requirements in terms of: what, how, where, when and why context.

The first research objective was to develop a detailed framework for process risk and uncertainty, to help companies understand the NPD-ETO process and the approaches to knowledge sharing. This was established to support hypothesis (i).

- A new framework for modelling for NPD-ETO was presented in Chapter 5
- The framework was developed on two assumptions
    1. NPD is not a singular strategy, but instead it is a continuum of strategies for companies that manufacture-to-stock to those that engineer-to-order.
    2. The nature of the NPD-ETO activity can differ, and that both the activity and its representation can be customised.

7.6 Research Objective (2)

The second objective was to develop a measurement of process assurance across NPD-ETO activities, as well as against previous past projects. This was established to support hypothesis (ii).

- A new measure for process quality in process modelling
- The need for this measure to consider the factors of process robustness, tooling/resource effectiveness and skill and experience of the individual or team.
- The application of cross impact coefficients was demonstrated as part of a case study within Sulzer Pumps (UK) and Laker Vent Engineering in chapter six.
- The cross impact coefficients were used to compare the process inputs, controls and methods and outputs
- The development measure of cross impact an original contribution to the field of knowledge in the area of process modelling

In order to provide an explicit diagnosis of the NPD-ETO process the solution was to focus the attention on detailed modelling of process and activities. However to provide a holistic picture or aggregated view one needed to represent high level activities or abstract models. The levels of modelling and analysis and the corresponding units of analysis and analysis criteria are discussed below.

Modelling Approach

- To validate the proposed framework the NPD-ETO process activities of two manufacturing companies that supply both MTO and ETO manufactured products were analysed. The findings demonstrated how all the companies fitted into the framework.
- The proposed framework supports the company's satisfaction the hypothesis (i) and constitutes an original contribution to the field of knowledge in the area of NPD and the manufacturing interface.

Analysis Approach

IDEF Assessment & Cross Functional Analysis

- The proposed assessment supports the hypothesis (ii) and constitutes an original contribution to the field of knowledge in the area of NPD and the manufacturing interface.
- The 'Activity Assessment' was developed to help companies identify the potential NPD-ETO risks and vulnerabilities in terms of quality of tools and resources as well as the quality of knowledge being shared.

The 'cross impact matrix' was presented in chapter five

- The 'cross impact matrix' was developed to help companies understand the framework for process quality and approaches to identify the quality as well as highlight the potential risks or vulnerabilities within the NPD-ETO activities.
- The application of the 'cross impact matrix' was demonstrated as part of the case study undertaken at Sulzer Pumps (UK).
- The 'cross impact' was used to analyse the company's NPD-ETO project performance and NPD processes in relation to the analysis framework. This enabled them to assess the resource usage and cross impact within the core business processes.
- The analysis assessed the 'output quality' as well as quality of the knowledge (explicit and tacit) and the tools and resources available within each activity and its contribution to the overall performance of the NPD-ETO project. This led to the process improvement and knowledge sharing recommendations.
- The development of the 'cross impact' supports the hypothesis (i) and constitutes an original contribution to the field of knowledge in the area of process modelling.

The methodology proposed in this thesis attempts to provide a structured framework for project and process risk and this was achieved via the two longitudinal case studies

Contribution

- Provide an improved business process based, multiple-perspective, (in terms of hierarchy and perception) assessment of the NPD process and ETO manufacturing organisation; the combination of which was lacking in existing tools which were consequently not delivering the desired results.
- Provide an improved performance measurement methodology or system for ETO manufacturing project environments, which features the combination of which lacks in existing methods or tools.
- Proved a knowledge sharing methodology geared towards project-driven manufacturing environments, by combining a number of features not available together in a single tool within the budget and implementation capability of an industrial engineer or project manager.

7.7 Research Objective (3)

The third objective was to develop a structured approach and the framework for the tool, to support and manage the effective knowledge transfer within the NPD-ETO process. This was established to support the underpinning hypothesis and supporting hypothesis (i) & (ii).

- The framework for a project sharing ETO knowledge was presented in Chapters 5 and 6.
- The 'SETOK' framework supports the strategies for knowledge sharing, based on the distinct characteristics of explicit and tacit knowledge in the knowledge management literature.
- The proposed system uses a generic activity assessment based on IDEF(0) principles, with the support of process analysis criteria.
- A classification system is introduced to organise the libraries of project and process knowledge sharing characteristics and generic 'points of commitment' within the NPD-ETO process.
- To identify the vulnerabilities within the system, the user specifies process resource attributes. The system uses case history data to generate an instance predefined potential risks or 'hotspots' for future NPD-ETO projects.

- The proposed system's structure and semantics were modelled using MS Access
- The tools and technologies required to develop a prototype system, and realise the proposed system were outlined.

The main site development and testing was at Sulzer Pumps (UK) Ltd. The implementation methodology enabled a systematic and structured analysis of the organisational, operational and project management issues of their NPD-ETO process.

The research lead to two further developments of the methodology and tool (Chapter 6), which considered two elements:

1. Implementation Approach
2. Knowledge Sharing Approach

Contribution

The methodology and tools developed in the research enable managers to analyse their resources in detail, focussing on the process (as opposed to functions) within a structured and coherent framework, at different levels (in terms of detail) and from different perspectives (senior management (strategic) middle management, team, and individual perspectives). The process modelling methodology and tool is used as an implementation mechanism, which enables managers to model their organisation and use the models for detailed analysis and enhance knowledge sharing within the organisation.

7.8 Original Contribution

The need for this programme of research was driven by the lack of existing academic material in this domain. It was felt by effectively answering the set of research questions, and successfully demonstrating the viability of the research hypothesis, this thesis presents an Sharing-ETO-Knowledge Framework that satisfies the a support framework in the field of NPD-ETO, knowledge management project management, and business process management, it makes significant contribution to the theory building of that adds to the research base in a field that has suffered from the definite lack of quality material and published guidelines.

The methodology and tool developed in the research enable managers to analyse their resources in detail, focussing on the process (as opposed to functions) within a structured and coherent framework, at different levels (in terms of detail) and from different perspectives (senior management (strategic) middle management, team, and individual perspectives). The process modelling methodology and tool is used as an implementation mechanism, which enables managers to model their organisation and use the models for detailed analysis and enhance knowledge sharing within the organisation.

Two further case studies

The following research elements contributed to the field of ETO and knowledge sharing support:

- The development of a framework to support and coordinate knowledge sharing with ETO manufacturers
- The development of a "process reliability matrix' and the measures of process quality constitute an original contribution to the field of knowledge in the area of process modelling
- The development 'ETO knowledge sharing support system' that constitutes an original contribution to the field of knowledge in the project management support.

The research presented in this thesis in part contributed to the following conference publications:

1. **Reid, H. Ismail, M. Rashid, S. MacLeod,** 'Enhancing New Process Introduction (NPI) within an SME manufacturer' International Conference Manufacturing Responsiveness, (ICMR), Liverpool, UK (2006).
2. **I Reid, H. Ismail and G. Cockerham,** 'Knowledge Sharing within both Make-to-Order and Engineer-to-Order Manufacturing Enterprises'

International Conference Manufacturing Responsiveness, (ICMR), Liverpool, UK. (2006).

3. **IR Reid, G Cockerham and C. Pickford,** 'A Framework for project-based learning within ETO product development', Paper presented at the 11th International Conference Manufacturing Responsiveness, Sheffield, UK, Sept 7-9th (2004).

4. **IR Reid and C Pickford,** 'The Design and Development of a Knowledge Transfer Framework and Methodology for Integrated Product Design (IPD)', International Conference Design for Excellence', Brunel University, UK. (2000)

5. **IR Reid, and C Pickford,** 'A Total Design Process Framework & Knowledge Management Methodology for an Engineering Product Design Process', Paper presented at the 11th International Conference on Concurrent Engineering, July 17-21st Lyon, France, (2000)

7.9 Limitations of the Research & Suggestions for Future Work

Several limitations to the research presented in this thesis can be identified. Consequently further actions and developments can be established for future work. Specific limitations include:

- Larger Cross Section of Companies
- Qualitative scoring system: High, Medium or Low ranking rather than a quantitative 1-10 scoring system

Cross Impact Coefficients

Chapter 5 presented how the application and behaviour of the cross impact coefficients was applied to both cases studies at Sulzer Pumps (UK) and Laker Vent Engineering. However, it is suggested that further investigation be required to analyse multiple examples of different ETO and MTO projects. This would require further case studies to be taken in a number of ETO and MTO organisations.

Chapter 6 also presented a number of working prototypes that were developed to demonstrate the main functional elements of the proposed 'project tracking support system'. However, an integral prototype system was beyond the limited time constraints of the research project. Therefore the primary area of future work would be to develop such a prototype.

The main elements that would require future work are:

- A module to satisfy project 'hotspots' or 'points of commitment'
- A user interface to integrate the individual ETO project templates

Knowledge Sharing Support System

Chapter five presented a number of working prototypes that were developed to demonstrate the core NPD-ETO processes of the proposed 'project tracking system'. However, an integrated prototype system is beyond the limited time constraints of the research project. Therefore, the primary area of future work would be to develop the prototype further.

The main elements would require future work:

- A module to satisfy NPD-ETO templates
- A user interface to integrate the new process models

7.9.1 Adventure in Research

On reflection of this whole research experience, I would probably say it has changed my life for ever, from the way I work, the way I think and the way face new challenges. Initially I was a bit intimidating as knew nothing about this PhD experience, so I had nothing to compare it with, except either the search for the 'Holy Grail', or the compulsive characteristics of Captain Ahab or Moby Dick.

As I travelled through each step of the project, I found that I became more obsessed with new knowledge and became more aware of its intricacies, across the three core themes of NPD, ETO and knowledge sharing. I found one of the most interesting aspects of the research, likely because I was using the multi-methods approach to the research methodology. New and interesting perspectives seemed to rise with each phase as did themes and patterns. The ongoing analysis of the developing the SETOK framework and methodology was one of the most exciting aspects of the research, keeping my enthusiasm peaked even when the results and findings of my research were personally disappointing.

Overall, I would classify my experience as quite good. Probably what I found most engaging was the interactions with the different case study companies. Applied research is a skill, which I am sure can be enhanced but is likely an intuitive skill as well. I was challenged to reflect on myself, the company and the process for optimum value during this project and I think it offered me personal growth and insight into myself, others and how I work.

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Appendix A: NPD Survey & Findings

1.1 Survey

The literature chapter examined the existing tools and technologies that support the NPD process and the extent to which these tools are and techniques was well as knowledge management methodologies and techniques are being applied within such MTO and ETO manufacturing enterprises, little is understood about their application. The survey was to provide an insight into NPD practices and to establish an insight into the general awareness of NPD practices in UK based engineering and manufacturing companies. It was intended that the survey process and results should be used for familiarisation of the subject area of NPD. However, the researcher used the opportunity it presented to generate descriptive data from which it might be possible to:

- To discover the strategic objectives in the NPD process
- To capture influential factors of the design process within NPD process
- determine how widespread the application of NPD tools and techniques is amongst companies;
- discover if firms that have benefited from implementing NPD practices
- see if a particular type of firm is more likely to apply NPD processes

Existing survey of NPD design practices and application of particular technologies were already available (Tzokas, Hultink and Hart, 2004) and (Nijssen E.J., and Frambach, R. T., 2000). However, the researcher believed that reference to existing work in isolation would detract from the intended purpose of the survey, namely, familiarisation of the subject matter.

1.2 Overview of the Survey Design

A combination of both qualitative and quantitative approaches was used for the research data and survey design. Depending on the nature of the nature of the question and the research data required, the most appropriate approach was adopted. Where data was subject to suitable controls and suited to statistical analysis, a quantitative approach was adopted. Where data did not lend itself to such analysis being more descriptive, a qualitative approach was adopted. In many cases, the respondents were asked to justify quantitative data with qualitative reasoning.

The most severe limitation of the survey research method is a low response rate. There are a number of reasons for this might occur. Surveys can be lost, or not reach the intended purpose; this is especially true when the name of the person is not known. Companies are often busy and may not have the time or resources available to complete the survey. Even with the best intensions a survey may never be finished or returned.

A low response rate not only reduces the number of respondents, but also increases the likelihood of response bias being introduced. By nature, the respondents who take the time to complete and return the survey are likely to be interested in the subject area. This characteristic can often misrepresent the entire sample population.

To reduce the chances of a low response rate, careful considerations was given to the design and appearance of the survey instrument. The survey was intentionally (some five pages in length) and was estimated to take approximately twenty minutes to complete. Questions were clearly worded to reduce ambiguity. Detailed and lengthy explanations were avoided. A covering letter accompanied the survey to inform the respondent of the research findings (see Appendix A) was forwarded on completion of the project.

1.2.1 Selection of Survey Population

The sample population consisted of 150 UK based engineering and manufacturing companies known to be actively designing new products. The 150 named personnel was selected from Sheffield Hallam University's licenced 'Kompass' database.

1.2.2 Pre-testing and Pilot Survey

The survey instrument was circulated to colleagues within the university with experience of NPD tools and techniques, and methods, to be pre-tested. A number of questions were considered difficult to answer or ambiguous, and as a result were modified. The revised survey was sent to 15 companies belonging to the sample size, to assess the likely responses. From this pilot survey, 6 companies responded, giving the researcher the confidence to distribute the survey instrument to the remaining sample population.

1.2.3 Analysis of the survey results

The data from the research results was analysed using a general purpose spreadsheet application. The researcher believed that dedicated statistical software would be 'overkill' for the analysis required, entailing an unnecessary learning curve.

1.3 Survey Content

The survey instrument (See Appendix A) was comprised of the following sections:

Respondent Details

This section of the questionnaire was linked to obtain the details about the respondents, this information was required fro contact purposes only, and was treated in the strictest of confidence.

Section A- Company Background

Section A of the questionnaire was intended to provide background information to the surveyed companies. Questions include SIC classification the companies belonged to, number of employees, annual turnover, company strategy and business functions.

Section B- Product Range

Section B of the questionnaire focused on the surveyed companies product range, including the manufacturing method whether it's a make-to-stock to an engineer-to-order scenario. It was intended to provide information on the companies' main product lines and included the number of variants, number of non-standard components, and design costs.

Section C- NPD Management

Section C focused on the NPD and design process, including modifications, design reviews, software the surveyed companies used, including hardware and the methods employed to design new products, assemblies and components

Section D- NPD Tools

Section C intended to identify the scope of NPD tools used by the survey companies. Other questions included reviews and design changes and modifications

Section E- Continuous Improvement

The final section of the questionnaire was intended to identify the areas for continuous improvement, the survey companies planned to invest in, over the next two-year period.

1.4 Research Findings

The findings are based upon the participation of 31 companies that responded to the survey. From the companies' responses to the questions, 26 respondents were considered suitable for the analysis. A response rate of 17.3% was achieved.

1.4.1 Section A: Company Information

The survey population was restricted to UK engineering and manufacturing based companies. All respondents companies resided within a "S.I.C. Classification, Division 3, companies. The distribution of companies according to their S.I.C. category is given in Table 4.1.

	SIC Category	%
1	Metal Goods	12%
2	Mechanical Engineering	42%
3	Office Machinery & Data Processing	0%
4	Electrical and Electronic Engineering	8%
5	Motor Vehicle parts	15%
6	Other Transportation	19%
7	Instrument Engineering	0%
8	Other	4%

Table 0-1; SIC category of respondent companies

The Mechanical Engineering category, 42% and the other transportation category 19% had the highest population. Due to the multidisciplinary nature of the product development process, the respondents from the Mechanical Engineering had elements of Electronic & Electrical Engineering incorporate into the products and therefore were indirectly contributed to the responses.

1.4.1.1 Company Size

The distribution of respondents according to their number of employees is given in Table 4.2 below.

Number of Employees	%
1-50	35%
51-250	15%
251- 1000	38%
1001 and over	12%

Table 0-2; Number of employees in the companies

The distribution of respondents according to their annual turnover is given in Table 4.3.

Annual Turnover	%
Under £5m	7%
£5m - Under £25m	34%
£25m – Under £100m	22%
£100m – Under £200m	16%
Over £200m	15%
Confidential	6%

Table 0-3; Annual Turnover

1.4.1.2 Business Strategy

The survey companies asked to rank their business strategy in order of importance- Cost, Delivery, Time, Quality, Flexibility, Innovation, Service and Other- they worked towards and if so which other strategic drivers does the company work towards. The distribution of respondents according to the business strategy is given in Table 4.4.

Business Strategy	
Cost	94%
Delivery	79%
Quality	54%
Time	53%
Flexibility	37%
Innovation	31%
Service	21%

Table 0-4; Business Strategy of the respondent companies

1.4.1.3 Resource Allocation

The surveyed companies were then asked what activities – marketing, research, product development, manufacturing/production, - they also carried out and if so how many people were involved in each activity. The distribution to the activities is given in Figure 4.2.

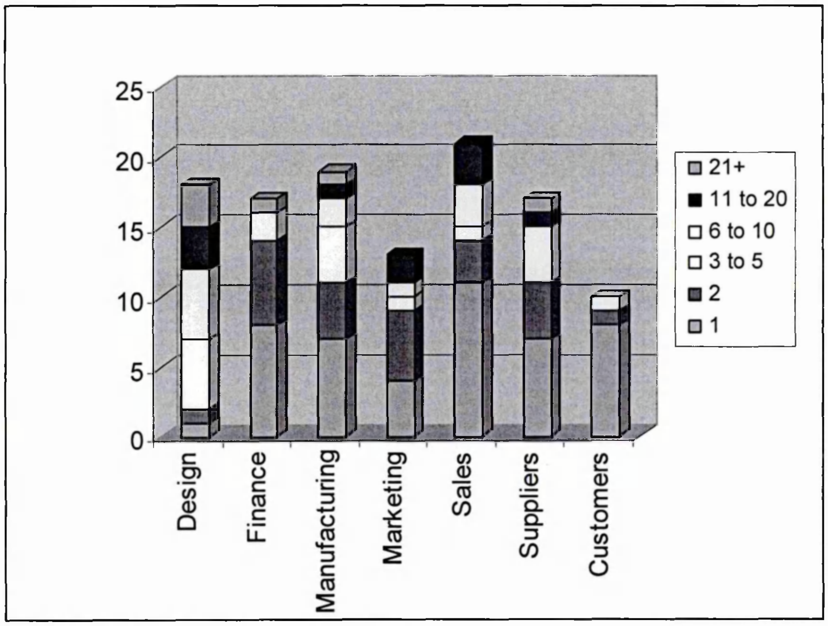


Figure 0-1; Number of People involved in the NPD activities by the respondent companies

The sample population (as discussed in section 4.1.2) was chosen from the database of known companies known to have an extensive NPD teams. As expected, the majority respondents within the automotive and power generation industry sectors had extensive capabilities in terms of design and supplier resources.

1.4.1.4 Management Structure

Management Structure	%
Very Hierarchical	38%
Limited Hierarchical	58%
Project Based	4%
Matrix Based	12%
Other	0%

Table 0-5; Management Structure in the companies

The surveyed companies were then asked what activities about the hierarchy of the organisation -Very Hierarchical, Limited Hierarchical, Project Based, Matrix Base and other. As expected, the majority of the respondents operated within a limited hierarchy at 58% and 38% Very Hierarchical and 12% operating within a matrix based management structure.

1.5 Section B: Product Range

1.5.1.1 Product Types

The survey companies were asked about the types of products- components to be sold for further assembly, subassemblies to be sold for further assembly, finished marketable assemblies – they produced. The distribution of the respondents according to the product types is given in Table 4.6.

Type of Products	%
Components to be sold for further assembly	31%
Sub-assemblies to be sold for further assemby	42%
Finished marketable products	73%

Table 0-6; Types of products produced by the respondent companies

The majority of the respondents 73% produced finished marketable products, 35% of the respondents produced one type of product only and 39% produced two types of product.

1.5.1.2 Manufacturing/Production Typology

The Survey companies were asked about the types of products and manufacturing typology – products that are make-to-stock, assembled-to-order, make-to-order and engineer-to-order they produced. The distribution of respondents according to the product types is given in Table 4.7.

Manufacturing Method	%
Make-to-Stock (MTS)	21%
Assembled-to-Order (ATO)	27%
Make-to-Order (MTO)	34%
Engineer-to-Order (ETO)	16%

Table 0-7; Manufacturing typologies employed by the respondent companies

1.5.2 Product Structure and Design

The surveyed companies were asked to specify their main product lines, and the approximate percentage contribution to sales turnover for each core line. The range of the product lines for each respondent correspond to the SIC classification in which they resided.

For each product line, the surveyed companies were also asked to specify:

(a) the number of product types/variants available

(b) average number of components per product

(c) percentage of non–standard components; specifically designed in each product

The number of respondents according to the number of product types/variants in the production line contributing most to the sales turnover is given in Table 4.8.

Product Types/Variants	%
1-10	12%
11-100	35%
101- 1,000	19%
Over 1,000	8%
Unlimited	27%

Table 0-8; Types of products produced by the respondent companies

The distribution of the respondents according to the average number of components in the production line contributing most to sales turnover is given in Table 4.9.

No. of Components in Product Line	%
1-10	15%
11-100	12%
101- 1,000	23%
1,001 -10,000	27%
Over 10,000	23%

Table 0-9; Types of products produced by the respondent companies

The distribution of the respondents according to the percentage of non-standard components in the product line contributing most to sales turnover is given in Table 4.10.

% of Non-Standard Components	%
Under 10%	35%
10- Under 20%	15%
20- Under 40%	4%
40- Under 60%	27%
60- Under 80%	8%
Over 80%	12%

Table 0-10; Types of products produced by the respondent companies

1.5.2.1 Relative cost of the Design

The surveyed companies were asked to estimate what percentage of total production costs are incurred within the design process. The distribution of respondents according to the percentage of product costs due tot eh design process is given in Table 4.11.

% of Product Cost of Design	%
Under 20%	23%
20- Under 40%	4%
40- Under 60%	19%
60- Under 80%	27%
Over 80%	27%

Table 0-11; Types of products produced by the respondent companies

1.6 Section C: NPD Process

1.6.1.1 Time Allocation to NPD

The surveyed companies were asked to specify existing NPD process, and the approximate percentage of time spent on their NPD activities. The percentage of the respondents' time allocation is given in Figure 4.3.

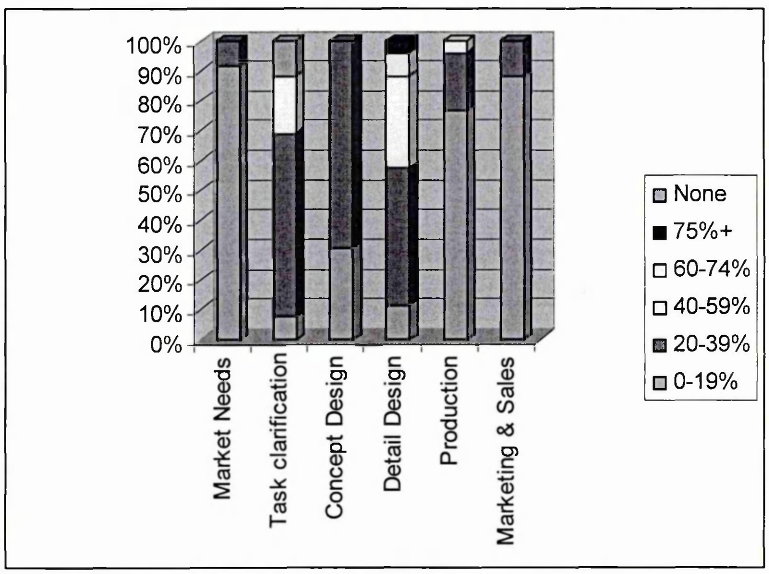


Figure 0-2; Percentage of time spent on the NPD activities by the respondent companies

1.6.1.2 NPD Risk

The surveyed companies were then asked to specify the percentage of NPD problems, and the approximate the likelihood of risk in their NPD process. The percentage of the respondents NPD problems is given in Table 4.12.

NPD Risk	%
Market Needs	50%
Task clarification	65%
Concept Design	69%
Detail Design	73%
Production	69%
Marketing & Sales	73%

Table 0-12; NPD Risk by the respondent companies

1.6.1.3 Organisation Involvement in the Design Process

The surveyed companies were then asked to specify which functions support the Design process. The percentage of the respondents NPD problems is given in Figure 4.4.

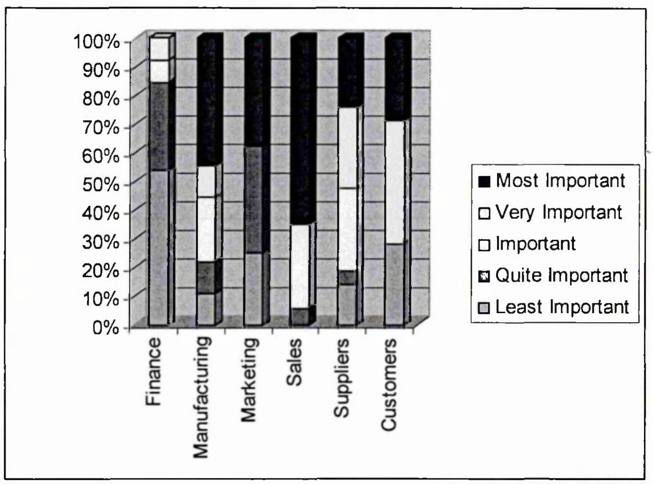


Figure 0-3; Percentage of departmental support in the design process by the respondent companies

1.6.1.4 Design Modifications

The surveyed companies were also asked about the number of design modifications occur during the NPD process. The distribution of respondents according to the number of design modifications is given in Table 4.13.

Design Modifications	%
1 to 3	15%
3 to 5	31%
5 to 10	42%
10 or more	8%

Table 0-13; Number of Design modifications by the respondent companies

1.6.1.5 NPD Problems across different manufacturing typologies

The surveyed companies were then asked to specify the percentage of uncertainty across their product mix of make-to-stock to engineer-to-order. The percentage of the respondents NPD problems is given in Table 4.14.

NPD Uncertainty	%
Market Needs	42%
Task clarification	73%
Concept Design	81%
Detail Design	69%
Production	65%
Marketing & Sales	77%
TOTALS	12%

Table 0-14; NPD Uncertainty by the respondent companies

1.6.2 Section D: NPD Tools and Techniques Process

The survey companies were asked what NPD tools and techniques – QFD, FMEA, Value Analysis, Taguchi, DFM/A – they employed for in their NPD process. The percentage of the respondents employing each of the techniques is given in Table 4.15.

NPD Tools	%
Simultaneous Engineering/CE	81%
DFM/A	58%
FMEA	54%
VA/VE	42%
QFD	35%
Taguchi Quality Loss	23%

Table 0-15; NPD Tools employed by the respondent companies

1.6.3 Awareness of NPD Tools and Techniques

The surveyed companies were asked what NPD tools they were familiar with and used- QFD, FMEA, DFM/A, VA/VE, CE or Simultaneous Engineering and Taguchi Quality Loss Function. The distribution of respondents according to the NPD tools is given in Figure 4.16.

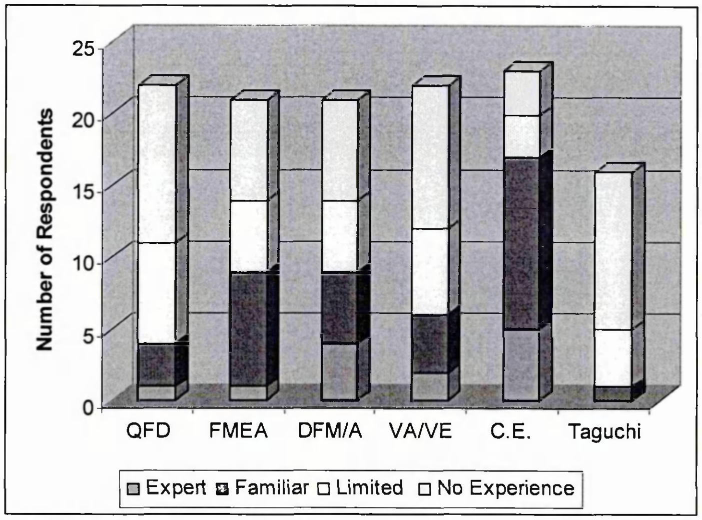


Figure 0-4; Percentage of awareness of NPD Tools used by the respondent companies

1.6.4 Application of NPD Tools within the NPD Process

The surveyed companies were then asked where they apply the specific tool within their NPD processes - Market Needs, Task clarification, Concept Design, Detail Design, Production and Marketing & Sales. The distribution of respondents according to the NPD tools is given in Figure 4.17.

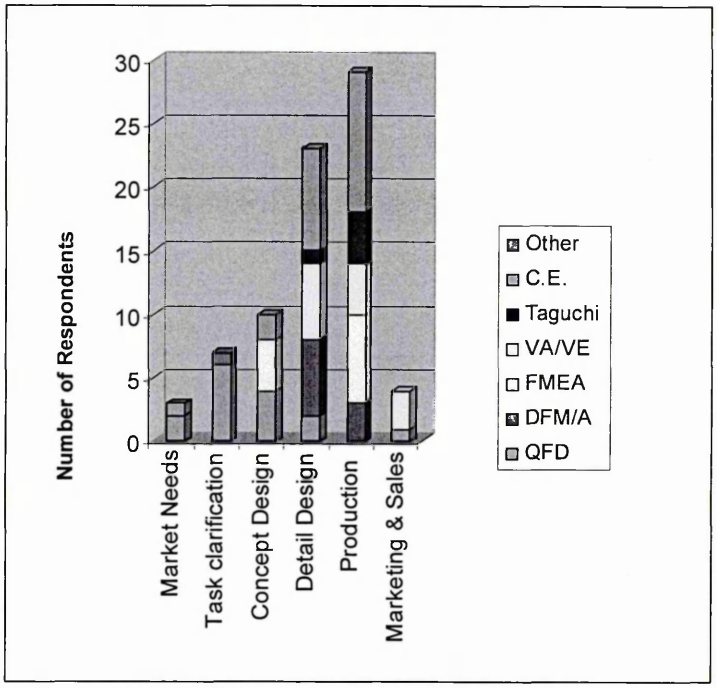


Table 0-16; Distribution of NPD tools and techniques used within the product development process used by the respondent companies

The majority of respondents (84%) used concurrent engineering practices, this was 'as expected' from the sample of the population (discussed in section 4.2.1).

1.6.4.1 Product & Component Design

The surveyed companies were asked what methodologies -2D drafting, 3D solid modelling, Finite Element Analysis (FEA), CAD/CAM, Rapid Prototyping they employed for the design of product and components. The percentage of respondents employing each of the methodologies is given in Table 4.18 below.

Hardware	%
2D drafting	88%
Databases	73%
3D CAD	65%
CAE & Rapid Prototyping	54%
FEA	31%
Simulation	27%

Table 0-17; Methodologies employed by the respondent companies

The majority of respondents (88%) used CAD 2D drafting, this was 'as expected' from the sample of the population (discussed in section 4.2.1). However only 27% used two principle systems and 65% of the respondents used more than two systems.

1.6.5 Section E: Continuous Improvement

The surveyed companies were asked to specify the working relationship with other key departments with the organisation when managing product development. Table 4.19 gives the distribution of the respondents according to the relationship types.

Working Relationships across departments	%
Intimate	42%
Social	8%
Distant	31%
Hostile	19%

Table 0-18; Working Relationships by the respondent companies

The surveyed companies were asked to specify what Continuous Improvement (C.I.) initiatives have been initiated to encourage better relationships between key departments involved in the NPD process. The percentage of respondents using C.I. programmes is given in Table 4.20 below.

Process Improvements	%
Management Meetings	69%
Workshops	35%
Training	27%
Monthly Reviews	38%
6 Monthly Reviews	58%
E-business systems	35%
Post Mortem	23%
Other	31%

Table 0-19; Continuous Improvement Initiatives by the respondent companies

Interestingly, only 27% of the respondents employed training programmes as part of their continuous improvement initiatives. Also only 23% of respondents conducted a post mortem on NPD projects.

1.7 Summary

This chapter presented the research findings from the UK based engineering and manufacturing companies. The main objective of the survey was to provide an insight into the application and awareness of NPD practices, and to establish a picture of current NPD practices in manufacturing the engineering companies. The survey process (including the market needs, task clarification, conceptual design, detailed design, manufacturing assembly, marketing and sales) served the intended task, and thorough understanding of the subject area was achieved.

The survey showed that most of the companies produced a number product lines, with each line consisting product variants and non-standard parts. The majority of respondents spent less than 19% their time on the marketing and sales process. However 73% of the respondents found the marketing and sales was associated with risk.

The respondents employed a number of NPD techniques. The most popular was found to be Concurrent Engineering (CE) closely followed by DFM/A. Likewise the respondents employed most of the techniques within the detail design and production phases of the NPD process. The respondents from both the transport and aerospace industry sector employed a more than just one tool.

Of most significance, survey results reinforced the conclusions of Chapter 2 (see section 2.11 that specific tools to support and manage the NPD process within MTO/ETO manufacturing projects are not being applied. Furthermore the survey showed that 42% of the respondents had an intimate working relationship, whist 31% of the respondents felt distant from their colleagues across other departments. This furthermore supports the under pining hypothesis and subsequent objective to develop a structured approach to knowledge sharing across NPD projects.

1.8 Cover Letter

Sheffield Hallam University

School of Engineering
Howard Building
Sheffield

Tel 0114 2553091
5th August 1999

Dear Sir /Madam

The department of engineering is currently engaged in a research programme aim at improving the design and product development process

A questionnaire has been compiled to identify a range of current NPD 'best practices' in manufacturing and engineering companies. We would be grateful if you could assist us by completing the enclosed questionnaire personally, or forwarding it to an appropriate person within your company. It is appreciated that you time is valuable, and with this in mind the questionnaire has been designed to be as brief as possible. It is believed that the questionnaire should not take no more than twenty minutes to complete.

The information is for the purposes of research only, and will be treated in the strictest of confidence. If you consider a question to be confidential and inappropriate to your company, then please ignore the question concerned. Please feel free to expand on your answers or comment on the questions; use the reverse side of the page if necessary.

If you have any questions regarding the questionnaire or our research in general, then please do not hesitate to contact us at the above address.

We would very much like it if you could return the questionnaire as soon as possible in order for our analysis to begin. A prepaid self addressed envelope is included for your convenience.

Yours Sincerely

Iain Reid

1.9 NPD Survey Instrument

Sheffield Hallam University

SURVEY OF NPD PRACTICES

Iain Reid

ABOUT YOU

Surname ______________________ Forename ________________

Job Title ____

Company Name ____

Address ____

____ Postcode _______

Telephone ________________ Fax _______________ E-mail _______

ABOUT YOUR COMPANY

1. Which of the following best describes your company's main business activity:

S.I.C. Classification, Division 3, Engineering

☐	1. Metal Goods	☐	2. Motor Vehicle parts
☐	3. Mechanical Engineering	☐	4. Other Transportation
☐	5. Office Machinery & Data Processing	☐	6. Instrument Engineering
☐	7. Electrical and Electronic Engineering	☐	8. Other (please specify)__________

2. How many employees are there in the organisation? (tick one box only)

☐ 1-50 ☐ 51-250 ☐ 251-1000 ☐ Over 1000

3. What is the annual turnover of your organisation? (tick on box only)

☐	Under £5m	☐	£5m - Under £25m	☐	£25m -Under £100m
☐	£100m - Under £200m	☐	Over £200m	☐	Confidential

4. What is your business strategy? (tick on box only)

☐	Cost	☐	Quality	☐	Flexibility	☐	Service
☐	Delivery	☐	Time	☐	Innovation	☐	Other

5. What is your Management Structure? (tick on box only)

☐ Very Hierarchical ☐ Limited Hierarchical - Other

☐ Project Based ☐ Matrix Based

Section C NPD Process

1. What types of product does your company mainly produce? (tick on box only)

☐ Components to be sold for further assembly

☐ Sub-assemblies to be sold for further assembly

☐ Finished marketable products

2. For each product line, please specify:

a) What are the number of product variants in your product lines?

1 ________________% **2** ________________% **3** ________________%

b) What are the number of components per product?

1 ________________% **2** ________________% **3** ________________%

c) What percentage of non-standard components per product?

1 ________________% **2** ________________% **3** ________________%

3. What percentage of total product cost is due to the design of the product? ____%

Section C NPD Process

1. Which of the following percentages best describes your NPD time allocation?

NPD Time Allocation	0-19%	20-39%	40-59%	60-74%	75%+	None
Market Needs						
Task clarification						
Concept Design						
Detail Design						
Production						
Marketing & Sales						

2. What percentage of the following activities accumulates risk?

NPD Risk	%
Market Needs	
Task clarification	
Concept Design	
Detail Design	
Production	
Marketing & Sales	

3. Please indicate the number of people involved in the NPD process?

	Number people involved in the NPD Activity					
Functions supporting the NPD	1	2	3 to 5	6 to 10	11 to 20	21+
Design						
Finance						
Manufacturing						
Marketing						
Sales						
Suppliers						
Customers						

4. Q11. In your opinion rank the importance of the following activities supporting the NPD process? (tick on box only)

Functions supporting the Design Process	Least Important	Quite Important	Important	Very Important	Most Important
Finance					
Manufacturing					
Marketing					
Sales					
Suppliers					
Customers					

5. What number of design modifications within a typical NPD project? (tick on box only)

☐ 1 to 3 ☐ 4 to 6 ☐ 7 to 10

☐ 11 or more

6. What is your manufacturing method by percentage?

Make-to-Stock (MTS)	_____	%
Assembled-to-Order (ATO)	_____	%
Make-to-Order (MTO)	_____	%
Engineer-to-Order (ETO)	_____	%

Section D NPD Tools

1. What is your principle NPD Tool

Simultaneous Engineering/CE _____

DFM/A _____

FMEA _____

VA/VE _____

QFD ______

Taguchi Quality Loss ______

Other ______

2. What is your level of expertise (tick on box only)

NPD Tools	Expert	Familiar	Limited	Experience
QFD				
FMEA				
DFM/A				
VA/VE				
C.E.				
Taguchi				

3. Where in the NPD stages do you apply these tools (tick on box only)

NPD Stages							**Tools**
	1	2	3	4	5	6	
NPD Stages	QFD	DFM/A	FMEA	VA/VE	Taguchi	C.E.	Other
Market Needs							
Task clarification							
Concept Design							
Detail Design							
Production							
Marketing & Sales							

4. What hardware methodologies do you employ within you NPD process (tick on box only)

☐ 2D drafting ☐ Databases ☐ 3D CAD

☐ CAE & Rapid Prototyping ☐ FEA ☐ Simulation

Section E Continuous Improvement

1. How would you best describe the working relationships with other departments (tick on box only)

☐	Intimate	☐	Social
☐	Distant	☐	Hostile

2. What methodologies do you employ within you NPD process

☐	Management Meetings	☐	Monthly Reviews	☐	Post Mortems
☐	Workshops	☐	6 Monthly Reviews	☐	Other
☐	Training	☐	E-business systems	☐	

Finally

Would you like to receive a copy of the findings?

☐	Yes	☐	No

1.10 NPD Survey Report

Sheffield Hallam University

RESULTS OF NPD PRACTICES

Iain Reid

Sheffield Hallam University

School of Engineering
Howard Building
Sheffield

Tel 0114 2553091

<Company Address>
February 2000

Dear Sir /Madam

You may remember in August 1999 the School of Engineering conducted a survey of NPD practices in the UK engineering and manufacturing companies. We would like to thank you for part participation and support.

The survey identified a range of current practices in NPD, and the application of supporting tools and techniques. The results will support the current research programme that aims to improve the level and support offered by continuous improvement programmes and tools and techniques for the design and development of new products.

We have enclosed a summary of the main survey findings based on our preliminary analysis. If you wish to discuss these survey findings or our research in general, then please do not hesitate to contact us at the above address.

Thank you once again.

Yours Sincerely,

Iain Reid

SURVEY OF NPD PRACTICES

The findings for each question are calculated based on the number of responses. Where data for the question was not provided, only the valid number of responses was used. In these cases the number of valid responses are indicated. For ease of reference the results are presented in the same format as the original questionnaire.

POPULATION FEATURES

Number of questionnaires posted	150
Number of responses	31
Number of valid responses analysed	25
Percentage response rate	16.7%

RESPONDENT DETAILS

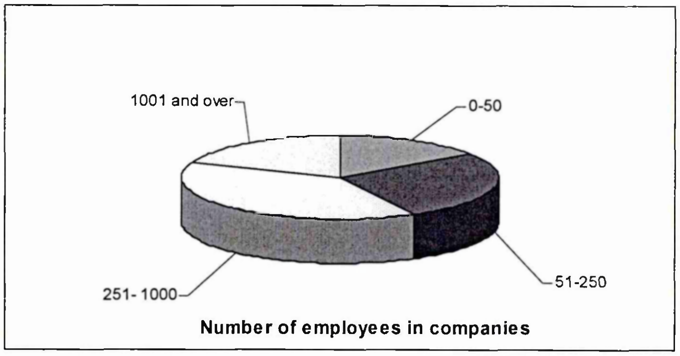
The section the questionnaire was intended to obtain information about the above respondents and their job titles. This information was required for contact purposes only and will continue to be treated in the strictest of confidence.

ABOUT YOUR COMPANY

Question 1. Which of the following best describes your company's main business activity:

SIC Category		%
1	Metal Goods	8%
2	Mechanical Engineering	42%
3	Office Machinery & Data Processing	0%
4	Electrical and Electronic Engineering	8%
5	Motor Vehicle parts	19%
6	Other Transportation	19%
7	Instrument Engineering	0%
8	Other	4%

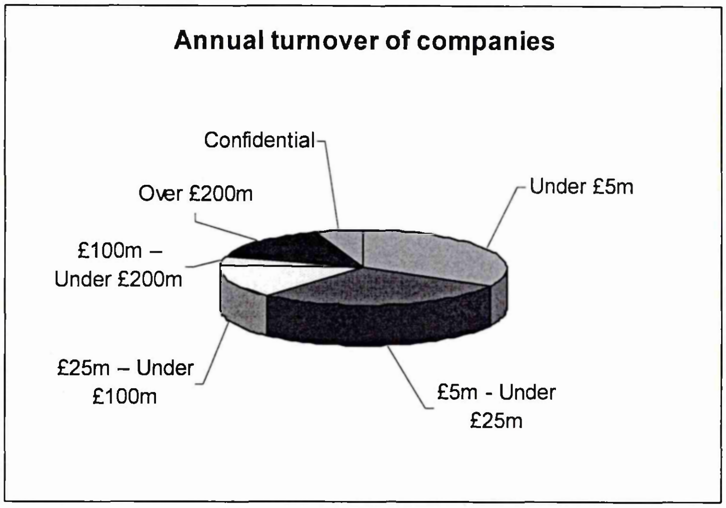
Question 2. How many employees are there in the organisation?



Number of Employees	%
0-50	35%
51-250	15%
251- 1000	38%
1001 and over	12%

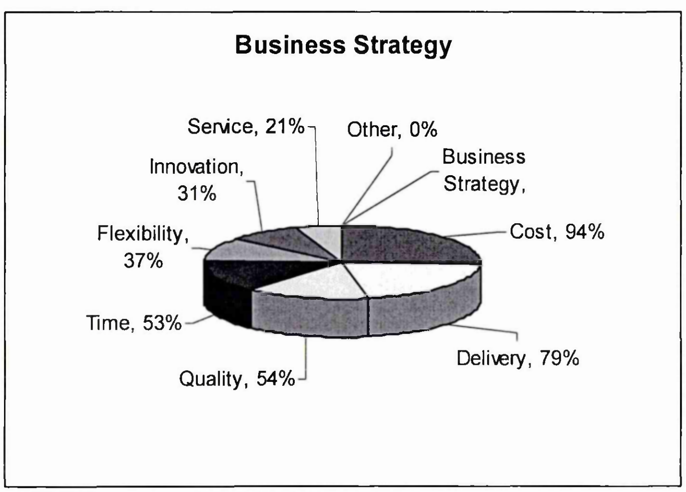
Question 3 What is the annual turnover of your organisation?

Annual Turnover	%
Under £5m	35%
£5m - Under £25m	31%
£25m – Under £100m	15%
£100m – Under £200m	4%
Over £200m	15%
Confidential	6%



Question 4. What is your business strategy?

Business Strategy	
Cost	94%
Delivery	79%
Quality	54%
Time	53%
Flexibility	37%
Innovation	31%
Service	21%
Other	0%



Question 5. What is your Management Structure?

Management Structure	%
Very Hierarchical	38%
Limited Hierarchical	58%
Project Based	4%
Matrix Based	12%
Other	0%

Section C NPD Process

Question 1. What types of product does your company mainly produce?

Type of Products	%
Components to be sold for further assembly	31%
Sub-assemblies to be sold for further assembly	42%
Finished marketable products	73%

Question 2. For each product line, please specify:

a) What are the number of product variants in your product lines?

Product Types/Variants	%
1_10	12%
11-100	35%
101- 1,000	19%
Over 1,000	8%
Unlimited	27%

b) What are the number of components per product?

No. of Components in Product line	%
1_10	15%
11-100	12%
101- 1,000	23%
1,001-10,000	27%
Over 10,000	23%

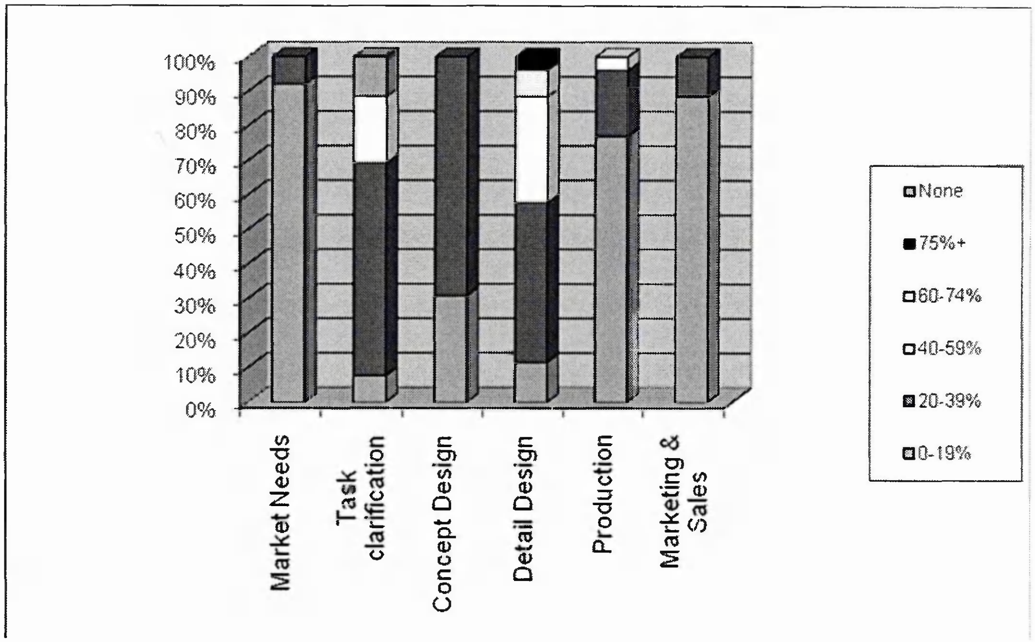
c) What percentage of non-standard components per product?

% of Non-Standard Components	%
Under 10%	35%
10- Under 20%	15%
20- Under 40%	4%
40- Under 60%	27%
60- Under 80%	8%
Over 80%	12%

Question 3 What percentage of total product cost is due to the design of the product?

% of Product Cost of Design	%
Under 20%	23%
20- Under 40%	4%
40- Under 60%	19%
60- Under 80%	27%
Over 80%	27%

Question 1. Which of the following percentages best describes your NPD time allocation?

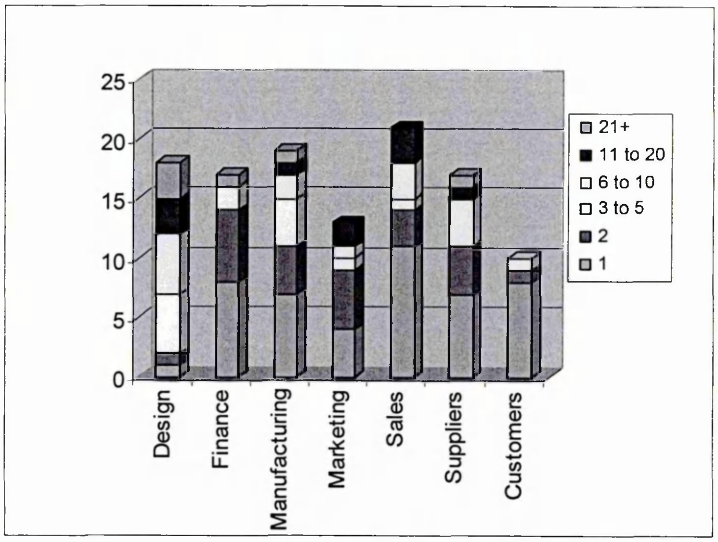


NPD Time Allocation

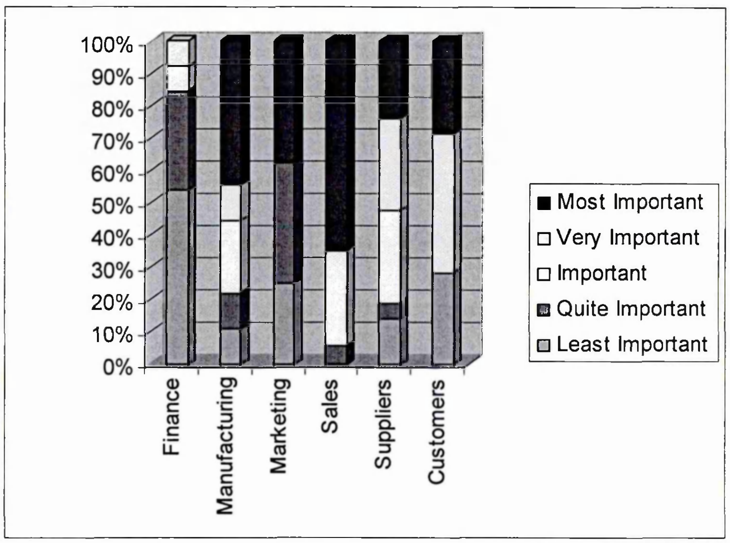
Question 2. What percentage of the following activities accumulates risk?

NPD Risk	%
Market Needs	50%
Task clarification	65%
Concept Design	69%
Detail Design	73%
Production	69%
Marketing & Sales	73%

Question 3. Please indicate the number of people involved in the NPD process?



Question 4. In your opinion rank the importance of the following activities supporting the NPD process?



Question 5. What number of design modifications within a typical NPD project?

Design Modifications	%
1 to 3	15%
4 to 6	31%
7 to 10	42%
11 or more	8%

Question 6. What is your manufacturing method by percentage?

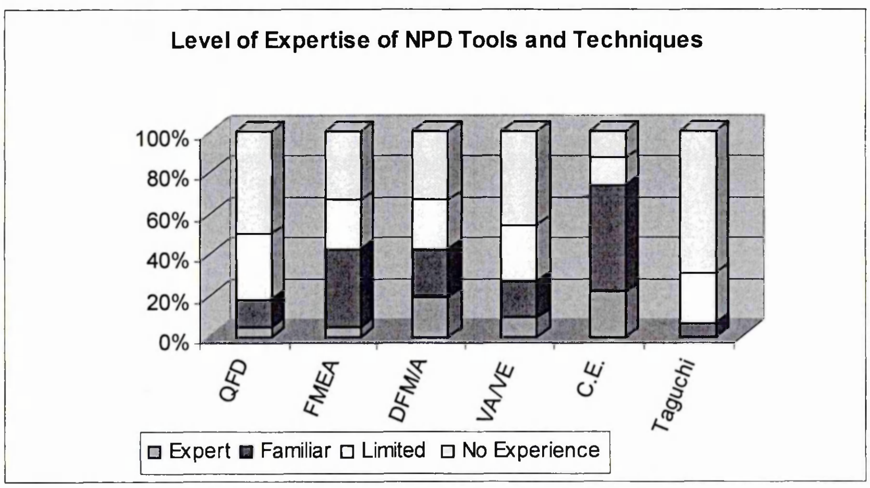
Manufacturing Method	%
Make-to-Stock (MTS)	23%
Assembled-to-Order (ATO)	38%
Make-to-Order (MTO)	54%
Engineer-to-Order (ETO)	35%

Section D NPD Tools

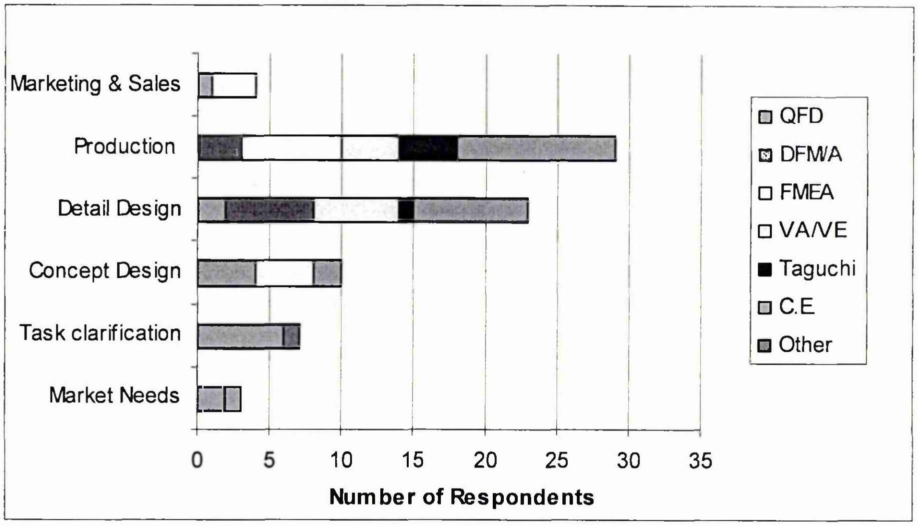
Question 1. What is your principle NPD Tool

NPD Uncertainty	%
Market Needs	42%
Task clarification	73%
Concept Design	81%
Detail Design	69%
Production	65%
Marketing & Sales	77%
TOTALS	12%

Question 2. What is your level of expertise



Question 3. Where in the NPD stages do you apply these tools



Question 4. What hardware methodologies do you employ within you NPD process

Hardware	%
2D drafting	88%
Databases	73%
3D CAD	65%
CAE & Rapid Prototyping	54%
FEA	31%
Simulation	27%

Question 1. How would you best describe the working relationships with other departments

Working Relationships across departments	%
Intimate	42%
Social	8%
Distant	31%
Hostile	19%

Question 2. What methodologies do you employ within you NPD process (tick on box

Process Improvements	**%**
Management Meetings	69%
Workshops	35%
Training	27%
Monthly Reviews	38%
6 Monthly Reviews	58%
E-business systems	35%
Post Mortems	23%
Other	31%

Appendix B: MTO/ETO INTERVIEW DATASHEET

ABOUT YOU

Surname ______________________ Forename ____________________

Job Title ____

Telephone ________________ Fax ________________ E-mail _______

PART 1 ABOUT YOUR COMPANY

1. Describe your product portfolio

2. How many employees are there in the organisation? (tick one box only)

☐ 1-50 ☐ 51-250 ☐ 251-1000 ☐ Over 1000

3. What is the annual turnover of your organisation? (tick on box only)

☐ Under £5m ☐ £5m - Under £25m ☐ £25m -Under £100m

☐ £100m - Under £200m ☐ Over £200m ☐ Confidential

4. What is your business strategy? (tick on box only)

☐ Cost ☐ Quality ☐ Flexibility ☐ Service

☐ Delivery ☐ Time ☐ Innovation ☐ Other

6. What is your Management Structure? (tick on box only)

☐ Very Hierarchical ☐ Limited Hierarchical ☐ Other

☐ Project Based ☐ Matrix Based

7. What percentage of your product range is MTS, ATO, MTO, ETO?

- **Make to Stock (MTS):** Where the demand for a clearly defined product range is known or forecast
- **Assembly to Order (ATO):** Components are manufactured to forecast, possibly part assembled & stored in a warehouse buffer
- **Make to Order (MTO):** Standard products from a predetermined range/catalogue are requested by the customer
- **Engineer-to-Order (ETO)** : A standard product range is offered with additional modifications & customisations being made on request

MTS__________________%	ATO__________________%
MTO__________________%	ETO__________________%

8. On average, how accurate is your cost estimation compared to your actual cost price

	Excellent	Good	Fair	Poor
MTS				
ATO				
MTO				
ETO				

PART II ORGANISATION & MANAGEMENT ISSUES

1. What are your Issues/Problems in Organisation and Management of NPD-ETO, please give examples and how would you rank them High, Medium or low? Please rank accordingly:

Issues /Problems	H-M-L or N/A	Comments
Organisational Structure		
Strategic and Marketing Issues		
Design & Development		
Product Complexity		
NPD Issues		
Product Customisation		

Design Change Ability		
Product Specification		
Product Standardisation		
Technical Expertise		
Management Issues & Responsibilities		
Supplier Involvement		
Customer Involvement		
Project Management		
H.R & Cultural issues		
Communication		
Flexibility & Commitment		
Functional issues		
Process Issues		
Performance Measures		
Risk Management		
Resources Available		
Data Transfer		
Supplier Performance		
Client Knowledge		
Client Approval		
Scheduling Ability		
Capacity Planning		
Logistics/Transportation		
Information Flow		
Client Information		
Company Policy & Procedures		
Information Sharing Process		
Sharing Knowledge		
Documentation Flow		
Manufacturing issues		
Capacity Planning Ability		
Scheduling Ability		
Modification Ability		
Product Progress Dates		
Delivery Reliability		
Inventory Control		
Productivity		
Order Cycle (time from order delivery to customer)		
Other		

2. Analysis of the NPD Process within Customer-Driven (MTO/ETO) Manufacturers

The aim was to establish the bottlenecks or problem steps, at what stage they occurred and for what reasons. This would establish which stages or phases of the NPD-ETO process have most problems and what they were. Only people who directly involved understood the NPD procedure were interviewed such as project managers, design and development engineers and management and other functional managers and specialists.

NPD Stages	Total Number of Stages	% of NPD	No of Steps with problems	% contribution to overall problems	% of stage with problems	Reasons

3. Drivers and Enablers for given requirements

In this section we examine how the organisation creates value in terms of NPD-ETO. We do this by thinking of the NPD process as a 'system' which given a certain input or driver, delivers value (output) using transformation processes (enablers) such as 'Quality', 'Cost', 'Lead Time', 'Flexibility', 'Responsiveness' , 'Innovation', 'Supplier Information', Product Range , etc

Requirement	Enabler	Driver

4. What number of design modifications within a typical NPD project? (tick on box only)

☐ 1 to 3 ☐ 4 to 6 ☐ 7 to 10

☐ 11 or more

Critical Phases or 'Hot Spots' in NPD (Q5)

5. What are the critical decision making activities in your NPD process and explain why they are so important? e.g. selection of product type

Critical Decision Making Activities

6. Use of Performance Measures (Q6)

Use of performance measures or Key Performance Indicators for organisational aspects of NPD-ETO did exist but they were the standard (such as product cost, supplier costs of factored items, quality rework costs and time related metrics. Organisational issues are looked at by directors and the senior management teams during some kind of management reviews.

Use of Performance Measures

1. Type of Decision Support Techniques most frequently used (Q1)

Example: Project Management, NPD Management, Process Improvement, Production Management, Information Management, etc

Application	Explanation
Example: Optimisation of information flow	Management Procedures & Internal Quality Audits

Knowledge Sharing: In this question the aim was to find what the critical activities within NPD-ETO process were the main considerations when making such decisions in terms of management and coordination of such NPD-ETO projects. Please rank accordingly

Preferred Knowledge Sharing Output	H-M-L
The information feedback of previous projects	
Knowledge sharing across the organisation	
Capturing tacit knowledge (resides in people's heads)	
Accessibility of previous projects	
The ability of repeating previous ETO Projects	
Predictability of future forecasts	
Supplier knowledge and understanding	
Organisational learning (learning from experiences)	

2. Knowledge Sharing Mechanisms (Q2):

Examples:
Informal Meeting, Database, Social Gathering, Email, Knowledge Based System, Hard Copy Document/Report, Formal Meeting, Minutes/Memo, Phone call, Internet/Intranet, Spreadsheet, Library Archive, Word Doc , Video Conferencing. Please rank accordingly

Knowledge Sharing Mechanisms	H-M-L

3. Most Preferred Application of Modelling and Analysis (Q3)

NPD Process, Manufacturing Processes, Resource Allocation, Human Resource Management, Information Flow Optimisation, Organisation Structure etc

Most Preferred Application	Explanation
1. ____________	
2. ____________	
3. ____________	
4. ____________	
5. ____________	
6. ____________	

4. Preferred Type of Output for Knowledge Sharing (Q4),

Example: Process Values / Benchmarks / process loops, project risk, value added activities, Checklists, Story Telling, Actual Cost Saving to Estimated....etc

Please rank accordingly (Highest (1=30; 2=20 3=10) Lowest)

Rank	Output Type	H-M-L

5. Potential Users of Decision Support & Project-Based Analysis (Q5)

Users	Analysis Tool	H-M-L

4. Structure of Modelling and Analysis Tool (Q6)

Analysis Tool	Explanation

Appendix C: KNOWLEDGE SHARING ASSESSMENT

ETO Questionnaire: Knowledge Sharing Assessment

I am currently studying for a PH.D. titled 'Refining the Engineer-to-Order (ETO) process'. ETO products are characterised by a customer requesting a response from a contractor to a project specification. I have been working closely with the quality department developing the process mapping side of the Quality Management System. As part of my research I am looking into learning process of product development, in particular identify the scope of knowledge sharing within ETO.

A major problem for organisations engaged in engineer-to-order activities is how they learn from what are essentially "one-off" projects. The ability of firms to produce to cost, schedule and to full specification depends on their ability to efficiently allocate resources and to coordinate their specialised knowledge and technologies to solve design problems and prevent costly redesign feedback loops.

A key question therefore is: by what means are critical interfaces managed and by what processes can new knowledge be captured, managed, embedded and disseminated to support future projects?

QUESTION: WHAT DO WE LEARN FROM ONE-OFF PROJECTS & HOW DO SHARE THAT EXPERIENCE?

Please take 30 minutes time to perform the questionnaire, if you have any queries or problems please contact me.

Kind regards,

Iain Reid.

Section 1: Background

1 What is your background?

Mechanical Engineering	Production Engineering	Sales/Tendering	R & D
Electrical Engineering	Quality	Testing	Other:

2 Which of the following best describes your current position?

Design Engineer	Sales Engineer	Projects Engineer	Manager
Manufacturing Engineer	Tendering Engineer	Test Engineer	Quality
Production Engineer	Project Manager	Buyer/Expeditor	Estimating
Finance	Commercial	Applications	Other:

3 How much experience do you have in your current position?

<1 year | 1_5 years | 6_10 years | 11_19 years | 20+ years

4 How much experience do you have as a supervisor/ manager?

<1 year | 1_5 years | 6_10 years | 11_19 years | 20+ years | N/A

5 How long have you been with this company?

<1 year | 1_5 years | 6_10 years | 11_19 years | 20+ years

6 In relation to the two following questions, in your opinion rate the on-going issues & frustrations from preventing you from work getting work done.

KEY 0= Not important 5=Very important X= Don't know

a) What are the on-going issues?

- Delivery performance
- Customer changes
- Communication of information
- Quality issues (non-conformances & rework)
- Infeasibility of design requirements
- Testing
- Time efficiency / cycle times (schedule)
- Budget allocation
- Unanticipated schedule delay in one area
- Supply Chain Management
- Return On Sales (profitability)
- Other: ____________________

b) Which causes the most frustration?

- Waiting for information from the other team members
- Coordinating with other team members
- Unfavourable analysis or test results
- Unfavourable commercial aspects to do with quotations
- Waiting decision approvals
- Waiting for information from suppliers
- Waiting for information from customers
- Receiving incomplete, unclear or wrong information
- Detection of failures
- Resolving problems for other people
- Other: ____________________

7

Do you think that your role contributes to the following activities:

	Y/N
The design of the product	
The manufacture of the product	
The management of the orders	
The selling of the product	
The management of the company	

8 Of the following questions: please indicate your responsibilities:

	Y/N
Do you make decisions on behalf of the company?	
Do you receive work instructions from other departments?	
Do you create work instructions for other departments?	
Are you the sole responsible person doing your job?	
Do other people use your experiences to create records?	
Do other people try to communicate their learning experiences with you?	

9 Can your job be done by other people within the company if necessary and to what extent (please circle accordingly)?

Y/N

Percentage (%)				
0%	25%	50%	75%	100%

10 How much control do you have on the decisions you make?
Please use the following scale: (No Control = 1 Total Control= 5)

(No)		Control level		(Total)
1	2	3	4	5

11 Please answer the 4 following questions by using the key in the right hand box

a) To what extent are your decisions being reviewed & measured ?
b) To what extent are your decisions / experiences shared with others?
c) To what extent do others share their decisions / experiences with you?
d) To what extent are your decisions recorded?
e) How often are your records referred back to on future projects?

KEY
1= Not at all
2 = Rarely
3= Sometimes
4= Often
5= Always

12 Please answer the 2 following questions; circle accordingly using the key below:

a) How much of the information you receive is complete?	1%	25%	50%	75%	100%
b) How much of the information you receive is received on time?	1%	25%	50%	75%	100%

13 Please indicate the most common method used in sharing this information & its effectiveness
Please use the following scale: (low effectiveness = 1 moderate effectiveness = 3 high effectiveness = 9

Written		**Electronic**		**Phone**		**Face to Face**	
Memos		E-mail		impromptu		Scheduled	
Reports		Electronic docs		Scheduled		Informal	

Section 2: Learning by Sharing

14 In your opinion, please rate the following by using the key in the right hand box

a) Best practices are shared?
b) Different opinions are expressed by consensus?
c) Problems are traced to the root cause?
d) Short term solutions are usually avoided?
e) Personal opinions are usually expressed?
f) Do you feel you learn a lot from other people?
g) Do you feel that your experience enhances other peoples knowledge?

KEY
1= not at all
2 = Rarely
3= Sometimes
4= Often
5= Always

15 Please indicate which of the following are the best methods for conveying company knowledge?
Please use the following scale: (low effectiveness = 1 moderate effectiveness = 3 high effectiveness = 9

	Notice Boards		Discussion Groups
	Storytelling		Spontaneous, one off meetings
	Check boxes & review sheets		Informally: Groups
	Skills / competence matrix		Informally: Individuals
	Problem solving workshops		Other:____________________

16 Please indicate the effectiveness of the following for sharing personnel knowledge:
Please use the following scale: (low effectiveness = 1 moderate effectiveness = 3 high effectiveness = 9

Written		**Electronic**		**Phone**		**Face to Face**	
Memos		E-mail		impromptu		Scheduled	
Reports		Electronic docs		Scheduled		Informally	

17 Please indicate how you normally receive/communicate information in the following statements?

	Written	Electronic	Phone	Scheduled Meetings	Informal / Hall Talk
Receiving work instructions					
Reporting any or new changes / modifications					
Reporting progress					
Confirmation of work completed					

18 **Please indicate which of the following questions you consider to be important to supporting communication and rate them accordingly:**
1 = not important, to 5 = of critical importance (see example)

	Important? Yes	Rating scale 1 to 5
Example: Use of Slogans	X	2
Training of personnel in information & knowledge sharing		
Intranet systems		
Support from staff functions (e.g. quality engineering)		
Incentive systems		
Process mapping / flowcharting systems		
Procedures and Auditing		
Work Groups / Teams		
A suggestion Scheme		
Promotion through information boards		
Promotion through internal media (magazines)		
Promotion through verbal communication		
Promotion through regular visits by management		
a quality award model (e.g. British Quality Award, EFQM)		
ISO 9001:2000 (ISO 9000)		
Continuous Improvement programmes		
Other:		

Section 3 The vehicle Knowledge Sharing

19 **In your opinion please indicate if you use the following by marking with an "X" in the appropriate column and by using the following scale from 1= not important, to 5 of critical importance:**

	Problem Solving Tools	YES	NO	Use partly	Don't Know	Importance (scale 1-5)
Process Modelling Tools	Process Mapping Tools (Flowcharting)					
	KPIs (Key Performance Indicators)					
	Balance Scorecards					
	SPC (statistical processing control)					
	Databases					
	Knowledge Base Systems / Expert Systems					
	FMEA (Failure Modes and Effect Analysis)					
	QFD (Quality Function Deployment)					
	VA Value Analysis					
Decision Support Tools	Cross Functional Teams					
	Industrial Surveys					
	Creativity tools / idea generation tools (e.g. SWOT)					
	Brainstorming					
	Display / visualisation tools (charts, histograms)					
	Management Methods e.g. Gantt, Pert					
	Competence Matrix (weighted selection, voting)					
	Case Based Reasoning					
	Standardisation tools (job descriptions, procedures)					
	Other:____________________					

20 **Which of the tools mentioned in Q19 do you use to encourage knowledge sharing:**

One tool ☐
A model of the process ☐
A decision support tool ☐
A collection of tools ☐

Any comments: ____________________

21 **In your opinion, please rate the following for contribution to knowledge sharing?**
Please circle accordingly using the key below
1 = Low contribution, to 5 = High contribution

	L	Contribution Level			H
Product Development	1	2	3	4	5
Manufacturing process	1	2	3	4	5
Organisation structures	1	2	3	4	5
Suppliers	1	2	3	4	5
Human Resource Management	1	2	3	4	5
Information flow	1	2	3	4	5
Customer behaviour	1	2	3	4	5
Other:____________					

22 **Please indicate which of the following questions you consider to be important for sharing personal knowledge and indicate the rating of importance using the scale below**

Please mark with a 'X' and circle accordingly using the key below

1 = not important, to 5 = of critical importance

	Indicator (X)	Don't Know	Importance level L	M	H
Increase the knowledge base of the organisation			1	3	5
To retain the knowledge & experience within the organisation			1	3	5
To share individuals experiences before they transfer, leave or retire			1	3	5
Improve the learning curve on future projects			1	3	5
Improve the commercial & technical awareness of the product			1	3	5
Improve, organisation, co-operation and communication			1	3	5
Improve quality conformance			1	3	5
Improve customer awareness			1	3	5
Improve the 'front end' of the design process			1	3	5
Improve process, product, organisational awareness			1	3	5
Highlight critical points in product development process			1	3	5
Improve delivery performance			1	3	5
Reduce Cost			1	3	5
Improve information flow			1	3	5
Increase customer responsiveness			1	3	5
Increase manufacturing productivity			1	3	5
Highlight the knowledge experts within the organisation			1	3	5
Increase employee skills, experiences, awareness			1	3	5
Sharing personal experience			3	4	5
Because knowledge sharing is a management directive			3	4	5
Other:____________________			3	4	5

Section 4 Incentive schemes

23 **Does your company employ an incentive scheme?** Y/N

24 **Do you think incentive schemes are a good idea for knowledge sharing?** Y/N

25 **What incentive schemes do you employ or would like to employ?**

	USED	Desire	Importance Rating (1-5)
Suggestions are evaluated and rewarded within monetary award			
Suggestions are evaluated & rewarded with non monetary award (e.g. meal for 2)			
All suggestions receive nominal recognition irrespective of whether or not they are implemented (box of chocolates, points towards a gift catalogues)			
knowledge sharing activities are rewarded through bonuses			
knowledge sharing activities are rewarded through salary schemes			
Recognition by publicising the improvement			
Other:____________________			

Section 5 Developing Organisational Learning

Definition: "Organisational Learning is a ingrained philosophy for anticipating, reacting and responding to change, complexity and uncertainty". A company can respond to new information by altering the very "programming" by which information is processed and evaluated.

26 **In your opinion, have there been improvements to organisational learning in the following areas:**

(please circle accordingly)	A) Change Better	Worse	B) Contribution to Organisational Learning Small	Medium	Large
The design of the product	+	-	1	2	3
The manufacture of the product	+	-	1	2	3
The management of the orders	+	-	1	2	3
The selling of the product	+	-	1	2	3
The management of the company	+	-	1	2	3
Other:__________			1	2	3
__________			1	2	3

Appendix D: Longitudinal Case Study: Sulzer Pumps

1.10.1 Company Background

Sulzer Pumps (UK) Ltd is one of ten Sulzer Pump Division factories across the world. Their product range consists of engineered pumps with a focus on the oil and gas, HPI and the power generation industries. The dedicated design and manufacture of centrifugal pumps, some of the world's largest and most powerful pumps have been designed, manufactured, packaged and tested at this particular facility for customers all over the world.

Design is done according to stringent safety codes and standards. There is a substantial interaction between the client, consultant, contractors, and suppliers. Most of the previous designs are stored in a database for future use. Manufacturing engineers are sometimes involved in product design. Few projects from different customers are carried out simultaneously. Project duration and cost depend on the scope of work and complexity of the product. Design iteration and rework is time consuming as the certain project milestones require customer approval as well as client witness tests. The concept and detailed design can sometimes take up to a year to complete for complex products such as the pump and packing project. The general lead time phases are represented in Figure 7.2 below:

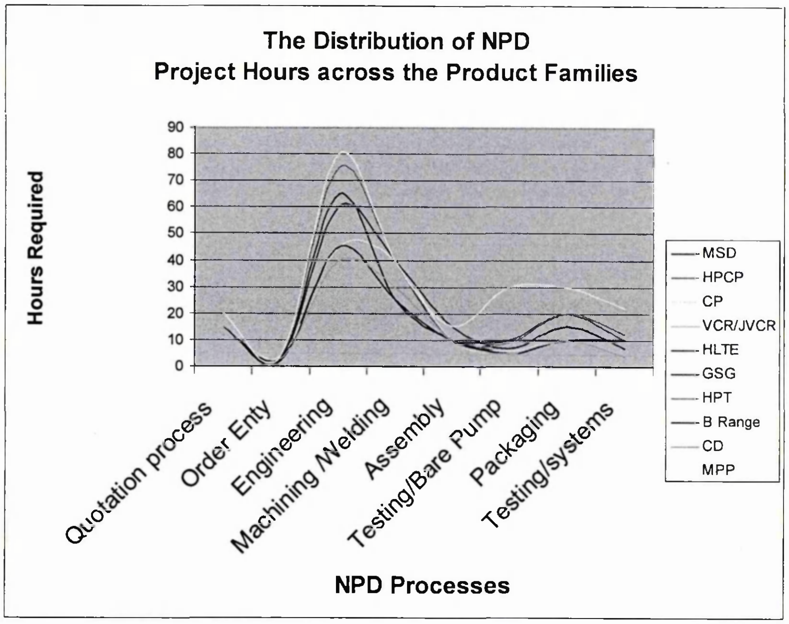


Figure 0-1; The Distribution of NPD Project Hours across the Product Families

1.10.2 Competitive Markets

To sustain growth and maintain the company's position in an increasing competitive marketplace, Sulzer Pumps considered new approaches to their product development strategy. Sulzer has a strong reputation for technical innovation, engineering design and quality of service that has allowed them to grow substantially. Over the last four years the company has experienced favourable market conditions and boosted its order intake by 28.9% and sales by 22.7%. This is compared to 7% growth in 2003. In 2006 Sulzer Pumps achieved a 20% market share in both upstream (production) and downstream (processing) of the Oil and Gas market, 15% in Power Generation and 10% in Pulp and Paper markets.

However, as oil exploration moves further offshore into deeper water, the oil reservoir pressures increase far beyond those experienced in the past. Therefore, injection pumps used to support the oil reservoir pressure need injection pressures far above their existing centrifugal pump design range (See Table 2.1).

Product Technology	Equipment Type	Water Injection	Pipeline	Booster	Sea Water Lift	Fire Fighting	Auxiliaries
Barrel Pumps	HPcp/HPcpV	■	■				
	GSG	■	■				
	CP	■	■				
Horizontal Split Pumps	SMH/SMHV			■		■	■
	HPDM		■				
	MSD	■	■				
	HSB		■				
Vertical Pumps	BK				■	■	■
	CVA						■
	VCR			■			
Single Stage Pumps	Z Range			■			■
	CAP			■			
	CD		■	■			■
Multiphase Pumps	MPP		■	■			

Table 0-1; Sulzer Pump's Core Product Range

1.10.3 Product Complexity

In 2001, the company was awarded the manufacturing and testing of a prototype injection pump with the highest pressure in the world. The pump will have 12 stages arranged 6+6 in a back-to back configuration running at 6000 rpm. Faced with the challenge of developing the pump the customer recognised that seawater and eventually produced water injection was not only vital to the Project success but that the required injection pressures were far beyond those previously experienced within the Oil Industry. They decided to take the unprecedented step of funding pump companies to develop designs to meet their needs. Sulzer Pumps acknowledge this vitally important contribution by the customer that enabled much valuable analysis to be completed at the design contract stage prior to manufacture.

The design criteria established by BP, the customer were:

- "The water injection pumps are critical to the timing of the Project and the platform's overall uptime
- It is a requirement that the water injection pumps be highly reliable and safe
- Efficiency is important due to the large horsepower required, however, a small sacrifice in efficiency would be preferred over ANY sacrifice in reliability
- Therefore the pump design must consider reliability and the ability to operate the pumps safely as the two highest priorities."

The pump was vital to the customers' project success. Since a pump with such high pressure had never been built before, a prototype pump was manufactured and extensively tested. The customer's requirements including the standards of API 610, 8th edition, could be met. Rotordynamic tests were carried out running the pump at full speed and full load (Figure 7.3) with two times new running clearances simulating end-of-life condition. The customer then released an order for three additional complete pump units. The whole package weighed around 120 tons. This new and innovative development of ultra-high-pressure injection pumps allowed Sulzer Pumps to extend its range of pumps in order to meet even more challenging customer demands. In recent year Sulzer Pumps' commitment to the oil and gas market was demonstrated by the EUR 3 million expansion to its existing test facility that enabled the testing to take place.

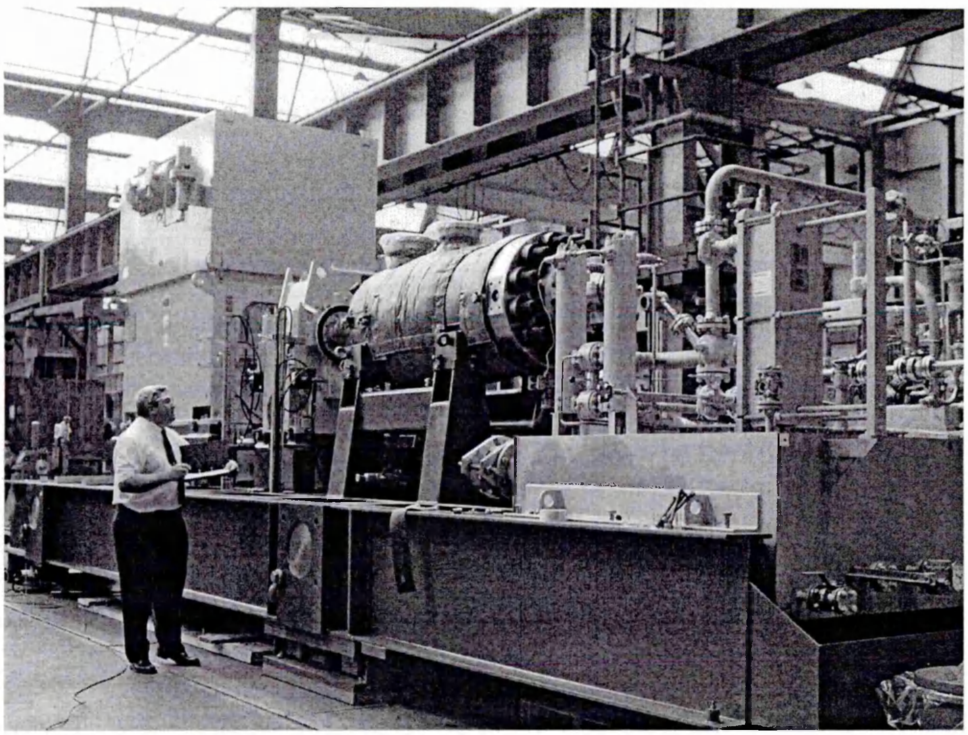


Figure 0-2; Sulzer's HpCp "Thunder Horse"

The company identified an opportunity to supply prototype design to supply a seawater supplied injection pump. The pump rated duty is at a flow rate of 338 m3/hr (1458 US gpm) and a pressure of 605 bar (8575 psi). This pressure is around 50% higher than previously achieved.

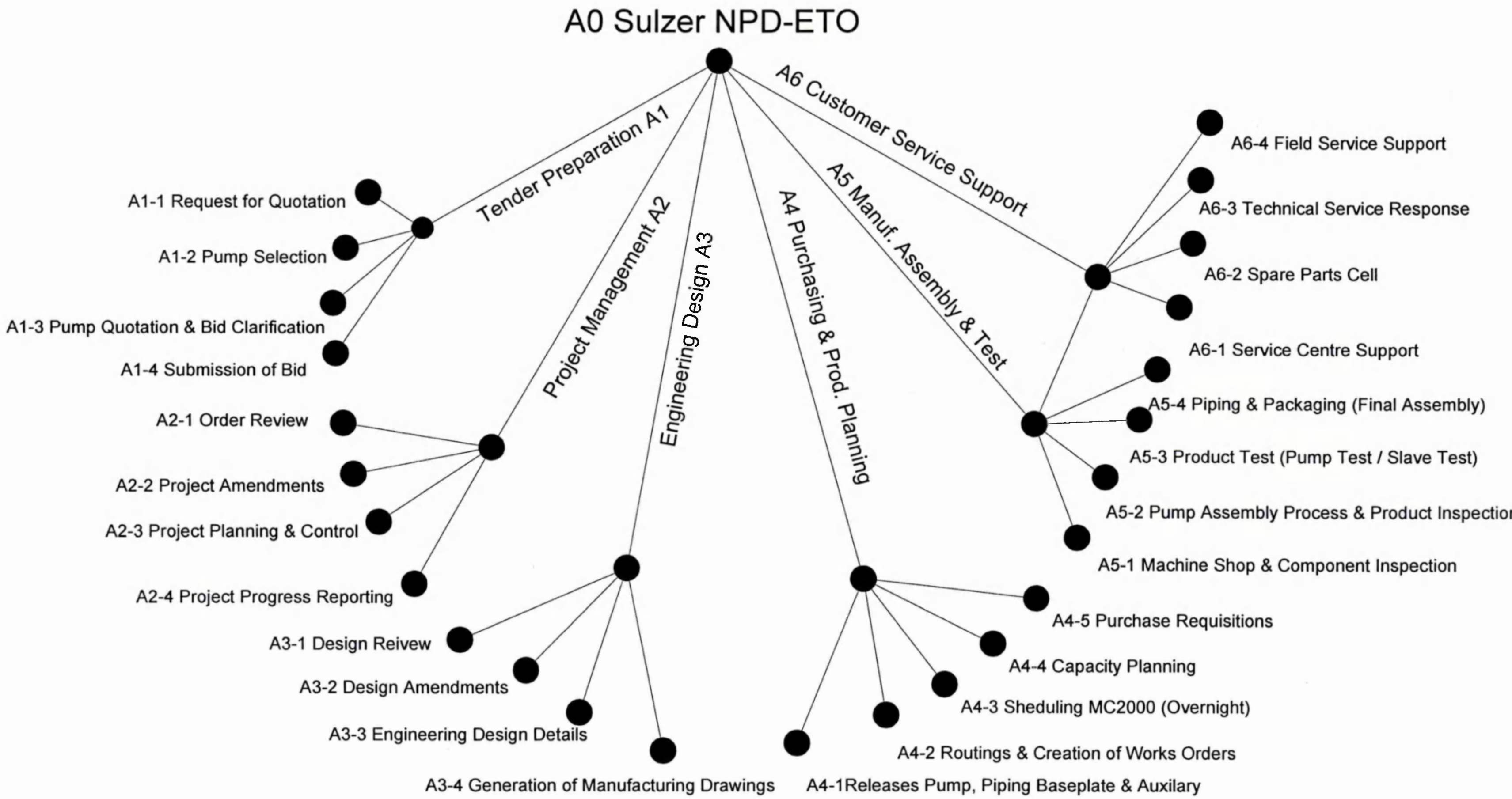
Department	**Problem Requirements** or Requirements which are needed to improved to improve the quality of the contribution	**Contributions** (or Output) of the department to the NPD-ETO phase which are effected either as a direct result of the input or the quality of the resources available
Marketing	Customer Feedback from site takes too long and is incomplete	Quality of data and the form that the salesman sees needs to be in a single format.
Marketing	No formal process for Benchmarking, competitor information	Quality of Marketing and Sales rational is effected
Marketing	No strip down of competitive products or published prices, competitively tendered, spying game or competitive game	Quality of Marketing and Sales rational is effected
Sales	No vehicle to drive the information back Tendering is an unstructured enquiry (cheapest solution, best engineer solution, most efficient solution, knowing the best manufacturers, delivery performance to the customer)	Lessons associated to cost are essential underestimation, over estimation (cost matrix)
Tendering	Tendering an unstructured enquiry, you have to asses what he wants, then you have to assess the best way of doing it, i.e. what's going to get you the order, the cheapest solution, the best engineered solution, most efficient solution.	Tendering have to put a bid together the pump is only 20% of the total pump information, you have to know the certain sizes of gear boxes, who are the best manufactures, or more than likely who's going to get you a price in time, so you can get a price in time into the customer
Projects	Provide guidance, support to a team of projects & engineer to their task of satisfying the customers requirements profitably, taking to different functions of the organisation to lobby support from mangers within the company	Ability to meet Milestones, allows us to our performance as a company to meet the customers milestones,
Project	Project estimations against budgeted expenditure	• Estimating errors • Cost over runs • Late deliveries • Extra profit made • Something we charged the customer
Projects	To influence suppliers and also to talk to customers on a number of issues ranging from obtaining feedback on project performance or appeasing customers after company non performance.	Experience, knowledge, judgement and interpersonal skills would then determine how the project engineer has, or might have influenced our particular performance. 40 Explicit Knowledge, 60% knowledge •

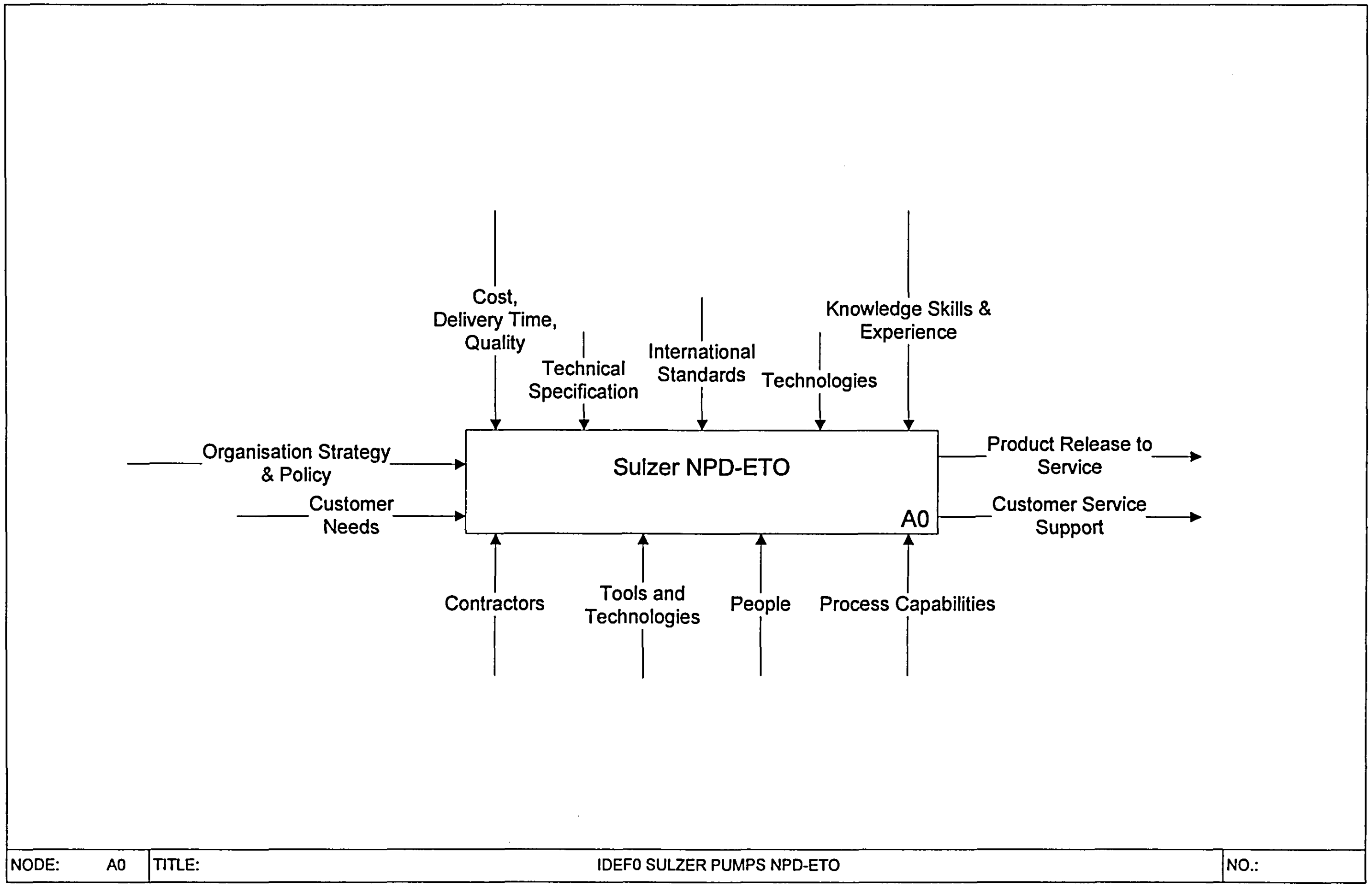
Table 0-2; Design & Development Phase analysis Level 2

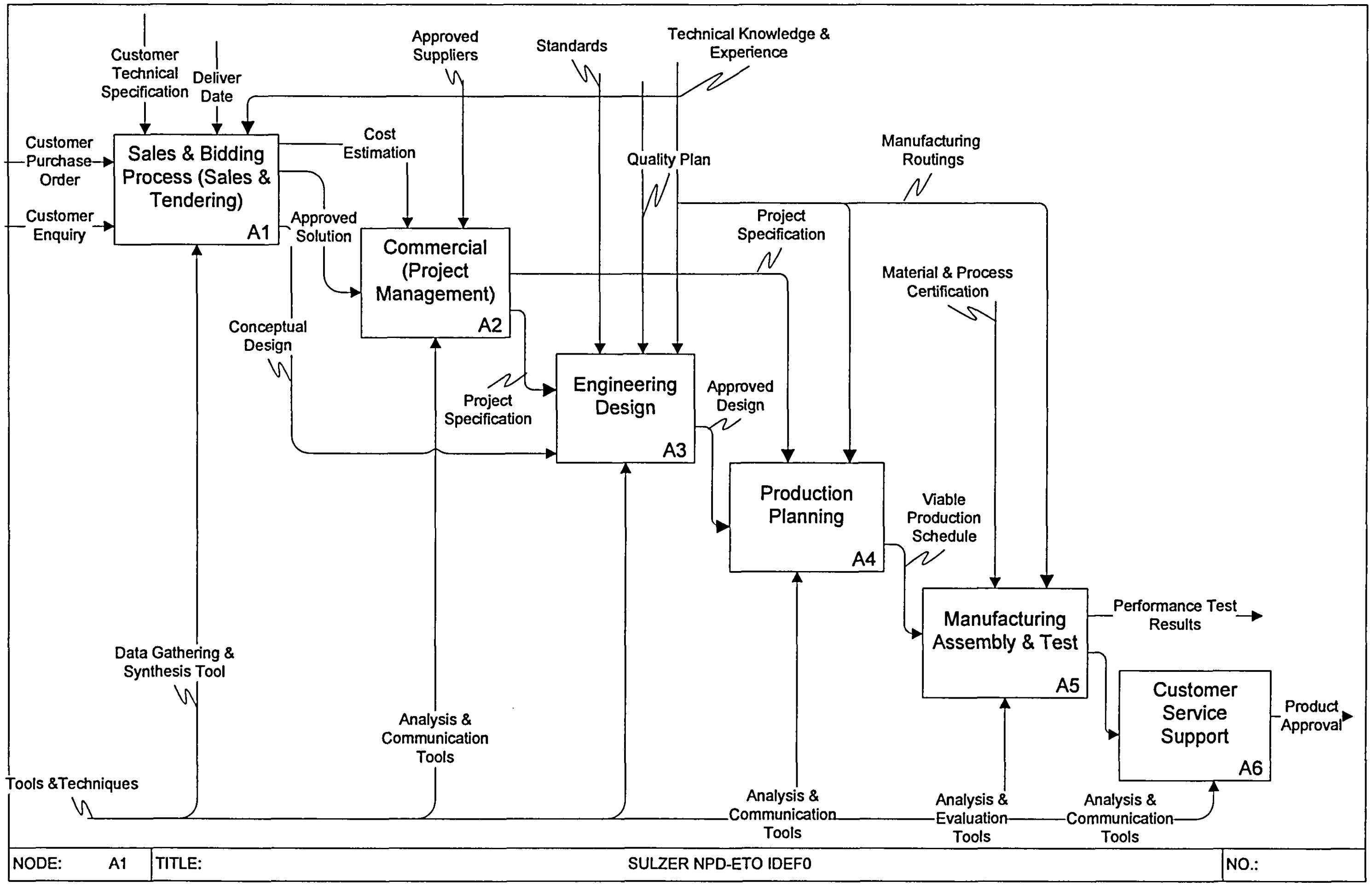
Department	**Problem Requirements** or Requirements which are needed to improved to improve the quality of the contribution	**Contributions** (or Output) of the department to the NPD-ETO phase which are effected either as a direct result of the input or the quality of the resources available
Engineering	Engineering you going to produce an objective that you're produced before or produced something similar to it before, so you can structure the process fairly readily that you go through and put in points where you sign it off and it's check and all those other processes that you would have in a design and manufacturing environment.	• The hydraulic design is fixed, the mechanical design is predetermined as well, the layout and weather you can get the equipment in • Information of the order set is not always not clear and difficult to clarify as what is required such as metallurgy, Projects/Contracts rely on client and suppliers
Engineering	• Define order, review reference lists • Define design control plan • Review Orderset, Data-sheets, GA and BOM • Create factored releases, engineering releases, so that they can be purchased • Actions, create factored releases, engineering, plus supplementary releases in 'jobscope' adding factored items e.g. motors, seal systems, mechanical seals, couplings so that they can be purchased	• No report of whether the previous design was good or bad • Material combinations, i.e. impeller no wear rings time searching for information on job scope, but not easy to find no keyword search, you only by numbers • Negative Feedback/not positive feedback, general design factors • Feedback of manufacture, impossibly • No real guidelines of how long it should take you,
Quality	• Time consuming finding the relevant information • Engineering changes before releasing, no formal method (just changed within jobscope)	• Not getting all the clients requirements in the plan and passed on to raw materials • Changes occur and updates are made to the Quality Plan, Wielding requirements, Material requirements and Paint specifications
Purchasing	• Required date • Item type generic item type • Individual article number (like items)	• Do not realise of the lead time (feedback is informal) • Asking more questions • Work load 'fits & starts'

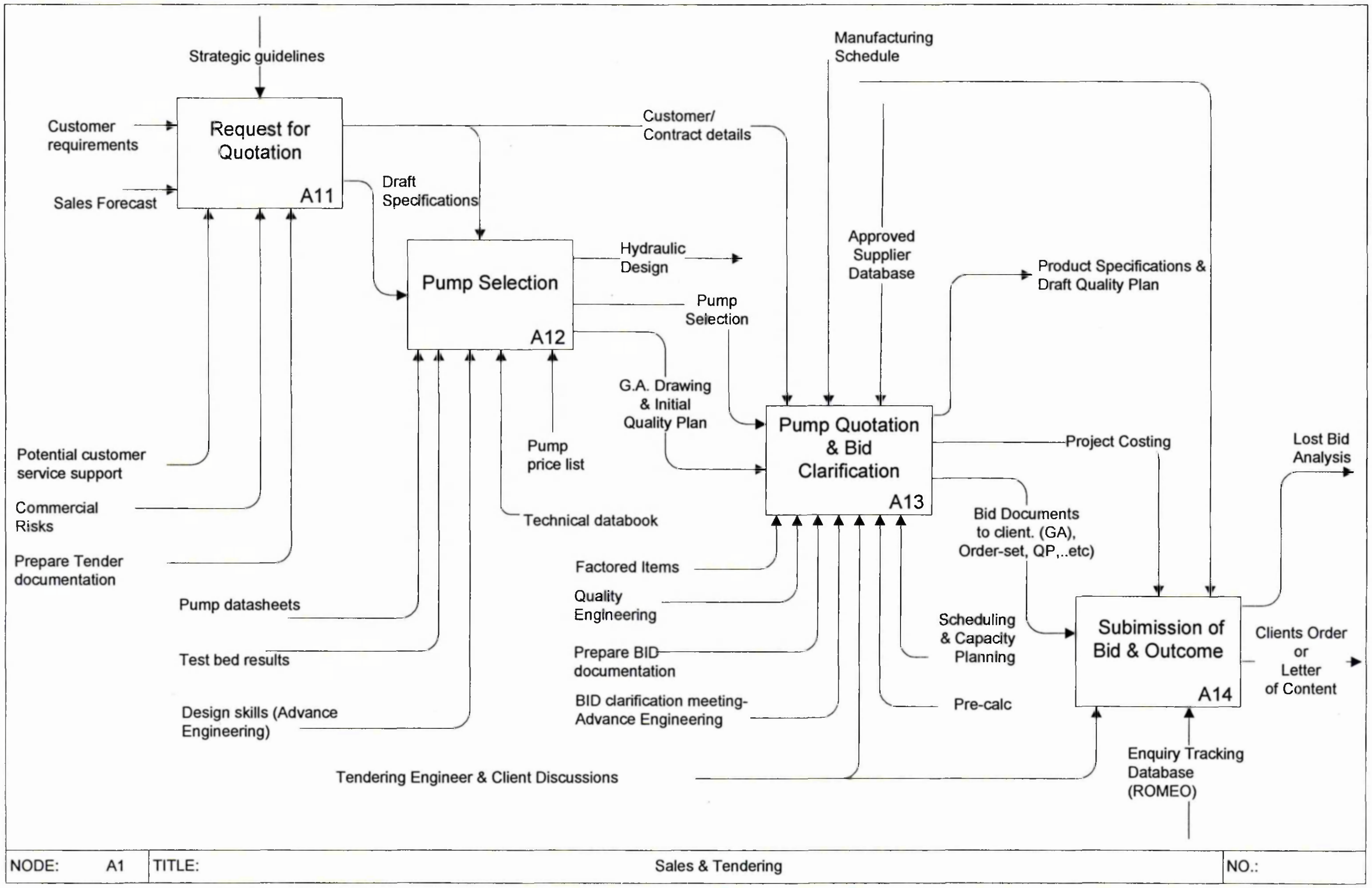
Table 0-3; Design & Development Phase analysis Level 2

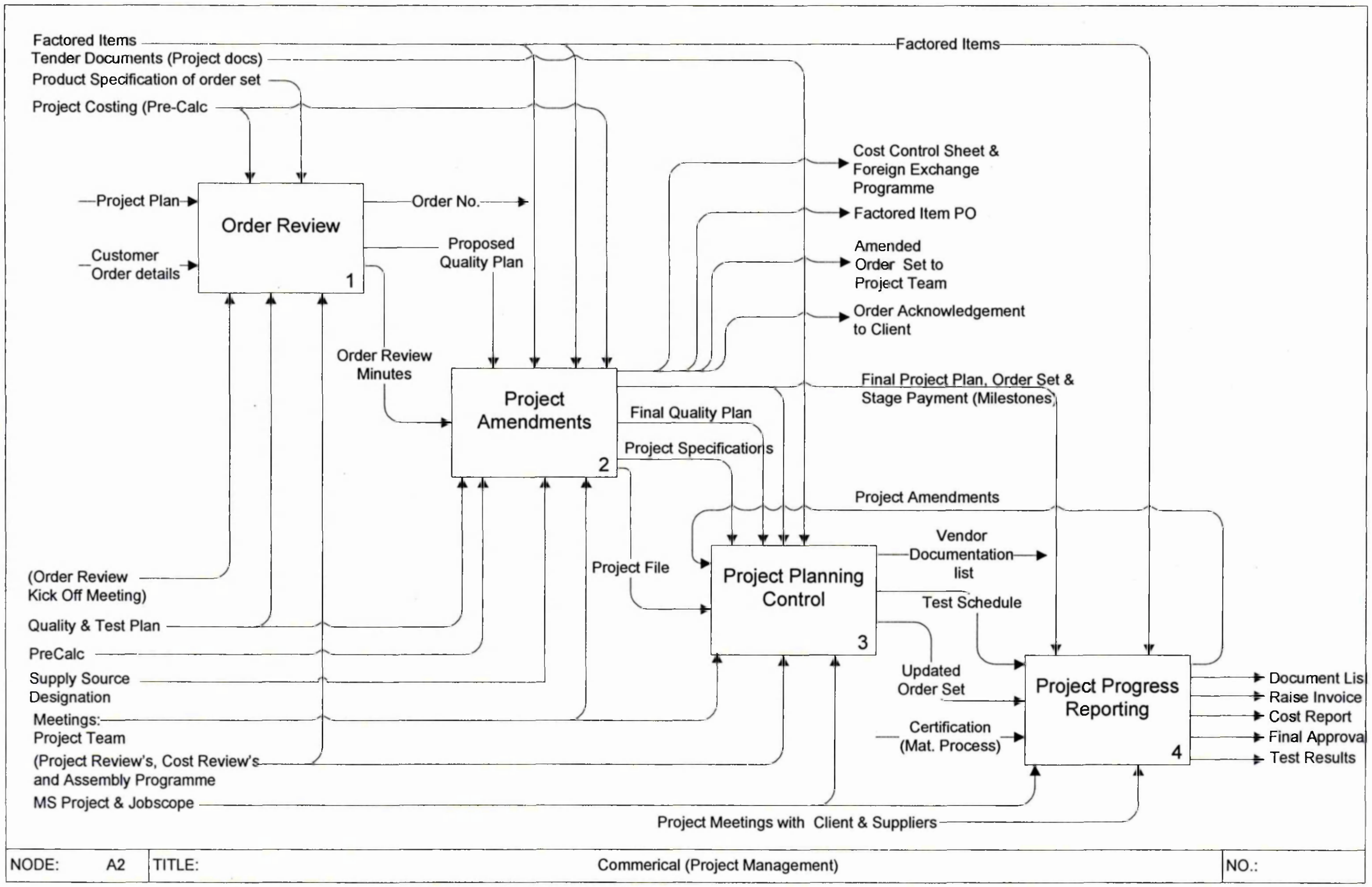
Appendix E: IDEF0: NPD-ETO PROCESS MODELS

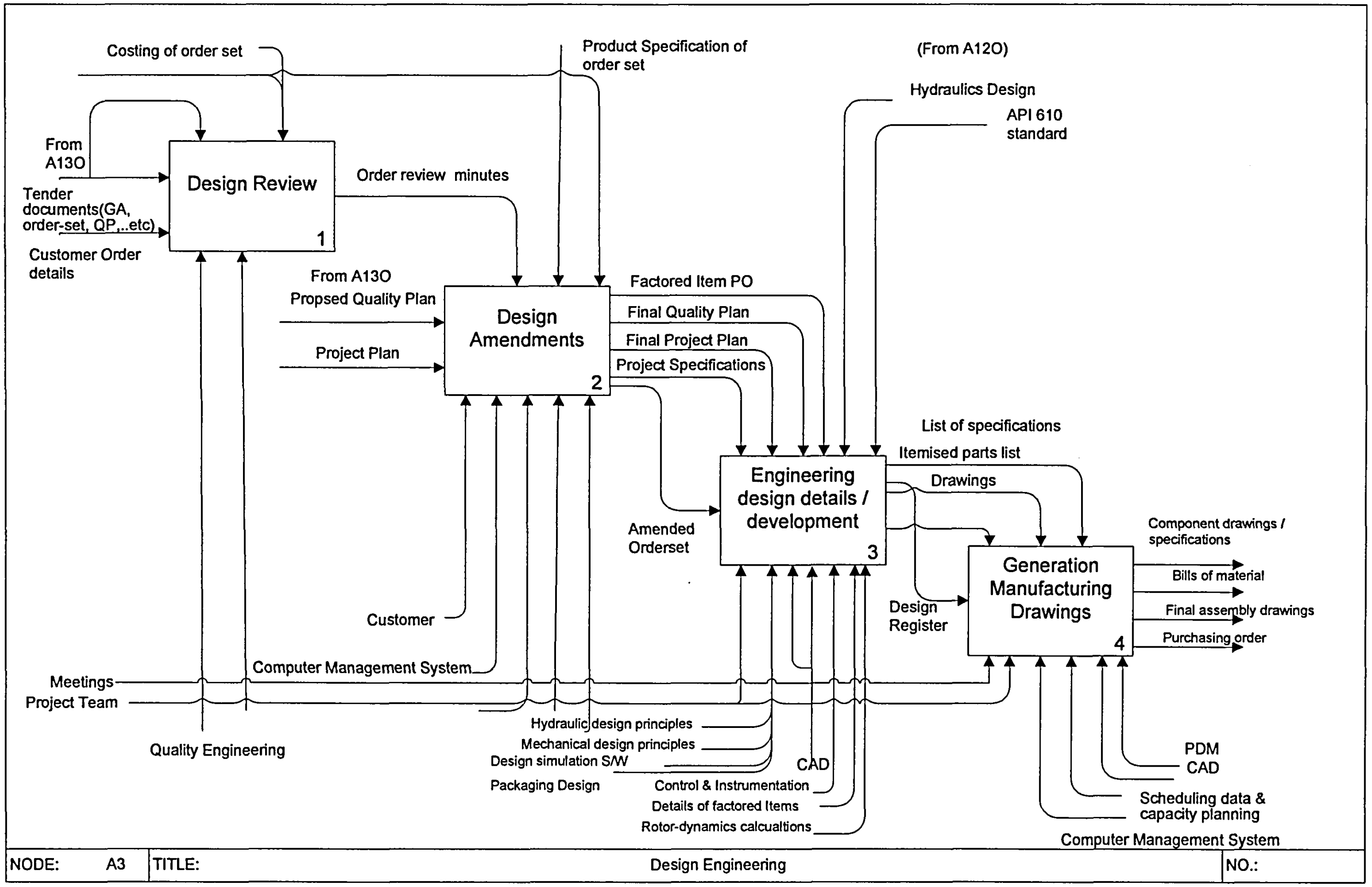


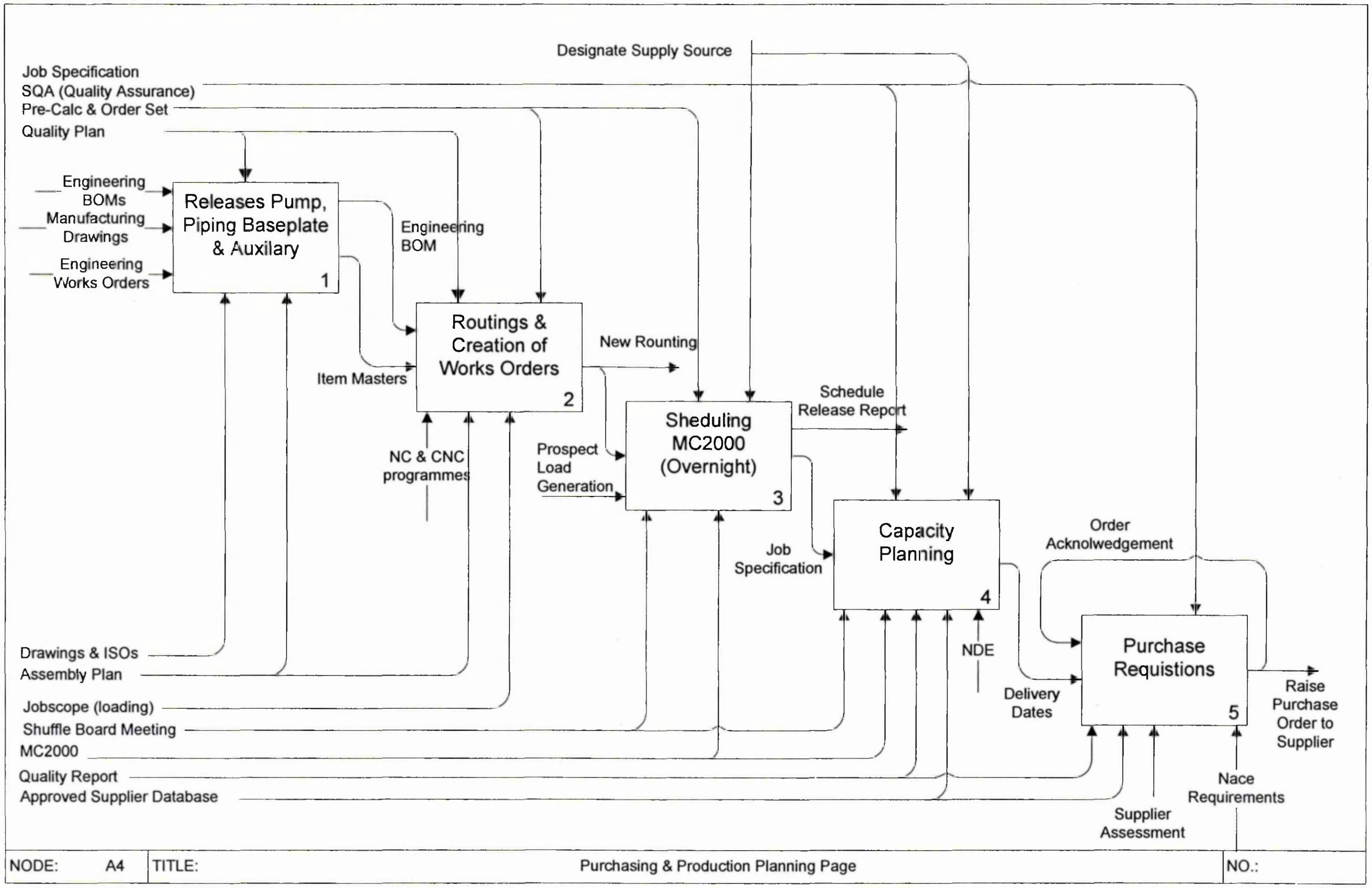

Cost,
Delivery Time,
Quality
Technical
Specification
International
Standards
Technologies
Knowledge Skills &
Experience
Organisation Strategy
& Policy
Customer
Needs
Sulzer NPD-ETO
A0
Product Release to
Service
Customer Service
Support
Contractors
Tools and
Technologies
People
Process Capabilities
NODE: A0
TITLE: IDEF0 SULZER PUMPS NPD-ETO
NO.:

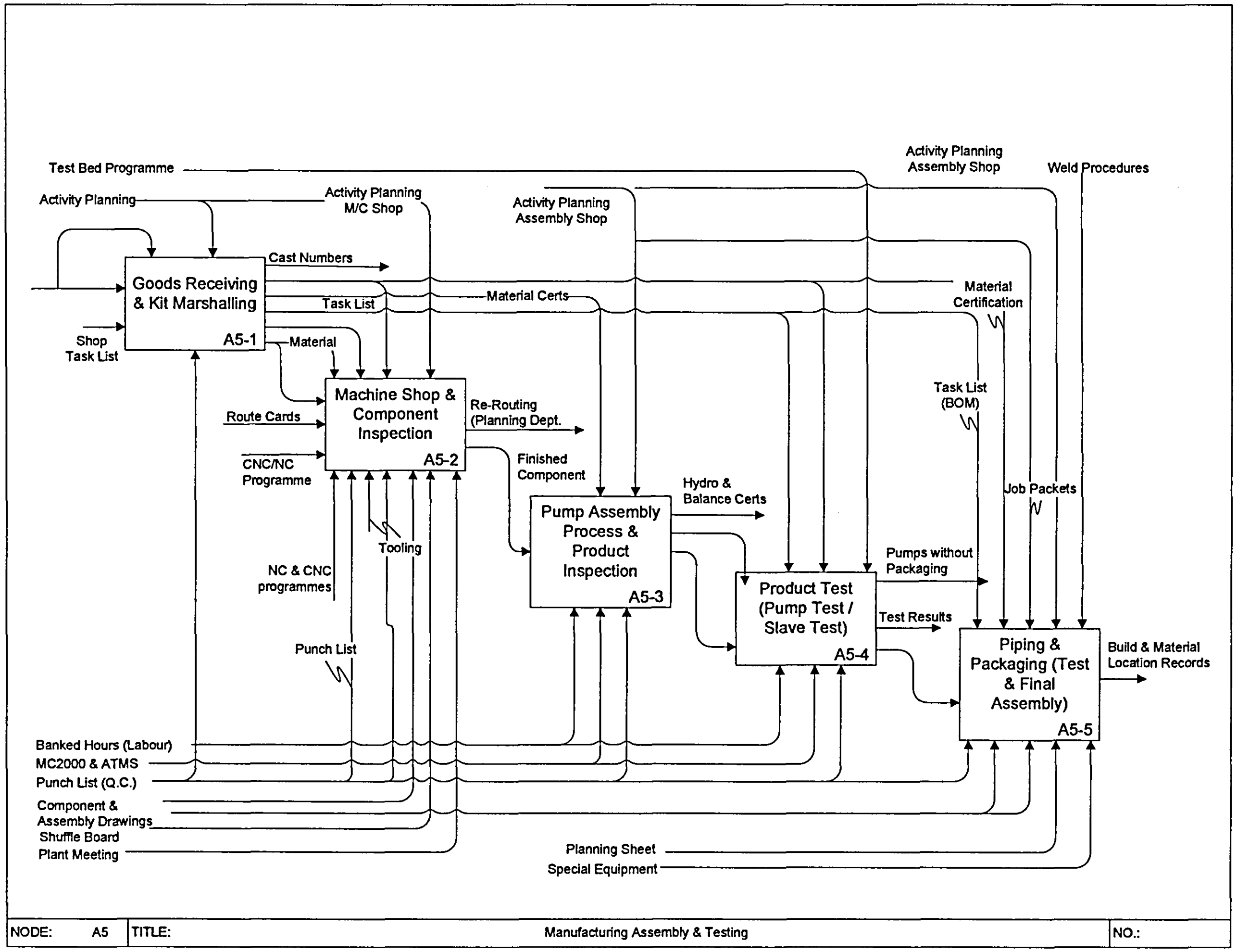

Customer Technical Specification
Deliver Date
Approved Suppliers
Standards
Technical Knowledge & Experience
Customer Purchase Order
Customer Enquiry
Sales & Bidding Process (Sales & Tendering) A1
Cost Estimation
Approved Solution
Commercial (Project Management) A2
Quality Plan
Manufacturing Routings
Project Specification
Material & Process Certification
Conceptual Design
Project Specification
Engineering Design A3
Approved Design
Production Planning A4
Viable Production Schedule
Manufacturing Assembly & Test A5
Performance Test Results
Customer Service Support A6
Product Approval
Data Gathering & Synthesis Tool
Analysis & Communication Tools
Tools &Techniques
Analysis & Communication Tools
Analysis & Evaluation Tools
Analysis & Communication Tools
NODE: A1
TITLE: SULZER NPD-ETO IDEF0
NO.:

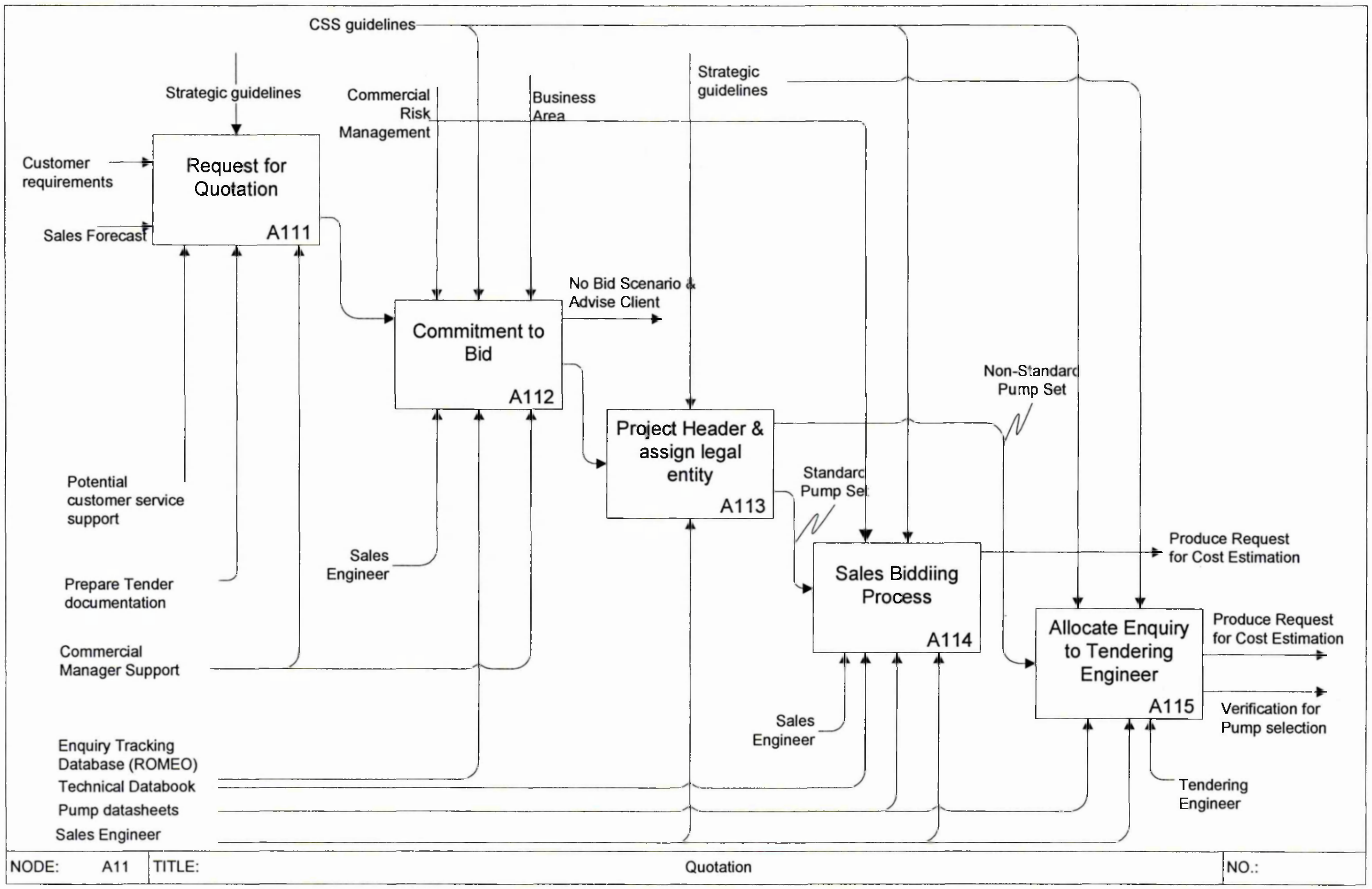

Strategic guidelines
Customer requirements
Sales Forecast
Request for Quotation
A11
Customer/ Contract details
Draft Specifications
Pump Selection
A12
Hydraulic Design
Pump Selection
G.A. Drawing & Initial Quality Plan
Pump price list
Technical databook
Manufacturing Schedule
Approved Supplier Database
Pump Quotation & Bid Clarification
A13
Product Specifications & Draft Quality Plan
Project Costing
Bid Documents to client. (GA), Order-set, QP,..etc)
Lost Bid Analysis
Subimission of Bid & Outcome
A14
Clients Order or Letter of Content
Enquiry Tracking Database (ROMEO)
Potential customer service support
Commercial Risks
Prepare Tender documentation
Pump datasheets
Test bed results
Design skills (Advance Engineering)
Factored Items
Quality Engineering
Prepare BID documentation
BID clarification meeting- Advance Engineering
Scheduling & Capacity Planning
Pre-calc
Tendering Engineer & Client Discussions
NODE: A1
TITLE: Sales & Tendering
NO.:


Factored Items
Tender Documents (Project docs)
Product Specification of order set
Project Costing (Pre-Calc
Project Plan
Customer Order details
Order Review
1
Order No.
Proposed Quality Plan
Order Review Minutes
Project Amendments
2
Final Quality Plan
Project Specifications
Project File
Cost Control Sheet & Foreign Exchange Programme
Factored Item PO
Amended Order Set to Project Team
Order Acknowledgement to Client
Final Project Plan, Order Set & Stage Payment (Milestones)
Project Amendments
Project Planning Control
3
Vendor Documentation list
Test Schedule
Updated Order Set
Certification (Mat. Process)
Project Progress Reporting
4
Document Lis
Raise Invoice
Cost Report
Final Approva
Test Results
(Order Review Kick Off Meeting)
Quality & Test Plan
PreCalc
Supply Source Designation
Meetings:
Project Team
(Project Review's, Cost Review's and Assembly Programme
MS Project & Jobscope
Project Meetings with Client & Suppliers
NODE: A2
TITLE: Commerical (Project Management)
NO.:

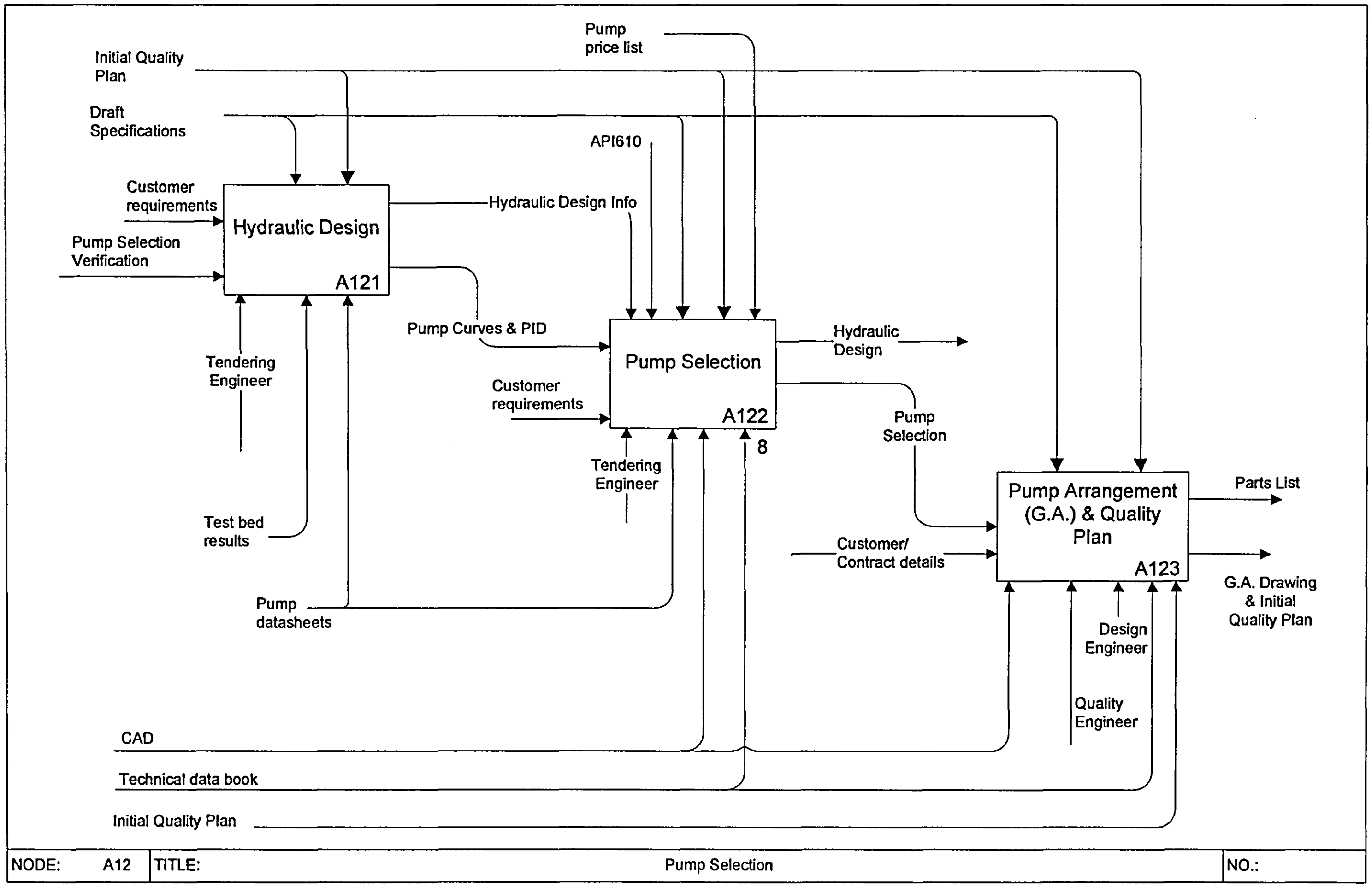

Costing of order set
Product Specification of order set
(From A12O)
Hydraulics Design
API 610 standard
From A13O
Tender documents(GA, order-set, QP,..etc)
Customer Order details
Design Review
1
Order review minutes
From A13O
Propsed Quality Plan
Project Plan
Design Amendments
2
Factored Item PO
Final Quality Plan
Final Project Plan
Project Specifications
List of specifications
Itemised parts list
Drawings
Engineering design details / development
3
Amended Orderset
Component drawings / specifications
Bills of material
Final assembly drawings
Purchasing order
Generation Manufacturing Drawings
4
Design Register
Customer
Computer Management System
Meetings
Project Team
Quality Engineering
Hydraulic design principles
Mechanical design principles
Design simulation S/W
Packaging Design
CAD
Control & Instrumentation
Details of factored Items
Rotor-dynamics calcualtions
PDM
CAD
Scheduling data & capacity planning
Computer Management System
NODE: A3
TITLE: Design Engineering
NO.:

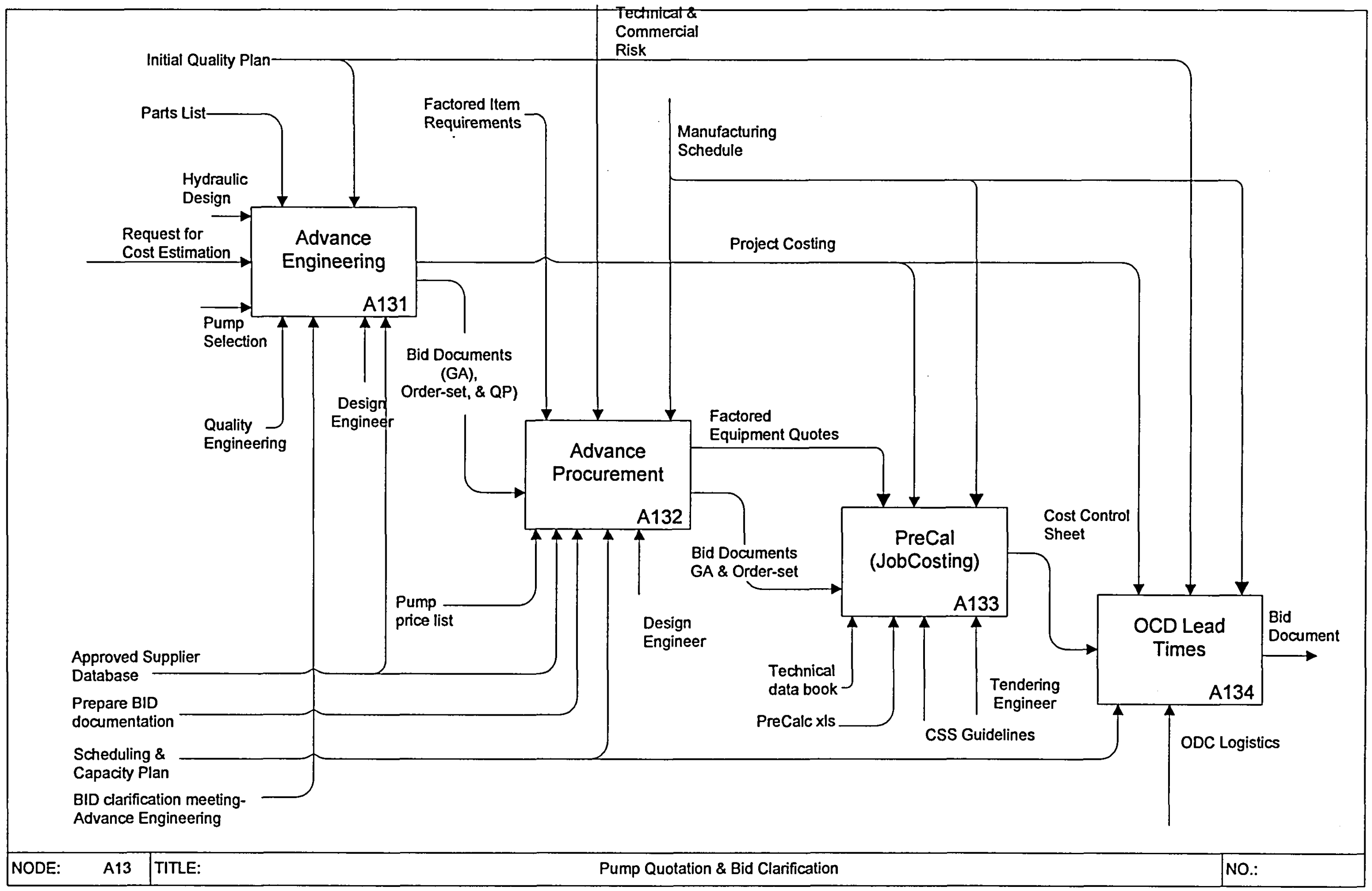

Designate Supply Source
Job Specification
SQA (Quality Assurance)
Pre-Calc & Order Set
Quality Plan
Engineering BOMs
Manufacturing Drawings
Engineering Works Orders
Releases Pump, Piping Baseplate & Auxilary
1
Engineering BOM
Item Masters
Routings & Creation of Works Orders
2
New Rounting
NC & CNC programmes
Prospect Load Generation
Sheduling MC2000 (Overnight)
3
Schedule Release Report
Job Specification
Capacity Planning
4
NDE
Order Acknolwedgement
Purchase Requistions
5
Delivery Dates
Raise Purchase Order to Supplier
Nace Requirements
Supplier Assessment
Drawings & ISOs
Assembly Plan
Jobscope (loading)
Shuffle Board Meeting
MC2000
Quality Report
Approved Supplier Database
NODE: A4
TITLE: Purchasing & Production Planning Page
NO.:


Test Bed Programme
Activity Planning
Activity Planning M/C Shop
Activity Planning Assembly Shop
Activity Planning Assembly Shop
Weld Procedures
Goods Receiving & Kit Marshalling
A5-1
Shop Task List
Cast Numbers
Task List
Material Certs
Material
Material Certification
Machine Shop & Component Inspection
A5-2
Route Cards
CNC/NC Programme
Re-Routing (Planning Dept.
Finished Component
Task List (BOM)
Tooling
NC & CNC programmes
Pump Assembly Process & Product Inspection
A5-3
Hydro & Balance Certs
Job Packets
Pumps without Packaging
Product Test (Pump Test / Slave Test)
A5-4
Test Results
Piping & Packaging (Test & Final Assembly)
A5-5
Build & Material Location Records
Punch List
Banked Hours (Labour)
MC2000 & ATMS
Punch List (Q.C.)
Component & Assembly Drawings
Shuffle Board
Plant Meeting
Planning Sheet
Special Equipment
NODE: A5
TITLE: Manufacturing Assembly & Testing
NO.:

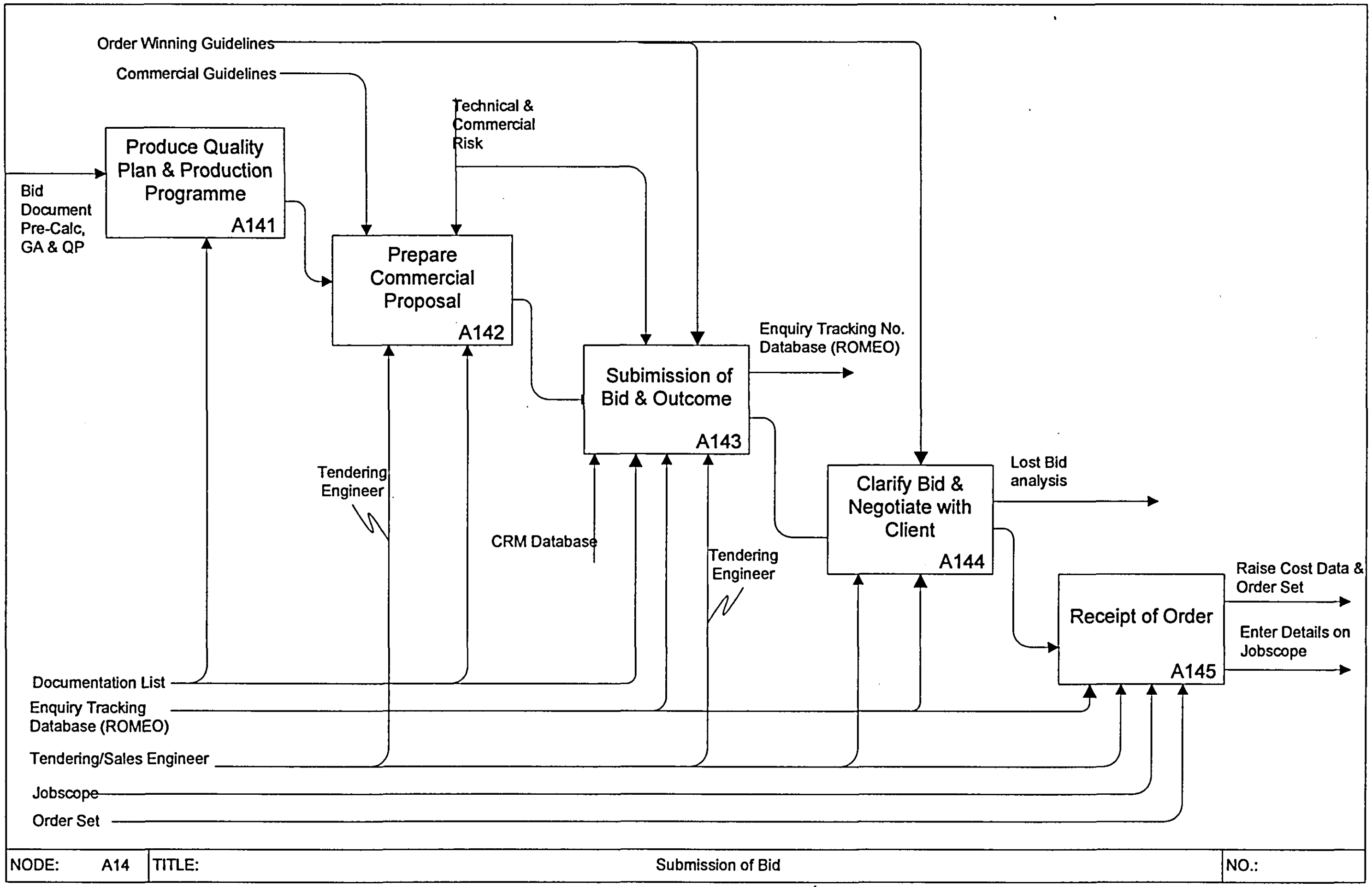


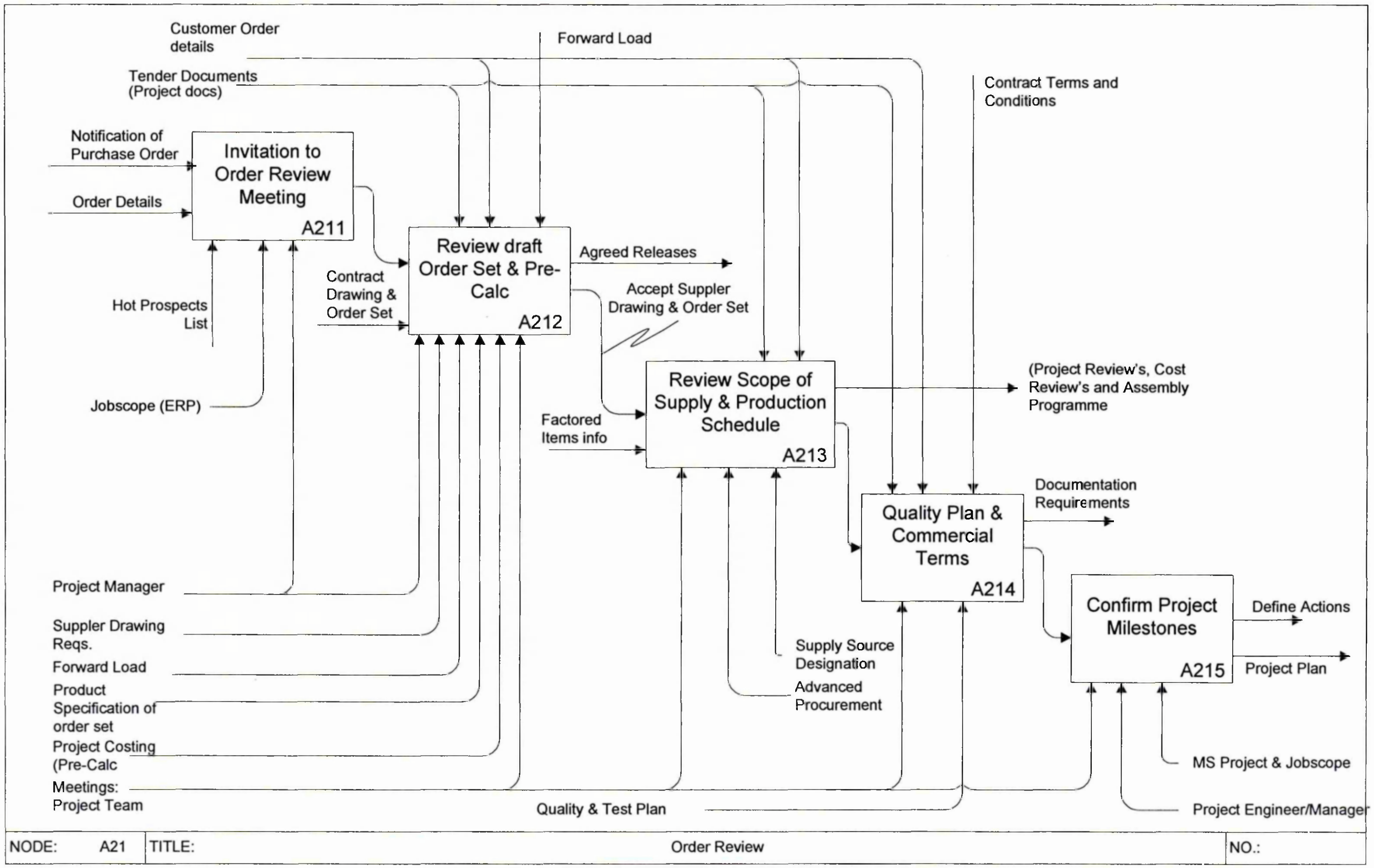
CSS guidelines
Strategic guidelines
Commercial Risk Management
Business Area
Strategic guidelines
Customer requirements
Sales Forecast
Request for Quotation
A111
Commitment to Bid
A112
No Bid Scenario & Advise Client
Project Header & assign legal entity
A113
Non-Standard Pump Set
Standard Pump Set
Sales Biddiing Process
A114
Produce Request for Cost Estimation
Allocate Enquiry to Tendering Engineer
A115
Produce Request for Cost Estimation
Verification for Pump selection
Potential customer service support
Prepare Tender documentation
Commercial Manager Support
Sales Engineer
Sales Engineer
Tendering Engineer
Enquiry Tracking Database (ROMEO)
Technical Databook
Pump datasheets
Sales Engineer
NODE: A11
TITLE: Quotation
NO.:

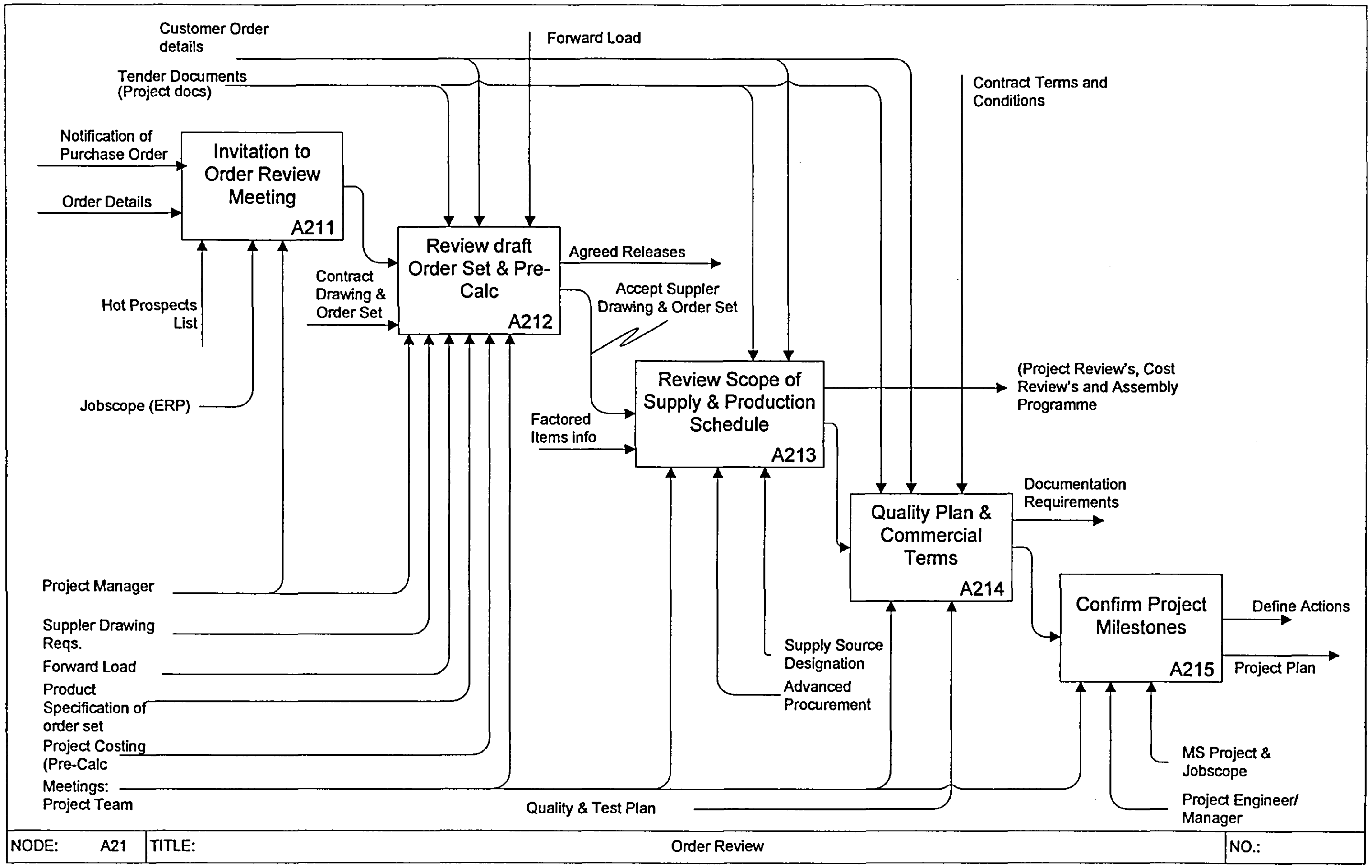

Initial Quality Plan
Draft Specifications
Pump price list
API610
Customer requirements
Pump Selection Verification
Hydraulic Design
A121
Hydraulic Design Info
Pump Curves & PID
Tendering Engineer
Test bed results
Pump datasheets
Pump Selection
A122
8
Customer requirements
Tendering Engineer
Hydraulic Design
Pump Selection
Customer/ Contract details
Pump Arrangement (G.A.) & Quality Plan
A123
Parts List
G.A. Drawing & Initial Quality Plan
Design Engineer
Quality Engineer
CAD
Technical data book
Initial Quality Plan
NODE: A12
TITLE: Pump Selection
NO.:



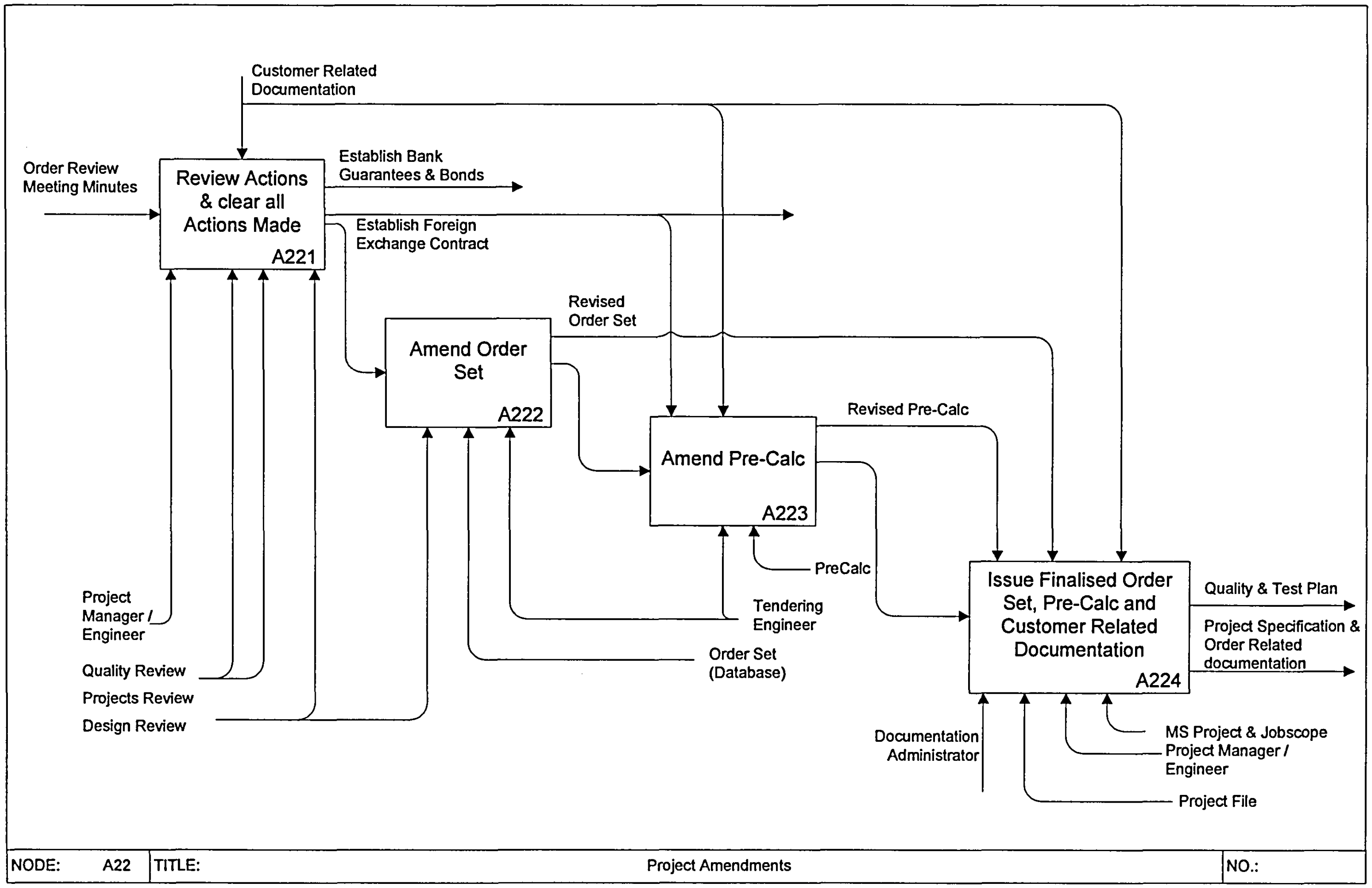
Technical &
Commercial
Risk
Initial Quality Plan
Parts List
Factored Item
Requirements
Manufacturing
Schedule
Hydraulic
Design
Request for
Cost Estimation
Advance
Engineering
A131
Project Costing
Pump
Selection
Bid Documents
(GA),
Order-set, & QP)
Quality
Engineering
Design
Engineer
Advance
Procurement
A132
Factored
Equipment Quotes
Bid Documents
GA & Order-set
PreCal
(JobCosting)
A133
Cost Control
Sheet
Pump
price list
Design
Engineer
OCD Lead
Times
A134
Bid
Document
Approved Supplier
Database
Prepare BID
documentation
Technical
data book
PreCalc xls
Tendering
Engineer
CSS Guidelines
ODC Logistics
Scheduling &
Capacity Plan
BID clarification meeting-
Advance Engineering
NODE:
A13
TITLE:
Pump Quotation & Bid Clarification
NO.:

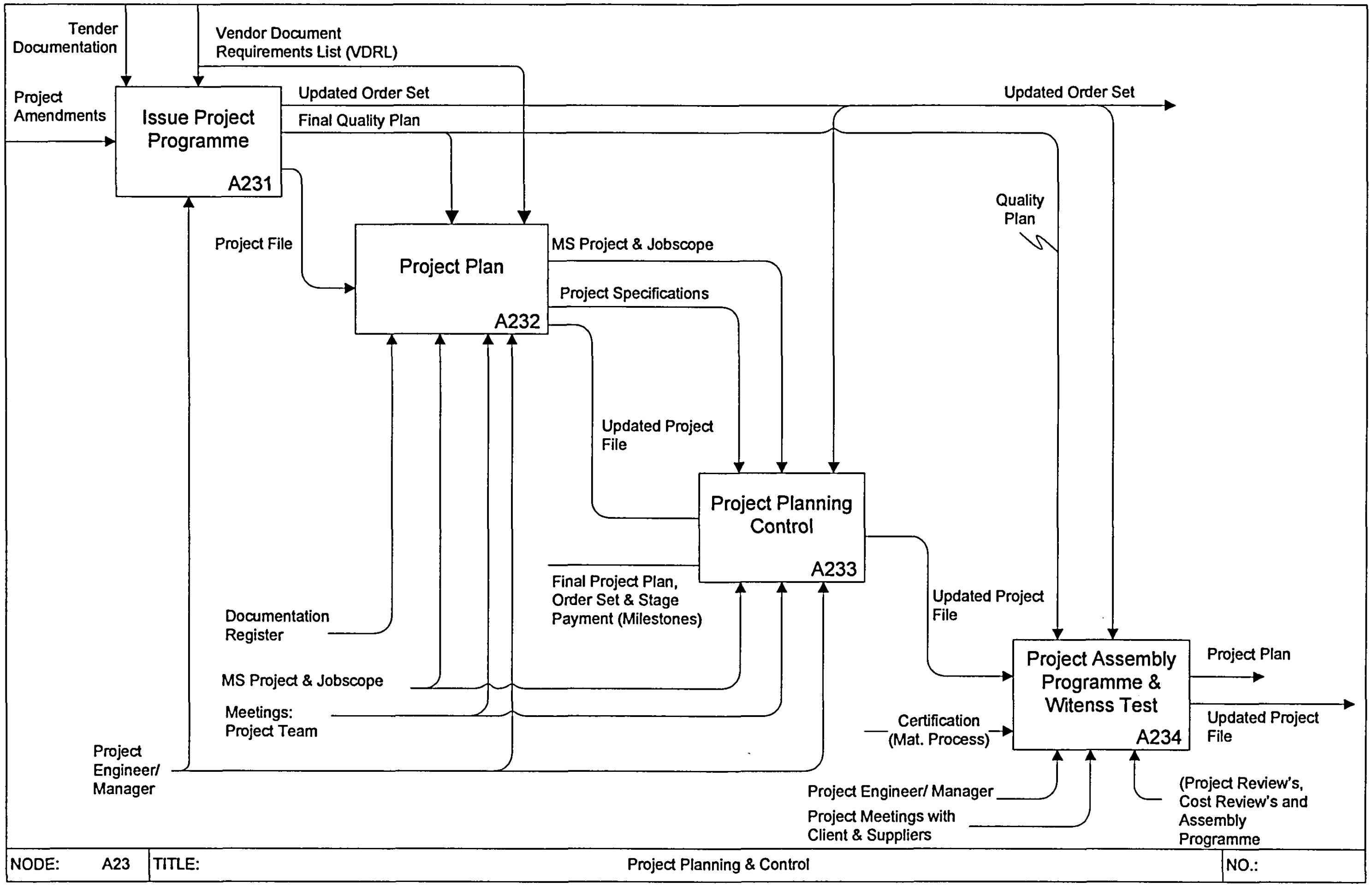

Order Winning Guidelines
Commercial Guidelines
Technical & Commercial Risk
Bid Document Pre-Calc, GA & QP
Produce Quality Plan & Production Programme
A141
Prepare Commercial Proposal
A142
Subimission of Bid & Outcome
A143
Enquiry Tracking No. Database (ROMEO)
Tendering Engineer
CRM Database
Tendering Engineer
Clarify Bid & Negotiate with Client
A144
Lost Bid analysis
Receipt of Order
A145
Raise Cost Data & Order Set
Enter Details on Jobscope
Documentation List
Enquiry Tracking Database (ROMEO)
Tendering/Sales Engineer
Jobscope
Order Set
NODE: A14
TITLE: Submission of Bid
NO.:

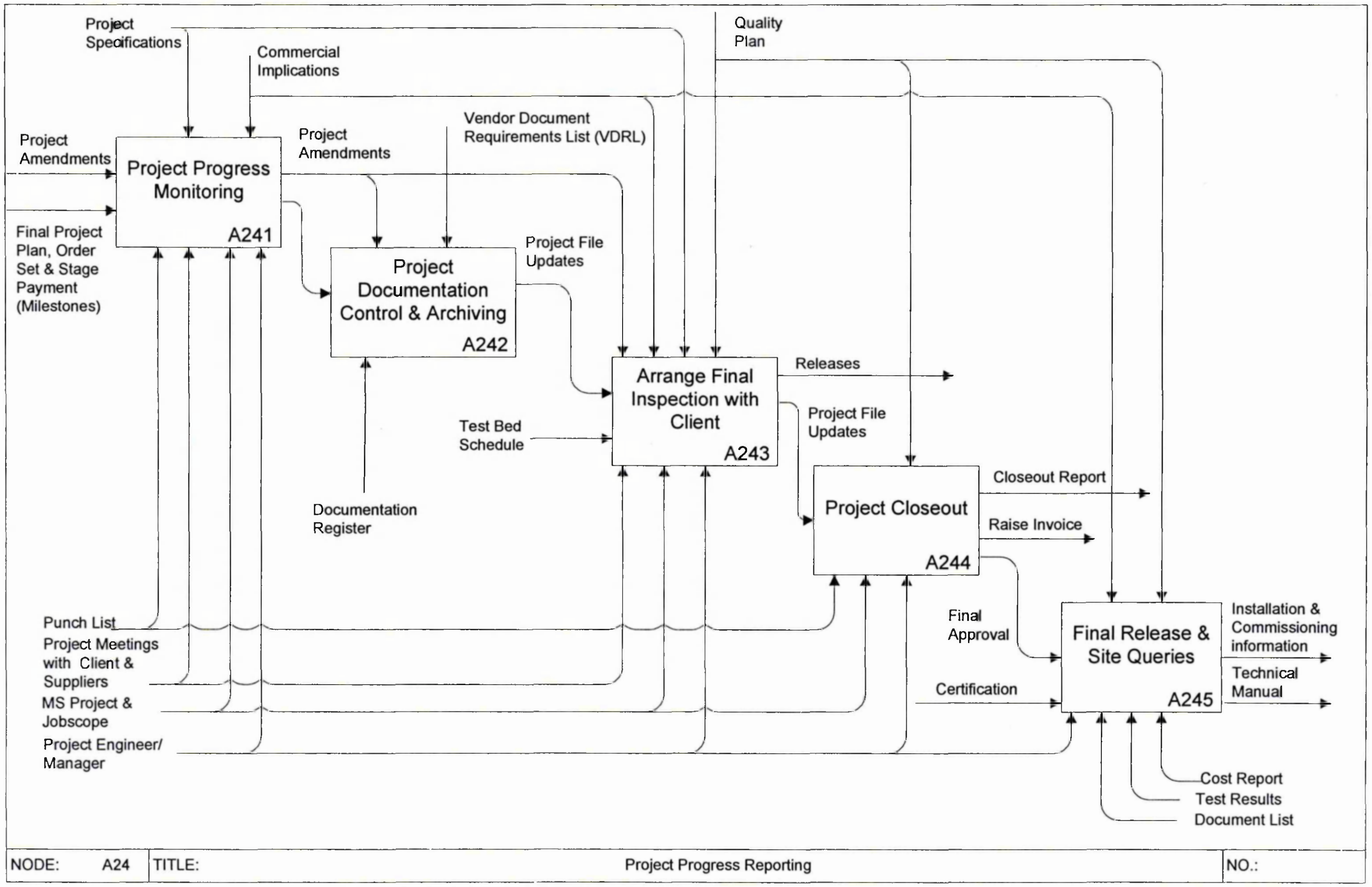

Customer Order details
Tender Documents (Project docs)
Forward Load
Contract Terms and Conditions
Notification of Purchase Order
Order Details
Invitation to Order Review Meeting
A211
Review draft Order Set & Pre-Calc
A212
Agreed Releases
Accept Supplier Drawing & Order Set
Contract Drawing & Order Set
Hot Prospects List
Jobscope (ERP)
Review Scope of Supply & Production Schedule
A213
(Project Review's, Cost Review's and Assembly Programme
Factored Items info
Quality Plan & Commercial Terms
A214
Documentation Requirements
Confirm Project Milestones
A215
Define Actions
Project Plan
Project Manager
Suppler Drawing Reqs.
Forward Load
Product Specification of order set
Project Costing (Pre-Calc
Meetings: Project Team
Supply Source Designation
Advanced Procurement
MS Project & Jobscope
Quality & Test Plan
Project Engineer/Manager
NODE: A21
TITLE: Order Review
NO.:

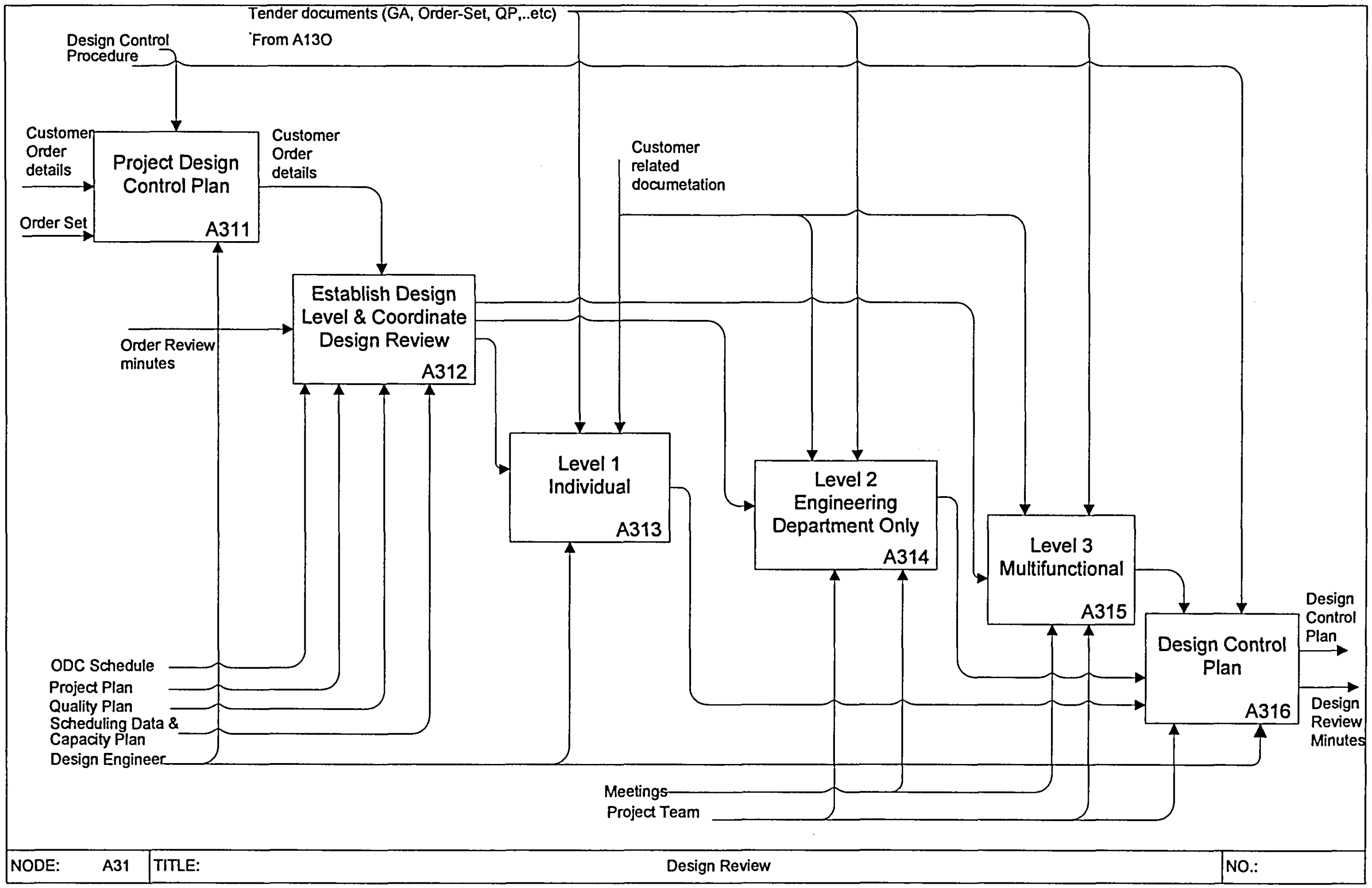


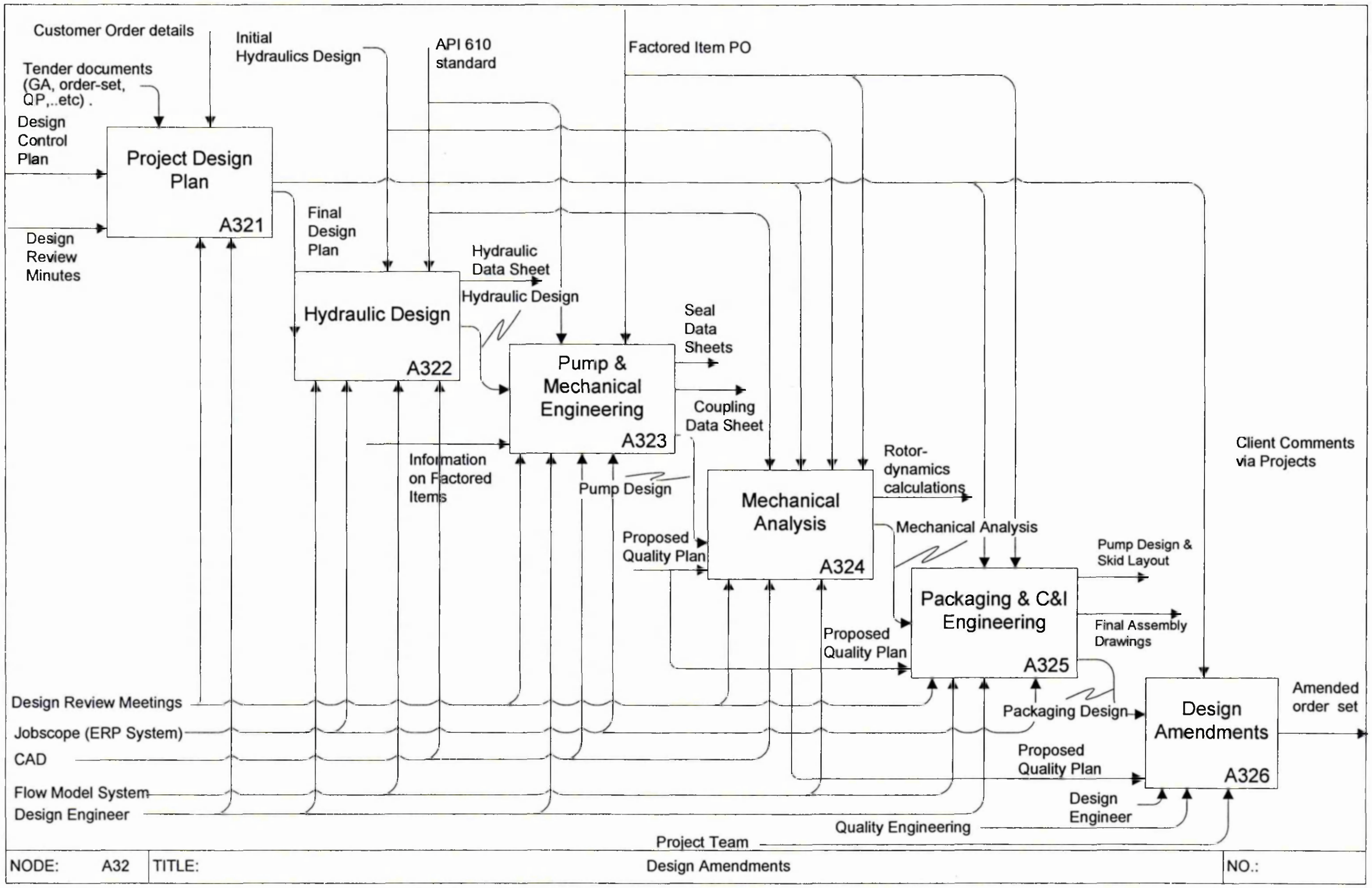
Customer Order details
Tender Documents (Project docs)
Forward Load
Contract Terms and Conditions
Notification of Purchase Order
Order Details
Invitation to Order Review Meeting
A211
Review draft Order Set & Pre-Calc
A212
Agreed Releases
Accept Supplier Drawing & Order Set
Contract Drawing & Order Set
Hot Prospects List
Jobscope (ERP)
Review Scope of Supply & Production Schedule
A213
(Project Review's, Cost Review's and Assembly Programme
Factored Items info
Documentation Requirements
Quality Plan & Commercial Terms
A214
Confirm Project Milestones
A215
Define Actions
Project Plan
Project Manager
Suppler Drawing Reqs.
Forward Load
Product Specification of order set
Project Costing (Pre-Calc
Meetings: Project Team
Supply Source Designation
Advanced Procurement
MS Project & Jobscope
Project Engineer/ Manager
Quality & Test Plan
NODE: A21
TITLE: Order Review
NO.:


Customer Related Documentation
Order Review Meeting Minutes
Review Actions & clear all Actions Made
A221
Establish Bank Guarantees & Bonds
Establish Foreign Exchange Contract
Amend Order Set
A222
Revised Order Set
Amend Pre-Calc
A223
Revised Pre-Calc
PreCalc
Tendering Engineer
Order Set (Database)
Issue Finalised Order Set, Pre-Calc and Customer Related Documentation
A224
Quality & Test Plan
Project Specification & Order Related documentation
Documentation Administrator
MS Project & Jobscope
Project Manager / Engineer
Project File
Project Manager / Engineer
Quality Review
Projects Review
Design Review
NODE: A22
TITLE: Project Amendments
NO.:

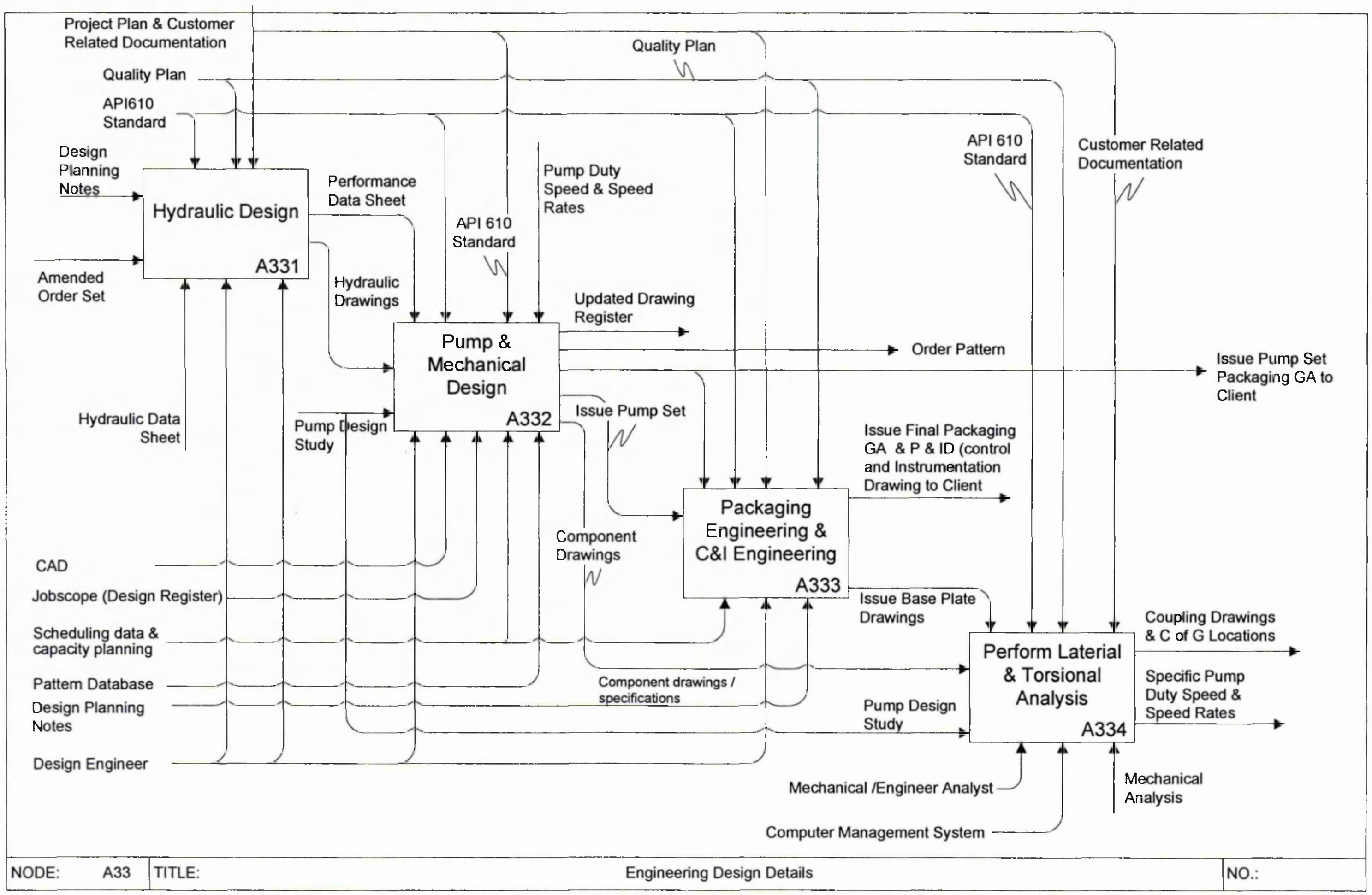

Tender Documentation
Vendor Document Requirements List (VDRL)
Project Amendments
Issue Project Programme
A231
Updated Order Set
Final Quality Plan
Updated Order Set
Quality Plan
Project File
Project Plan
A232
MS Project & Jobscope
Project Specifications
Updated Project File
Project Planning Control
A233
Final Project Plan, Order Set & Stage Payment (Milestones)
Updated Project File
Project Assembly Programme & Witenss Test
A234
Project Plan
Updated Project File
Certification (Mat. Process)
Documentation Register
MS Project & Jobscope
Meetings: Project Team
Project Engineer/ Manager
Project Engineer/ Manager
Project Meetings with Client & Suppliers
(Project Review's, Cost Review's and Assembly Programme
NODE: A23
TITLE: Project Planning & Control
NO.:

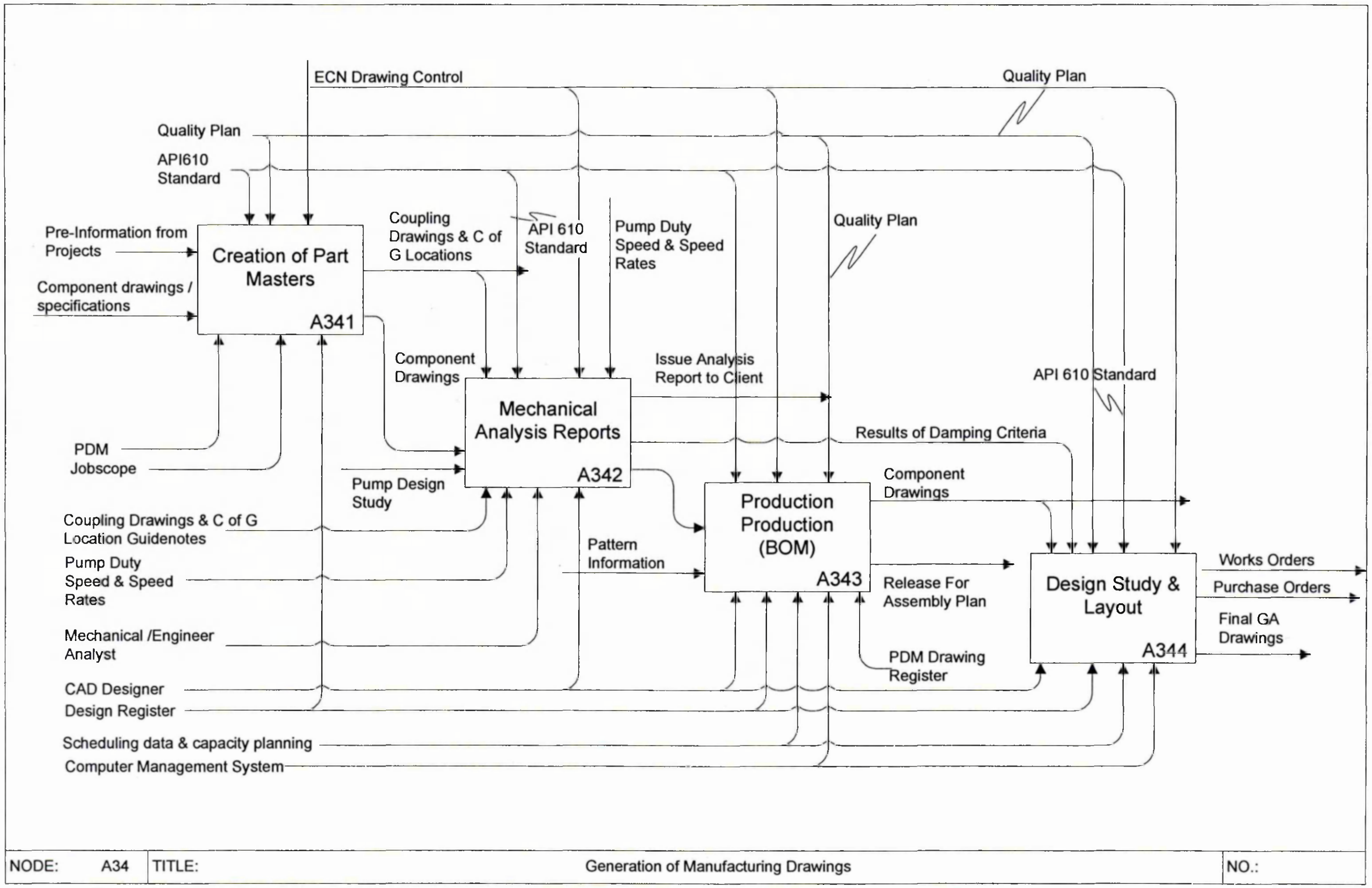

Project Specifications
Commercial Implications
Quality Plan
Project Amendments
Project Progress Monitoring
A241
Final Project Plan, Order Set & Stage Payment (Milestones)
Project Amendments
Vendor Document Requirements List (VDRL)
Project Documentation Control & Archiving
A242
Project File Updates
Documentation Register
Test Bed Schedule
Arrange Final Inspection with Client
A243
Releases
Project File Updates
Project Closeout
A244
Closeout Report
Raise Invoice
Final Approval
Certification
Final Release & Site Queries
A245
Installation & Commissioning information
Technical Manual
Cost Report
Test Results
Document List
Punch List
Project Meetings with Client & Suppliers
MS Project & Jobscope
Project Engineer/ Manager
NODE: A24
TITLE: Project Progress Reporting
NO.:


Tender documents (GA, Order-Set, QP,..etc)
From A13O
Design Control Procedure
Customer Order details
Order Set
Project Design Control Plan
A311
Customer Order details
Establish Design Level & Coordinate Design Review
A312
Order Review minutes
Customer related documetation
Level 1 Individual
A313
Level 2 Engineering Department Only
A314
Level 3 Multifunctional
A315
Design Control Plan
A316
Design Control Plan
Design Review Minutes
ODC Schedule
Project Plan
Quality Plan
Scheduling Data & Capacity Plan
Design Engineer
Meetings
Project Team
NODE: A31
TITLE: Design Review
NO.:

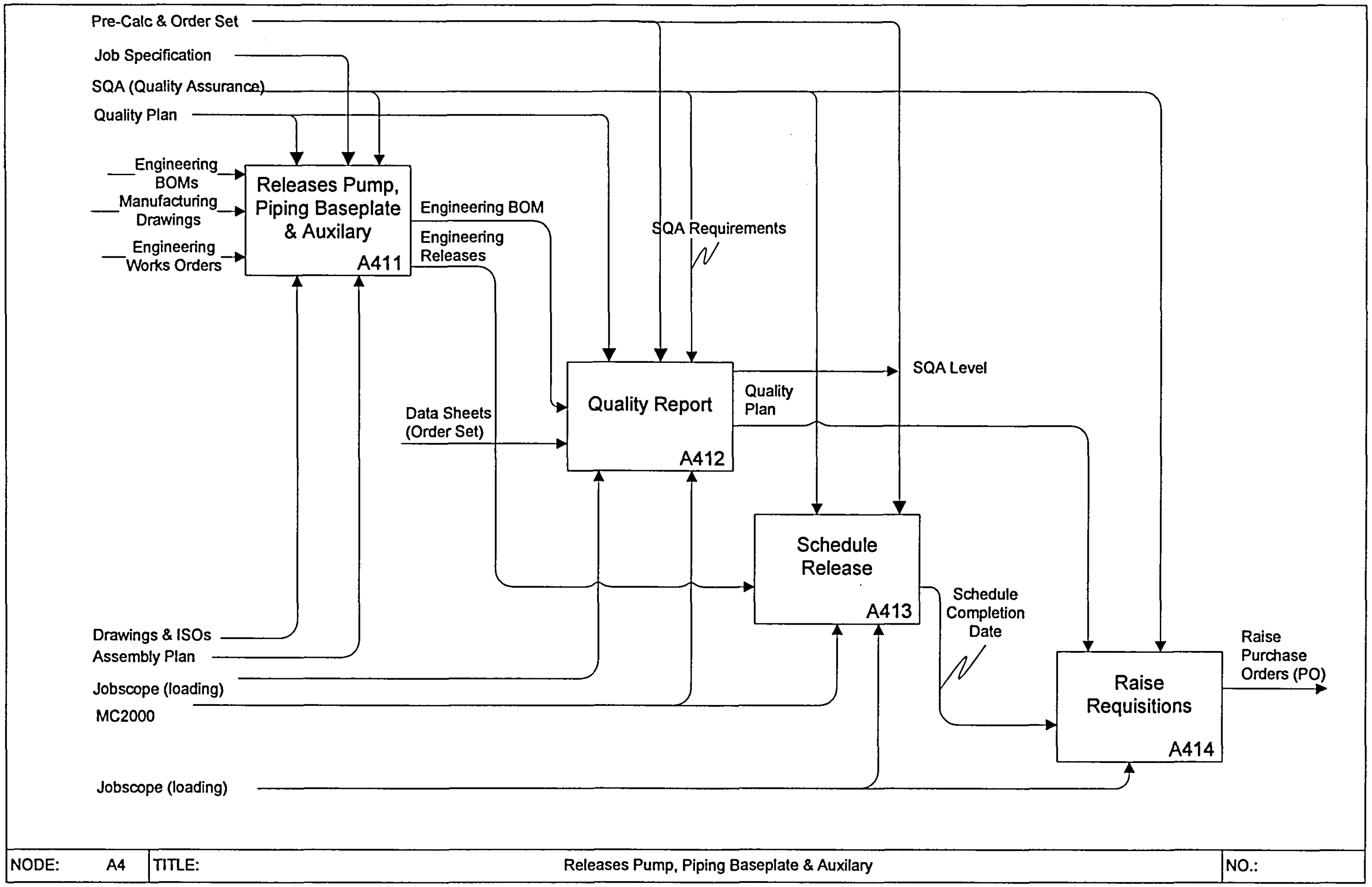


Customer Order details
Tender documents (GA, order-set, QP,..etc) .
Design Control Plan
Design Review Minutes
Initial Hydraulics Design
API 610 standard
Factored Item PO
Project Design Plan
A321
Final Design Plan
Hydraulic Design
A322
Hydraulic Data Sheet
Hydraulic Design
Pump & Mechanical Engineering
A323
Seal Data Sheets
Coupling Data Sheet
Information on Factored Items
Pump Design
Proposed Quality Plan
Mechanical Analysis
A324
Rotor-dynamics calculations
Mechanical Analysis
Proposed Quality Plan
Packaging & C&I Engineering
A325
Pump Design & Skid Layout
Final Assembly Drawings
Client Comments via Projects
Packaging Design
Proposed Quality Plan
Design Amendments
A326
Amended order set
Design Engineer
Design Review Meetings
Jobscope (ERP System)
CAD
Flow Model System
Design Engineer
Quality Engineering
Project Team
NODE: A32
TITLE: Design Amendments
NO.:

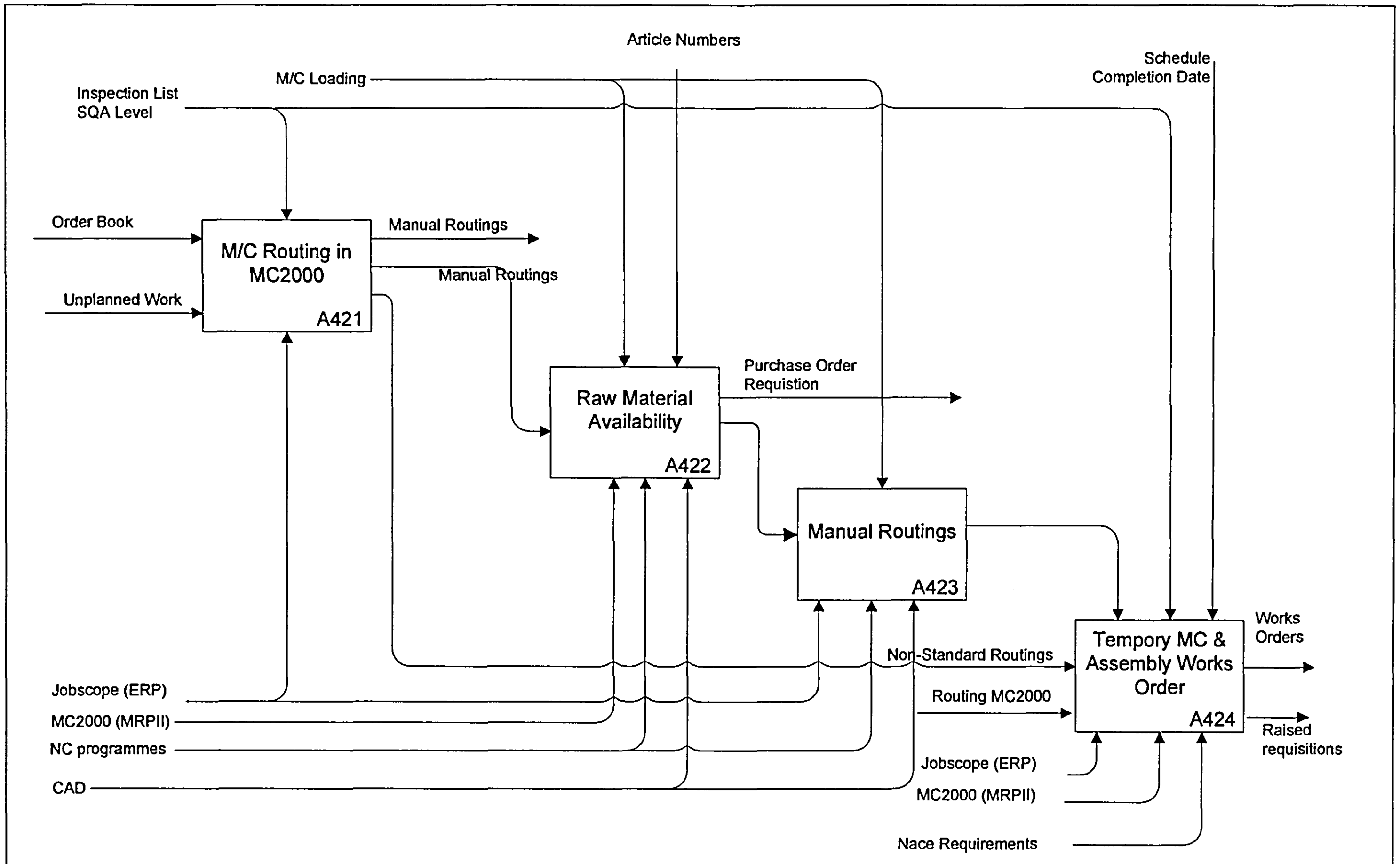

Project Plan & Customer Related Documentation
Quality Plan
API610 Standard
Design Planning Notes
Amended Order Set
Hydraulic Design
A331
Hydraulic Data Sheet
Performance Data Sheet
Hydraulic Drawings
API 610 Standard
Pump Duty Speed & Speed Rates
Updated Drawing Register
Pump & Mechanical Design
A332
Pump Design Study
Issue Pump Set
Component Drawings
Order Pattern
Issue Pump Set Packaging GA to Client
Issue Final Packaging GA & P & ID (control and Instrumentation Drawing to Client
Packaging Engineering & C&I Engineering
A333
Issue Base Plate Drawings
Component drawings / specifications
Pump Design Study
API 610 Standard
Customer Related Documentation
Perform Laterial & Torsional Analysis
A334
Coupling Drawings & C of G Locations
Specific Pump Duty Speed & Speed Rates
Mechanical /Engineer Analyst
Computer Management System
Mechanical Analysis
CAD
Jobscope (Design Register)
Scheduling data & capacity planning
Pattern Database
Design Planning Notes
Design Engineer
NODE: A33
TITLE: Engineering Design Details
NO.:



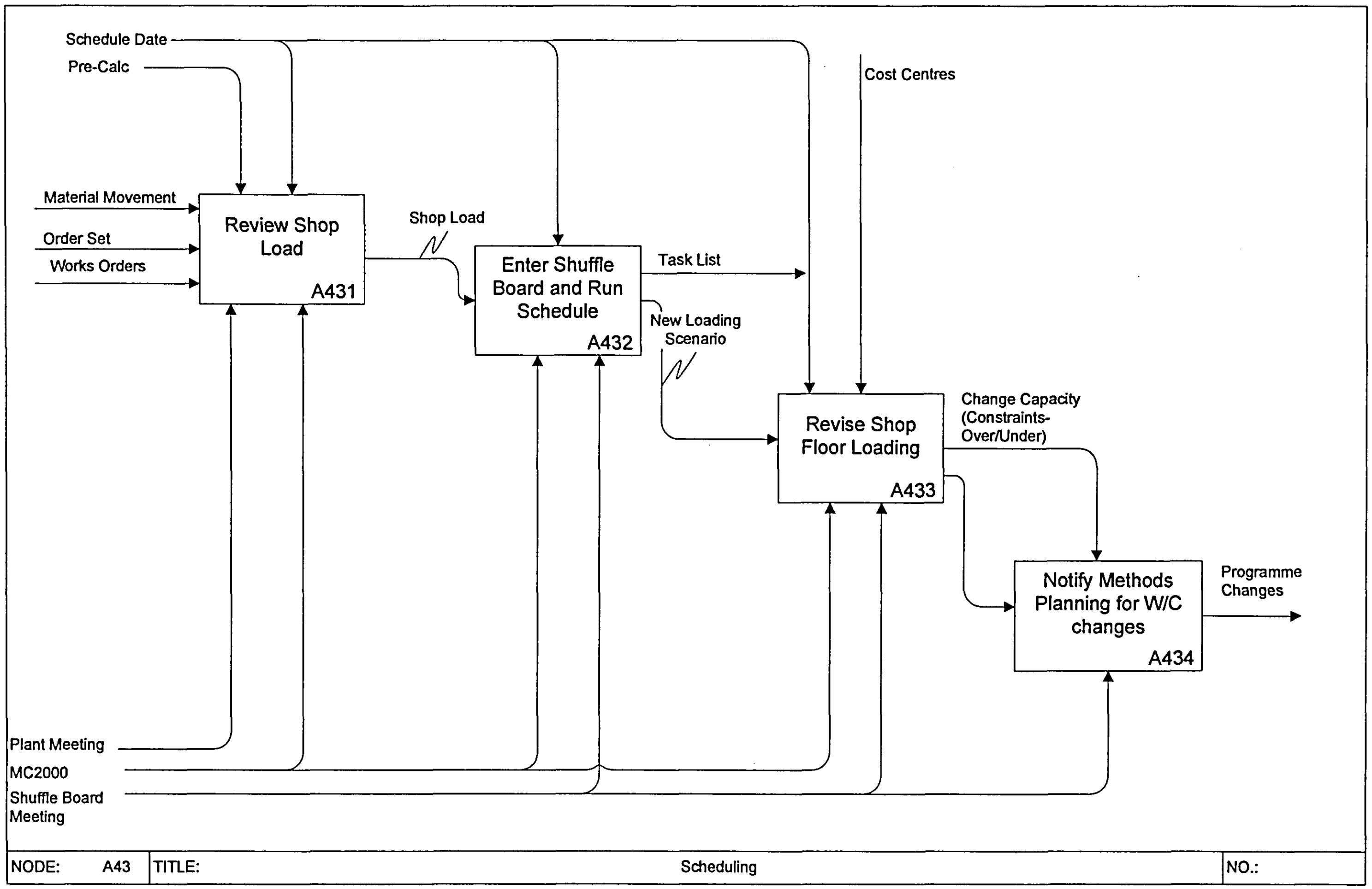
ECN Drawing Control
Quality Plan
Quality Plan
API610 Standard
Pre-Information from Projects
Component drawings / specifications
Creation of Part Masters
A341
Coupling Drawings & C of G Locations
API 610 Standard
Pump Duty Speed & Speed Rates
Quality Plan
Component Drawings
Issue Analysis Report to Client
API 610 Standard
Mechanical Analysis Reports
A342
Results of Damping Criteria
PDM
Jobscope
Pump Design Study
Component Drawings
Production Production (BOM)
A343
Coupling Drawings & C of G Location Guidenotes
Pattern Information
Works Orders
Purchase Orders
Pump Duty Speed & Speed Rates
Release For Assembly Plan
Design Study & Layout
A344
Final GA Drawings
Mechanical /Engineer Analyst
PDM Drawing Register
CAD Designer
Design Register
Scheduling data & capacity planning
Computer Management System
NODE: A34
TITLE: Generation of Manufacturing Drawings
NO.:



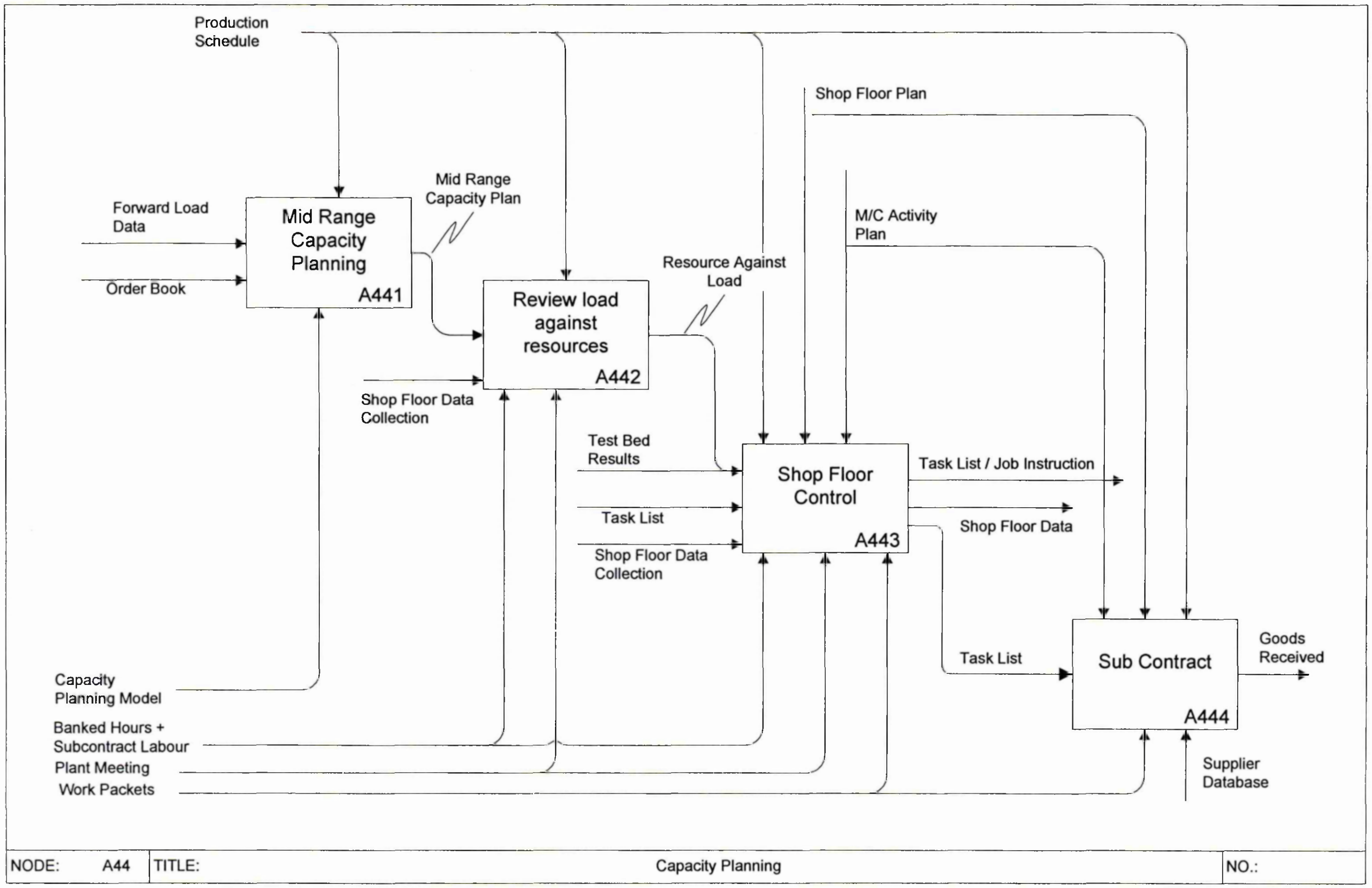
Pre-Calc & Order Set
Job Specification
SQA (Quality Assurance)
Quality Plan
Engineering BOMs
Manufacturing Drawings
Engineering Works Orders
Releases Pump, Piping Baseplate & Auxilary
A411
Engineering BOM
Engineering Releases
SQA Requirements
Data Sheets (Order Set)
Quality Report
A412
SQA Level
Quality Plan
Schedule Release
A413
Schedule Completion Date
Raise Requisitions
A414
Raise Purchase Orders (PO)
Drawings & ISOs
Assembly Plan
Jobscope (loading)
MC2000
Jobscope (loading)
NODE: A4
TITLE: Releases Pump, Piping Baseplate & Auxilary
NO.:

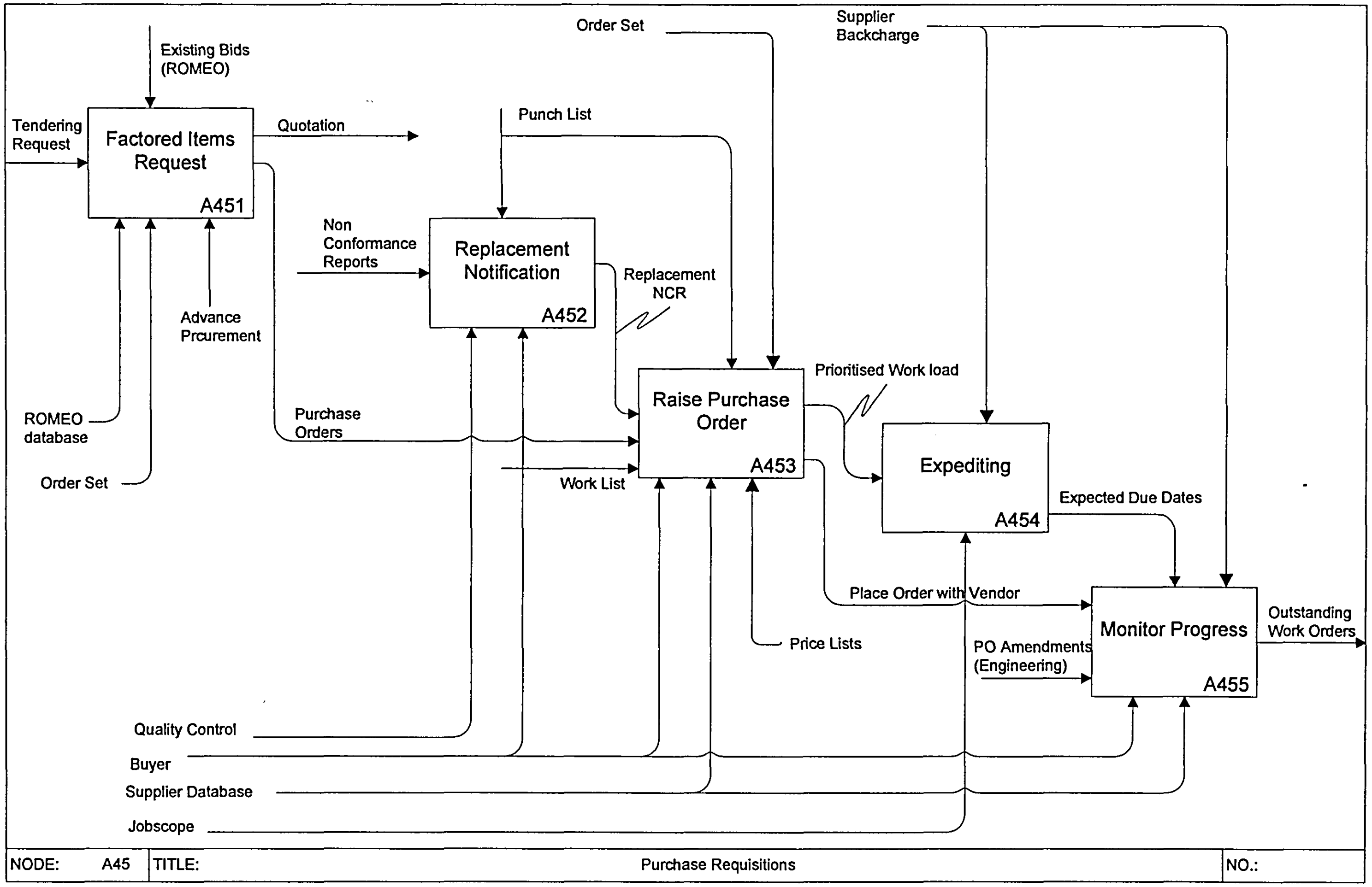


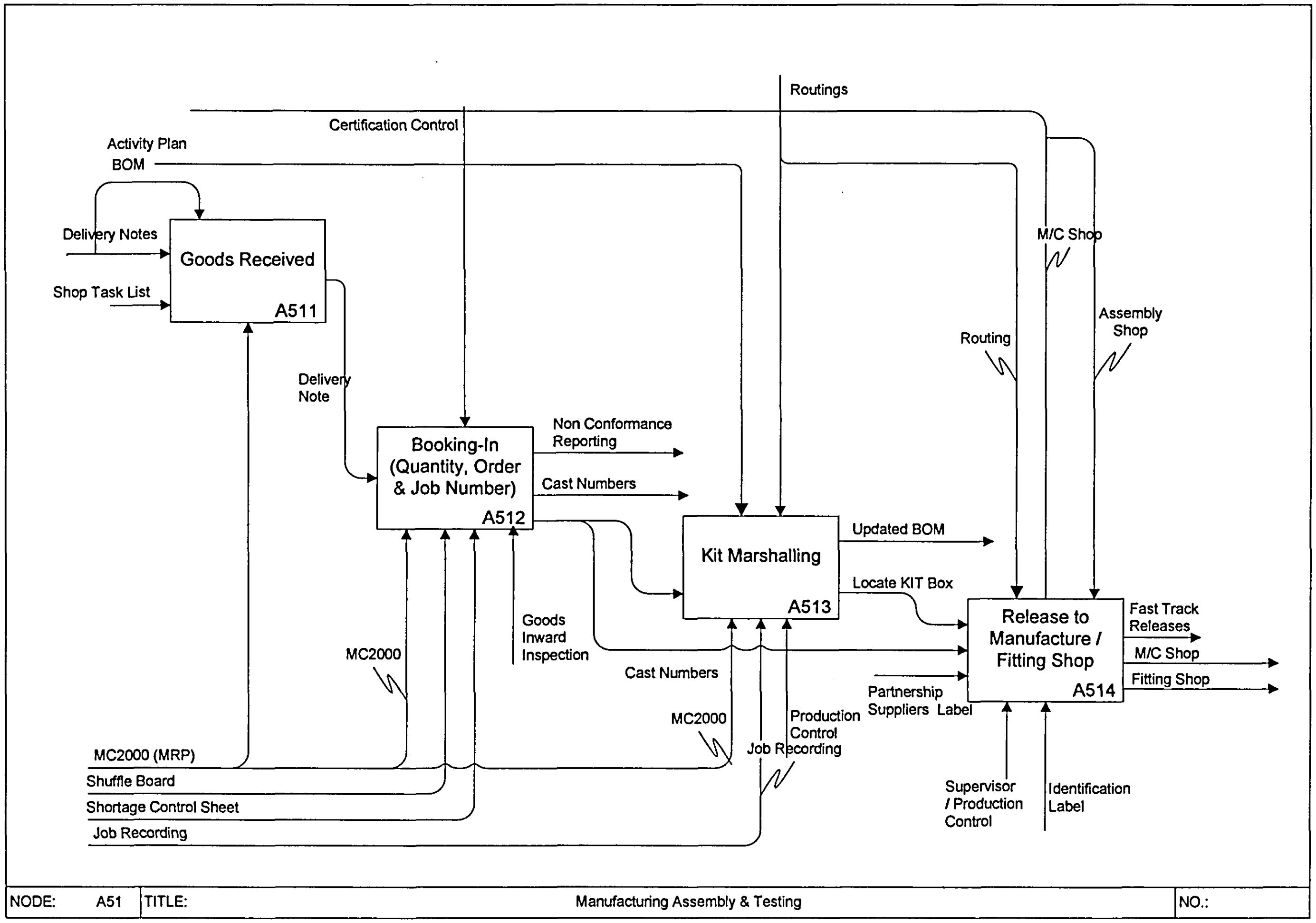
NODE: A42	TITLE: Routings & Creation of Works Orders	NO.:



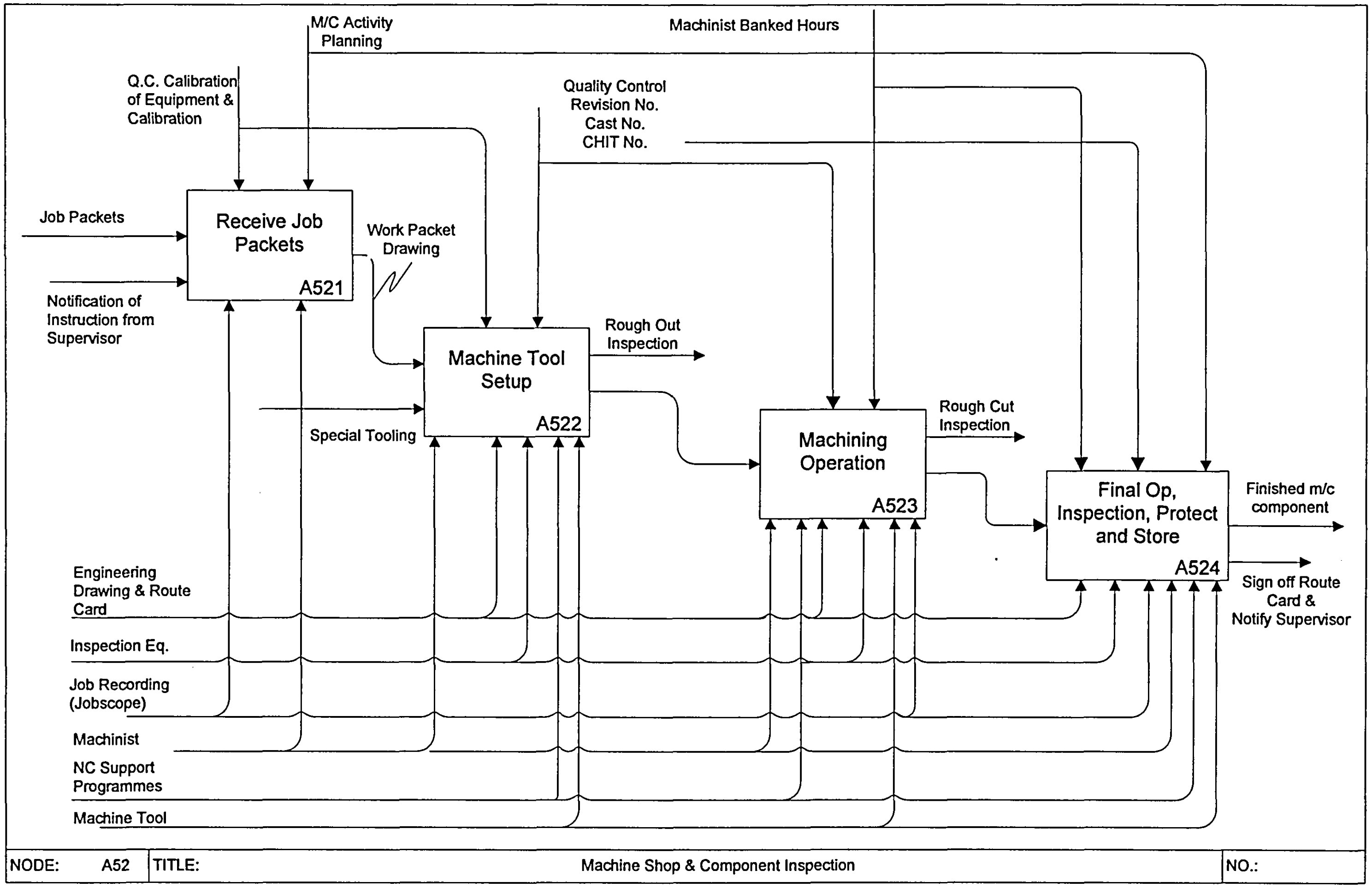
Schedule Date
Pre-Calc
Material Movement
Order Set
Works Orders
Review Shop Load
A431
Shop Load
Enter Shuffle Board and Run Schedule
A432
Task List
New Loading Scenario
Cost Centres
Revise Shop Floor Loading
A433
Change Capacity (Constraints- Over/Under)
Notify Methods Planning for W/C changes
A434
Programme Changes
Plant Meeting
MC2000
Shuffle Board Meeting
NODE: A43
TITLE: Scheduling
NO.:


Production Schedule
Forward Load Data
Order Book
Mid Range Capacity Planning
A441
Mid Range Capacity Plan
Review load against resources
A442
Shop Floor Data Collection
Resource Against Load
Shop Floor Plan
M/C Activity Plan
Test Bed Results
Task List
Shop Floor Data Collection
Shop Floor Control
A443
Task List / Job Instruction
Shop Floor Data
Task List
Sub Contract
A444
Goods Received
Supplier Database
Capacity Planning Model
Banked Hours + Subcontract Labour
Plant Meeting
Work Packets
NODE: A44
TITLE: Capacity Planning
NO.:

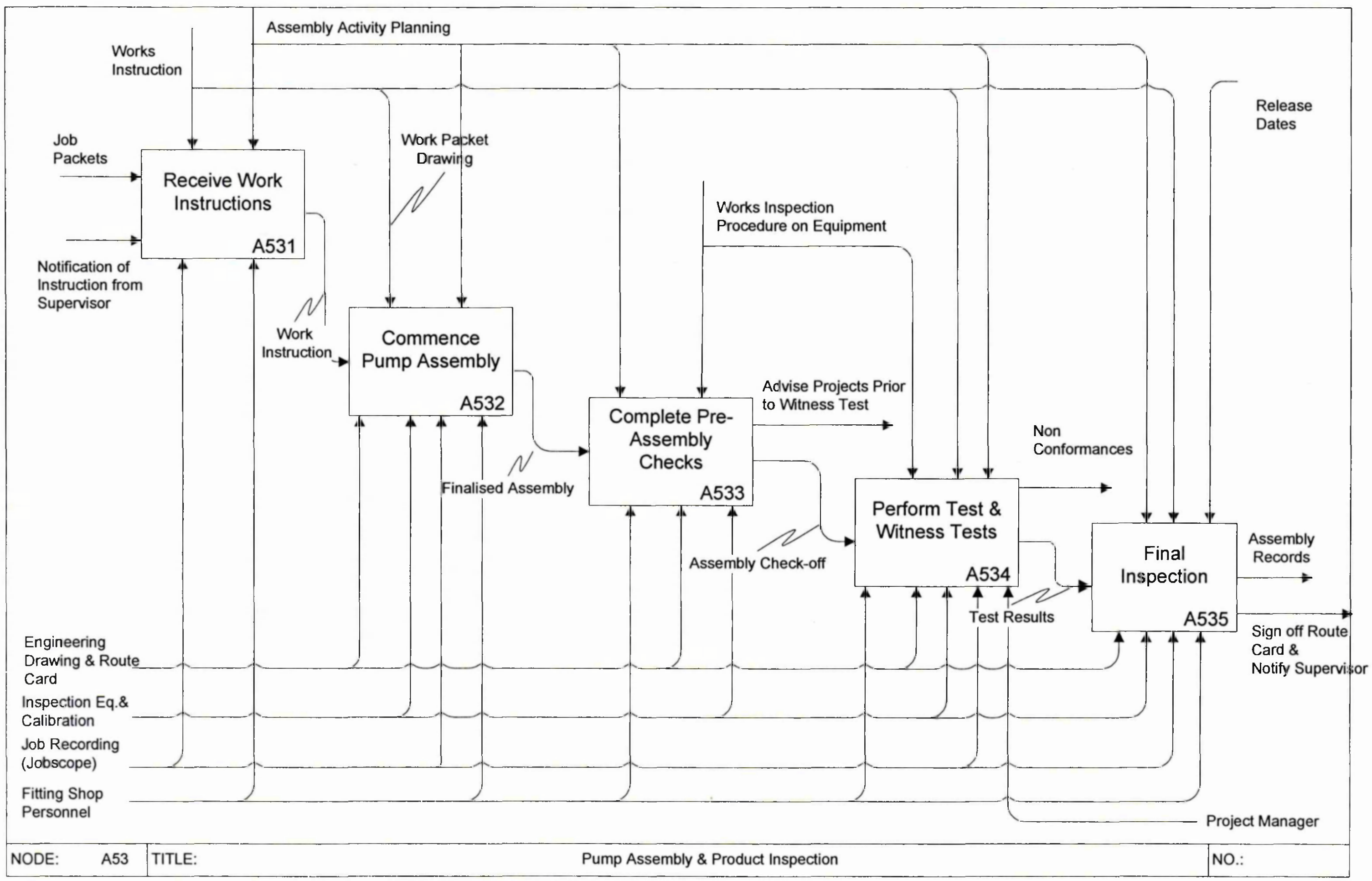

Existing Bids (ROMEO)
Tendering Request
Factored Items Request
A451
Quotation
ROMEO database
Order Set
Advance Prcurement
Purchase Orders
Non Conformance Reports
Replacement Notification
A452
Punch List
Replacement NCR
Order Set
Raise Purchase Order
A453
Work List
Price Lists
Prioritised Work load
Supplier Backcharge
Expediting
A454
Expected Due Dates
Place Order with Vendor
PO Amendments (Engineering)
Monitor Progress
A455
Outstanding Work Orders
Quality Control
Buyer
Supplier Database
Jobscope
NODE: A45
TITLE: Purchase Requisitions
NO.:

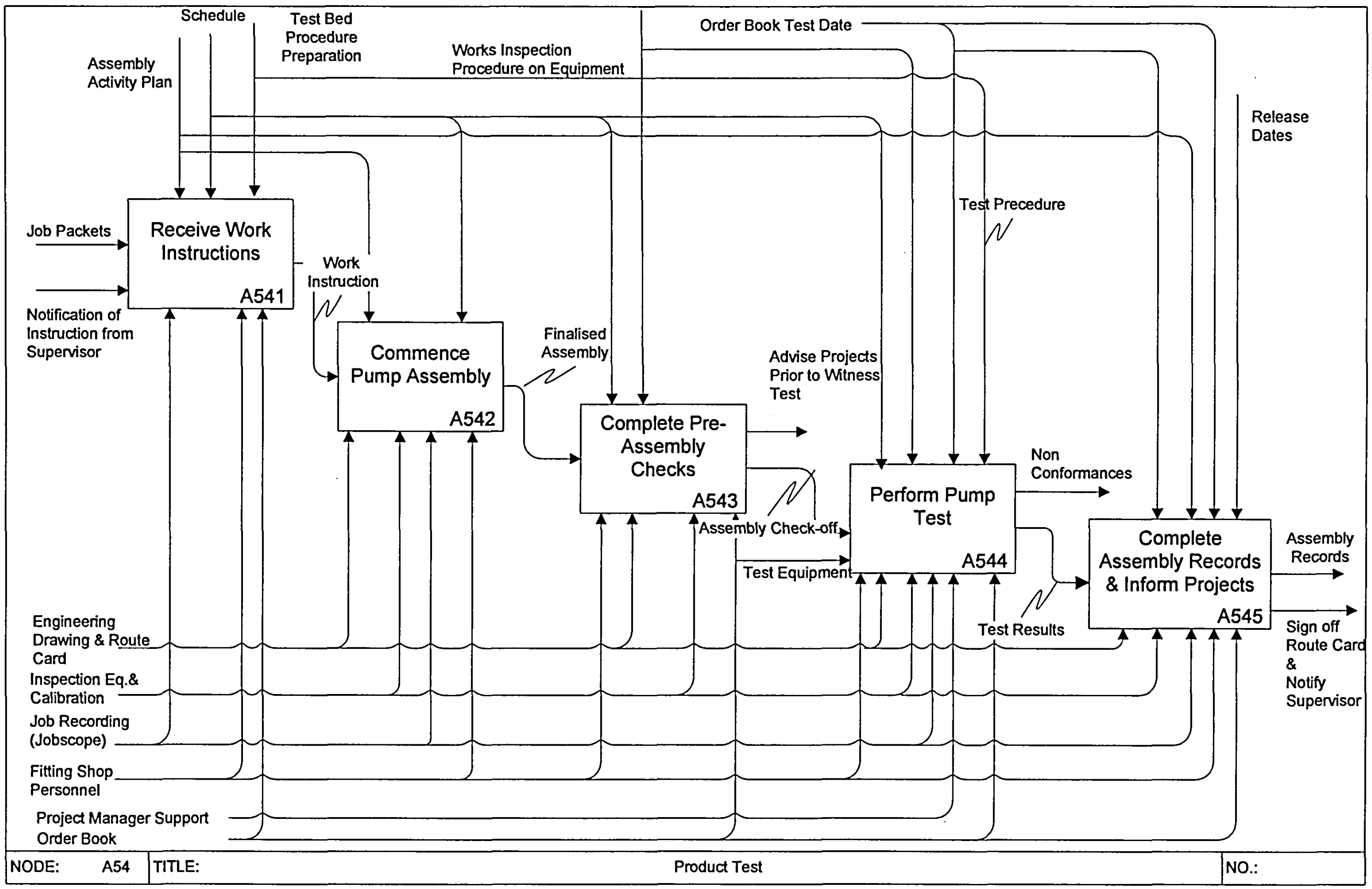


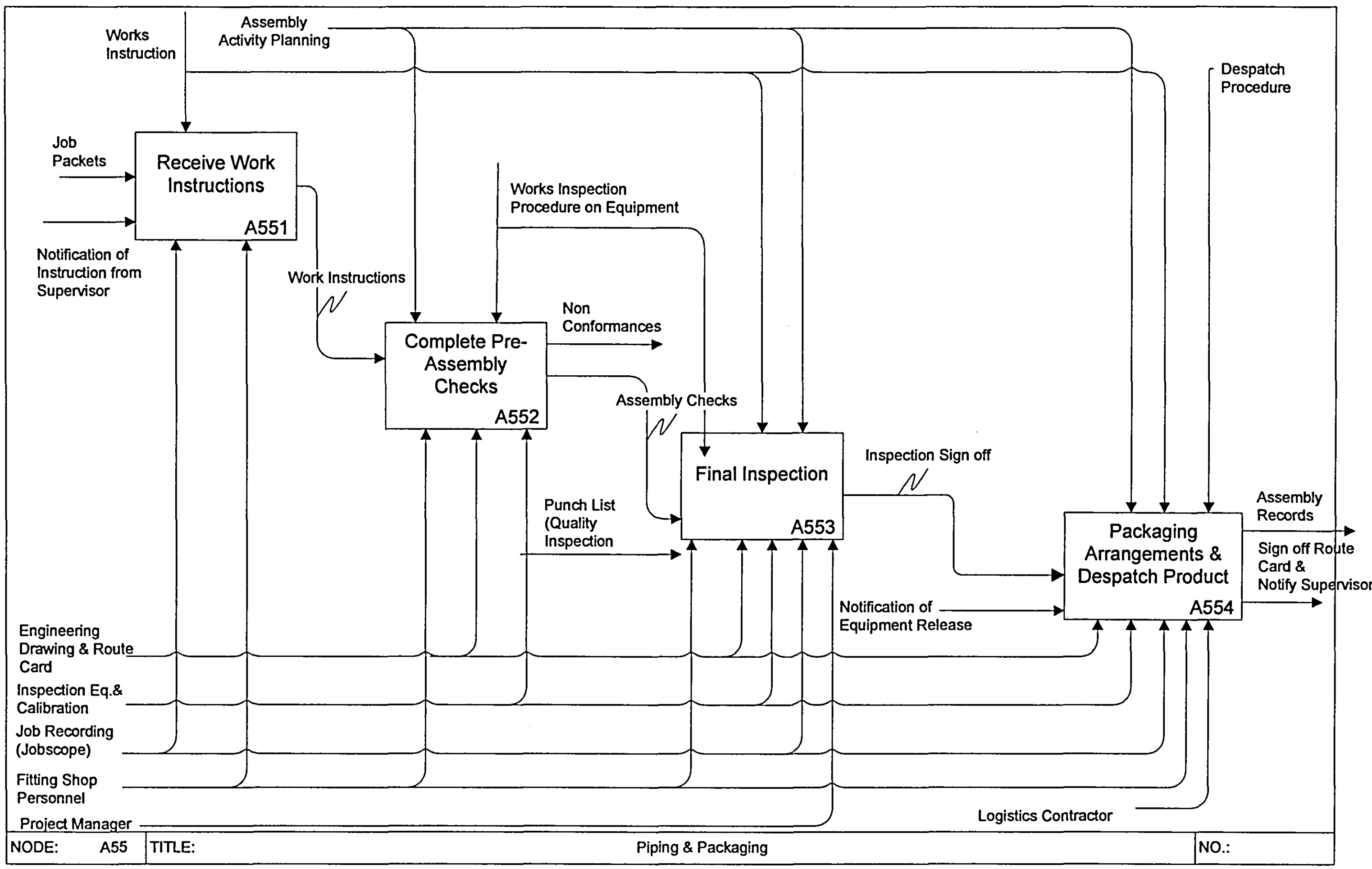
Routings
Certification Control
Activity Plan
BOM
Delivery Notes
Shop Task List
Goods Received
A511
Delivery Note
Booking-In (Quantity, Order & Job Number)
A512
Non Conformance Reporting
Cast Numbers
Kit Marshalling
A513
Updated BOM
Locate KIT Box
Release to Manufacture / Fitting Shop
A514
Fast Track Releases
M/C Shop
Fitting Shop
M/C Shop
Routing
Assembly Shop
Goods Inward Inspection
MC2000
Cast Numbers
MC2000
Production Control
Job Recording
Partnership Suppliers
Label
Supervisor / Production Control
Identification Label
MC2000 (MRP)
Shuffle Board
Shortage Control Sheet
Job Recording
NODE: A51
TITLE: Manufacturing Assembly & Testing
NO.:



M/C Activity Planning
Machinist Banked Hours
Q.C. Calibration of Equipment & Calibration
Quality Control Revision No. Cast No. CHIT No.
Job Packets
Receive Job Packets
A521
Work Packet Drawing
Notification of Instruction from Supervisor
Machine Tool Setup
A522
Rough Out Inspection
Special Tooling
Machining Operation
A523
Rough Cut Inspection
Final Op, Inspection, Protect and Store
A524
Finished m/c component
Sign off Route Card & Notify Supervisor
Engineering Drawing & Route Card
Inspection Eq.
Job Recording (Jobscope)
Machinist
NC Support Programmes
Machine Tool
NODE: A52
TITLE: Machine Shop & Component Inspection
NO.:


Assembly Activity Planning
Works Instruction
Job Packets
Notification of Instruction from Supervisor
Receive Work Instructions
A531
Work Instruction
Work Packet Drawing
Commence Pump Assembly
A532
Finalised Assembly
Works Inspection Procedure on Equipment
Complete Pre-Assembly Checks
A533
Advise Projects Prior to Witness Test
Assembly Check-off
Perform Test & Witness Tests
A534
Non Conformances
Test Results
Release Dates
Final Inspection
A535
Assembly Records
Sign off Route Card & Notify Supervisor
Engineering Drawing & Route Card
Inspection Eq.& Calibration
Job Recording (Jobscope)
Fitting Shop Personnel
Project Manager
NODE: A53
TITLE: Pump Assembly & Product Inspection
NO.:


Schedule
Assembly Activity Plan
Test Bed Procedure Preparation
Works Inspection Procedure on Equipment
Order Book Test Date
Release Dates
Job Packets
Notification of Instruction from Supervisor
Receive Work Instructions
A541
Work Instruction
Commence Pump Assembly
A542
Finalised Assembly
Complete Pre-Assembly Checks
A543
Advise Projects Prior to Witness Test
Assembly Check-off
Test Equipment
Test Precedure
Perform Pump Test
A544
Non Conformances
Test Results
Complete Assembly Records & Inform Projects
A545
Assembly Records
Sign off Route Card & Notify Supervisor
Engineering Drawing & Route Card
Inspection Eq.& Calibration
Job Recording (Jobscope)
Fitting Shop Personnel
Project Manager Support
Order Book
NODE: A54
TITLE: Product Test
NO.:



Works Instruction
Assembly Activity Planning
Despatch Procedure
Job Packets
Receive Work Instructions
A551
Notification of Instruction from Supervisor
Work Instructions
Works Inspection Procedure on Equipment
Non Conformances
Complete Pre-Assembly Checks
A552
Assembly Checks
Final Inspection
A553
Inspection Sign off
Punch List (Quality Inspection
Packaging Arrangements & Despatch Product
A554
Assembly Records
Sign off Route Card & Notify Supervisor
Notification of Equipment Release
Engineering Drawing & Route Card
Inspection Eq.& Calibration
Job Recording (Jobscope)
Fitting Shop Personnel
Project Manager
Logistics Contractor
NODE: A55
TITLE: Piping & Packaging
NO.:

Appendix F: IDEF-ROBUSTNESS MODEL

	Target	Quotation				
		6000	9000	5000	10000	10000
NODE		A111	A112	A113	A114	A115
	Bm	1921	2753	1225	3361	3265

	A11 Quotation	Resource Description	Explicit Knowledg	Tool Quality	Tacit Knowledge	Input ID	Ci	mi	Wni	Wci	A111	A112	A113	A114	A115
Input	I2	Sales Forecast	8	5	8	I2	320	1	20%	0.63	1				
Controls	C2	Business Area	8	8	8	C2	512	1	20%	1.00		1			
	C3	CSS Guidelines	4	6	7	C3	168	4	80%	0.33		1	1	1	1
	C4	Commercial Risk Management	8	6	9	C4	432	2	40%	0.84		1		1	
	C5	Strategic Guidelines	7	8	7	C5	392	2	40%	0.77			1		1
	C9	Hydraulic Design Info	5	6	7	C9	210	5	100%	0.41	1	1	1	1	1
Resources & Tools	R1	CAD	8	5	7	R1	280	5	100%	0.55	1	1	1	1	1
	R2	CSS Guidelines	7	8	9	R2	504	3	60%	0.98	1			1	1
	R3	Commercial Manager Support	8	6	9	R3	432	2	40%	0.84	1	1			
	R4	Enquiry Tracking Databaase	8	8	7	R4	448	2	40%	0.88		1		1	
	R5	Pump Data Sheets	6	7	8	R5	336	2	40%	0.66				1	1
	R7	Quality Plan	9	8	5	R7	360	2	40%	0.70				1	1
Outputs	O1	Pumps Curves & P&ID	5	5	7	O1	175	5	100%	0.34	1	1	1	1	1
	O2	No Bid Scenario	3	4	8	O2	96	1	20%	0.19		1			
	O3	Cost Estimation Request	7	8	8	O3	448	2	40%	0.88				1	1
	O4	Request for Pump Verification	7	7	8	O4	392	1	20%	0.77					1

Mean	344.1
Max	512.0
Min	96.0

Mean	51.3
Max	72.6
Min	40.6

	A111	A112	A113	A114	A115
nj	6	9	5	10	10
Kpi	32%	31%	25%	34%	33%
Rn	25.0	15.4	35.6	15.7	15.0
Rco	53.4	40.6	72.6	46.1	43.7

		A12 Pump Selection Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge
Inputs	I1	Customer Requirements	5	6	9
	I2	Sales Forecast	8	5	8
	I3	Customer Contracts	8	8	8
	I4	Pump Verification	8	7	8
Controls	C1	Draft Specifications	5	5	7
	C2	Initial Quality Plan	6	6	6
	C3	Pump Price List	10	8	7
	C4	AP610 standard	9	6	8
	C5	Hydraulic Design Info	5	6	7
Resources & Tools	R1	CAD	8	5	7
	R2	Pump Data Sheets	6	7	8
	R3	Technical Data Book	7	8	5
	R4	Quality Plan	9	8	5
	R5	Test Bed Results	9	8	9
Outputs	O1	Pumps Curves & P&ID	5	5	7
	O2	Parts List	6	8	8
	O3	GA Drawing & Initial Quality Plan	8	8	9
	O4	Hydraulic Design	6	6	6
	O5	Pump Selection	7	7	8
	O6	Bid Docs (GA, Ordeset & QP)	7	7	8

Input ID	Ci	mi	Wni	Wci
I1	270	2	67%	0.42
I2	320	1	33%	0.49
I3	512	1	33%	0.79
I4	448	1	33%	0.69
C1	175	2	67%	0.27
C6	216	2	67%	0.33
C7	560	2	67%	0.86
C8	432	1	33%	0.67
C9	210	1	33%	0.32
R1	280	3	100%	0.43
R5	336	3	100%	0.52
R6	280	1	33%	0.43
R7	360	2	67%	0.56
R8	648	1	33%	1.00
O1	175	3	100%	0.27
O5	384	1	33%	0.59
O6	576	1	33%	0.89
O7	216	1	33%	0.33
O8	392	1	33%	0.60
O14	392	1	33%	0.60

Mean	359.1
Max	648.0
Min	175.0

Mean	39.2
Max	46.1
Min	32.7

	Pump Selection		
Target	8000	12000	11000
NODE	A121	A122	A123
Bm	2399	4076	3870
	1	1	
	1		
			1
	1		
		1	1
		1	1
		1	1
			1
	1		
	1	1	1
	1	1	1
		1	
	1	1	
		1	
	1	1	1
		1	
			1
			1
			1
		1	
nj	8	12	11
Kpi	30%	34%	35%
Rn	10.0	6.5	6.3
Rco	46.1	38.8	32.7

Category	ID	A13 Pump Quotation & Bid Clarification – Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge
Inputs	I5	Requestion for Cost Estimating	7	8	9
	I6	Pump Selection	6	8	9
	I7	Hydraulic Design	6	9	9
	C6	Initial Quality Plan	6	6	6
Controls	C10	Technical & Commercial Risk	7	6	9
	C11	Factored Item Requirements	7	8	8
	C12	Parts List	7	8	7
	C13	Manufacturing Schedule	7	8	8
	C14	Project Costing	7	7	8
Resources & Tools	R2	CSS Guidelines	7	8	9
	R6	Technical Data Book	7	8	5
	R9	Approved Supplier Database	8	7	8
	R10	Bid Forms & Docs	9	8	9
	R11	Scheduling & Capactity Plan	8	6	9
	R12	Bid Clarification Meeting	7	7	9
	R13	Pre-Calc system	8	8	8
	R14	Pump Price Lists	6	6	8
	R15	ODC logisitics	7	8	9
Outputs	O9	Cost Control Sheet	8	6	9
	O13	Bid Docs (GA, Ordeset & QP)	7	7	8

Input ID	Ci	mi	Wni	Wci
I5	504	1	25%	0.78
I6	432	1	25%	0.67
I7	486	1	25%	0.75
C6	216	4	100%	0.33
C10	378	1	25%	0.58
C11	448	1	25%	0.69
C12	392	1	25%	0.60
C13	448	3	75%	0.69
C14	392	2	50%	0.60
R2	504	1	25%	0.78
R6	280	1	25%	0.43
R9	448	1	25%	0.69
R10	648	2	50%	1.00
R11	432	1	25%	0.67
R12	441	1	25%	0.68
R13	512	1	25%	0.79
R14	288	1	25%	0.44
R15	504	1	25%	0.78
O9	432	1	25%	0.67
O14	392	3	75%	0.60

Mean	428.9
Max	648.0
Min	216.0

Mean	29.1
Max	46.4
Min	19.7

	Pump Quotation & Bid Clarification			
Target	8000	9000	7000	5000
NODE	A131	A132	A133	A134
Bm	3511	3698	2784	1952
	1			
	1			
	1			
	1	1	1	1
		1		
		1		
	1			
		1	1	1
			1	1
			1	
			1	
		1		
	1	1		
		1		
	1			
			1	
		1		
				1
			1	
	1	1		1
nj	8	9	7	5
Kpi	44%	41%	40%	39%
Rn	6.8	7.4	8.6	20.0
Rco	19.7	26.8	23.2	46.4

A14 Submision of Bid

		Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge
Inputs	I8	Bid Docs (GA, Ordeset & QP)	7	7	8
Controls	C10	Technical & Commercial Risk	7	6	9
	C15	Order Winning Guidelines	8	8	9
	C16	Commercial Guidelines	7	8	9
Resources & Tools	R16	Documnetation List	8	8	8
	R17	Equiry Tracking Database (Romeo)	7	8	7
	R18	Jobscope (ERP system)	8	7	7
	R19	Order Set (PDM)	6	7	6
	R20	CRM system	8	9	9
Outputs	O10	Enquiry No. (Enquiry Tracking Database)	7	8	8
	O11	Lost Bid Analysis	4	6	8
	O12	Cost Data & Orderset	7	8	9
	O13	Enter Order Details on Jobscope	8	7	8

Input ID	Ci	mi	Wni	Wci
I8	392	1	20%	0.60
C10	378	2	40%	0.58
C15	576	2	40%	0.89
C16	504	1	20%	0.78
R16	512	3	60%	0.79
R17	392	3	60%	0.60
R18	392	3	60%	0.60
R19	252	1	20%	0.39
R20	648	1	20%	1.00
O10	448	1	20%	0.69
O11	192	1	20%	0.30
O12	504	1	20%	0.78
O13	448	1	20%	0.69

Mean	433.7
Max	648.0
Min	192.0

Mean	27.7
Max	40.2
Min	18.2

	Submission of Bid				
Target	3000	3000	7000	3000	5000
NODE	A141	A142	A143	A144	A145
Bm	1408	1466	3346	976	1988
I8	1				
C10		1	1		
C15		1	1		
C16	1				
R16	1	1	1		
R17			1	1	1
R18			1	1	1
R19					1
R20			1		
O10			1		
O11				1	
O12					1
O13					1
nj	3	3	7	3	5
Kpi	47%	49%	48%	33%	40%
Rn	9.5	19.0	10.4	19.0	8.9
Rco	18.2	33.7	26.5	40.2	19.7

		A21 Order Review Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge
Inputs	I1	Notifcation of P.O.	9	3	9
	I2	Order Details	9	10	9
	I3	Contract Drawing & Orderset	6	5	7
	I4	Factored Items info	8	7	8
Controls	C1	Customer order details	7	8	7
	C2	Tender Documents (proj info)	7	7	6
	C3	Forward Load information	8	7	9
	C4	Contract Terms & Conditions	6	8	9
Resources	R1	Hot Propospects List	8	9	10
	R2	Supplier Drawing Requirements	9	9	7
	R3	Supply Source Designation	9	10	8
	R4	Forward Load	8	9	9
	R5	Product Spec (Orderset)	8	9	7
	R6	Project Costing (Pre-Cal)	9	8	9
	R7	Meetings Project Team	9	8	9
	R8	Quality & Test Plan	7	8	8
	R9	MS Project	8	7	9
	R10	Jobscope	9	8	8
Outputs	O2	Agreed Releases	6	8	8
	O3	Acceptance of Orderset and Supplier DRW	8	8	9
	O4	Project Review's Cost Reviews & Assembly Prog.	6	6	6
	O5	Defined Project Actions	7	7	8
	O6	Project Plan	8	7	8
	O7	Documentation Requirements	7	7	8

Input ID	Ci	mi	Wni	Wci
I1	243	1	20%	0.47
I2	810	1	20%	1.58
I3	210	1	20%	0.41
I4	448	1	20%	0.88
C1	392	3	60%	0.77
C2	294	3	60%	0.57
C3	504	3	60%	0.98
C4	432	1	20%	0.84
R1	720	1	20%	1.41
R2	567	1	20%	1.11
R3	720	1	20%	1.41
R4	648	1	20%	1.27
R5	504	1	20%	0.98
R6	648	1	20%	1.27
R7	648	5	100%	1.27
R8	448	1	20%	0.88
R9	504	1	20%	0.98
R10	576	2	40%	1.13
O1	384	1	20%	0.75
O2	576	1	20%	1.13
O3	216	1	20%	0.42
O4	392	1	20%	0.77
O5	448	1	20%	0.88
O6	392	1	20%	0.77

Mean	488.5
Max	810.0
Min	210.0

Mean	33.5
Max	49.7
Min	20.4

	A21 Order Review				
Target	5000	12000	6000	7000	5000
	A211	A212	A213	A214	A215
Bm	1712	3769.06	1858	2226	448
	1				
	1				
		1			
			1		
		1	1	1	
		1	1	1	
		1	1	1	
				1	
	1				
		1			
		1			
		1			
		1			
		1			
	1	1	1	1	1
				1	
					1
	1				1
		1			
		1			
			1		
					1
					1
				1	
nj	5	12	6	7	5
Kpi	34%	31%	31%	32%	9%
Rn	11.1	5.2	16.7	13.0	11.1
Rco	26.4	20.4	49.7	40.0	30.8

		A22 Project Amendments	Explicit Knowledge	Tool Quality	Tacit Knowledge
		Resource Description			
Inputs	I1	Order Release Mintutes	7	8	7
Controls	C1	Customer Related Documents	7	7	8
	C2	Foreign Exchange Contract	8	6	8
	C3	Revised Pre-Calc	8	8	9
	C4	Revised Orderset	8	7	8
Resources	R1	Quality Review	8	8	9
	R2	Project Review	9	8	8
	R3	Design Review	9	8	9
	R4	Orderset (Database)	8	8	8
	R5	PreCal (xls)	9	8	9
	R6	MS Project	8	7	8
	R7	Jobscope	8	9	8
	R8	Project File	8	8	8
Outputs	O2	Establish Bank Guarantees and Bonds	8	7	8
	O3	Establsed Foreign Exchange Contract	8	7	9
	O4	Quality & Test Plan	8	7	10
	O5	Project Specification & Order related Docs	7	8	8

Input ID	Ci	mi	Wni	Wci
I1	392	1	33%	0.60
C1	392	3	100%	0.60
C2	384	1	33%	0.59
C3	576	1	33%	0.89
C4	448	1	33%	0.69
R1	576	2	67%	0.89
R2	576	2	67%	0.89
R3	648	2	67%	1.00
R4	512	1	33%	0.79
R5	648	2	67%	1.00
R6	448	1	33%	0.69
R7	576	1	33%	0.89
R8	512	1	33%	0.79
O1	448	1	33%	0.69
O2	504	1	33%	0.78
O3	560	1	33%	0.86
O4	448	1	33%	0.69

Mean	508.7
Max	648.0
Min	384.0

Mean	21.1
Max	29.5
Min	8.9

	A22 Project Amendments			
Target	8000	6000	3000	6000
	A221	A222	A223	A224
Bm	3920	3408	1616	2936
	1			
	1		1	1
	1			
			1	
		1		
	1	1		
	1	1		
	1	1		
		1		
		1	1	
				1
				1
				1
	1			
	1			
				1
				1
nj	8	6	3	6
Kpi	49%	57%	54%	49%
Rn	5.7	7.4	16.7	3.7
Rco	22.0	23.9	29.5	8.9

		A23 Project Planning and Control Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge	Input ID	Ci	mi	Wni	Wci	A231	A232	A233	A234
Inputs	I1	Project Amendments	8	8	7	I1	448	1	25%	0.55	1			
	I2	Final Project Plan (orderset, milestones)	7	8	7	I2	392	1	25%	0.48			1	
	I3	Certification	8	8	7	I3	448	1	25%	0.55				1
Controls	C1	Vendor Document Requirement List	7	6	7	C1	294	2	50%	0.36	1	1		
	C2	Updated Orderset	8	8	8	C2	512	3	75%	0.63		1	1	1
	C3	Final Quality Plan	9	8	8	C3	576	3	75%	0.71		1	1	1
	C4	Project Plan (Jobscope)	9	8	8	C4	576	1	25%	0.71			1	
	C5	Project Specifications	9	8	9	C5	648	1	25%	0.80			1	
Resources	R1	Documentation Register	9	8	7	R1	504	1	25%	0.62		1		
	R2	MS Project & Jobscope	9	8	9	R2	648	2	50%	0.80		1	1	
	R3	Project Meetings with Client and Suppliers	9	9	9	R3	729	2	50%	0.90		1	1	
	R4	Project Reviews	9	10	9	R4	810	2	50%	1.00		1	1	
	R5	Assembly Programme	9	9	9	R5	729	1	25%	0.90				1
Outputs	O2	Updated Project File	9	9	9	O2	729	1	25%	0.90				1
	O3	Project Plan	9	9	8	O3	648	1	25%	0.80				1

	A23 Project Planning and Control			
Target	2000	7000	8000	6000
	A231	A232	A233	A234
Bm	742	4073	4891	3642
nj	2	7	8	6
Kpi	37%	58%	61%	61%
Rn	10.0	11.4	8.0	7.4
Rco	13.2	38.1	29.7	19.9

Mean	579.4
Max	810.0
Min	294.0

Mean	25.2
Max	38.1
Min	13.2

		A24 Project Progress Reporting Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge	Input ID	Ci	mi	Wni	Wci	A241	A242	A243	A244	A245
Inputs	I1	Project Amendments	9	7	6	I1	378	1	20%	0.52	1				
	I2	Final Project Plan, Order Set & Stage Payments	10	7	9	I2	630	1	20%	0.86	1				
Controls	I3	Test Bed Schedule	8	8	8	I3	512	1	20%	0.70			1		
	I4	Certification	9	8	8	I4	576	1	20%	0.79					1
	C1	Project Amendments	9	7	7	C1	441	2	40%	0.60		1	1		
	C2	Projects Specifications	8	8	8	C2	512	2	40%	0.70	1		1		
	C3	Commerical Implications	9	8	7	C3	504	3	60%	0.69	1		1		1
	C4	Vendor Documentation Requirements List	9	9	9	C4	729	1	20%	1.00		1			
	C5	Quality Plan	9	9	8	C5	648	3	60%	0.89			1	1	1
Resources	R1	Punch List	9	9	9	R1	729	4	80%	1.00	1		1	1	1
	R2	Project Meetings with Client & Suppliers	10	8	8	R2	640	2	40%	0.88	1		1		
	R3	Documentation Register	9	9	9	R3	729	1	20%	1.00		1			
	R4	MS Project & Jobscope	8	7	9	R4	504	3	60%	0.69	1		1	1	
	R5	Cost Report	8	8	8	R5	512	1	20%	0.70					1
	R6	Test Results	8	9	7	R6	504	1	20%	0.69					1
	R7	Documentation List	9	8	9	R7	648	1	20%	0.89					1
Outputs	O2	Project File Updates	9	7	8	O2	504	4	80%	0.69	1	1	1	1	
	O3	Raise Invoice	9	8	8	O3	576	1	20%	0.79				1	
	O4	Closeout Report	7	6	7	O4	294	1	20%	0.40				1	
	O5	Installation & Commissioning Information	9	5	8	O5	360	1	20%	0.49					1
	O6	Technical Manual	9	7	9	O6	567	1	20%	0.78					1

	Ci
Mean	547.5
Max	729.0
Min	294.0

Mean	34.1
Max	46.1
Min	20.3

	IDEF Process Group				
Target	8000	4000	9000	5000	7000
	A241	A242	A243	A244	A245
Bm	4401	2403	4994	3255	5048
nj	8	4	9	6	9
Kpi	55%	60%	55%	65%	72%
Rn	12.5	12.5	12.8	16.7	6.0
Rco	39.0	20.3	43.1	46.1	22.2

A31 Design Review

Category	ID	Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge
Inputs	I1	Customer Details	7	8	8
	I3	Order Set	8	7	7
	I5	Order Review Minutes	8	8	7
Controls	C1	Design Control Procedure	7	8	8
	C2	Tender Documents (GA, order set, QP Pre-Cal)	7	7	8
	C3	Customer Order Details	8	8	9
	C4	Customer Related Documentation	7	8	8
Resources & Tools	R1	ODC Schedule	9	9	9
	R2	Project Plan	9	7	8
	R3	Quality Plan	8	9	9
	R4	Scheduling & Capacity Planning	9	9	9
	R5	Meeting	8	9	9
	R6	Project Team	7	8	9
Outputs	O1	Customer Order Details	8	8	9
	O2	Design Control Plan	7	9	9
	O3	Design Review Minutes	8	9	8

Input ID	Ci	mi	Wni	Wci
I1	448	1	25%	0.61
I3	392	1	25%	0.54
I5	448	1	25%	0.61
C1	448	1	25%	0.61
C2	392	2	50%	0.54
C3	576	1	25%	0.79
C4	448	2	50%	0.61
R1	729	1	25%	1.00
R2	504	1	25%	0.69
R3	648	1	25%	0.89
R4	729	1	25%	1.00
R5	648	1	25%	0.89
R6	504	1	25%	0.69
O1	576	1	25%	0.79
O2	567	0	0%	0.78
O3	576	0	0%	0.79

Mean	539.6
Max	729.0
Min	392.0

Mean	11.8
Max	33.3
Min	0.0

	IDEF Process Group			
Target	3000	7000	2000	4000
	A311	A312	A313	A314
Bm	1288	4210	840	1992
I1	1			
I3	1			
I5		1		
C1	1			
C2			1	1
C3		1		
C4			1	1
R1		1		
R2		1		
R3		1		
R4		1		
R5				1
R6				1
O1		1		
O2				
O3				
nj	3	7	2	4
Kpi	43%	60%	42%	50%
Rn	0.0	0.0	20.0	7.1
Rco	0.0	0.0	33.3	14.1

		A32 Design Amendments / Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge
Inputs	I1	Design Control Plan	7	7	9
	I3	Order Review Minutes	7	9	7
	I5	Proposed Quality Plan	8	9	8
Controls	C1	Tender Documents (GA, order set, QP Pre-Cal)	7	8	8
	C2	Customer Order Details	8	8	7
	C3	Hydraulic Design	9	9	9
	C4	API 610 Standard	9	8	10
	C5	Factored Item P.O.s	8	8	8
	C6	Client's Amendments	6	6	7
Resources & Tools	R1	Design Review Meetings	9	9	9
	R2	Jobscope	8	8	8
	R3	CAD	9	8	9
	R4	Flow Model System	9	9	10
Outputs	O1	Final Design Plan	9	9	9
	O2	Hydraulic Design	9	9	9
	O3	Hydraulic Data Sheets	9	10	9
	O4	Seal Data Sheets	8	9	9
	O5	Pump Design	8	9	9
	O6	Coupling Data Sheets	9	9	9
	O7	Rotodynamic Calculations	8	9	9
	O8	Packaging Design	8	9	8
	O9	Pump Design & Skid Layout	7	8	8
	O10	Final Assembly Drawings	9	9	8
	O11	Amended Order Set	9	7	9

Input ID	Ci	mi	Wni	Wci
I1	441	1	33%	0.54
I3	441	1	33%	0.54
I5	576	1	33%	0.71
C1	448	1	33%	0.55
C2	448	1	33%	0.55
C3	729	2	67%	0.90
C4	720	2	67%	0.89
C5	512	2	67%	0.63
C6	252	3	100%	0.31
R1	729	3	100%	0.90
R2	512	4	133%	0.63
R3	648	3	100%	0.80
R4	810	3	100%	1.00
O1	729	1	33%	0.90
O2	729	1	33%	0.90
O3	810	1	33%	1.00
O4	648	1	33%	0.80
O5	648	1	33%	0.80
O6	729	1	33%	0.90
O7	648	1	33%	0.80
O8	576	0	0%	0.71
O9	448	0	0%	0.55
O10	648	0	0%	0.80
O11	567	0	0%	0.70

	Ci
Mean	601.9
Max	810.0
Min	252.0

	Wci
Mean	54.6
Max	50.4
Min	23.8

	IDEF Process Group			
Target	9000	6000	11000	8000
	A321	A322	A323	A324
Bm	5206	3752	6937	4687
I1	1			
I3	1			
I5				1
C1	1			
C2	1			
C3	1		1	
C4		1	1	
C5			1	1
C6		1	1	1
R1	1		1	1
R2	1	1	1	1
R3		1	1	1
R4		1	1	1
O1	1			
O2	1			
O3		1		
O4			1	
O5			1	
O6			1	
O7				1
O8				
O9				
O10				
O11				
nj	9	6	11	8
Kpi	58%	63%	63%	59%
Rn	5.6	18.5	9.1	13.6
Rco	23.8	50.4	40.2	49.3

A33 Engineering Design Details

Category	ID	Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge
Inputs	I1	Design Planning Notes	7	8	7
	I2	Amended Order Set	8	7	7
	I3	Pump Design Study	9	8	8
Controls	C1	API 610 Standard	8	8	9
	C2	Quality Plan	8	9	9
	C3	Project Plan & Customer Documentation	7	8	8
	C4	Performance Data Sheets	9	9	9
	C5	Pump Duty Speeds and Speed Rates	9	10	9
	C6	Pump Set Packaging GA	8	9	8
Resources & Tools	R1	CAD	9	9	8
	R2	Hydraulic Data Sheets	9	10	9
	R3	Jobscope (Design Register)	9	9	8
	R4	Scheduling Data & Capacity Planning	9	9	9
	R5	Design Planning Notes	8	9	7
	R6	Computer Management System	9	8	9
Outputs	O1	Hydraulic Drawings	9	9	8
	O2	Performance Data Sheets	9	10	8
	O3	Pump Set	8	9	9
	O4	Final Packaging GA & P&ID	8	9	8
	O5	Base Plate Drawing	8	9	9
	O6	Update Drawing Register	9	8	8
	O6	Pattern Requirements	9	9	9
	O7	Pump Set and Packaging	9	8	8
	O8	Coupling Drawings	9	9	9
	O9	Specific Pump Duty Speeds and Speed Rates	8	9	8

Input ID	Ci	mi	Wni	Wci
I1	392	1	25%	0.48
I2	392	1	25%	0.48
I3	576	1	25%	0.71
C1	576	4	100%	0.71
C2	648	4	100%	0.80
C3	448	4	100%	0.55
C4	729	1	25%	0.90
C5	810	1	25%	1.00
C6	576	1	25%	0.71
R1	648	1	25%	0.80
R2	810	1	25%	1.00
R3	648	1	25%	0.80
R4	729	2	50%	0.90
R5	504	1	25%	0.62
R6	648	1	25%	0.80
O1	648	1	25%	0.80
O2	720	1	25%	0.89
O3	648	1	25%	0.80
O4	576	1	25%	0.71
O5	648	1	25%	0.80
O6	576	1	25%	0.71
O6	729	1	25%	0.90
O7	576	1	25%	0.71
O8	729	1	25%	0.90
O9	576	1	25%	0.71

Mean	622.4
Max	810.0
Min	392.0

Mean	36.5
Max	46.1
Min	23.0

	IDEF Process Group			
Target	8000	13000	8000	6000
	A331	A332	A333	A334
Bm	4634	8341	4705	3625
I1	1			
I2	1			
I3		1		
C1	1	1	1	1
C2	1	1	1	1
C3	1	1	1	1
C4		1		
C5		1		
C6			1	
R1		1		
R2	1			
R3		1		
R4		1	1	
R5			1	
R6				1
O1	1			
O2	1			
O3		1		
O4			1	
O5			1	
O6		1		
O6		1		
O7		1		
O8				1
O9				1
nj	8	13	8	6
Kpi	58%	64%	59%	60%
Rn	4.0	2.7	4.5	50.0
Rco	36.1	23.0	40.7	46.1

		A34 Generation of Manufacturing Drawings Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge
Inputs	I1	Pre-information from Projects	6	8	9
	I2	Component Drawing Specifications	8	9	8
	I3	Pump Design Study	9	9	10
	I4	Pattern Information	7	8	9
Controls	C1	API610 Standard	9	9	9
	C2	Quality Plan	9	8	9
	C3	Coupling Drawings & C&G Locations	7	8	9
	C4	Pump Duty Speed and Speed Rates	9	7	9
	C5	Results of Damping Criteria	9	10	9
	C6	Component Drawings	9	9	9
Resources & To	R1	PDM (CAD)	8	9	9
	R2	Jobscope	9	9	9
	R3	Coupling Drawings & C&G Locations Guide notes	7	9	9
	R4	Pump Duty Speed and Speed Rates	9	10	9
	R5	CAD	9	9	9
	R6	Design Register	9	8	9
	R7	Scheduling Data & Capacity Planning	9	9	9
	R8	Computer Management System	9	8	9
Outputs	O1	Component Drawings	9	9	9
	O2	Coupling Drawings & C&G locations	9	9	9
	O3	Mechanical Analysis	9	9	10
	O4	Releases for Assembly Plan	9	8	9
	O6	Works Orders	8	8	7
	O7	Final Manufacturing GA Drawing	9	8	9
	O8	Purchase Orders	8	8	8

Input ID	Ci	mi	Wni	Wci
I1	432	1	25%	0.53
I2	576	1	25%	0.71
I3	810	1	25%	1.00
I4	504	1	25%	0.62
C1	729	4	100%	0.90
C2	648	4	100%	0.80
C3	504	1	25%	0.62
C4	567	1	25%	0.70
C5	810	1	25%	1.00
C6	729	0	0%	0.90
R1	648	1	25%	0.80
R2	729	1	25%	0.90
R3	567	1	25%	0.70
R4	810	1	25%	1.00
R5	729	3	75%	0.90
R6	648	4	100%	0.80
R7	729	2	50%	0.90
R8	648	2	50%	0.80
O1	729	1	25%	0.90
O2	729	1	25%	0.90
O3	810	1	25%	1.00
O4	648	1	25%	0.80
O6	448	1	25%	0.55
O7	648	1	25%	0.80
O8	512	1	33%	0.63

Mean	653.6
Max	810.0
Min	432.0

Mean	44.1
Max	62.1
Min	34.3

	IDEF Process Group			
Target	9000	11000	7000	10000
	A341	A342	A343	A344
Bm	5868	7326	4779	6549
I1	1			
I2	1			
I3		1		
I4		1		
C1	1	1	1	1
C2	1	1	1	1
C3		1		
C4		1		
C5				1
C6				
R1	1			
R2	1			
R3		1		
R4		1		
R5		1	1	1
R6	1	1	1	1
R7			1	1
R8			1	1
O1	1			
O2	1			
O3		1		
O4			1	
O6				1
O7				1
O8				1
nj	9	11	7	10
Kpi	65%	67%	68%	65%
Rn	3.6	3.6	6.6	43.3
Rco	34.5	34.3	62.1	45.4

A41 Releases, Pump, Piping Base Plate & Auxilary

		Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge	Input ID	Ci	mi	Wni	Wci	A411	A412	A413	A414
Inputs	I1	Engineering BOMs	9	9	7	I1	567	1	25%	0.78	1			
	I2	Manufacturing Drawings	9	9	7	I2	567	1	25%	0.78	1			
	I3	Engineering Works Orders	9	9	8	I3	648	1	25%	0.89	1			
	I4	Data Sheets (Order Set)	9	8	8	I4	576	1	25%	0.79		1		
Controls	C1	Job Specification	8	7	8	C1	448	1	25%	0.61	1			
	C2	SQA (Quality Assurance)	8	8	9	C2	576	4	100%	0.79	1	1	1	1
	C3	Pre-Calc Order Set	9	9	9	C3	729	2	50%	1.00		1	1	
	C4	Quality Plan	8	9	8	C4	576	2	50%	0.79	1	1		
Resources & Tools	R1	Drawings & ISOs	8	9	8	R1	576	1	25%	0.79	1			
	R2	Assembly Plan	7	8	9	R2	504	1	25%	0.69	1			
	R3	Jobscope (Loading)	8	9	7	R3	504	2	50%	0.69		1		1
	R4	MC2000 (Scheduling)	9	9	7	R4	567	2	50%	0.78		1	1	
Outputs	O1	Enginering BOM	8	9	7	O1	504	1	25%	0.69	1			
	O2	Engineering Releases	9	9	9	O2	729	1	25%	1.00	1			
	O3	SQA Levels	8	8	8	O3	512	1	25%	0.70		1		
	O4	Quality Plan	9	8	9	O4	648	1	25%	0.89		1		
	O5	Schedule Completion Date	8	9	9	O5	648	1	25%	0.89			1	
	O5	Raise P.Os	8	9	10	O5	720	1	25%	0.99				1

	Ci
Mean	588.8
Max	729.0
Min	448.0

Mean	31.0
Max	41.3
Min	13.5

	IDEF Process Group			
Target	10000	8000	4000	3000
	A411	A412	A413	A414
Bm	3760	1865	1376.06	1191
ni	10	8	4	3
Kpi	38%	23%	34%	40%
Rn	1.9	4.2	6.0	44.4
Rco	13.5	29.2	40.0	41.3

Group	ID	A42 Routings & Creation of Works Orders Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge
Inputs	I1	Order Book	9	9	7
	I2	Unplanned Work	6	9	7
	I3	Routings MC2000	7	9	8
	I4	Non Standard Routings	6	5	7
Controls	C1	M/C loading	8	9	8
	C2	Inspection List SQA	8	8	9
	C3	Article Numbers	9	9	9
	C4	Schedule Completion Date	8	9	8
Resources & Tools	R1	Jobscope ERP)	8	9	9
	R2	MC2000 (MRP)	7	8	9
	R3	NC programmes	8	9	8
	R4	CAD	9	9	9
	R5	NACE Requirements	9	8	9
Outputs	O1	Manual Routings	8	9	7
	O2	Purchase Order Requisitions	9	9	9
	O3	Works Orders	8	8	8
	O4	Raised Requisitions	9	8	9

Input ID	Ci	mi	Wni	Wci
I1	567	1	25%	0.78
I2	378	1	25%	0.52
I3	504	1	25%	0.69
I4	210	1	25%	0.29
C1	576	2	50%	0.79
C2	576	2	50%	0.79
C3	729	1	25%	1.00
C4	576	1	25%	0.79
R1	648	3	75%	0.89
R2	504	2	50%	0.69
R3	576	2	50%	0.79
R4	729	2	50%	1.00
R5	648	1	25%	0.89
O1	504	1	25%	0.69
O2	729	1	25%	1.00
O3	512	1	25%	0.70
O4	648	1	25%	0.89

	Ci
Mean	565.5
Max	729.0
Min	210.0

Mean	25.6
Max	41.9
Min	16.4

	IDEF Process Group			
Target	5000	6000	4000	9000
	A421	A422	A423	A424
Bm	2673	3843	2529	4826
I1	1			
I2	1			
I3				1
I4				1
C1		1	1	
C2	1			1
C3		1		
C4				1
R1	1		1	1
R2		1		1
R3		1	1	
R4		1	1	
R5				1
O1	1			
O2		1		
O3				1
O4				1
nj	5	6	4	9
Kpi	53%	64%	63%	54%
Rn	2.0	6.7	3.8	14.8
Rco	23.3	20.7	41.9	16.4

		A43 Scheduling										IDEF Process Group			
											Target	9000	4000	2000	2000
												A431	A432	A433	A434
		Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge	Input ID	Ci	mi	Wni	Wci	Bm	5548	2682	1224	1386
Inputs	I1	Material Movement	7	8	7	I1	392	1	25%	0.48		1			
	I2	Order Set	8	8	8	I2	512	1	25%	0.63		1			
	I3	Works Orders	7	8	9	I3	504	1	25%	0.62		1			
Controls	C1	Schedule Date	9	9	9	C1	729	1	25%	0.90		1			
	C2	Pre-Calc	9	8	8	C2	576	4	100%	0.71		1	1	1	1
	C3	Cost Centres	8	7	8	C3	448	0	0%	0.55					
	C4	Capacity Constraints (Under/Over)	9	8	9	C4	648	2	50%	0.80			1	1	
Resources & Tools	R1	Plant Meeting	9	10	9	R1	810	1	25%	1.00		1			
	R2	MC2000	8	9	9	R2	648	1	25%	0.80		1			
	R3	Shuffle Board Meeting	9	10	9	R3	810	2	50%	1.00			1		1
Outputs	O1	Shop Load	9	9	9	O1	729	1	25%	0.90		1			
	O2	New Loading Scenario	8	9	9	O2	648	1	25%	0.80		1			
	O3	Programme Changes	8	9	9	O3	648	1	25%	0.80			1		

Mean	623.2
Max	810.0
Min	392.0

Mean	43.9
Max	64.7
Min	10.4

	A431	A432	A433	A434
nj	9	4	2	2
Kpi	62%	67%	61%	69%
Rn	3.5	3.1	6.3	0.0
Rco	10.4	39.6	64.7	61.0

		A44 Capacity planning Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge
Inputs	I1	Forward Load Data	8	8	9
	I2	Order Book	7	7	9
	I3	Test Bed Results	8	8	9
	I4	Task List	9	8	9
	I5	Shop Floor Data	9	9	9
Controls	C1	Production Schedule	9	9	9
	C2	Shop Floor Plan	9	9	9
	C3	M/C Activity Plan	9	10	9
Resources & Tools	R1	Capacity Planning Model	9	9	9
	R2	Banked Hours (Database)	9	10	10
	R3	Plant Meeting	9	9	9
	R4	Work Packets	9	9	9
	R5	Supplier Databse	9	9	9
Outputs	O1	Task List/Job Instruction	8	8	9
	O2	Mid Range Capacity	9	8	9
	O3	Resource Against Load	8	9	9
	O4	Shop Floor Data	9	7	9
	O5	Task list	8	8	9
	O4	Goods Receiving	6	8	9

Input ID	Ci	mi	Wni	Wci
I1	576	1	25%	0.64
I2	441	1	25%	0.49
I3	576	1	25%	0.64
I4	648	1	25%	0.72
I5	729	1	25%	0.81
C1	729	4	100%	0.81
C2	729	2	50%	0.81
C3	810	2	50%	0.90
R1	729	1	25%	0.81
R2	900	2	50%	1.00
R3	729	2	50%	0.81
R4	729	2	50%	0.81
R5	729	1	25%	0.81
O1	576	1	25%	0.64
O2	648	1	25%	0.72
O3	648	1	25%	0.72
O4	567	1	25%	0.63
O5	576	1	25%	0.64
O4	432	1	25%	0.48

Mean	657.9
Max	900.0
Min	432.0

Mean	30.0
Max	35.7
Min	23.3

	IDEF Process Group			
Target	5000	5000	11000	6000
	A441	A442	A443	A444
Bm	3123	3735	7569	4158
I1	1			
I2	1			
I3			1	
I4			1	
I5		1		
C1	1	1	1	1
C2			1	1
C3			1	1
R1	1			
R2		1	1	
R3		1	1	
R4			1	1
R5				1
O1			1	
O2	1			
O3		1		
O4			1	
O5			1	
O4				1
nj	5	5	11	6
Kpi	62%	75%	69%	69%
Rn	2.7	4.5	3.3	33.3
Rco	23.3	34.1	26.8	35.7

A51 Goods Receving Inspection

	ID	Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge
Inputs	I1	Delivery Notes	9	7	8
	I2	Shop Task Last	8	8	9
	I3	Partnership Supplier Information (Labels)	9	7	9
Controls	C1	Certification Control	9	8	8
	C2	Routings	8	9	8
	C3	Activity Plan	9	8	8
	C4	M/C Shop	8	8	8
	C5	Assembly Shop	9	8	9
Resources & Tools	R2	MC2000 (MRP)	9	8	9
	R3	Shuffle Board	9	9	8
	R4	Shortage Control Sheet	8	8	7
	R5	Job Recording	9	8	8
	R6	Goods Inwards Inspection	9	8	9
	R7	Production Control	9	9	7
	R8	Production Labels	9	8	9
Outputs	O1	Delivery Notes	8	8	9
	O2	Cast Numbers	9	8	9
	O3	Non Connformance Reporting	8	7	8
	O4	Updated BOM	8	9	9
	O5	Kit Boxes	9	9	8
	O6	Releases to Fitting/Assembly Shop	9	8	8
	O7	Releases to Machine Shop	9	9	8
	O8	Fast Track Releases	8	8	7

		IDEF Process Group			
Target		3000	8000	7000	10000
		A511	A512	A513	A514
Bm		1800	4568	10719	5766

Input ID	Ci	mi	Wni	Wci	A511	A512	A513	A514
I1	504	1	25%	0.78		1		
I2	576	1	25%	0.89	1			
I3	567	1	25%	0.88				1
C1	576	1	25%	0.89		1		
C2	576	2	50%	0.89			1	1
C3	576	2	50%	0.89			1	1
C4	512	1	25%	0.79				1
C5	648	1	25%	1.00				1
R2	648	3	325%	1.00	1	1	11	
R3	648	1	25%	1.00		1		
R4	448	1	25%	0.69		1		
R5	576	1	25%	0.89			1	
R6	648	1	25%	1.00		1		
R7	567	2	50%	0.88			1	1
R8	648	1	25%	1.00				1
O1	576	1	25%	0.89	1			
O2	648	1	25%	1.00		1		
O3	448	1	25%	0.69		1		
O4	648	1	25%	1.00			1	
O5	648	1	25%	1.00			1	
O6	576	1	25%	0.89				1
O7	648	1	25%	1.00				1
O8	448	1	25%	0.69				1

Mean	580.8
Max	648.0
Min	448.0

Mean	23.3
Max	49.7
Min	9.5

	A511	A512	A513	A514
nj	3	8	7	10
Kpi	60%	57%	153%	58%
Rn	2.6	1.0	13.7	10.0
Rco	24.0	9.5	49.7	9.9

		A52 Machine Shop & Component Inspection Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge
Inputs	I1	Job Packets	9	8	9
	I2	Notification of Instruction	9	8	9
	I3	Special Tooling	8	9	8
Controls	C1	QC of Equipment & Calibraton	9	8	9
	C2	M/C Activity Planning	9	9	8
	C3	Quality Control (Rev No. Cast No. Chit No.)	9	9	9
	C4	Machinist Banked Hours	10	9	9
Resources & Tools	R1	Engineering Drawing & Route Card	9	8	8
	R2	Inspection Equipment	8	9	8
	R3	Job Recording (Jobscope)	9	9	8
	R4	Machine Tool	9	9	9
	R5	NC Support Programmes	8	9	8
Outputs	O1	Work Packet Drawing	8	9	8
	O2	Rough Out Inspection	8	8	9
	O3	Rough Cut Inspection	8	8	9
	O4	Finished M/C component	9	9	9
	O5	Signed off Route Card & Notify Supervisor	8	8	9

Input ID	Ci	mi	Wni	Wci
I1	648	1	25%	0.80
I2	648	1	25%	0.80
I3	576	1	25%	0.71
C1	648	2	50%	0.80
C2	648	3	75%	0.80
C3	729	3	75%	0.90
C4	810	2	50%	1.00
R1	576	3	75%	0.71
R2	576	3	75%	0.71
R3	648	3	75%	0.80
R4	729	3	75%	0.90
R5	576	3	75%	0.71
O1	576	1	25%	0.71
O2	576	1	25%	0.71
O3	576	1	25%	0.71
O4	729	1	25%	0.90
O5	576	1	25%	0.71

Mean	637.9
Max	810.0
Min	576.0

Mean	45.0
Max	55.5
Min	28.3

	IDEF Process Group			
Target	6000	8000	9000	10000
	A521	A522	A523	A524
Bm	3816	4986	5868	6597
I1	1			
I2	1			
I3		1		
C1	1	1		
C2	1		1	1
C3		1	1	1
C4			1	1
R1		1	1	1
R2		1	1	1
R3	1		1	1
R4		1	1	1
R5		1	1	1
O1	1			
O2		1		
O3			1	
O4				1
O5				1
nj	6	8	9	10
Kpi	64%	62%	65%	66%
Rn	4.2	6.9	8.3	50.0
Rco	28.3	46.9	55.5	49.4

	IDEF Process Group				
Target	5000	6000	6000	7000	7000
	A531	A532	A533	A534	A535
Bm	3176	4311	4257	4887	5031

		A53 Pump Assembly & Product Inspection Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge	Input ID	Ci	mi	Wni	Wci	A531	A532	A533	A534	A535
Inputs	I1	Job Packets	8	8	8	I1	512	1	20%	0.57	1				
	I2	Notification of Instructiton from Supervisor	7	9	9	I2	567	1	20%	0.63	1				
Controls	C1	Work Instructions	9	9	8	C1	648	4	80%	0.72	1	1		1	1
	C2	Assembly Activity Planning	9	9	9	C2	729	2	40%	0.81			1	1	
	C3	Works Packet Drawing	9	8	8	C3	576	1	20%	0.64		1			
	C4	Works Inspection Procedure on Equipment	9	9	9	C4	729	2	40%	0.81			1	1	
	C5	Release Dates	10	9	9	C5	810	1	20%	0.90					1
Resources & Tools	R1	Engineering Drawing & Route Card	9	9	9	R1	729	4	80%	0.81		1	1	1	1
	R2	Inspection Equipment & Calibration	10	9	10	R2	900	4	80%	1.00		1	1	1	1
	R3	Job Recording	9	9	9	R3	729	3	60%	0.81	1	1			1
	R4	Project Manager Support	7	9	8	R4	504	1	20%	0.56				1	
Outputs	O1	Work Instruction	9	8	10	O1	720	1	20%	0.80	1				
	O2	Finalised Assembly	9	9	9	O2	729	1	20%	0.81		1			
	O3	Assembly Check-off	9	9	9	O3	729	1	20%	0.81			1		
	O4	Assembly Records	8	9	9	O4	648	1	20%	0.72					1
	O5	Adivse Projects prior to Witness Test	7	7	9	O5	441	1	20%	0.49			1		
	O6	Non Conformances (NCRs)	8	9	9	O6	648	1	20%	0.72				1	
	O7	Route Card Sign off & notify Supervisor	9	7	9	O7	567	1	20%	0.63					1
	O8	Test Results	9	7	9	O8	567	0	0%	0.63					

Mean	656.9
Max	900.0
Min	441.0

Mean	38.6
Max	48.1
Min	26.8

	A531	A532	A533	A534	A535
nj	5	6	6	7	7
Kpi	64%	72%	71%	70%	72%
Rn	4.3	8.0	5.8	39.3	39.3
Rco	26.8	48.1	37.3	42.4	41.2

		A54 Product Test Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge
Inputs	I1	Job Packets	8	8	8
	I2	Notification of Instructiton from Supervisor	7	9	9
	I3	Test Equipment	8	8	9
Controls	C1	Activity Assembly Plan	9	9	9
	C2	Schedule	9	7	9
	C3	Test Bed Precedure Preparation	8	7	9
	C4	Works Inspection Procedure on Equipment	9	9	9
	C5	Order Book Test Data	9	9	9
	C6	Release Dates	9	8	9
Resources & Tools	R1	Engineering Drawing & Route Card	9	9	10
	R2	Inspection Equipment & Calibration	9	8	10
	R3	Job Recording	7	7	9
	R4	Project Manager Support	8	8	9
	R5	Order Book	8	8	9
Outputs	O1	Works Instruction	9	8	10
	O2	Finalised Assembly	9	9	9
	O3	Advise Projects Prior to Witness Test	7	7	9
	O4	Assembly Check-off	9	9	9
	O5	Non Conformances Reporting (NCRs)	8	9	9
	O6	Test Results	8	7	9
	O7	Assembly Records	9	7	9
	O8	Sign off Route Card & Notify Supervisor	9	9	9

Input ID	Ci	mi	Wni	Wci
I1	512	1	20%	0.63
I2	567	1	20%	0.70
I3	576	1	20%	0.71
C1	729	3	60%	0.90
C2	567	2	40%	0.70
C3	504	5	100%	0.62
C4	729	2	40%	0.90
C5	729	2	40%	0.90
C6	648	1	20%	0.80
R1	810	4	80%	1.00
R2	720	4	80%	0.89
R3	441	4	80%	0.54
R4	576	4	80%	0.71
R5	576	4	80%	0.71
O1	720	1	20%	0.89
O2	729	1	20%	0.90
O3	441	1	20%	0.54
O4	729	1	20%	0.90
O5	648	1	20%	0.80
O6	504	1	20%	0.62
O7	567	1	20%	0.70
O8	729	1	20%	0.90

Mean	625.0
Max	810.0
Min	441.0

Mean	49.6
Max	59.7
Min	42.5

	IDEF Process Group				
Target	9000	6000	9000	11000	11000
	A541	A542	A543	A544	A545
Bm	5192	3933	5652	6813	7029
I1	1				
I2	1				
I3				1	
C1	1	1			1
C2	1		1		
C3	1	1	1	1	1
C4			1	1	
C5				1	1
C6					1
R1		1	1	1	1
R2		1	1	1	1
R3	1	1		1	1
R4	1		1	1	1
R5	1		1	1	1
O1	1				
O2		1			
O3			1		
O4			1		
O5				1	
O6				1	
O7					1
O8					1

nj	9	6	9	11	11
Kpi	58%	66%	63%	62%	64%

Rn	6.8	9.6	7.7	47.7	50.0
Rco	42.5	59.7	50.2	47.1	48.3

		A55 Piping & Packaging	Explicit Knowledge	Tool Quality	Tacit Knowledge
		Resource Description			
Inputs	I1	Job Packets	8	8	8
	I2	Notification of Instructiton from Supervisor	7	9	9
	I3	Punch List Quality Inspection	8	7	9
	I4	Notification of Equipment Release	9	9	9
Controls	C1	Activity Assembly Plan	9	7	9
	C2	Works Instruction	8	7	9
	C3	Works Instruction Procedure on Equipment	9	9	9
	C4	Depatch Procedure	9	9	9
Resources & Tools	R1	Engineering Drawing & Route Card	9	8	9
	R2	Inspection Equipment & Calibration	9	9	10
	R3	Job Recording	9	8	10
	R4	Project Manager Support	7	7	9
Outputs	O1	Works Instruction	8	8	9
	O2	Completed Assembly Checks	8	8	9
	O3	Non Conformance Reports (NCRs)	9	8	10
	O4	Inspection Sign-Off	9	8	9
	O5	Assembly Records	7	7	9
	O6	Sign off Route Card & Notify Supervisor	9	8	9

Input ID	Ci	mi	Wni	Wci
I1	512	1	25%	0.63
I2	567	1	25%	0.70
I3	504	1	25%	0.62
I4	729	1	25%	0.90
C1	567	3	75%	0.70
C2	504	3	75%	0.62
C3	729	2	50%	0.90
C4	729	1	25%	0.90
R1	648	3	75%	0.80
R2	810	3	75%	1.00
R3	720	3	75%	0.89
R4	441	1	25%	0.54
O1	576	1	25%	0.71
O2	576	1	25%	0.71
O3	720	1	25%	0.89
O4	648	1	25%	0.80
O5	441	1	25%	0.54
O6	648	1	25%	0.80

Mean	614.9
Max	810.0
Min	441.0

Mean	37.1
Max	43.2
Min	28.3

	IDEF Process Group			
Target	5000	6000	9000	9000
	A441	A442	A443	A444
Bm	2879	4050	5571	5796
	1			
	1			
			1	
				1
		1	1	1
	1		1	1
		1	1	
				1
		1	1	1
		1	1	1
	1		1	1
			1	
	1			
		1		
		1		
			1	
				1
				1

nj	5	6	9	9
Kpi	58%	68%	62%	64%

Rn	3.8	5.6	5.8	37.0
Rco	28.3	39.3	43.2	37.4

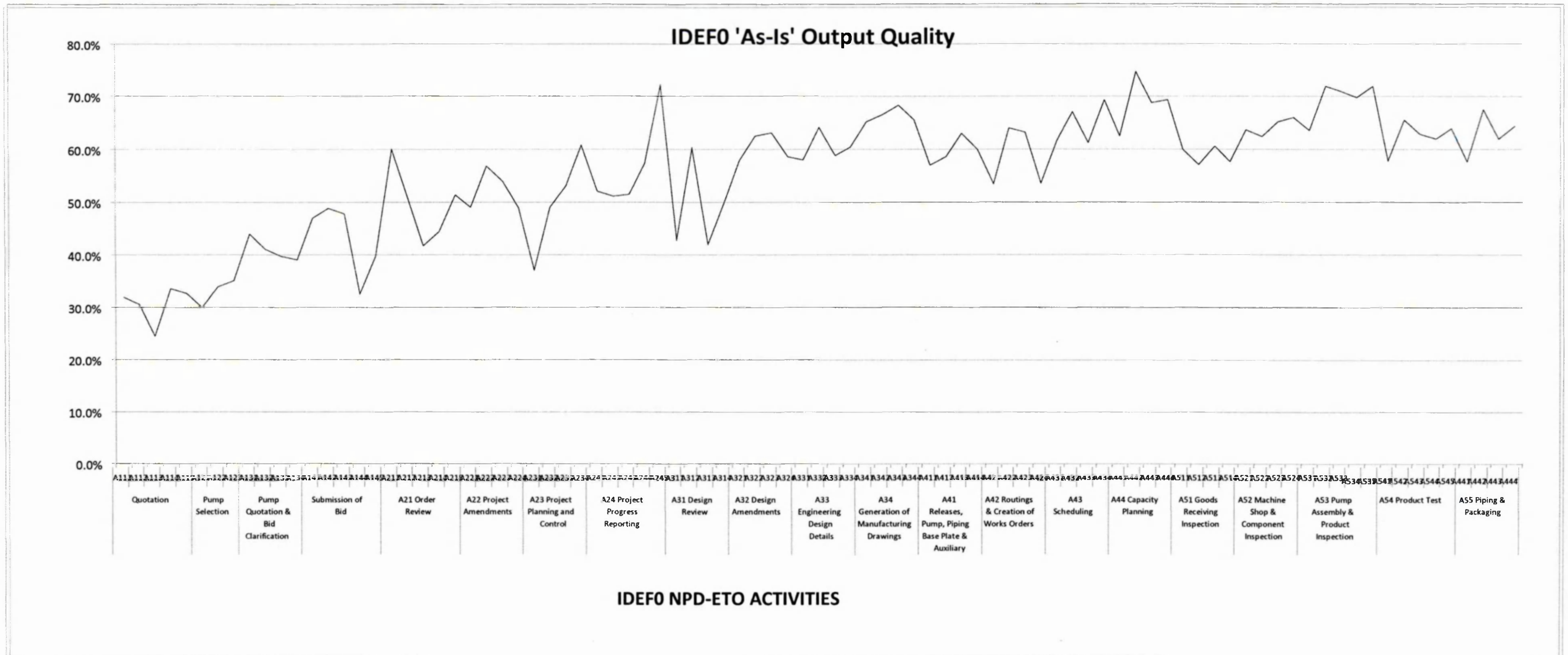
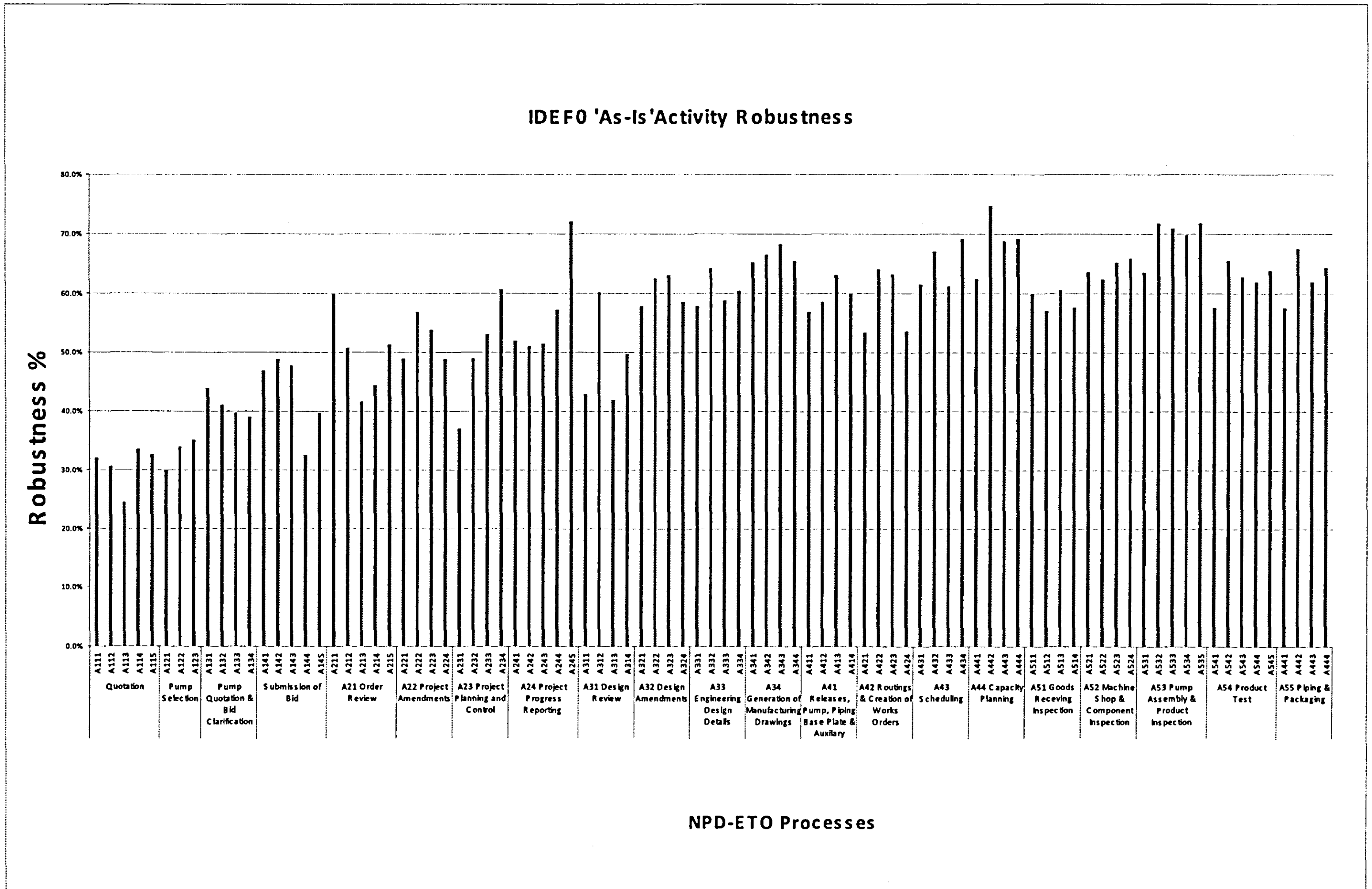


Figure 6.27; Resource Usage within the Existing NPD-ETO


IDEF0 'As-Is'Activity Robustness
Robustness %
80.0%
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
0.0%
Quotation
Pump Selection
Pump Quotation & Bid Clarification
Submission of Bid
A21 Order Review
A22 Project Amendments
A23 Project Planning and Control
A24 Project Progress Reporting
A31 Design Review
A32 Design Amendments
A33 Engineering Design Details
A34 Generation of Manufacturing Drawings
A41 Releases, Pump, Piping Base Plate & Auxilary
A42 Routings & Creation of Works Orders
A43 Scheduling
A44 Capacity Planning
A51 Goods Receving Inspection
A52 Machine Shop & Component Inspection
A53 Pump Assembly & Product Inspection
A54 Product Test
A55 Piping & Packaging
NPD-ETO Processes

		A24 Project Progress Reporting	Explicit Knowledge	Tool Quality	Tacit Knowledge	Input ID	CI	mi	Wni	Wci	8000 A241	4000 A242	9000 A243	5000 A244	7000 A245
		Resource Description													
Inputs	I1	Project Amendments	6	7	6	I1	252	1	20%	0.35	1				
	I2	Final Project Plan, Order Set & Stage Payments	10	7	9	I2	630	1	20%	0.86	1				
Controls	I3	Test Bed Schedule	8	8	8	I3	512	1	20%	0.70			1		
	I4	Certification	9	8	8	I4	576	1	20%	0.79					1
	C1	Project Amendments	4	7	7	C1	196	2	40%	0.27		1	1		
	C2	Projects Specifications	8	8	8	C2	512	2	40%	0.70	1		1		
	C3	Commerical Implications	9	8	7	C3	504	3	60%	0.69	1		1		1
	C4	Vendor Documentation Requirements List	9	9	9	C4	729	1	20%	1.00		1			
	C5	Quality Plan	9	9	8	C5	648	3	60%	0.89			1	1	1
Resources	R1	Punch List	9	9	9	R1	729	4	80%	1.00	1		1	1	1
	R2	Project Meetings with Client & Suppliers	10	8	8	R2	640	2	40%	0.88	1		1		
	R3	Documentation Register	9	9	9	R3	729	1	20%	1.00		1			
	R4	MS Project & Jobscope	8	7	9	R4	504	3	60%	0.69	1		1	1	
	R5	Cost Report	8	8	8	R5	512	1	20%	0.70					1
	R6	Test Results	8	9	7	R6	504	1	20%	0.69					1
	R7	Documentation List	9	8	9	R7	648	1	20%	0.89					1
Outputs	O2	Project File Updates	7	7	8	O2	392	4	80%	0.54	1	1	1	1	
	O3	Raise Invoice	9	8	8	O3	576	1	20%	0.79				1	
	O4	Closeout Report	2	2	4	O4	16	1	20%	0.02				1	
	O5	Installation & Commissioning Information	9	5	8	O5	360	1	20%	0.49					1
	O6	Technical Manual	9	7	9	O6	567	1	20%	0.78					1

Mean	511.2
Max	729.0
Min	16.0

Mean	34.2
Max	49.5
Min	16.8

	IDEF Process Group				
Target	8000	4000	9000	5000	7000
	A241	A242	A243	A244	A245
Bm	4163	2046	4637	2865	5048
nj	8	4	9	6	9
Performance	52%	51%	52%	57%	72%
Rn	12.5	12.5	12.8	16.7	6.0
Rco	39.2	16.8	43.3	49.5	22.2

Table 6.17; Activity Robustness and Cross Impact Matrix for Project Programme Reporting

Group	ID	A24 Project Progress Reporting – Resource Description	Explicit Knowledge	Tool Quality	Tacit Knowledge	Input ID	CI	mi	Wni	Wci	A241 (Target 9000, Bm 4785)	A242 (Target 5000, Bm 2787)	A243 (Target 10000, Bm 5378)	A244 (Target 6000, Bm 3639)	A245 (Target 8000, Bm 5432)
Inputs	I1	Project Amendments	9	7	6	I1	378	1	20%	0.52	1				
	I2	Final Project Plan, Order Set & Stage Payments	10	7	9	I2	630	1	20%	0.86	1				
Controls	I3	Test Bed Schedule	8	8	8	I3	512	1	20%	0.70			1		
	I4	Certification	9	8	8	I4	576	1	20%	0.79					1
	C1	Project Amendments	9	7	7	C1	441	2	40%	0.60		1	1		
	C2	Projects Specifications	8	8	8	C2	512	2	40%	0.70	1		1		
	C3	Commerical Implications	9	8	7	C3	504	3	60%	0.69	1		1		1
	C4	Vendor Documentation Requirements List	9	9	9	C4	729	1	20%	1.00		1			
	C5	Quality Plan	9	9	8	C5	648	3	60%	0.89			1	1	1
Resources	R1	Punch List	9	9	9	R1	729	4	80%	1.00	1		1	1	1
	R2	Project Meetings with Client & Suppliers	10	8	8	R2	640	2	40%	0.88	1		1		
	R3	Documentation Register	9	9	9	R3	729	1	20%	1.00		1			
	R4	MS Project & Jobscope	8	7	9	R4	504	3	60%	0.69	1		1	1	
	R5	Cost Report	8	8	8	R5	512	1	20%	0.70					1
	R6	Test Results	8	9	7	R6	504	1	20%	0.69					1
	R7	Documentation List	9	8	9	R7	648	1	20%	0.89					1
	R8	Knowledge Sharing System	8	8	6	R8	384	5	100%	0.53	1	1	1	1	1
Outputs	O2	Project File Updates	9	7	8	O2	504	4	80%	0.69	1	1	1	1	
	O3	Raise Invoice	9	8	8	O3	576	1	20%	0.79				1	
	O4	Closeout Report	7	6	7	O4	294	1	20%	0.40				1	
	O5	Installation & Commissioning Information	9	5	8	O5	360	1	20%	0.49					1
	O6	Technical Manual	9	7	9	O6	567	1	20%	0.78					1

	CI
Mean	540.0
Max	729.0
Min	294.0

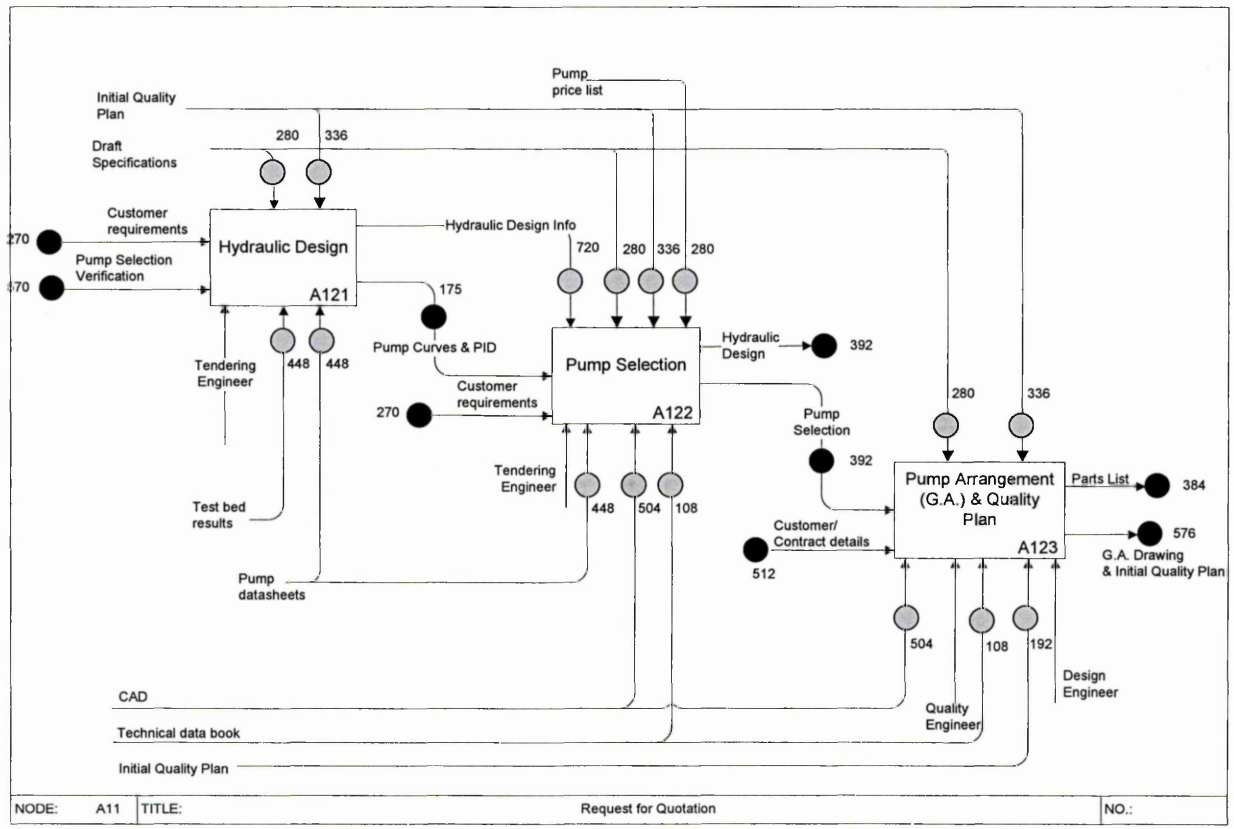
Mean	40.4
Max	51.8
Min	27.7

IDEF Process Group	A241	A242	A243	A244	A245
nj	9	5	10	7	10
Performance	53%	56%	54%	61%	68%
Rn	13.7	17.8	13.6	18.2	7.9
Rco	43.9	31.3	47.1	51.8	27.7

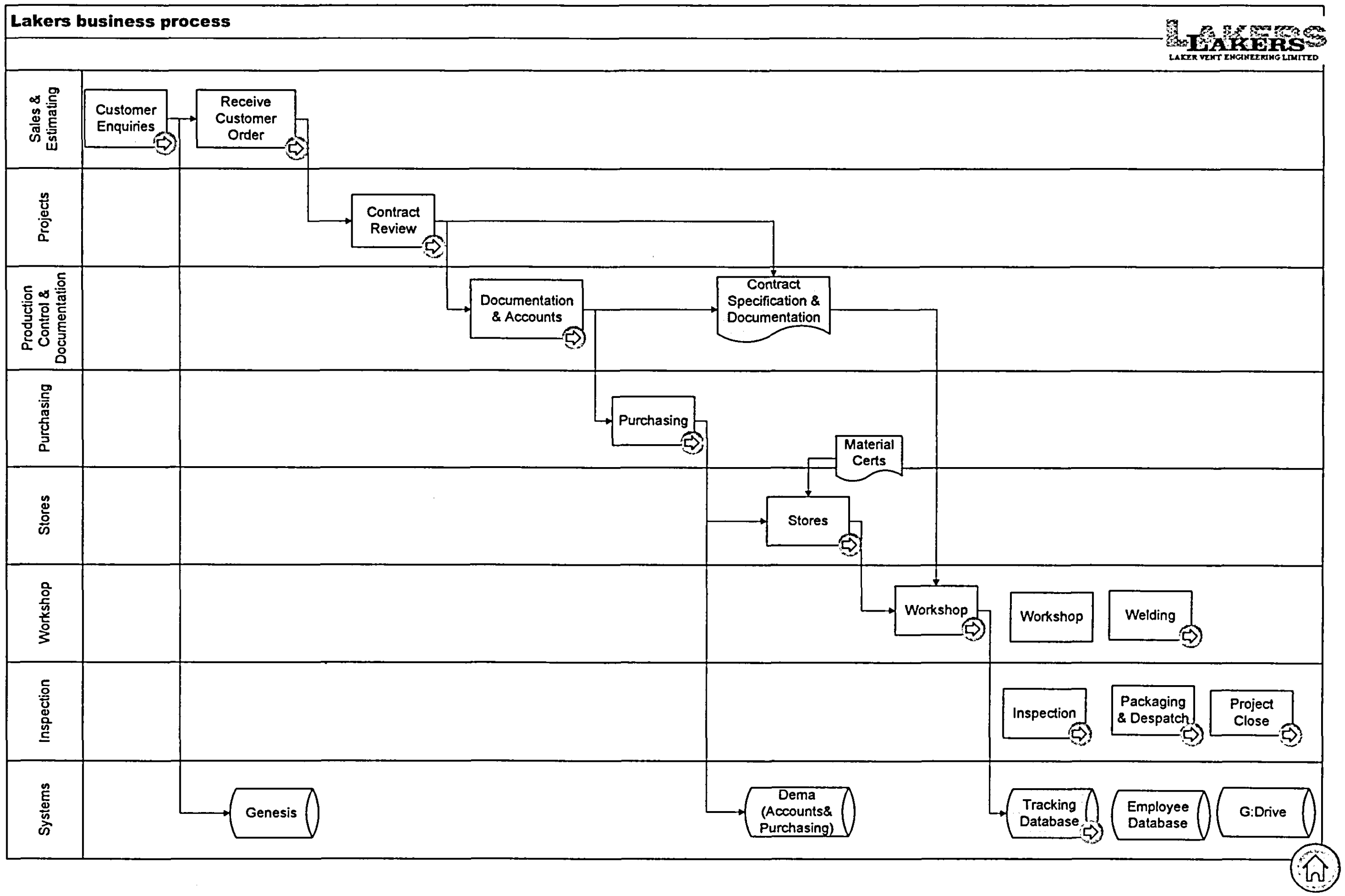
Table 0-1; New Additional-Knowledge Sharing System: Activity Robustness and Cross Impact Matrix

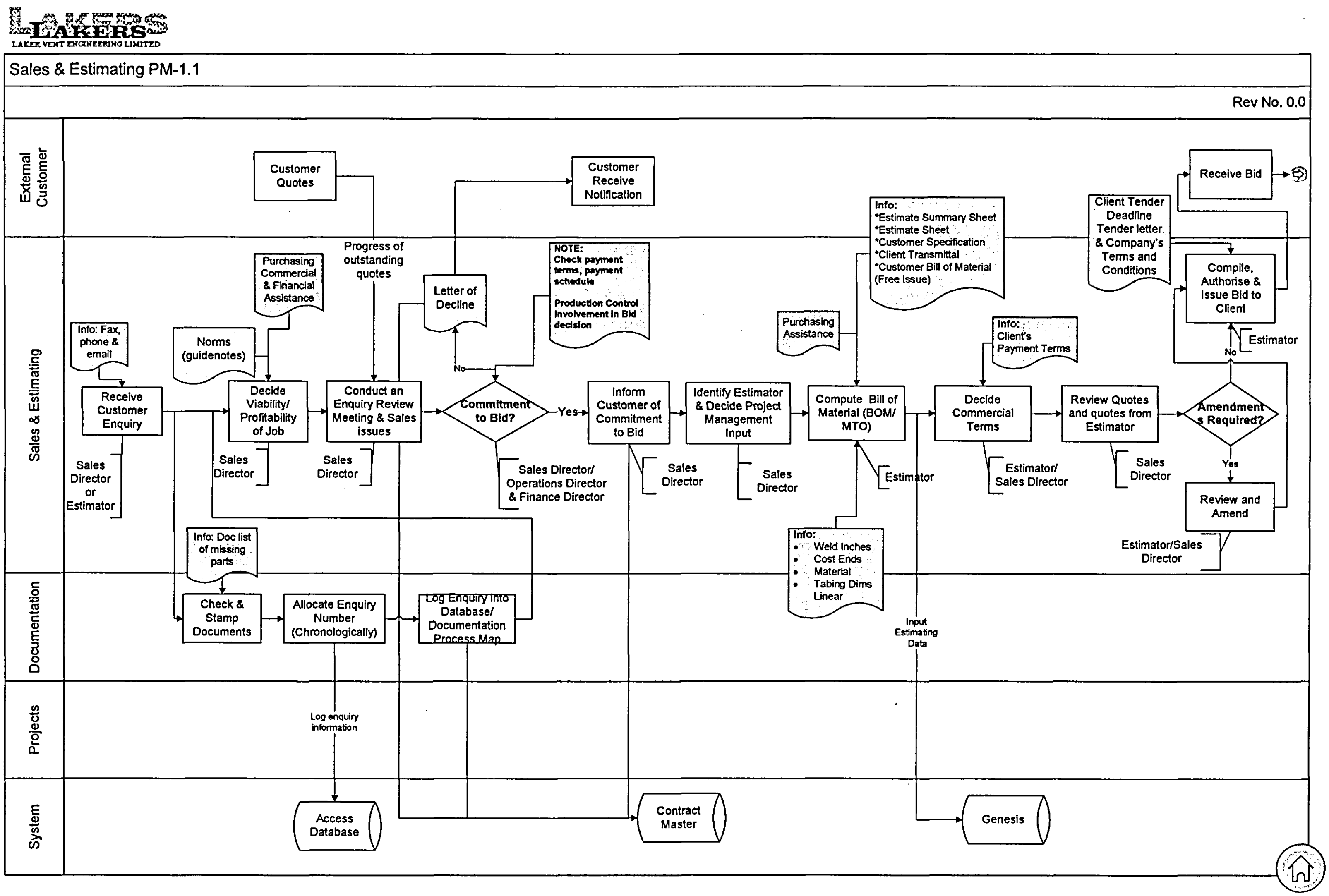
Appendix G: IDEF-K Assessment Model

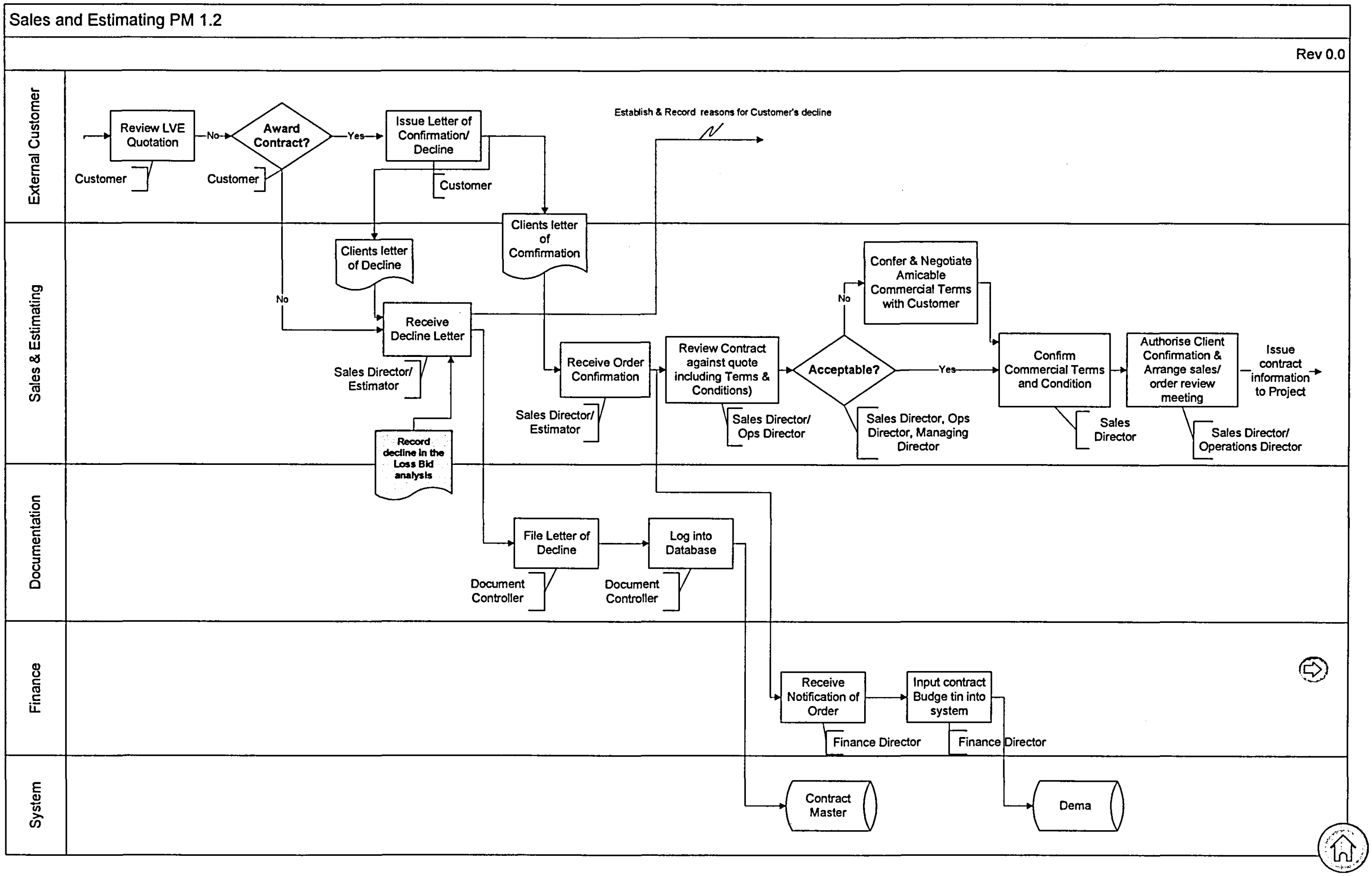
Appendix F: IDEF0 SULER NPD-ETO

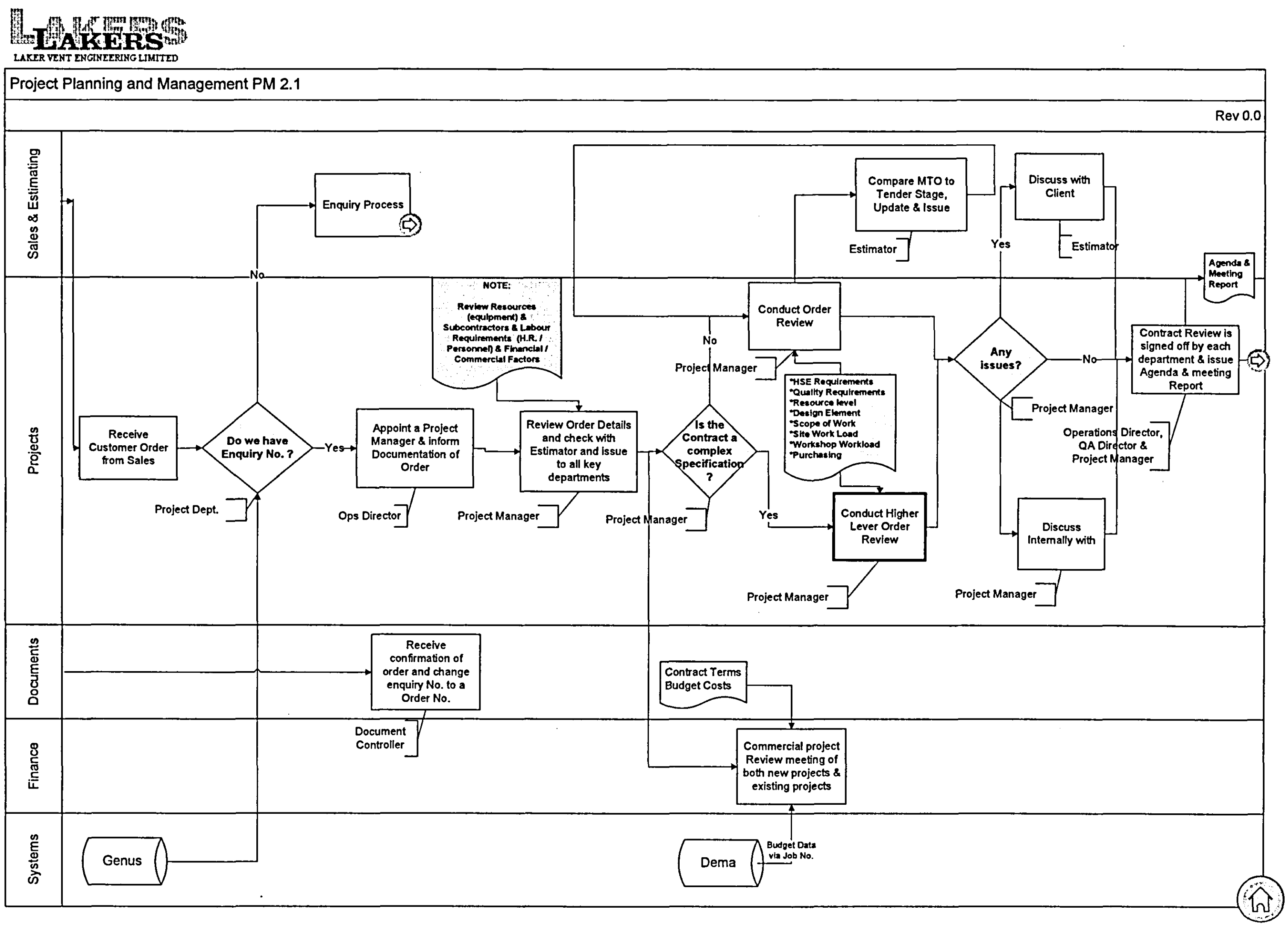


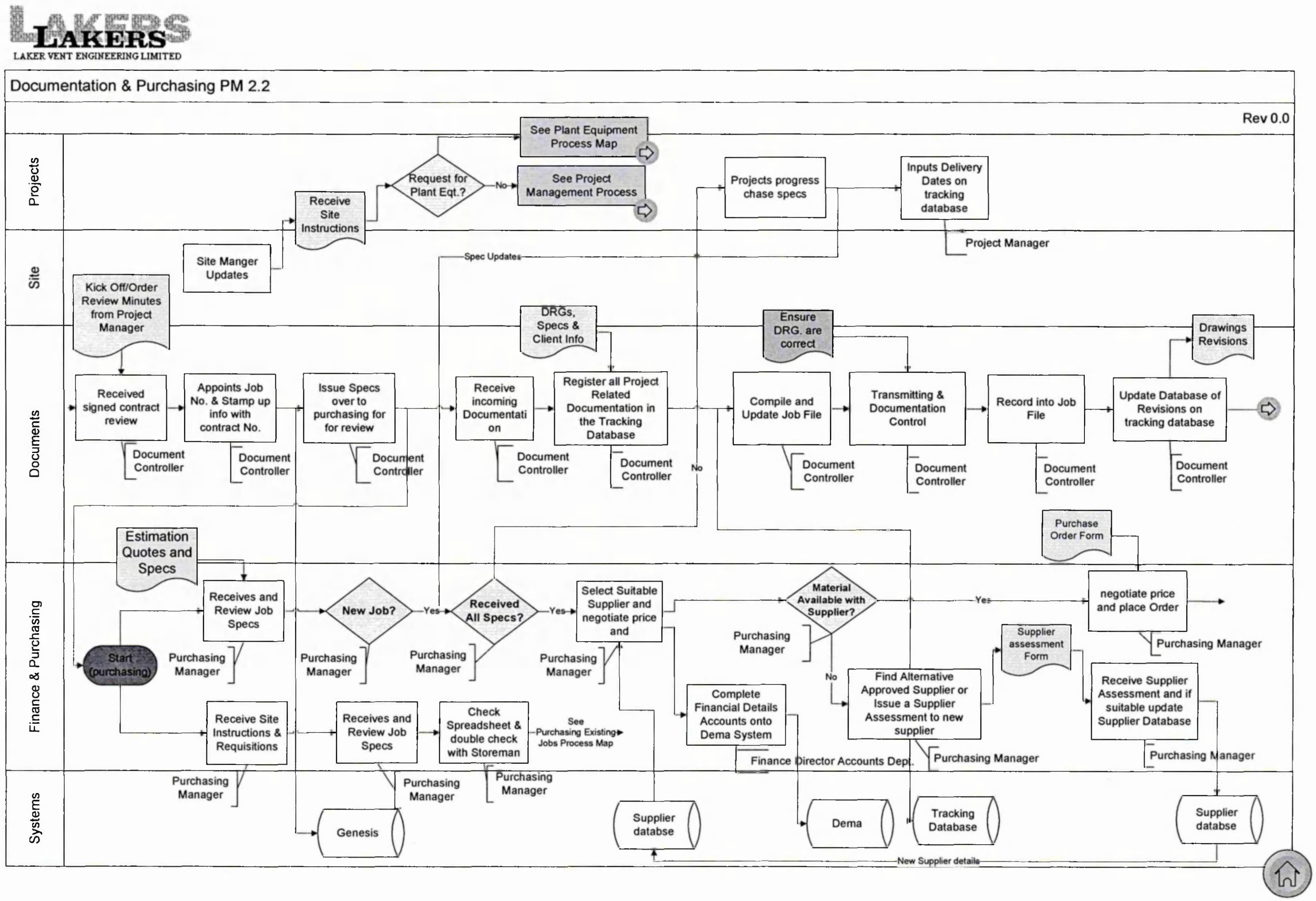
Appendix H: Process Maps: Laker Vent Engineering

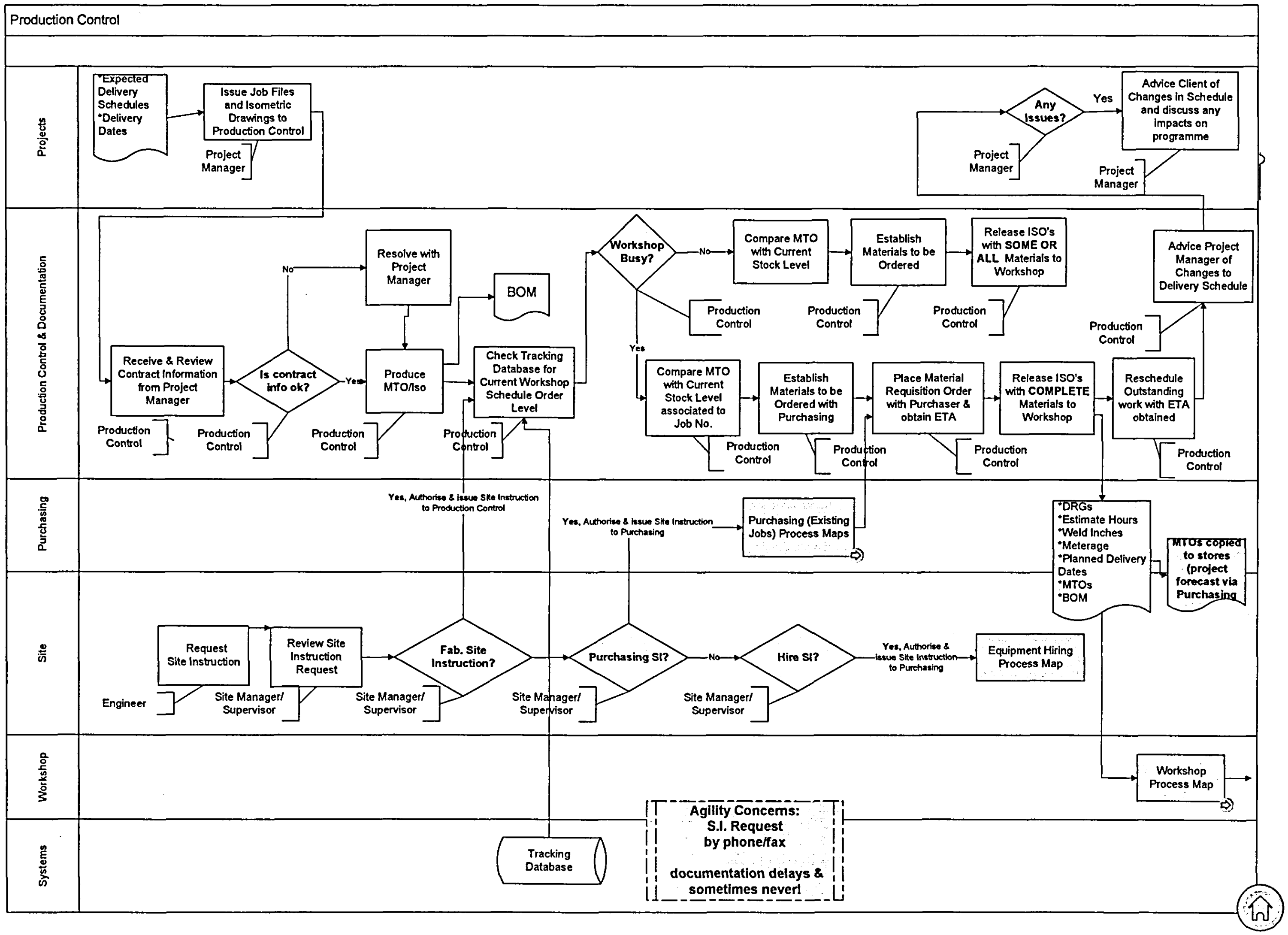


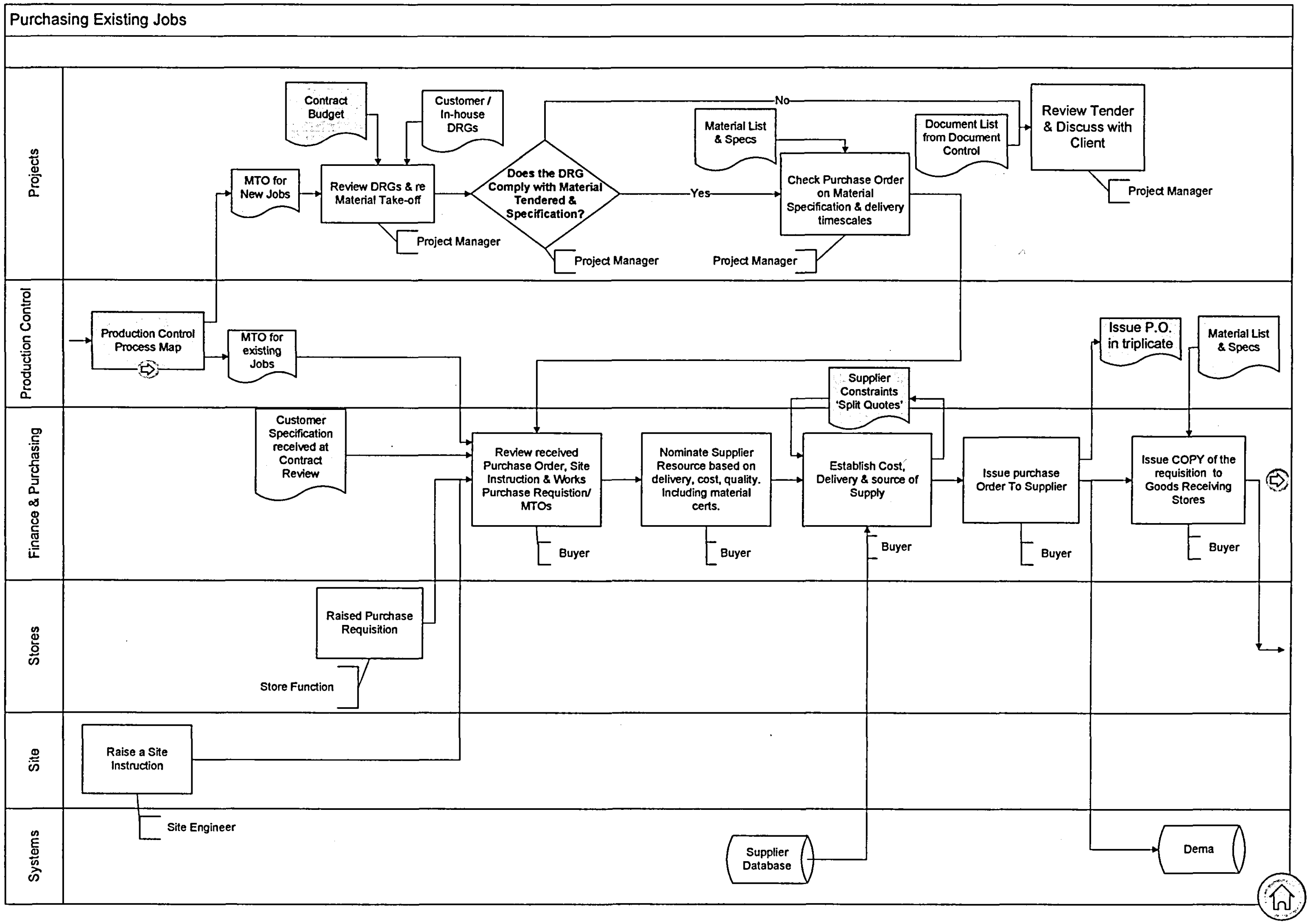

LAKERS
LAKER VENT ENGINEERING LIMITED
Sales & Estimating PM-1.1
Rev No. 0.0
External Customer
Sales & Estimating
Documentation
Projects
System
Customer Quotes
Customer Receive Notification
Receive Bid
Info: Fax, phone & email
Receive Customer Enquiry
Sales Director or Estimator
Norms (guidenotes)
Purchasing Commercial & Financial Assistance
Decide Viability/ Profitability of Job
Sales Director
Progress of outstanding quotes
Conduct an Enquiry Review Meeting & Sales issues
Sales Director
Letter of Decline
No
Commitment to Bid?
Yes
Sales Director/ Operations Director & Finance Director
NOTE: Check payment terms, payment schedule
Production Control Involvement in Bid decision
Inform Customer of Commitment to Bid
Sales Director
Identify Estimator & Decide Project Management Input
Sales Director
Purchasing Assistance
Info: *Estimate Summary Sheet *Estimate Sheet *Customer Specification *Client Transmittal *Customer Bill of Material (Free Issue)
Compute Bill of Material (BOM/ MTO)
Estimator
Info: Weld Inches, Cost Ends, Material, Tabing Dims, Linear
Info: Client's Payment Terms
Decide Commercial Terms
Estimator/ Sales Director
Review Quotes and quotes from Estimator
Sales Director
Client Tender Deadline Tender letter & Company's Terms and Conditions
Compile, Authorise & Issue Bid to Client
Estimator
No
Amendments Required?
Yes
Review and Amend
Estimator/Sales Director
Info: Doc list of missing parts
Check & Stamp Documents
Allocate Enquiry Number (Chronologically)
Log Enquiry into Database/ Documentation Process Map
Log enquiry information
Input Estimating Data
Access Database
Contract Master
Genesis

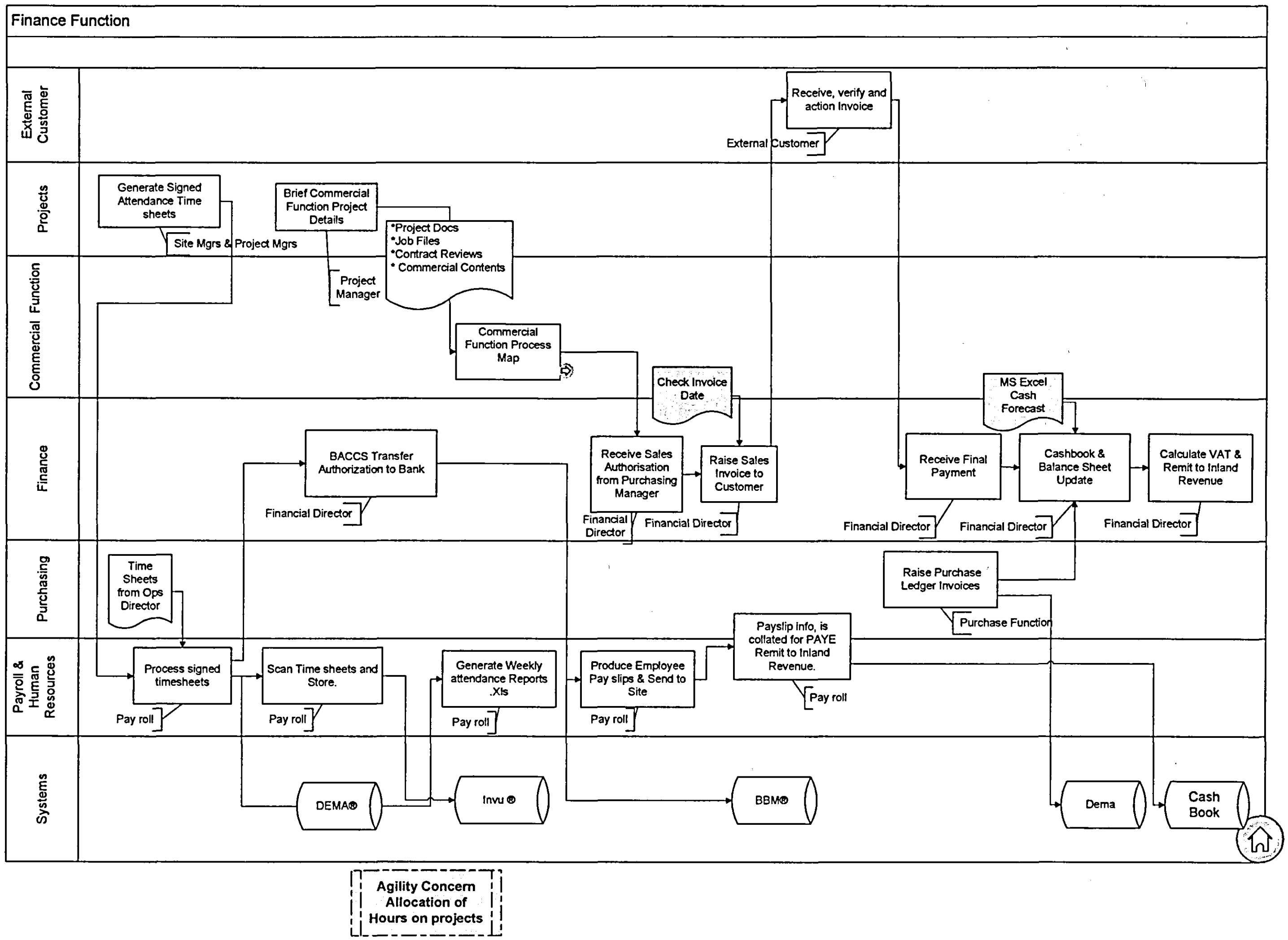

Sales and Estimating PM 1.2
Rev 0.0
External Customer
Sales & Estimating
Documentation
Finance
System
Review LVE Quotation
Customer
No
Award Contract?
Customer
Yes
Issue Letter of Confirmation/ Decline
Customer
Establish & Record reasons for Customer's decline
Clients letter of Decline
Clients letter of Comfirmation
No
Receive Decline Letter
Sales Director/ Estimator
Record decline in the Loss Bid analysis
Receive Order Confirmation
Sales Director/ Estimator
Review Contract against quote including Terms & Conditions)
Sales Director/ Ops Director
Acceptable?
No
Yes
Sales Director, Ops Director, Managing Director
Confer & Negotiate Amicable Commercial Terms with Customer
Confirm Commercial Terms and Condition
Sales Director
Authorise Client Confirmation & Arrange sales/ order review meeting
Sales Director/ Operations Director
Issue contract information to Project
File Letter of Decline
Document Controller
Log into Database
Document Controller
Receive Notification of Order
Finance Director
Input contract Budge tin into system
Finance Director
Contract Master
Dema

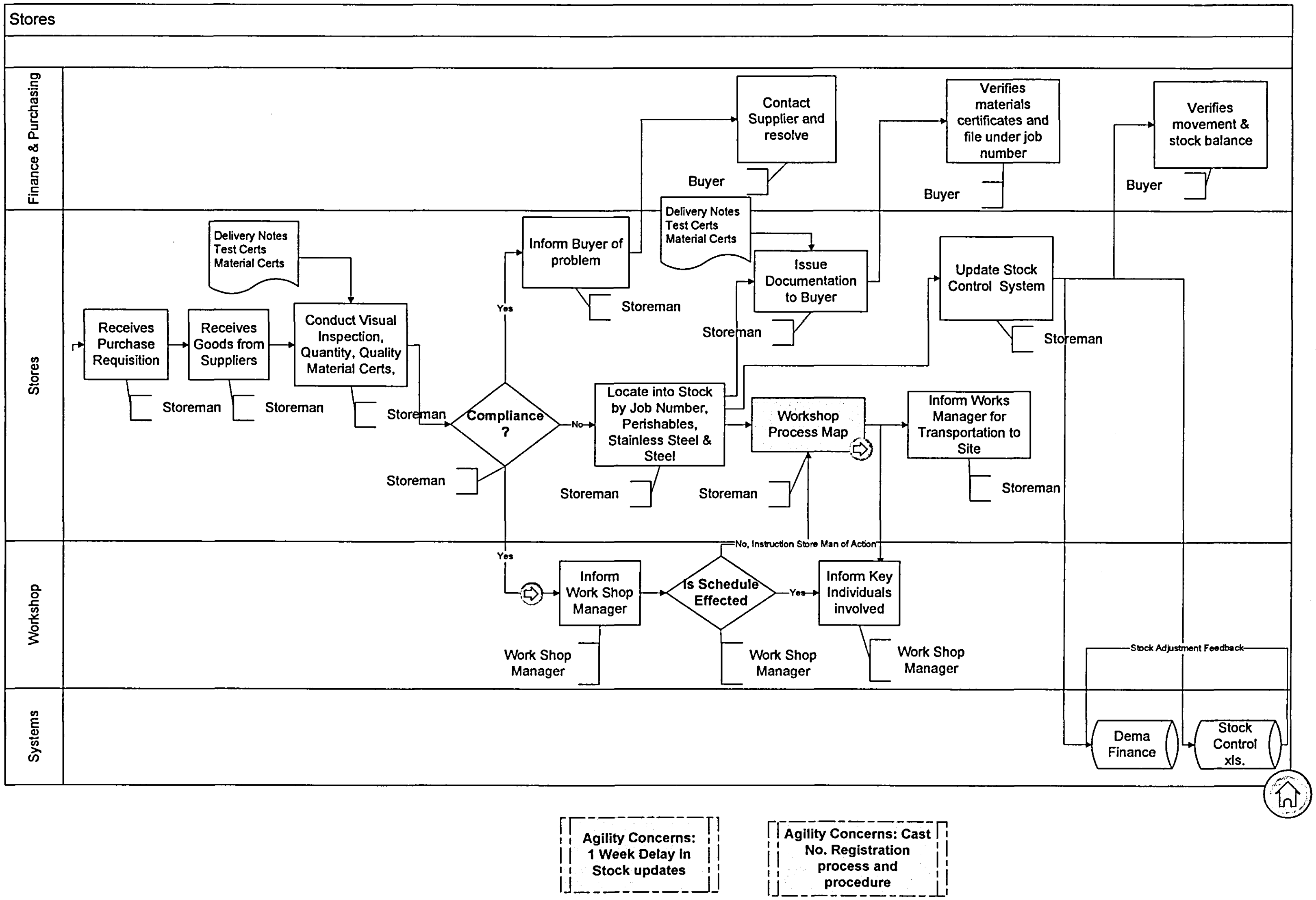

LAKERS
LAKER VENT ENGINEERING LIMITED
Project Planning and Management PM 2.1
Rev 0.0
Sales & Estimating
Projects
Documents
Finance
Systems
Receive Customer Order from Sales
Project Dept.
Do we have Enquiry No. ?
No
Yes
Enquiry Process
Appoint a Project Manager & inform Documentation of Order
Ops Director
NOTE: Review Resources (equipment) & Subcontractors & Labour Requirements (H.R. / Personnel) & Financial / Commercial Factors
Review Order Details and check with Estimator and issue to all key departments
Project Manager
Is the Contract a complex Specification ?
Conduct Order Review
Compare MTO to Tender Stage, Update & Issue
Estimator
*HSE Requirements
*Quality Requirements
*Resource level
*Design Element
*Scope of Work
*Site Work Load
*Workshop Workload
*Purchasing
Conduct Higher Lever Order Review
Any issues?
Discuss with Client
Discuss Internally with
Contract Review is signed off by each department & issue Agenda & meeting Report
Operations Director, QA Director & Project Manager
Agenda & Meeting Report
Receive confirmation of order and change enquiry No. to a Order No.
Document Controller
Contract Terms Budget Costs
Commercial project Review meeting of both new projects & existing projects
Genus
Dema
Budget Data via Job No.

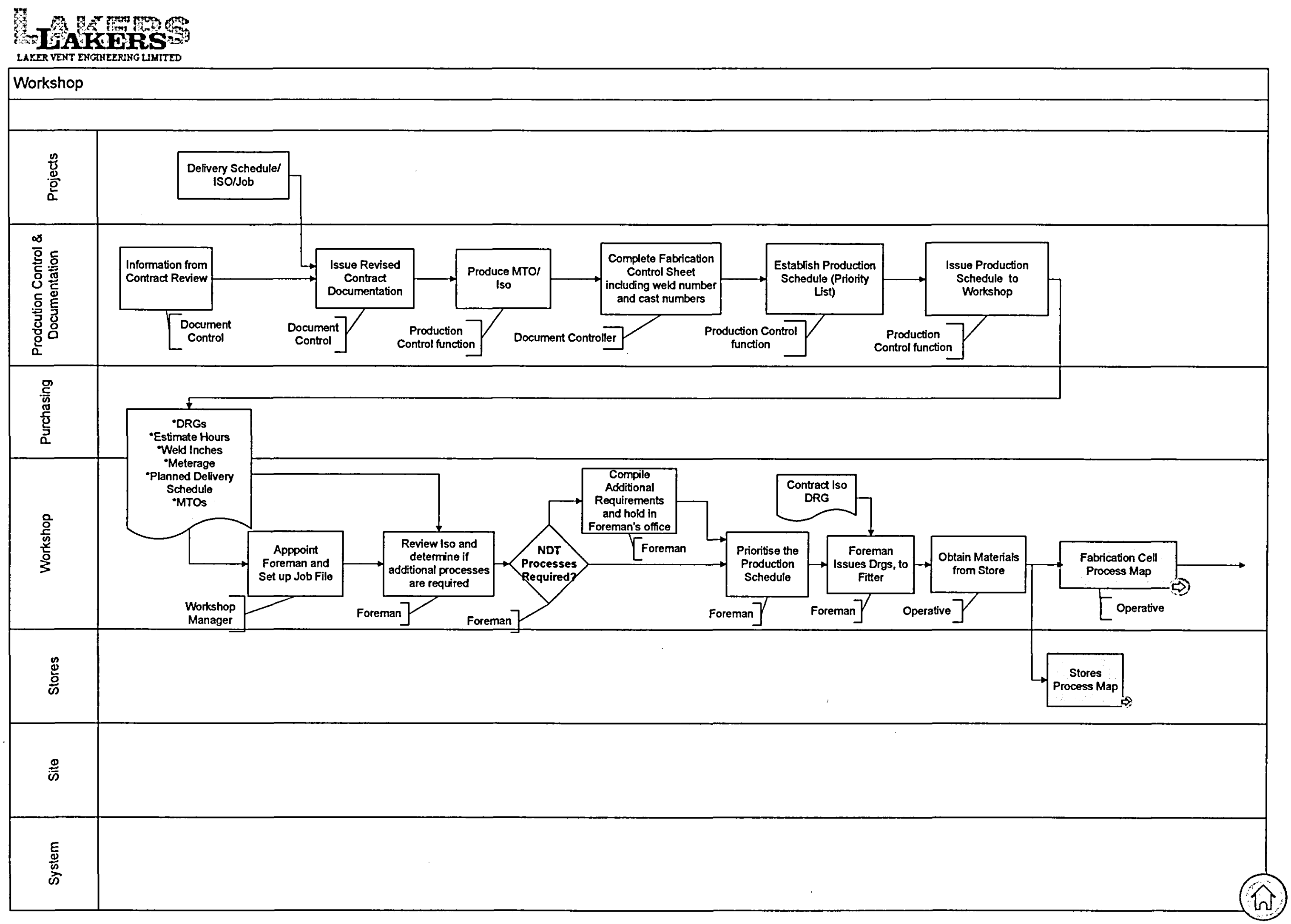

LAKERS
LAKER VENT ENGINEERING LIMITED
Documentation & Purchasing PM 2.2
Rev 0.0
Projects
Site
Documents
Finance & Purchasing
Systems
See Plant Equipment Process Map
Request for Plant Eqt.?
No
See Project Management Process
Receive Site Instructions
Site Manger Updates
Projects progress chase specs
Inputs Delivery Dates on tracking database
Project Manager
Spec Updates
Kick Off/Order Review Minutes from Project Manager
DRGs, Specs & Client Info
Ensure DRG. are correct
Drawings Revisions
Received signed contract review
Appoints Job No. & Stamp up info with contract No.
Issue Specs over to purchasing for for review
Receive incoming Documentation
Register all Project Related Documentation in the Tracking Database
Compile and Update Job File
Transmitting & Documentation Control
Record into Job File
Update Database of Revisions on tracking database
Document Controller
No
Purchase Order Form
Estimation Quotes and Specs
Receives and Review Job Specs
New Job?
Yes
Received All Specs?
Select Suitable Supplier and negotiate price and
Material Available with Supplier?
negotiate price and place Order
Purchasing Manager
Start (purchasing)
Supplier assessment Form
Receive Supplier Assessment and if suitable update Supplier Database
Find Alternative Approved Supplier or Issue a Supplier Assessment to new supplier
Complete Financial Details Accounts onto Dema System
Receive Site Instructions & Requisitions
Receives and Review Job Specs
Check Spreadsheet & double check with Storeman
See Purchasing Existing Jobs Process Map
Finance Director Accounts Dept.
Genesis
Supplier databse
Dema
Tracking Database
New Supplier details

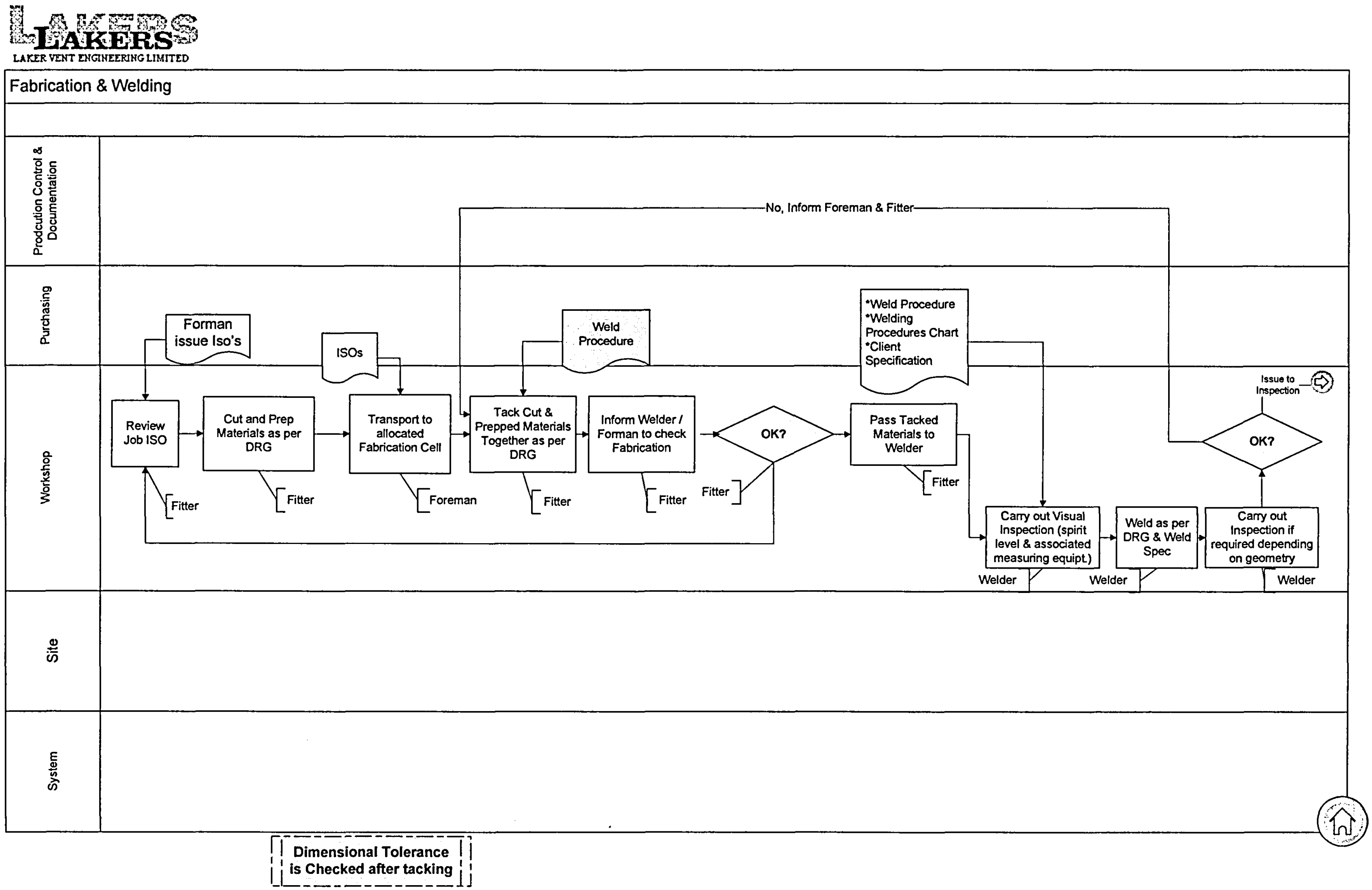

Production Control
Projects
Production Control & Documentation
Purchasing
Site
Workshop
Systems
*Expected Delivery Schedules *Delivery Dates
Issue Job Files and Isometric Drawings to Production Control
Project Manager
Any Issues?
Yes
Advice Client of Changes in Schedule and discuss any impacts on programme
Receive & Review Contract Information from Project Manager
Production Control
Is contract info ok?
No
Yes
Resolve with Project Manager
Produce MTO/Iso
BOM
Check Tracking Database for Current Workshop Schedule Order Level
Workshop Busy?
Compare MTO with Current Stock Level
Establish Materials to be Ordered
Release ISO's with SOME OR ALL Materials to Workshop
Advice Project Manager of Changes to Delivery Schedule
Compare MTO with Current Stock Level associated to Job No.
Establish Materials to be Ordered with Purchasing
Place Material Requisition Order with Purchaser & obtain ETA
Release ISO's with COMPLETE Materials to Workshop
Reschedule Outstanding work with ETA obtained
Yes, Authorise & Issue Site Instruction to Production Control
Yes, Authorise & Issue Site Instruction to Purchasing
Purchasing (Existing Jobs) Process Maps
*DRGs *Estimate Hours *Weld Inches *Meterage *Planned Delivery Dates *MTOs *BOM
MTOs copied to stores (project forecast via Purchasing
Request Site Instruction
Engineer
Review Site Instruction Request
Site Manager/ Supervisor
Fab. Site Instruction?
Purchasing SI?
Hire SI?
Yes, Authorise & Issue Site Instruction to Purchasing
Equipment Hiring Process Map
Workshop Process Map
Tracking Database
Agility Concerns: S.I. Request by phone/fax documentation delays & sometimes never!

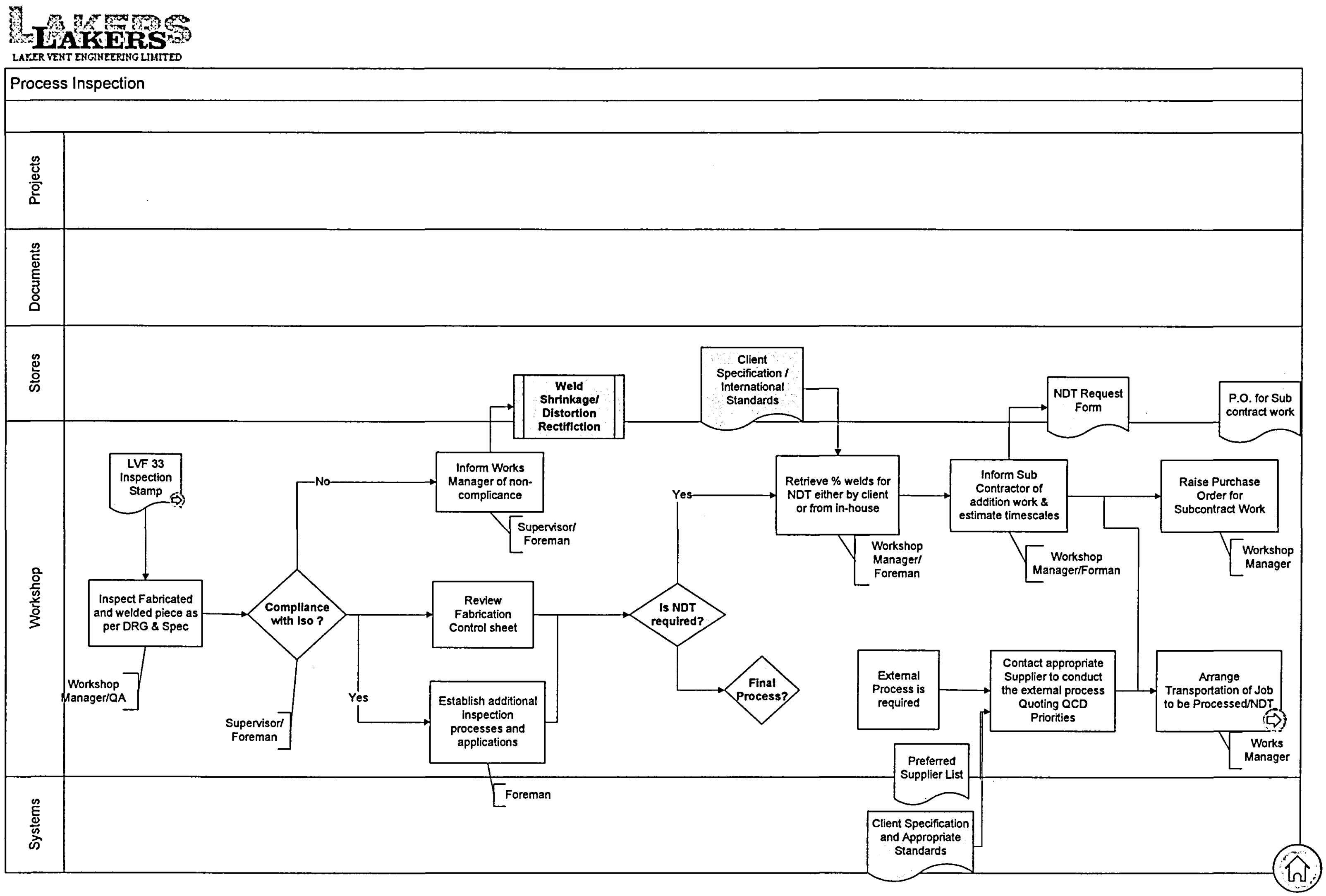

Purchasing Existing Jobs
Projects
Production Control
Finance & Purchasing
Stores
Site
Systems
Contract Budget
Customer / In-house DRGs
MTO for New Jobs
Review DRGs & re Material Take-off
Project Manager
Does the DRG Comply with Material Tendered & Specification?
Yes
No
Project Manager
Material List & Specs
Check Purchase Order on Material Specification & delivery timescales
Project Manager
Document List from Document Control
Review Tender & Discuss with Client
Project Manager
Production Control Process Map
MTO for existing Jobs
Issue P.O. in triplicate
Material List & Specs
Supplier Constraints 'Split Quotes'
Customer Specification received at Contract Review
Review received Purchase Order, Site Instruction & Works Purchase Requistion/ MTOs
Buyer
Nominate Supplier Resource based on delivery, cost, quality. Including material certs.
Buyer
Establish Cost, Delivery & source of Supply
Buyer
Issue purchase Order To Supplier
Buyer
Issue COPY of the requisition to Goods Receiving Stores
Buyer
Raised Purchase Requisition
Store Function
Raise a Site Instruction
Site Engineer
Supplier Database
Dema

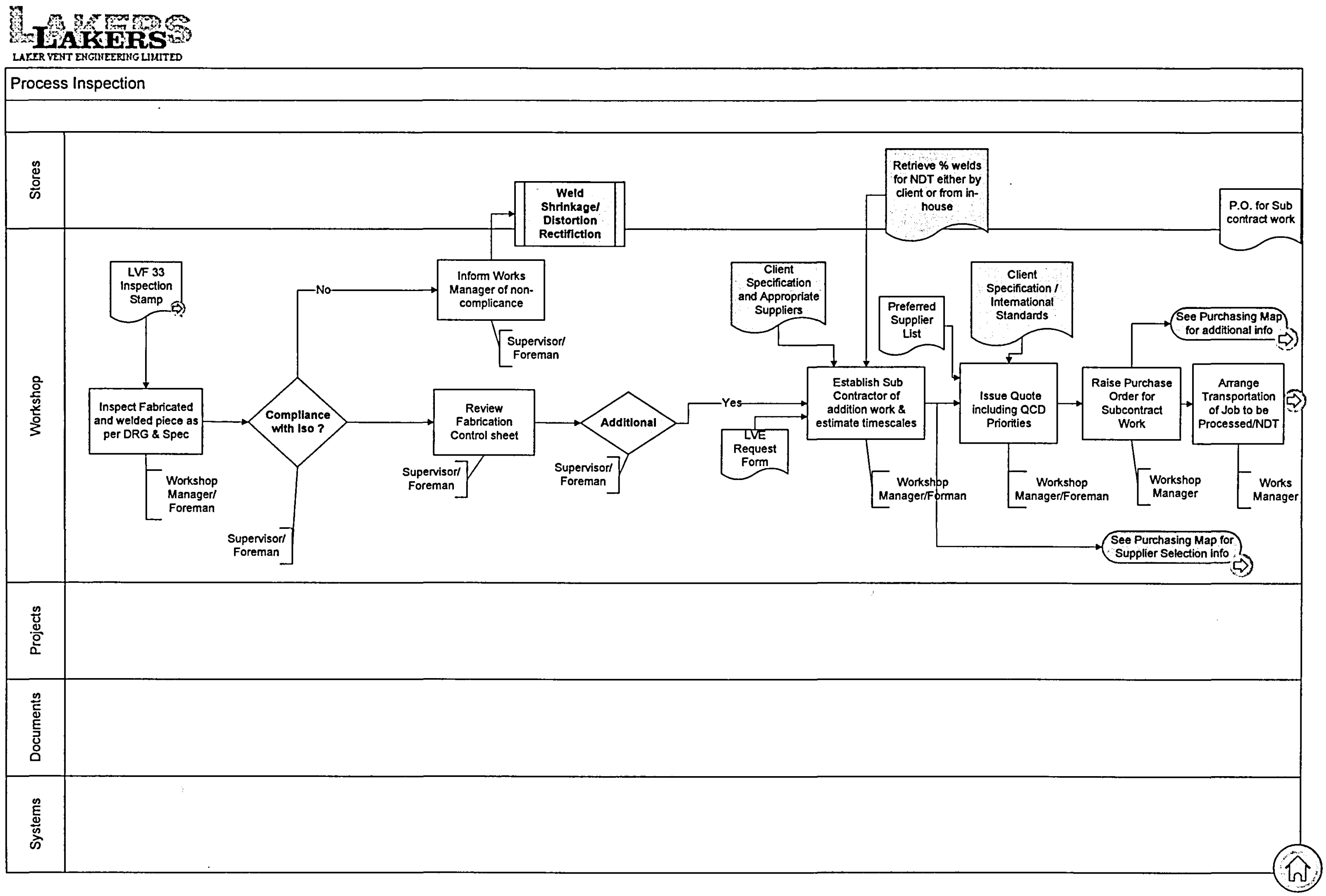

Finance Function
External Customer
Projects
Commercial Function
Finance
Purchasing
Payroll & Human Resources
Systems
Receive, verify and action Invoice
External Customer
Generate Signed Attendance Time sheets
Site Mgrs & Project Mgrs
Brief Commercial Function Project Details
Project Manager
*Project Docs
*Job Files
*Contract Reviews
* Commercial Contents
Commercial Function Process Map
Check Invoice Date
MS Excel Cash Forecast
BACCS Transfer Authorization to Bank
Financial Director
Receive Sales Authorisation from Purchasing Manager
Financial Director
Raise Sales Invoice to Customer
Financial Director
Receive Final Payment
Financial Director
Cashbook & Balance Sheet Update
Financial Director
Calculate VAT & Remit to Inland Revenue
Financial Director
Time Sheets from Ops Director
Raise Purchase Ledger Invoices
Purchase Function
Process signed timesheets
Pay roll
Scan Time sheets and Store.
Pay roll
Generate Weekly attendance Reports .Xls
Pay roll
Produce Employee Pay slips & Send to Site
Pay roll
Payslip Info, is collated for PAYE Remit to Inland Revenue.
Pay roll
DEMA®
Invu ®
BBM®
Dema
Cash Book
Agility Concern Allocation of Hours on projects

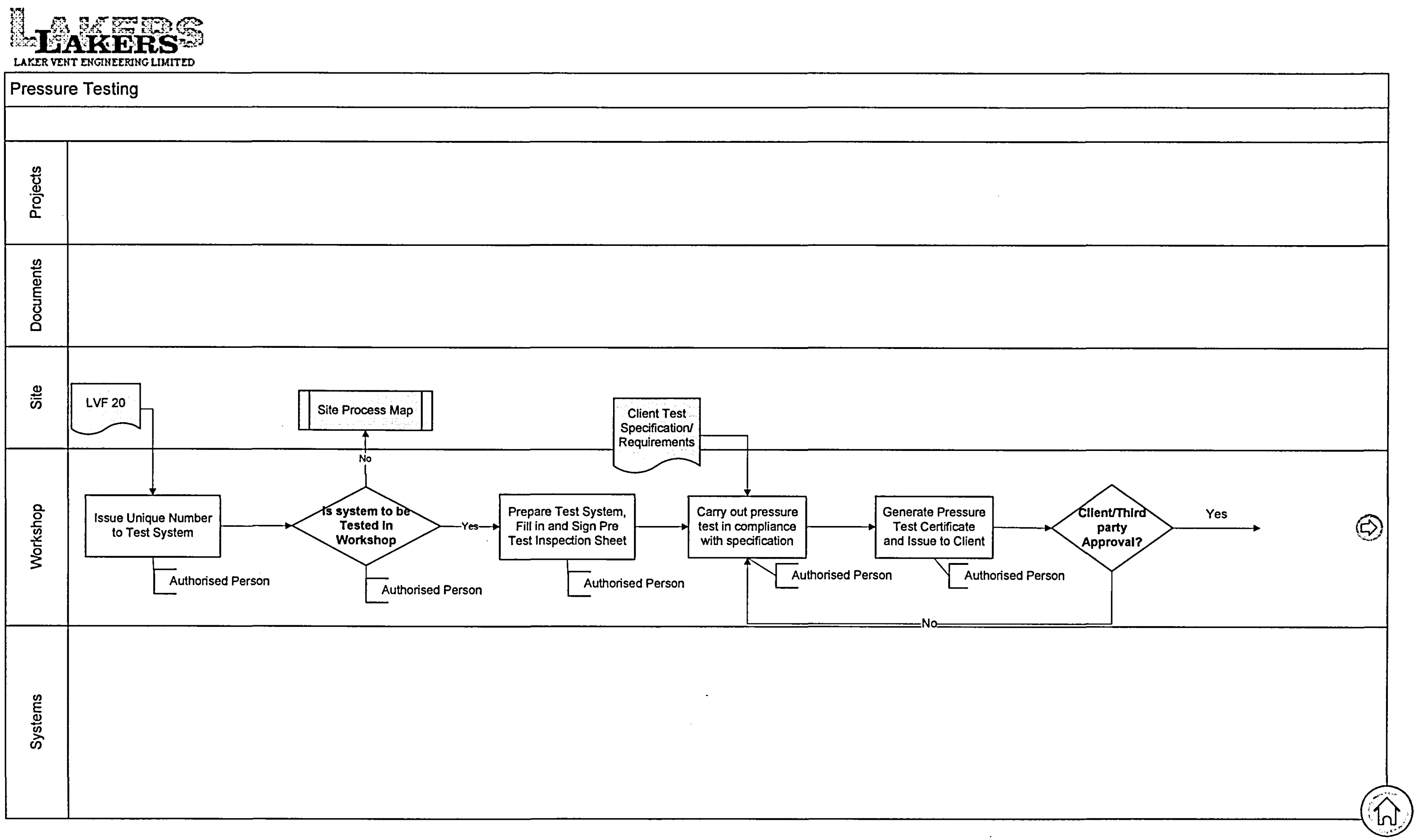

Stores
Finance & Purchasing
Stores
Workshop
Systems
Receives Purchase Requisition
Storeman
Receives Goods from Suppliers
Storeman
Delivery Notes
Test Certs
Material Certs
Conduct Visual Inspection, Quantity, Quality Material Certs,
Storeman
Compliance ?
Storeman
Yes
Inform Buyer of problem
Storeman
Contact Supplier and resolve
Buyer
No
Locate into Stock by Job Number, Perishables, Stainless Steel & Steel
Storeman
Delivery Notes
Test Certs
Material Certs
Issue Documentation to Buyer
Storeman
Verifies materials certificates and file under job number
Buyer
Workshop Process Map
Storeman
Update Stock Control System
Storeman
Verifies movement & stock balance
Buyer
Inform Works Manager for Transportation to Site
Storeman
Yes
Inform Work Shop Manager
Work Shop Manager
Is Schedule Effected
Work Shop Manager
No, Instruction Store Man of Action
Yes
Inform Key Individuals involved
Work Shop Manager
Stock Adjustment Feedback
Dema Finance
Stock Control xls.
Agility Concerns: 1 Week Delay In Stock updates
Agility Concerns: Cast No. Registration process and procedure

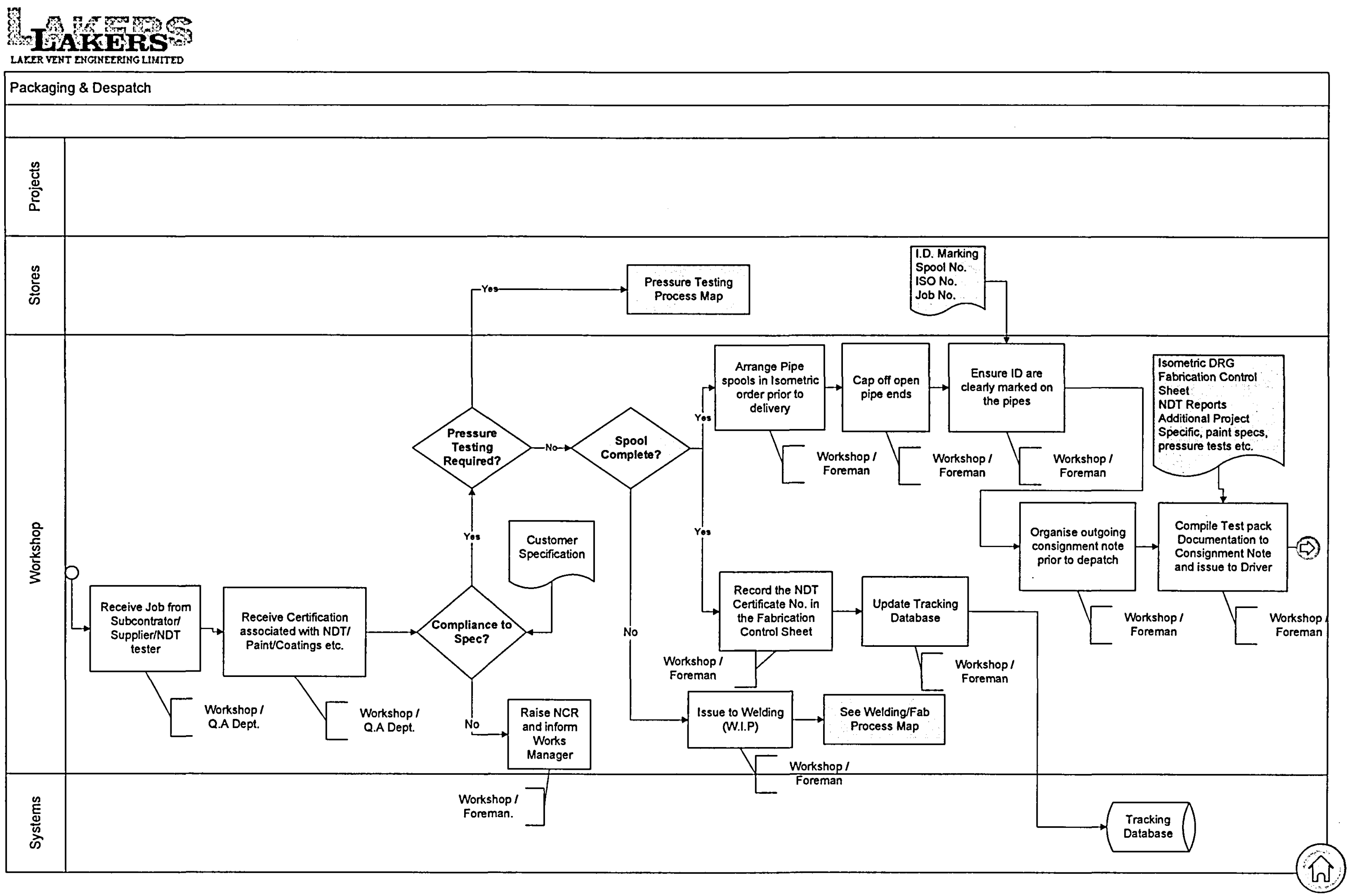

LAKERS
LAKER VENT ENGINEERING LIMITED
Workshop
Projects
Prodcution Control & Documentation
Purchasing
Workshop
Stores
Site
System
Delivery Schedule/ ISO/Job
Information from Contract Review
Document Control
Issue Revised Contract Documentation
Document Control
Produce MTO/ Iso
Production Control function
Complete Fabrication Control Sheet including weld number and cast numbers
Document Controller
Establish Production Schedule (Priority List)
Production Control function
Issue Production Schedule to Workshop
Production Control function
*DRGs
*Estimate Hours
*Weld Inches
*Meterage
*Planned Delivery Schedule
*MTOs
Appoint Foreman and Set up Job File
Workshop Manager
Review Iso and determine if additional processes are required
Foreman
NDT Processes Required?
Foreman
Compile Additional Requirements and hold in Foreman's office
Foreman
Prioritise the Production Schedule
Foreman
Contract Iso DRG
Foreman Issues Drgs, to Fitter
Foreman
Obtain Materials from Store
Operative
Fabrication Cell Process Map
Operative
Stores Process Map

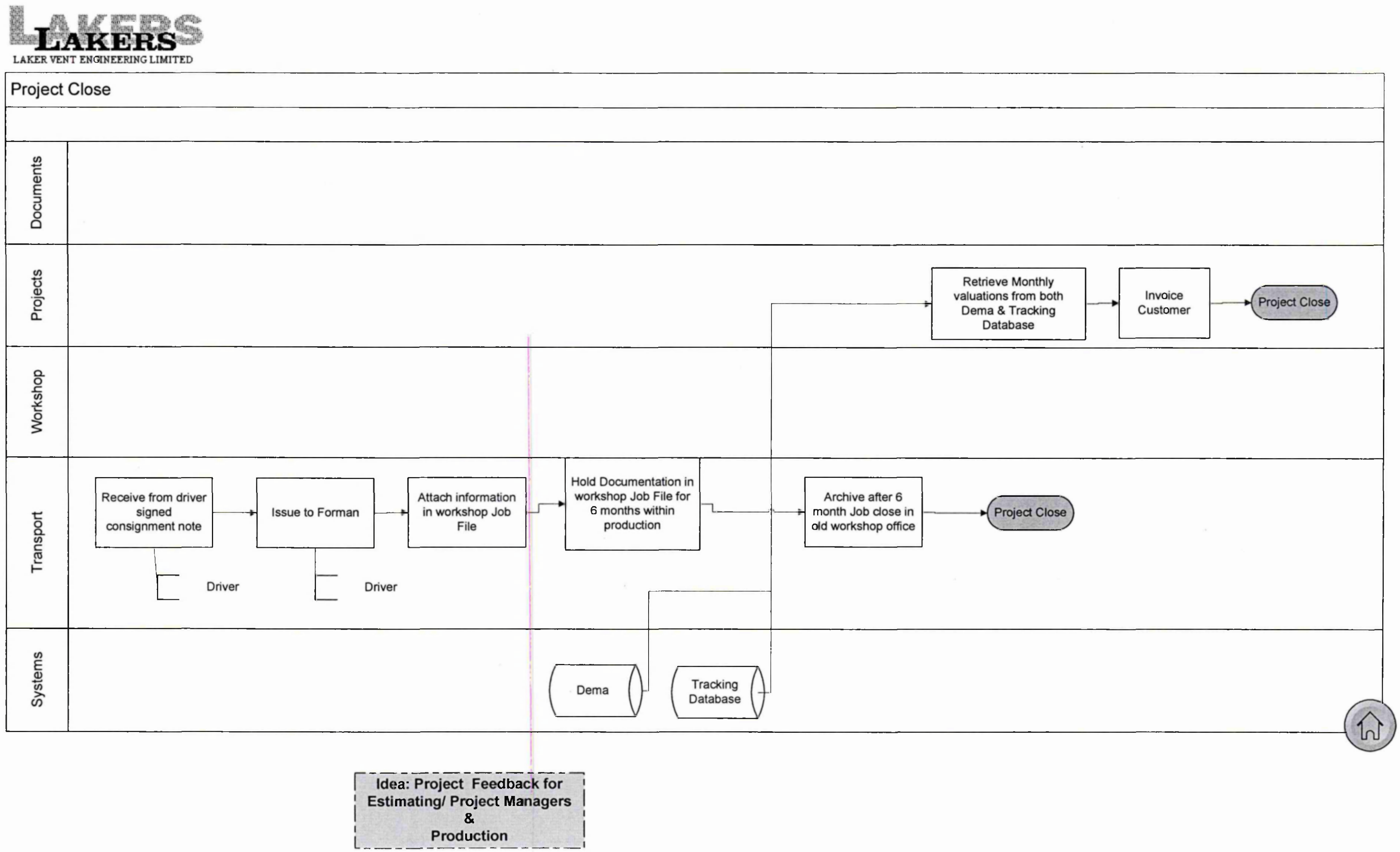

LAKER VENT ENGINEERING LIMITED
Fabrication & Welding
Prodcution Control & Documentation
Purchasing
Workshop
Site
System
No, Inform Foreman & Fitter
Forman issue Iso's
ISOs
Weld Procedure
*Weld Procedure
*Welding Procedures Chart
*Client Specification
Review Job ISO
Cut and Prep Materials as per DRG
Transport to allocated Fabrication Cell
Tack Cut & Prepped Materials Together as per DRG
Inform Welder / Forman to check Fabrication
OK?
Pass Tacked Materials to Welder
Carry out Visual Inspection (spirit level & associated measuring equipt.)
Weld as per DRG & Weld Spec
Carry out Inspection if required depending on geometry
OK?
Issue to Inspection
Fitter
Fitter
Foreman
Fitter
Fitter
Fitter
Fitter
Welder
Welder
Welder
Dimensional Tolerance is Checked after tacking


LAKERS
LAKER VENT ENGINEERING LIMITED
Process Inspection
Projects
Documents
Stores
Workshop
Systems
LVF 33 Inspection Stamp
Inspect Fabricated and welded piece as per DRG & Spec
Workshop Manager/QA
Compliance with Iso ?
Supervisor/ Foreman
No
Yes
Inform Works Manager of non-complicance
Supervisor/ Foreman
Weld Shrinkage/ Distortion Rectifiction
Review Fabrication Control sheet
Establish additional inspection processes and applications
Foreman
Is NDT required?
Yes
Final Process?
Client Specification / International Standards
Retrieve % welds for NDT either by client or from in-house
Workshop Manager/ Foreman
Inform Sub Contractor of addition work & estimate timescales
Workshop Manager/Forman
NDT Request Form
Raise Purchase Order for Subcontract Work
Workshop Manager
P.O. for Sub contract work
External Process is required
Contact appropriate Supplier to conduct the external process Quoting QCD Priorities
Preferred Supplier List
Client Specification and Appropriate Standards
Arrange Transportation of Job to be Processed/NDT
Works Manager


LAKERS
LAKER VENT ENGINEERING LIMITED
Process Inspection
Stores
Workshop
Projects
Documents
Systems
LVF 33 Inspection Stamp
Inspect Fabricated and welded piece as per DRG & Spec
Workshop Manager/ Foreman
Compliance with Iso ?
Supervisor/ Foreman
No
Inform Works Manager of non-complicance
Supervisor/ Foreman
Weld Shrinkage/ Distortion Rectifiction
Review Fabrication Control sheet
Supervisor/ Foreman
Additional
Supervisor/ Foreman
Yes
LVE Request Form
Client Specification and Appropriate Suppliers
Retrieve % welds for NDT either by client or from in-house
Establish Sub Contractor of addition work & estimate timescales
Workshop Manager/Forman
Preferred Supplier List
Client Specification / International Standards
Issue Quote including QCD Priorities
Workshop Manager/Foreman
Raise Purchase Order for Subcontract Work
Workshop Manager
See Purchasing Map for additional info
Arrange Transportation of Job to be Processed/NDT
Works Manager
P.O. for Sub contract work
See Purchasing Map for Supplier Selection info


LAKER VENT ENGINEERING LIMITED
Pressure Testing
Projects
Documents
Site
Workshop
Systems
LVF 20
Site Process Map
Client Test Specification/ Requirements
Issue Unique Number to Test System
Is system to be Tested In Workshop
No
Yes
Prepare Test System, Fill in and Sign Pre Test Inspection Sheet
Carry out pressure test in compliance with specification
Generate Pressure Test Certificate and Issue to Client
Client/Third party Approval?
Yes
No
Authorised Person
Authorised Person
Authorised Person
Authorised Person
Authorised Person


LAKER VENT ENGINEERING LIMITED
Packaging & Despatch
Projects
Stores
Workshop
Systems
Receive Job from Subcontrator/ Supplier/NDT tester
Workshop / Q.A Dept.
Receive Certification associated with NDT/ Paint/Coatings etc.
Workshop / Q.A Dept.
Compliance to Spec?
Customer Specification
Yes
No
Raise NCR and inform Works Manager
Workshop / Foreman.
Pressure Testing Required?
Yes
Pressure Testing Process Map
No
Spool Complete?
Yes
Arrange Pipe spools in Isometric order prior to delivery
Workshop / Foreman
Cap off open pipe ends
Workshop / Foreman
I.D. Marking
Spool No.
ISO No.
Job No.
Ensure ID are clearly marked on the pipes
Workshop / Foreman
Yes
Record the NDT Certificate No. in the Fabrication Control Sheet
Workshop / Foreman
Update Tracking Database
Workshop / Foreman
No
Issue to Welding (W.I.P)
Workshop / Foreman
See Welding/Fab Process Map
Tracking Database
Organise outgoing consignment note prior to depatch
Workshop / Foreman
Isometric DRG
Fabrication Control Sheet
NDT Reports
Additional Project Specific, paint specs, pressure tests etc.
Compile Test pack Documentation to Consignment Note and issue to Driver
Workshop / Foreman


LAKERS
LAKER VENT ENGINEERING LIMITED
Project Close
Documents
Projects
Workshop
Transport
Systems
Receive from driver signed consignment note
Driver
Issue to Forman
Driver
Attach information in workshop Job File
Hold Documentation in workshop Job File for 6 months within production
Archive after 6 month Job close in old workshop office
Project Close
Retrieve Monthly valuations from both Dema & Tracking Database
Invoice Customer
Project Close
Dema
Tracking Database
Idea: Project Feedback for Estimating/ Project Managers & Production

Appendix I: CROSS IMPACT ANALYSIS: LAKER VENT ENGINEERING

Resources	Resource Description Resources	Explicit Knowledge	Tool Quality	Tacit Knowledge
R1	Customer Spec Info (Delivery Date)	6	5	6
R2	Customer Quotes	6	3	9
R3	Customer BOM	5	4	8
R4	Material Take-off	4	5	8
R5	GA Drawing	6	3	8
R6	Estimation Sheet & Specs	5	4	8
R7	Documentation List	8	5	7
R8	Contract Master DB (Tracking Database)	5	7	6
R9	Supplier DB	7	8	8
R10	Terms & conditions	9	9	9
R11	Genesis DB	7	8	7
R12	Norm Guidenotes	9	8	9
R13	Bid Documentation	7	8	7
R14	Release Bid to client	7	8	8
R15	Lost Bid Analysis	5	5	4
R16	Order Confirmation	8	5	7
R17	Order Review	6	4	7
R18	Contract Labour Info	7	5	9
R19	Job File	7	7	7
R20	Contract Reviews	6	7	8
R21	Production Schedule	7	6	8
R22	Quality Requirements	8	7	8
R23	Workshop Loading	7	6	8
R24	Stock Control	9	6	8
R25	CAD	8	9	9
R26	ISO Drawings	8	7	5
R27	Drawing Revision Control	7	8	6
R28	Weld Procedures	6	7	8
R29	NDT Request Form	9	8	8
R30	Inspection & Test Forms	8	7	7
R31	Documnetation Control	5	7	7
R32	Cash Forecast & Budget	8	8	8
R33	Dema (Finance DB)	7	8	8

Process ID	Ci	mi	Wni	Wci
R1	180	6	50%	0.25
R2	162	3	25%	0.22
R3	160	3	25%	0.22
R4	160	2	17%	0.22
R5	144	2	17%	0.20
R6	160	3	25%	0.22
R7	280	1	8%	0.38
R8	210	3	25%	0.29
R9	448	4	33%	0.61
R10	729	3	25%	1.00
R11	392	2	17%	0.54
R12	648	2	17%	0.89
R13	392	3	25%	0.54
R14	448	1	8%	0.61
R15	100	1	8%	0.14
R16	280	1	8%	0.38
R17	168	1	8%	0.23
R18	315	1	8%	0.43
R19	343	3	25%	0.47
R20	336	4	33%	0.46
R21	336	4	33%	0.46
R22	448	3	25%	0.61
R23	336	4	33%	0.46
R24	432	5	42%	0.59
R25	648	1	8%	0.89
R26	280	5	42%	0.38
R27	336	2	17%	0.46
R28	336	4	33%	0.46
R29	576	5	42%	0.79
R30	392	5	42%	0.54
R31	245	4	33%	0.34
R32	512	6	50%	0.70
R33	448	6	50%	0.61

Mean	344.8
Max	729.0
Min	100.0

Mean	28.5
Max	38.7
Min	17.6

	Laker Vent NPD-ETO											
Target	7000	10000	6000	21000	10000	8000	6000	9000	5000	8000	3000	10000
NODE	PM 1.1 Sales & Estimating	PM 1.2 Sales & Estimating 2	PM 2.1 Project Planning	PM 2.2 Documentation 7 Purchasing	PM3.1 Production Control	PM 4.1 Purchasing	PM 5.1 Stores	PM 5.1 Workshop	PM 5.2 Fabrication & Welding	PM 4.3 Process Inspection	PM 5.6 Pressure Testing	PM 4.6 Packaging & Despatch
Bm	2200	3611	1896	7135	3732	3310	2153	3055	1764	3208	1008	3727
	1	1		1	1		1		1			
	1	1		1								
		1		1	1							
						1		1				
					1			1				
	1		1	1								
												1
	1			1								1
				1	1	1				1		
		1			1	1						
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	1	1										
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		1										
			1									
				1								
				1	1			1				
				1	1					1		1
			1	1				1			1	
								1		1		1
				1			1	1		1		
				1	1	1	1	1				
				1								
				1				1	1		1	1
				1						1		
				1		1			1	1		
				1				1	1	1		1
				1					1	1	1	1
				1		1	1					1
		1		1	1	1	1					1
	1		1		1	1	1					1

nj	7	10	6	21	10	8	6	9	5	8	3	10
Performan	31%	36%	32%	34%	37%	41%	36%	34%	35%	40%	34%	37%
Rn	15.1	9.0	12.7	8.3	15.2	17.1	24.5	13.3	25.0	15.1	26.2	15.2
Rco	23.3	17.6	22.7	24.3	30.2	30.9	38.7	26.9	36.6	26.8	33.3	31.3