APPLICATION OF PRODUCT DATA MANAGEMENT WITHIN THE PRODUCT DEVELOPMENT PROCESS

Thesis submitted in accordance with the requirements of the University of Huddersfield for the degree of Doctor of Philosophy

by

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ABSTRACT

Manufacturing companies need to be able to respond to customer demand quickly and accurately. This requires the capability to manage product data effectively. Product Data Management (PDM) systems have been identified as a solution to deliver this capability by providing the right information to the right people at the right time and in the right format.

The foundation of this research is that the concept of PDM is relevant and important within the product development process. This research focuses upon how the PDM concept is applied in practice to define and configure products and how it can be integrated with other major information systems to enable an enterprise wide information system. To enable the research aim, an extensive review of literature was undertaken to investigate the effectiveness of PDM in enhancing the product definition process and in creating an interface between different business functional areas.

A survey of PDM system usage was undertaken aimed at identifying the current level of PDM usage within manufacturing enterprises in the UK. This was followed up by three industrial case studies to provide some degrees of validation of the results obtained. A need for effective one time order capture was identified from the three case studies which led to the development of a model specification for a late product configuration tool. A prototype system was produced to validate the design specification and was successfully demonstrated to a collaborating company. During the submission of this thesis, the collaborating company and the university are working on funding a project to pursue with its implementation.

The work undertaken has firmly established the relevance of PDM within the product development process and the importance of effective interfaces between PDM and other manufacturing information systems. The research will be of interest to small and medium sized manufacturing companies searching solutions for improving the management of their product data to enhance product definition and configuration.

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LIST OF PUBLICATIONS

Refereed Publications:

1999 Little, D. and Lee, H.L.
Survey of PDM Systems in the UK's SMEs.
Control of The Institute of Operations Management, Vol. 25, No. 8, October 1999, pp. 21 - 26
[ISSN: 0266-1713]

1999 Little, D. and Lee, H.L.
Survey of PDM Systems in the UK's SMEs.
Proceedings of the 15th International Conference on Production Research, Limerick, Ireland, 9th - 13th August, 1999, Vol. 2, pp. 1773 - 1776
[ISBN: 1-874653-56-9]

2000 Lee, H.L., Little, D. and Dancer, D.
Production Tracking System for SMEs.
Proceedings of the 1st International Conference on Production and Operations Management, POM Sevilla 2000, Spain, 29th August - 2nd September 2000
[ISBN: 84-8009-102-9]
Note: Proceedings contained in a CD, therefore no page number.

2000 David Little, Hooi Leng Lee and David Dancer
Workflow Monitoring for Vehicle Assembly.
Proceedings to the 5th Annual Conference Logistics Research Network (LRN), Cardiff, Wales, UK, 7th - 8th September 2000
ISBN: 0-9537-9821-6]

2000 Little, D.; Hall, D.M.; Rhymer, S.J. and Lee, H.L.
The Development of a Late Product Configuration Tool and Procedural Ethos within SMEs.
Proceedings of the 16th National Conference on Manufacturing Research (NCMR), East London, UK, 8th - 9th September 2000, pp. 203 - 207
[ISBN: 1-860-58267-2]

2001 Lee H.L., Little D, and Hall D. M.
Development of a Generic Late Product Configuration Tool for Responsive Manufacture.
Proceedings of the 7th International Conference on Concurrent Enterprising (ICE), Bremen, Germany, 27th - 29th June 2001, pp. 395 - 401
[ISBN: 0-85358-098-7]

2001 Little D, Lee H.L. and Hall D. M.
Realising Effective One-Time Order Capture Through Effective Data Management.
Proceedings of the 18th International Manufacturing Conference (IMC), Dublin, Ireland, 5th - 7th September 2001, pp. 401 - 409
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Paper Submitted to Referees:

2002 Little D, Lee H.L. and Hall D. M.
Managing the Supply Base: A Supplier Development Methodology in the Assemble to Order Sector.
The International Journal of Operations and Production Management [Submitted in February 2002]

Refereed Paper Awaiting Publication:

2002 Little D, Lee H.L. and Hall D. M.
Foresight Vehicle Project: Increased Customer Responsiveness through Late Product Configuration.
Proceedings of the Society of Automotive Engineers 2002 World Congress, Detroit, USA, 4th - 7th March 2002

2002 Little D, Lee H.L. and Hall D. M.
Agile Assembly through Late Product Configuration.
Proceedings of the IFIP Working Group 5.7 International ASPM Conference on Strategic Manufacturing, Eindhoven, Holland, 9th - 12th September 2002

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1.0 INTRODUCTION

At the turn of the century, great business enterprises were founded on a single product. Examples of this are Ford (Model T), Raleigh (the standard Raleigh bicycle), and Beecham (Beecham's little liver pills). These products continued in production for decades without major change. That was then an ideal manufacturing environment with high volume and low variety. Examples of this environment still can be observed in Cussons Imperial Leather toilet soap and Coca-Cola.

However, as society became more affluent, customers became more discerning and more demanding. This led to a demand for more variety in product design with a consequent fall in volume. As variety increased with time, the manufacturing environment became more complex. The manufacturing paradigm thus began to shift from cost, quality, and delivery to include responsiveness to changing customer requirements or "agility" [Willis 1998, Vokurka and Fliedner 1998, Shewchuk 1998]. This places a heavy demand upon an organisation's information systems, a means to achieve agility.

To achieve true agility, an integrated enterprise wide information infrastructure is deemed necessary [Kidd 1994]. The objective is to enhance and to compress the existing product development and order fulfilment processes, through effective and efficient information management, in order to remain competitive and to survive today's global competition, as well as satisfying the paying customers. However, Yusuf reported that there is no fully integrated enterprise wide information system and that enterprises are at different levels of the implementation of a company wide model [Yusuf 1996].

The creation of an integrated information infrastructure requires a careful analysis of three fundamental elements: people, technology, and organisation [Barry and Duffill 1998, Prasad 1997a, Kidd 1994]. These three elements are important, complementary and mutually interdependent, and should be considered concurrently in the process of implementing such infrastructure. However, this is usually not the case in many businesses. For example, whilst many companies have in recent years embarked upon radical business improvement programmes, Roy quoted that evidence suggests that 70% of corporate change programmes fail due to the lack of consideration of all the three elements during the strategic planning stage [Roy et al 1998]. The author acknowledges the importance of these three elements necessary to achieve an integrated enterprise wide information infrastructure, however, this research focuses mainly on the issue of technology because its goal is to investigate effectiveness of product data management in the new product development process.

Product data is now recognised as a critical corporate resource [Sackett and Martin 1998, Gavin 1996] and a strategy for its development and management is essential [Williams 1997]. Computer integrated manufacturing (CIM) has emerged over the past years to create an architecture for effective utilisation of product data across a manufacturing enterprise [Scheer 1994]. Today we are seeing this extended to cover the whole supply chain [Bolmqvist et al 2000, Kruse 1999] and beyond [Pendrous 2000]. CIM was based and relied upon the identification of appropriate computer solutions to support the business strategy of an enterprise and to enable the integration of its activities and functions in an effective manner. The linking of 'islands of automation' was a common theme and the linking of the islands of design and manufacture was a particular concern.

One aspect of CIM that has been receiving much recent attention is Product Data Management (PDM). A PDM system may be developed in-house but more typically is a commercially available computer-based tool that allows the sharing of product data. In responding to today's mass customisation that leads to a more complex and wider range of products, PDM systems help to manage the large volume of critical product data resulting from the increasing number of electronic users. Successful PDM implementation is particularly important to allow a concurrent engineering approach to the product development process, especially in new product introduction, by providing the right information to the right person in the right time [McIntosh 1995].

1.1 Problems Definition

Co-operation between the sales, design, and manufacturing functions is of primary importance to the competitiveness of a manufacturing enterprise. This is evident in the production of products of high quality with minimum possible costs and shortest time to market whilst satisfying customer requirements. This is especially the case in today's manufacturing environment where there is a high level of product customisation, smaller batch production, and flexible customer and supplier arrangements [Barclay et al 1998]. However, there are still many manufacturing enterprises employing traditional 'over the wall' practices where customer order confirmation, product design and manufacturing proceed as a series of sequential activities. A solution is required to enable a smooth interface between sales, design and manufacturing in order to achieve an interactive and iterative sales, design and manufacturing environment. This solution can be realised through the implementation of an effective PDM to allow the integration of both product and process data within these three domains. Such solution can also facilitate right first time at the initial order entry stage.

The majority of commercially available software packages used to run a manufacturing business were developed without a global view of the manufacturing system [Jardim-Gonçales et al 1996]. Widespread use of such commercial tools, coupled with lack of understanding of the organisation's key business processes, has given rise to an unmanageable proliferation of computer systems and the accompanying explosion of product data. This has created new problems whilst solving others [Gascoigne 1995], besides creating islands of automation within an enterprise. Linking these islands of automation is critical in developing an integrated manufacturing environment capable of effectively supporting agile manufacturing. However, this is not an easy task and it relies heavily on the degree of interoperability between these islands of automation. It is important to look at other means to enable these islands of automation to communicate with each other without the creation of duplicated information.

The development of small and medium sized enterprises (SMEs) is seen by the UK government to be vital to the re-generation of the manufacturing base in this country [Humphries 1997]. For the purposes of this thesis, an SME is taken as an enterprise that employs less than 250 employees and has an annual sales income of less than £30 million. This is in accordance to the definition by the UK's Department of Trade and Industry (DTI). The European Community and DTI have identified SMEs as critical to future economic growth and job creation within the European Union. For example, in Northern Ireland, 98% of its manufacturing companies have less than 250 employees [Amstrong and Coyle 1999]. Therefore, it is important that any introduction of new technologies or methods should involve them. However, many new technologies are targeted only at large enterprises that have more resources available and are more up to date and more able to handle today's advanced technology [Bibb et al 2000]. This appears to be the case with PDM as well.

The introduction of PDM in the product development process has enabled accurate and correct information to be delivered to the right person at the right time in the right format [McIntosh 1995, Stark 1992]. PDM has been recognised as an enabling technology for CE [Gascoigne 1995, Esebeck et al 1995]. However it has not been fully understood and utilised within industry. This is especially the case in SMEs [Thoburn and Winters 1998, Miller 1996b]. Although there has been research carried out on developing frameworks for successful implementation of PDM systems, the emphasis is based upon the larger firm and examples of SMEs successfully embracing PDM are few and far between. It is important to identify the obstacles that are preventing SMEs involvement in PDM and also to provide solutions to overcome these obstacles.

1.2 Research Aims and Objectives

In order to address the problems defined in the previous section, the author strongly believes that it is important to first understand the concept of PDM and how it can help to achieve business needs. For this reason, this research focuses upon how the concept of PDM can be applied in practice to define and configure products and to provide an interface between other business areas within an organisation, mainly sales, design, and manufacturing. Furthermore, this approach allows the study of the effectiveness of PDM within the product development process without incurring heavy cost such as investment in a commercially available PDM system, which would be of interest to many SMEs.

The hypotheses underlying this research work are:

- An effective interface between PDM and relevant manufacturing control systems is essential to effective manufacturing performance, especially for the make-to-order manufacturing sector.
- PDM is applicable and can be as beneficial to the SME as it is to the larger enterprise when implemented from the right perspective and using the right methodology.

Here, the definition of a make-to-order manufacturer is one that produces high value capital goods such as those in the automotive industry, which also includes manufacturers who assemble-to-order and engineer-to-order.

To validate the above three hypotheses, the following three objectives have been established:

i To review the applications and effectiveness of PDM systems in the new product development process within manufacturing industry to enhance the product definition process.

ii To analyse the current interfaces between sales and design, design and manufacturing and the effectiveness of PDM software in improving these interfaces.

iii To identify appropriate models for PDM operations within SMEs.

Aligned with this, several important questions have been identified. This research intends to seek and provide answers to these identified questions:

- What is the current status of the product definition process?
- How effective are today's interfaces between sales and design, and design and manufacture?
- How applicable is PDM to the SME and are current commercial systems appropriate for them?
- What are the practical barriers to PDM implementation within SMEs?
- How can PDM be integrated with other business processes and information

systems, particularly between PDM, CAx, and manufacturing control systems such as MRPII and ERP?

1.3 Research Methodology

The research methodology was based upon the approved work plan in the bid for a university-funded research. The original work plan was made of ten key stages, however as the project progressed and due to some unforeseen difficulties encountered during the research, some modifications to the initial work plan were proved to be necessary.

The research methodology adopted for this study entails the use of both quantitative and qualitative methods. This balance combination of both methods is important as pointed out by Curran and Blackburn:

> *"The quantitative elements add 'bulk' to the findings and help support implicit / explicit claims to generaliz-ability that all research makes while the qualitative elements concentrate on 'why' issues: the reasons or causes that might underlie the pattern of findings discovered"*
>
> Curran and Blackburn [Curran and Blackburn 2001]

The method adopted includes a literature search and review, the design, distribution, and analysis of a questionnaire and a series of detailed case study investigations of the application of PDM concept within industry. The work plan to complete the research had been divided into six stages, each with defined activities and outputs.

The first stage was the induction period for the purpose of topic familiarisation. The output from this stage is the initial topic analysis. The second stage was to conduct the preliminary literature review that covers the past and current developments in PDM, with the emphasis on how PDM can be applied to define and configure products, as well as the integration of PDM with other information systems. The outputs for this second stage are the review of PDM status, an input to the research topic analysis and an extensive bibliography on PDM.

Stage three followed with the design and analysis of a survey instrument that analysed the actual current level of PDM systems usage against claims made by many PDM vendors. For the purpose of comparison between PDM systems usage in the UK and outside of the UK, the survey also included results obtained from respondents outside of the UK. An analysis report was generated and two papers were published upon the completion of this survey.

Three industrial case studies with two local manufacturing companies to examine the application of PDM were carried out in stage four. The chosen companies were of significantly different profiles in terms of organisation structure, products made, and the type of manufacturing information systems used. Although the two case study companies are both parts of larger groups, because of their distinct geographic location from the parent company, their actual plant size and their particular focus on make-to-order products, they exhibited most of the characteristics of the larger SME. Two papers were published upon the completion of these case studies.

The output of the three case studies led to the realisation of the need for a generic late product configuration tool in order to achieve effective one time order capture. Here, late product configuration is defined as the ability to configure a product based on customer initial requirements during the order entry stage as well we changes requested by customer when a confirmed order has proceeded to the production stage. Stage five continued with the development of a model specification for a generic late configuration tool. A prototype of this model was also produced and demonstrated to one of the collaborating companies. Three papers were published in conjunction with the overall output from the three case studies and the development of this late production configuration tool.

To ensure that the research work undertaken does reflect current thinking, a final review of the literature was carried out in stage six.

Figure 1.1 illustrates the activities that were carried out in this research, whereas Figure 1.2 summarises how the adopted activities address the objective and validate the hypotheses set in this research.

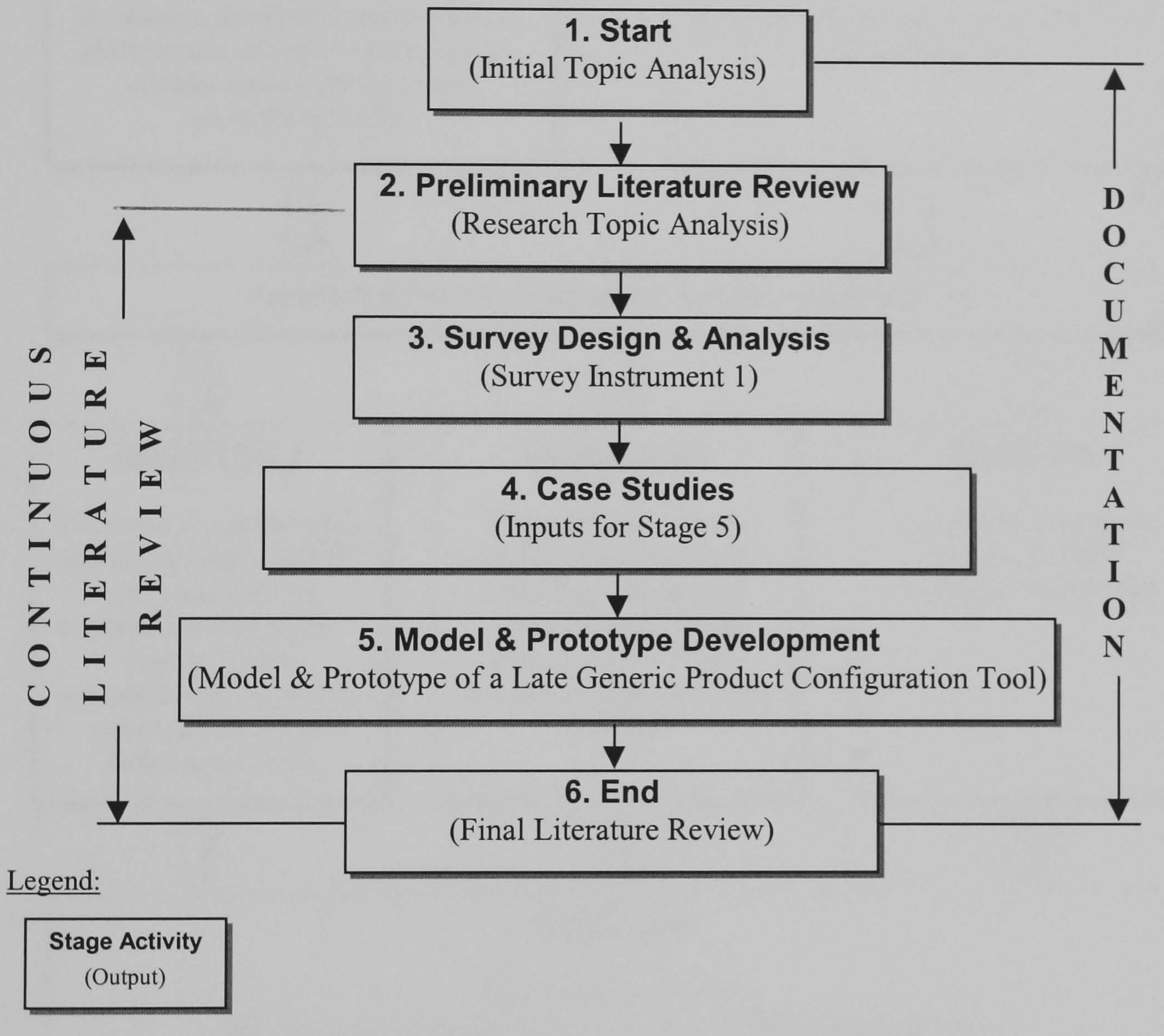


Figure 1.1 Major Research Activities Adopted

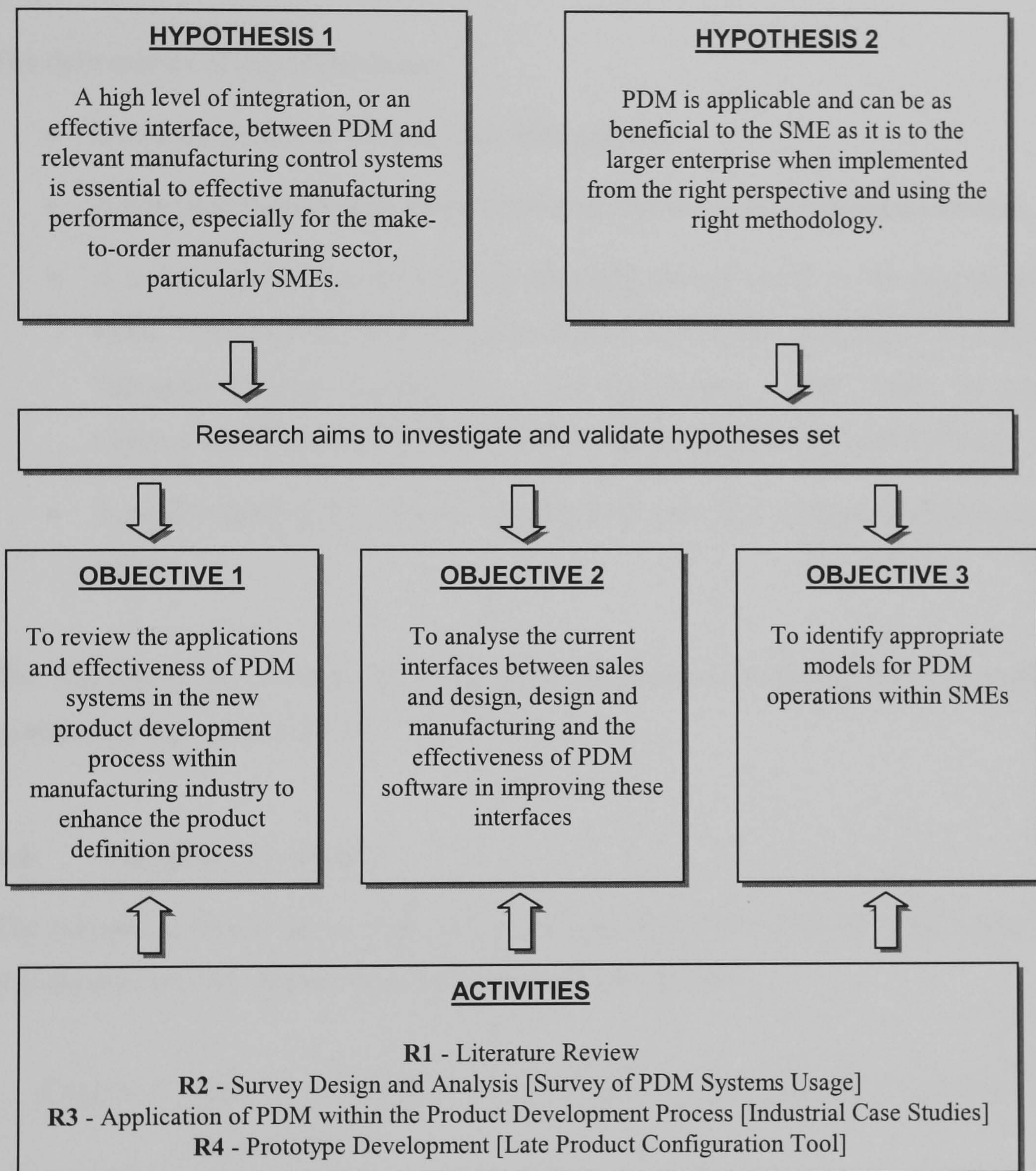


Figure 1.2 Research Methodology

1.4 Research Deliverables

The report of this research is presented in this written thesis as a properly documented record throughout the entire duration of the research.

The deliverables of this research are:

- Literature review of Product Data Management.
- A practical method to promote PDM awareness to manufacturing companies.
- A tool for production tracking and shortage control based on the concept of PDM. This tool also formed a part of the output from an EPSRC IMI Land Transport Project: Development of a Responsive Supply Chain in the Commercial Vehicle Sector, RESCOVS (Grant Reference GR/M43081/01).
- A model specification for the development of a late product configuration tool.

The findings of the research have also been disseminated to industrialists through conferences and journal articles.

1.5 Structure of Thesis

The purpose of this thesis is to document the overall results of this research project. It is divided into six chapters to allow easy and fast reference.

Chapter 1 gives an introduction to the objectives, the needs, and structure of this project.

Chapter 2 introduces the product development process and examines the literature pertaining to the initiation of product data management methods and software tools such as PDM systems within a modern integrated manufacturing system.

Chapter 3 discusses the design of the questionnaire aimed at establishing current PDM systems usage. The analysis and results of the questionnaire are presented.

Chapter 4 presents the three industrial case studies undertaken showing the applications of PDM concept within three different stages of the product development process, covering sales / marketing, design and engineering, and manufacturing.

Chapter 5 provides a brief recap of the work done in this research project with an overall discussion.

Chapter 6 marks the end of this thesis with the final conclusions of this research summarising the effectiveness of the adopted research methodology, the research findings, and the contributions to knowledge. Also included in this chapter are two recommendations for future work.

1.6 Summary

Manufacturing companies need to be able to respond to customer demand quickly and accurately. This requires the ability to achieve right first time on the product definition or specification during the initial new product development process, i.e. during the order entry stage. To realise this, manufacturing companies require an effective product data management that will ensure that relevant accurate and up-to-date product information is made available and accessible to the right people at the right time and in the right format. PDM systems offer such solution if implemented successfully. However, a significant gap exists between large manufacturing companies and SMEs in terms of benefiting from PDM systems. It is therefore necessary to investigate why SMEs are lacking behind this technology and to rectify the situation.

This research is aimed at investigating how the concept of PDM can be applied in practice to define and configure products and to provide an interface between other business areas within an organisation, mainly sales, design, and manufacturing.

These are two important aspects that need addressing in order to improve the product definition process. This research is of interest to manufacturing companies that are searching for effective ways of introducing effective management of product data to solve their business needs without requiring a huge investment cost during the trial stage, particularly useful for SMEs that are not aware of PDM systems.

2.0 LITERATURE REVIEW

The objective of this chapter is to address the first two research objectives mentioned in Chapter One as well as those questions raised in the previous chapter through the literature reviewed. This chapter aims to provide an introduction to the new product development process (NPD) and to review the main changes in the methods of product definition and the management of product data that have occurred with the advent of computer support. A particular focus will be the evolution of product data management methods and software tools such as PDM systems within a modern integrated manufacturing system.

This chapter begins with a brief review of the literature covering NPD. It then reviews the evolution of PDM systems and discusses some of the common issues related to PDM. The literature review continues with some of the more pertinent issues related to PDM, particularly the roles played by PDM systems in the product development and order fulfilment process. The involvement of SMEs in PDM systems is also discussed, mainly looking at the obstacles that deter PDM implementations within SMEs.

The literature review concludes by summarising how the literature addresses the two research objectives mentioned in Chapter One.

2.1 The New Product Development Process (NPD)

The inevitable trend towards customised products, ever-higher quality and faster deliveries to customers has put NPD on the agenda for delivering increased product quality, improved responsiveness to customers and lower unit cost. The pressing need is to capture customer requirements effectively and to translate these into a design specification, whist utilising existing design modules wherever possible, which then can be rapidly turned into a quality and cost effective product delivered within the agreed due date.

NPD is the means by which new or modified products are developed from the identification of initial customer needs, through to the realisation of these needs into products that are launched into the market. Over the last 40 years, there have been dramatic changes to NPD in an attempt to reduce both product costs and development times while to remain competitive. Esebeck quoted that back in the 1960s, new products were designed and re-designed by individual engineers, manually, without use of any structured design process [Esebeck et al 1995]. There were also only a few methods and tools available to assist them. However, since the first introduction of scientific and systematic procedures for the design of new products by Pahl and Beitz in 1977, many manufacturers had started employing such procedures to reduce product failures, higher costs and insufficient development time. Barclay reported that whilst in 1987 only 40% of the companies he surveyed had any form of product development procedure implemented, this figure had reached well over 90% in 1996 [Barclay et al 1998]. In fact, there is a British Standard dedicated to managing design activities within NPD called "British Standard 7000: Guide to Managing Product Design" [Burgess and Wallace 1995].

Today's market trends confirm the continuation of NPD as a change agent for many more years to come with the focus on high product variety and shorter product life cycles. For example, Barclay and Dann reported that the average life cycle of engineering based products in UK had dropped from fourteen years in 1993 to eight years in 1997 [Barclay and Dann 1998], a reduction in excess of 40%. Also, the literature shows that many methodologies and techniques have been developed over the years to facilitate cost reduction and shorter product lead-time [Ratchev et al 1999, Benedetto et al 1998, Wright 1997, Chung et al 1995, Bayliss et al 1995, Sullivan et al 1994]. This is important because the market reacts negatively to the announcements of delays. For example, McMillan of Boots Contract Manufacturing, UK, reported that they lost credibility and reputation for offering products that they could not deliver [McMillan 1998].

Table 2.1 shows an overall summarised view of the trends of NPD in the last 30 years, drawn from the literature.

	1970s	1980s	1990s
Business Environment	Regional	National	Global
Competitive Challenge	Cost, Quantity	Quality	Product Lead Time, Product Quality, Variety & Cost, Flexibility, Customer Satisfaction
Manufacturing Objectives	Using technologies to automate for efficiency	Emphasising on flexibility and integration	Creating a learning organisation to make continuous innovation to work smarter
Working Style	Departmentalised	Project Team	Virtual Team
Design Methodology	Re-inventing the wheels, Over the walls		Concurrent Engineering
Production System	Make to Stock		Engineer / Make to Order
Manufacturing Organisations	Centralised	Decentralised	World-wide
Automation	Islands	Interfaced	Integrated

Table 2.1 New Product Development Process Trends
[Drawn from: Hall et al. 1998, Johnson et al. 1998, Fitzgerald 1992]

- **Towards Responsive Manufacturing**

The manufacturing process has evolved from craft based production when mankind began to make primitive artefacts, to today's approach that is based on the concept of agile and global manufacturing [Rigby et al 2000]. Today, modern manufacturing strategies place the emphasis mainly on speed, flexibility, and responsiveness to customer needs. Agile manufacturing is a new concept for manufacturing responsiveness and was introduced by the US as a response for make-to-order products after the introduction of lean manufacturing by the Japanese for restoring their competitiveness [Kidd 1994].

The concept of agile manufacturing was articulated from the work of the Agile Manufacturing Enterprise Forum (AMEF) at Lehigh University's Iacocca Institute, USA, in 1991 [Shewchuk 1998]. Its aim was to combine the organisation, people, and technology into an integrated and co-ordinated interdependent system to be used for competitive advantage. Emphasising on the integrated approach required to remain competitive, Kidd defined agile manufacturing as:

> *"A methodology of integration that underpins the three primary resources of a company: innovative management structures and organisation, skill base of*

knowledgeable and empowered people, and flexible and intelligent technologies."

Kidd [Kidd 1994]

"Voice of customer" is important in any future design methods and manufacturing strategies that strive toward responsive manufacturing, just like in the craft based production [Ritchie and Black 1999], especially with today's increased practice of the mass customisation. In the past, manufacturers designed complex sub-assemblies and the final assembled products. Today's trend, however, does not provide an environment for NPD to be managed by individual persons and requires traditional rigid mass production techniques to be replaced with flexible manufacturing techniques. The need for integrating customer needs into product requirements [Ritchie and Black 1999] and increased supplier involvement [Hough 1998, Jung et al 1997] have added complexity to today's NPD. To manage such complexity, closer integration is necessary between all functions in all companies within the supply chain, not only on a regional scale but also on a global scale.

This is important because, today, many low-cost countries, which have become technologically sophisticated, are able to compete with high cost countries. In the UK, for example, changes in exchange rates have demonstrated the fragility of concentrating on minimum cost as an essential competitive weapon. On top of that, there are also other issues such as labour costs and various social related costs. It is therefore not surprising to know that many European based producers are adopting a combination of Western-designed and Eastern-made products [Woodcock et al 2000]. This trend is likely to accelerate and emphasises the importance of improved NPD processes.

It can be summarised that the major trends affecting today's NPD is increased competitive pressures such as continuous global competition including the low costs of newly industrialised nations, increased product variety and differentiation, decreased product lead-time and life cycle, reduction in manufacturing batch size, and a decline in repeat orders. Also, within today's market trends, new products very quickly become commodities, which are then copied by low cost producers.

Industrialised nations are forced to respond to these competitive pressures by implementing right first time philosophies, reducing both development and cost recovery time, increasing responsiveness, and by introducing more systematic, team-based and iterative approaches. All of which place emphasis upon a structured product development process.

2.1.1 The Importance of Technology to NPD

The industrialised world has seen a shift from labour- and capital-intensive industries to knowledge- and technology-based economies [Trott 1998]. According to Trott, as competition increases in markets throughout the world, technology has emerged as a significant business factor and a primary commodity. For example, in a study of the technology adoption practice of 20 major Asian manufacturers in 1997, it was identified that quality control was more easily achieved with technology rather than with manual quality control processes [Orr 1999]. Orr quoted that Sony Precision Engineering found that their workers were able to identify only 90% - 95% of quality defects, whereas the advanced manufacturing technology employed was able to identify nearly 100%.

To emphasise the importance of computer technology within NPD, research into the utilisation of product development methods in the UK, carried out in 1995, drew out one important point:

> *"In companies where product development methods were implemented on a computer, there was an increased perception that the method contributes strongly to product quality over companies where the method was implemented on a paper-based system."*
>
> Araujo [Araujo et al 1996]

From the manufacturing perspective, Ostwald and Muñoz provided examples of the use of computer technology, as shown in Table 2.2, to support modern manufacturing strategies [Ostwald and Muñoz 1997].

	Computerised Manufacturing Systems
1960s	Production and Inventory Control System; Numerical Control (NC)
1970s	Material Requirements Planning (MRP), Master Production Scheduling, Computer Numerical Control (CNC); Push Systems
1980s	Manufacturing Resource Planning (MRPII); Optimised Production Technology (OPT); Statistical Quality Control; Computer Aided Design and Manufacturing (CAD/CAM); Simulation; Pull Systems
1990s	Computer Integrated Manufacturing (CIM); Decentralisation; Simplification; Total Quality Management (TQM); Activity-Based Costing
2000s	"Intelligent" Manufacturing System; Flexible and Agile Automated Systems; Continuous Benchmarking Systems; Community Involvement; Continuous Infrastructure Improvement; Paperless Systems; Ergonomics and Safety System

Table 2.2 Manufacturing Systems to Support Manufacturing Strategies [Ostwald and Muñoz 1997]

- **Information and Communication Technology (ICT)**

Information and Communication Technology (ICT), an important aspect of computer technology, has been identified as crucial in supporting and enhancing today's NPD. ICT can be defined as the generic term for the convergence of computers, hardware, software, telecommunications, the Internet, electronics and the resulting information system [Gunasekaran et al 1999]. The underlying effect of the ICT evolution has been the realisation of the critical value of timely and accurate information in support of the product development process. For example, Little and Gavin quoted that:

> *"Effective use of information impacts upon what can be achieved as well as the way of achieving it!"*
>
> Little and Gavin [Little and Gavin 1994]

As global competition intensified, ICT investment has been re-focused to deliver faster, more reliable communication and integration of information throughout both local and global enterprises. Today, ICT has become an important part in the evolution of NPD as the central support system for decision making in order to attain design optimisation and innovation [Mainwaring 1999, Pham et al 1999, Taylor 1998, Mortimer 1994].

Web technology, a platform independent application, has emerged as a new type of information medium that facilitates fast access to a large amount of cross-referenced data [Rowell 1999]. For many businesses, web technology represents an opportunity that enables its users to take maximum advantage of their existing hardware and software investment. For example, web technology has been reported to provide a cheaper means of disseminating information and reduces the traditional assimilation problems between new technologies and legacy systems [Porter 2001, Rowell 1999].

However, it is important to note that ICT should not be pursued as an end itself, but for its contribution to cost control, product quality, and, most importantly, time to profit. Failing to recognise this is one of the reasons why many IT system implementations failed over the last decade [Manning and Wight 1998, Medhat 1994].

2.1.2 The Need for Efficient and Effective Management of Product and Process Data

With the increasing use of sophisticated computer technologies in NPD, manufacturing enterprises are generating massive quantities of data [Port 1998], especially from the design to production process. This data can be largely grouped into two groups: product data and process data. Process data provides information about the processes that create a product, such as engineering change, project approval and authorisation, product configuration, workflow, and information exchange. Product data can be divided into technical and non-technical information. Examples of non-technical information includes the direct and indirect product costing, marketing information, sales orders, purchase orders, correspondence, product warranty, etc. Examples of technical information include the following:

- Design specifications such as bills of material and design geometry
- CAD files such as engineering drawings and assembly diagrams
- CAE files such as engineering analysis results
- CAM files such NC programs
- Others like product instructions manual and manufacturing plans

All these data are used, created, processed, consulted, and multiplied, stored, etc. at different functional areas within an enterprise throughout the product life cycle, as shown in Figure 2.1.

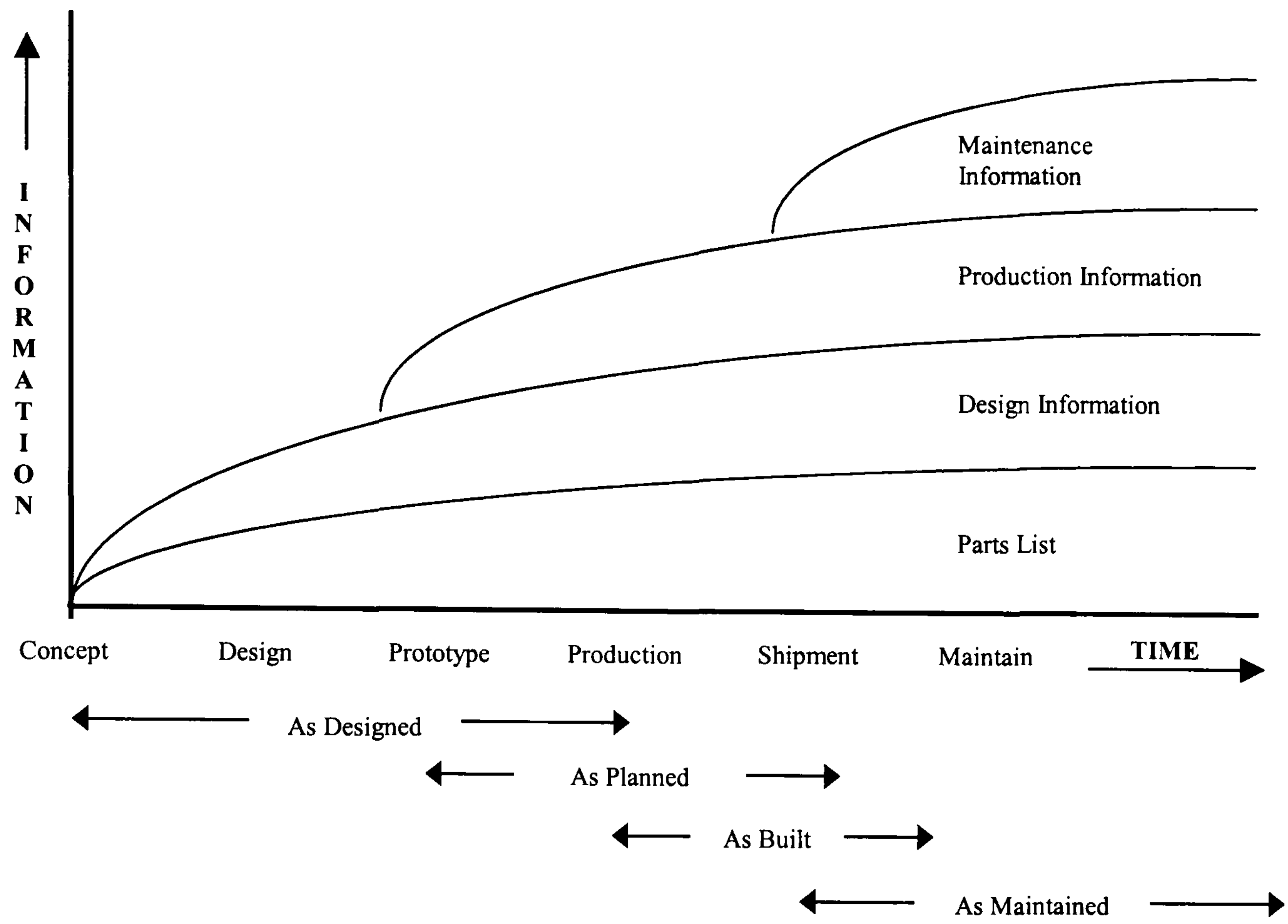


Figure 2.1 Information throughout the Product Life Cycle [Carroll 1998]

Clearly, product and process data is a critical resource to many enterprises and therefore the management of this data is a key consideration. A failure to recognise this will result in an organisation that is, at best, inefficient, slow, and suffering some drop in productivity. At worst, this failure will dictate a loss of control, resulting in errors, repeated errors and the associated burdens.

The rising need for fast access and effective sharing of relevant product data has identified a product data management structure that poorly serves the NPD process. Literature shows that searching for required product data during the design stage is often too time consuming for individuals and mistakes are repeated and work is duplicated because of a lack of rationalised access to relevant product data [Boyle et al. 1998, Surlis 1996, Koonce et al. 1996, Marsh and Wallace 1995, Court et al 1995, Beckert 1994]. This inadvertently results in poor product quality:

> *"If specific design data is difficult to locate, there is an ultimate loss of productivity and design decisions will be based on assumptions and incomplete data."*
>
> Rangan and Fulton [Rangan and Fulton 1991]

The literature has shown that efficient and effective access to, and sharing of, accurate and up to date product data has become an urgent need [Kidd 2001, Belecheanu et al 1999, Thuraisingham 1997]. This is especially the case since the outcome of any design process is heavily dependent on the availability and use of relevant product and process data while previously proven solutions are known to have a large impact on design decisions [Ackers et al 1995, Khadilkar and Stauffer 1995]. To achieve this, effective product data management is a pre-requisite. PDM is a concept about managing data that describes or defines the physical product, and the processes and documentation used to make and support the product. It enables the retrieval of useful information and then makes use of this information to aid decision-making. Without doubt, this is the case because it is only when information is interpreted from available product data and then used by individuals in some process that it becomes knowledge. The application of this knowledge then leads to actions and ultimately these become skills and expertise, as emphasised by Trott:

> *"Information is the central to the operation of companies and it is the stimulus for knowledge, know-how, skills and expertise."*
>
> Trott [Trott 1998]

2.1.3 Summary

The effective introduction of new products is critical to the performance of manufacturing companies in most industrial sectors. It is a measure of a company's strength in innovation and competitiveness in NPD. Manufacturing companies are forced to accept that the focus on NPD is on increasing product variety and shorter product life cycle. For many manufacturing industries, mass customisation with "voice of customer", agility and leanness are some of the vital prerequisites to survive in the current global competitive environment. NPD is no longer an isolated process; it requires close integration between all active members within the supply chain such as customers, suppliers, manufacturers, etc. and must be viewed as an integrated business process.

The proper use of advanced ICT has enhanced NPD in manufacturing enterprises. It facilitates shorter product lead-times and hence increases responsiveness to changes in the market along with improved product quality, as well as maintaining low product cost. However, to achieve these benefits, the management responsible for ICT investment needs to shift their perspective from the goal of individual productivity to the concept of organisational productivity with ICT as the agent of change.

Product data is a critical resource for business enterprises. Efficient product data management enables fast access to and effective sharing of the required product data. It adds value to the existing corporate resources by converting raw product data into information and then into knowledge to facilitate innovation and enhance collaboration. As quoted by Thirupathi and Roy:

> *"The NPD is only as effective as the decisions made within it, and as efficient as the speed with which the information required for each decision is made available."*
>
> Thirupathi and Roy [Thirupathi and Roy 1997]

2.2 Product Data Management (PDM) Systems

The management of product data has been an issue since complex products have been defined on paper, well before the advent of electronic media. In the past, inefficient documentation, change and control systems, while undesirable, had little impact on an enterprise [McIntosh 1995]. Today, however, efficient and formalised management of product data is becoming an important issue as many enterprises strive to be more responsive to change in order to remain competitive. This change of emphasis is contributed to by the increase in product variability, functionality and performance; stringent regulatory constraints; impact of quality standards; and geographical separation between sites.

As mentioned earlier, PDM is a concept about managing data that describes or defines the physical product and the processes and documentation used to make and support the product. PDM systems are commercially available computer-based tools that provide, electronically, the underlying database technology for managing all critical product data such as the collection, storage, access, control, dissemination, and archiving of such data. There are also some PDM systems that have been developed in-house by firms to suit a specific company's requirements.

One of the main advantages of PDM systems is their interoperability between heterogeneous systems within an enterprise to provide transparent access, both for the users and the application programs [Cheraghvandi 1995, Vroom 1994, Urban et al 1993]. This enables the right product data to be available to the right person in the right format at the right time. PDM systems also provide the solution to overcome problems associated with traditional paper-based systems, such as difficulty in managing large data volumes, slow access to the correct version of data, and high administration overhead costs. This is particularly the case with the increased use of CAD and CAM that produces larger and larger files that require storage. The loss of control over product configuration traceability and slow engineering change processes are other examples of the significant problems faced with paper-based systems [Keller-Jackson 1997].

2.2.1 The Evolution of PDM Systems

Prior to the availability of computer solutions, product data was stored in the form of large blueprints, drawings and card files of BOM data. This was difficult to handle and maintain. In the mid 1960s, microfiche and microfilm were developed as the main techniques used for the storage and retrieval of product data [McIntosh 1995]. This reduces handling problems significantly, however, McIntosh pointed out these techniques relied on punched card data format and addressed neither version control, configuration management, nor user-access. With the increasing use of computer technology in the 1970s, product data tended to be stored on a company mainframe. However, with the advent of powerful non-mainframe computers, product data then moved from the centralised mainframe environment to the decentralised computer environment. This led to the need to track where the latest revisions of data resided and to impose security and control systems.

PDM systems evolved from the needs of engineering design at the end of 1970s when the need to control product data became apparent. This was due to the proliferation of electronic product data and the increased in islands of automation within enterprises [Harris 1996]. The initial objective of PDM systems then was set at tracking drawings generated by CAD/CAM, with file managers co-ordinating the storage and retrievals of drawing. Harris noted that serious discussions of computerised engineering data management had led to the establishment of The Annual American Society of Mechanical Engineering (ASME) Database Symposium in the 1987. This later became a permanent entity in 1988, known as the ASME Engineering Database Program. However, early papers in this programme addressed only the initial focus of a database as a static product data repository to support isolated design automation functions and associated engineering logistics [Lee and Chen 1996, Rangan 1995].

Following the initiation of the Computer-aided Acquisition and Logistic Support (CALS) programme by the US Department of Defence in 1985, PDM was identified as a solution for adopting good practice and the integration of product data, its sharing and exchange [Stark 1992, Williamson 1992b]. When PDM systems were integrated with CAD systems in the late 1980s, drawing management was introduced and became one of PDM core functions. Up to that time, there was an overlapping of system capability between PDM and Electronic Document Management (EDMS) as both systems' primary function was to provide a product data repository to manage the relevant product documents.

The difference between both PDM and EDMS systems, in its simplest form, is that a PDM system uses product structure, usually a hierarchical bill of material and its relevant documentation, to manage the product data, whereas an EDMS system uses the document structure to manage the product data. EDMS capabilities were generally more robust on functions such as vaulting and distribution of large-scale files, whereas PDM systems were focused on integration with applications like CAD/CAM [Stark 1992]. EDMS systems have been viewed as a subset of PDM systems, however, with the merging of both technologies with inclusions of PDM capabilities into EDMS and vice versa, their differences in the terms and technology are rapidly dissolving.

The early 1990s saw the expansion of PDM beyond engineering in supporting the organisation with improved workflow. However, the emphasis then was still mainly on document structures, i.e. as an electronic document manager [Carroll 1998]. Following the introduction of product structure in the mid 1990s, product configuration management was introduced to enable effective management of the inter relationships between components, sub-assemblies, and assemblies. Since then, PDM systems have grown from the integration of geometric modelling, process planning and control, engineering analysis, and engineering data management systems, which allowed the integration of diverse data structures into a common framework [McMahon and Browne 1998].

From the mid 1990s, many PDM systems were able to support multi-disciplinary release procedures, a pre-condition vital for the management of change requests and engineering changes required in a concurrent engineering environment [Williamson 1992b]. Following that, attention was focused on transaction modelling, remote data access, distributed object environment, object linking and embedding, heterogeneity, and temporal management to enable successful implementation of concurrent engineering [Lee and Chen 1996].

Towards the end of 1990s, PDM developments mainly emphasised the dynamic complex demands of manufacturing environments and engineering processes. One of the important issues is for PDM to be an enterprise wide tool to increase the support for globally distributed enterprises or extended enterprises by using web technology [Chu and Fan 1999]. This replaced the conventional methods of sharing information using facsimile, electronic mailing, or file transfer protocol, which are time consuming, unreliable, and do not provide direct viewing or revision control capabilities. According to Chu and Fan, web technology has also changed the methods of PDM implementation where enterprises are now able to "pull" relevant product data from their databases instead of just "pushing" product data into them.

Web-enabled PDM systems also eliminate problems associated with software upgrading when using the traditional client / server computer architecture, which requires both the clients and server to be upgraded simultaneously [Hall 1998]. With the web-enabled PDM systems, only the server needs to be upgraded as the clients are generated from the server. This continuous availability of the system allows companies to provide the latest information continuously on a global basis, besides avoiding the huge cost and hassle of software upgrading that requires trained and experienced computer staff.

The challenge for PDM systems in the early 2000s is to enhance the product development process by having more intelligence to facilitate innovation [Trott 1998]. This involves the incorporation of knowledge management technology to include design guidelines within the product development process by using knowledge based engineering systems and expert systems rule checking [Kemp at al 2001, Medhat 1994]. This is important to enable better decision-making by using knowledge learnt from previous experience.

2.2.2 Definitions of PDM

As the needs for PDM systems evolved from engineering design, it is only natural that its definitions in the early days reflected and emphasised the processes within the design and engineering stage:

> *"PDM is Engineering Information Management (EIM), where it emphasises on both the engineering data and the engineering workflow to provide improved management of engineering process through better control of engineering data, of engineering activities, of engineering changes, and of product configurations."*
>
> Stark [Stark 1992]

McIntosh offered a similar definition as Stark's, where the emphasis was still very much related with engineering data, but involved with a wider scope to include the entire product development process:

> *"PDM is Engineering Data Management (EDM), a systematic planning, management, and control of all the engineering data required to adequately document a product from its inception, development, test and manufacture, through to its ultimate demise."*
>
> McIntosh [McIntosh 1995]

With the integration of PDM systems extended to include other business areas within an organisation, its definition is also extended to include other various product and process-related data and no longer confined to engineering data:

> *"PDM is about the management of all product data relating to parts, assemblies and products;*
> *The management of relationships between parts in an overall product design as the product structure;*
> *The ability to maintain configurations of parts in the product structure as a specific product definition;*
> *The management of the processes that create, modify and delete parts and products over their respective lifecycles."*
>
> Bryan [Bryan 1997]

Vroom offered the distinction between PDM and EDM but noted that due to the recent overlapping between these two areas, the distinction is not always clear:

> *"EDM addresses the optimisation of engineering by managing all engineering data and therefore is active within the engineering function, PDM deals with product and process data and addresses integration and optimal co-operation between functional areas throughout the product lifecycle."*
>
> Vroom [Vroom 1995]

Bourke distinguished PDM explicitly as the link between CAD and ERP:

> *"PDM is a component of Product Information Management (PIM) which also encompasses Computer Aided Design and Enterprise Resource Planning. The main objective of PIM is to unite and unify all the elements of the total product life cycle. PDM facilitates managing some portion of the product life cycle."*
>
> Bourke [Bourke 1997]

So far, these definitions show that PDM systems have been seen as information systems that enable the control and management of product data, as defined by Harris:

> *"PDM is a part of an overall information systems infrastructure which handles*

all tasks related to the managing of product data. This includes the storage, archiving and securing of data; the grouping of related data; the sharing and exchange of data between people and systems; the authorisation, release, distribution, history recording and change control of data. "

Harris [Harris 1996]

As the applications of PDM systems within the product life cycle become more intensified, its definition becomes broader. Subsequently its definition becomes even more generalised with the emphasis no longer referring to PDM solely as an information system. CIMdata looks at PDM as a strategy and an enabling technology to implement various business improvement programmes:

"PDM is a strategy of managing all product data and processes used throughout the product's lifecycle. It provides a common term, encompassing all systems that are used to manage product definition information and the processes used to support products. It is also an enabling technology for implementing many of the broad corporate re-engineering initiatives that manufacturers are currently instituting such as concurrent engineering and process re-engineering."

CIMdata [CIMdata 1996]

Viewing from the same perspective as CIMdata's but focusing more on the original emphasis of PDM, Elzen offered a much broader but precise definition:

"PDM is the discipline of making the right product and process related data available accessible to the right parties at the right time in the product lifecycle to support and enhance all business processes that create and/or use these data."

ESPRIT's RapidPDM [Elzen et al 1999]

For the purpose of this thesis, the following definition is adopted, which aligns with and best describes the focus of this research work:

"PDM is the management of all product and process related data within the product lifecycle to define, configure, produce and maintain the end product."

2.2.3 Core Functions of PDM Systems

Many of commercially available PDM systems offer basic functionality such as data vault, documents management, parts classification, product structure management, product configuration management, workflow, and project management, as shown in Figure 2.2. While not all of these functions exist in one commercially available system, Tinham noted that they could be added in as integrated modules [Tinham 1998].

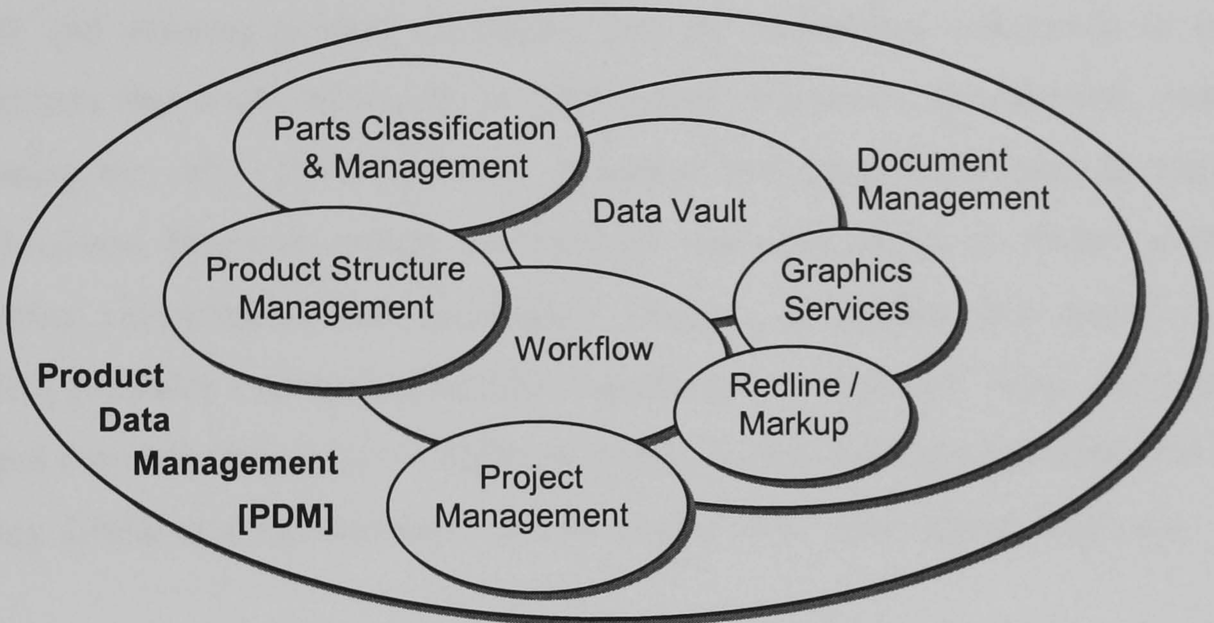


Figure 2.2 Functionality Scope of PDM [Port 1998]

- **Data Vault and Document Management**

The vault, heart of the PDM system, is the central repository for storing the product data. It can contain three types of data. They are the raw product data itself, data that provides information about the actual location of the product data, and meta-data (information about the product data such as product version, date created, object type, etc.) that facilitates the search and retrieval of required information [CIMdata 1996].

Document Management provides enterprises the rapid access to all types of documents, both paper-based and electronic-based documents. It concentrates on the handling of product-related documents by providing the management for both document storage in and retrieval from the vault. The efficiency of document management is based on its ability to manage documents' classification and dependencies, changes and versions, and also the collection and distribution of documents [Peltonen et al. 1996].

The vault and Document Management provide an environment that ensures a secure and distributed storage of data while maintain data integrity and access control. This is an important issue especially with today's rapid adoption of the web technology to publish and access product definition data. They support the capture of newly created and existing product definition data by embedding commands in other applications that create data such as CAD, word processors, spreadsheets, desktop publishing, etc. into a PDM interface. Access control mechanisms such as check-in and check-out functions ensure the integrity and consistency of product data by preventing simultaneous and inconsistent changes to product data stored. This indirectly provides a controlled engineering change environment. Also, all users are assigned access authorisation to different release levels of the product definition data by using rules that check attributes such as project, user name, object status, etc.

- **Workflow and Process Management**

Workflow and Process Management enable processes and procedures, which govern the way a job is to be carried out, to be modelled and managed electronically. Rowell defined the role of workflow as to facilitate the routing and dissemination of information to the right person at the right time [Rowell 1999]. It also aims to capture the process sequences undertaken by different groups within an organisation and to reconstruct the rationale behind design decisions [Kovacs et al 1998, McMahon and Browne 1998].

Workflow "glues" together the different organisations, processes, people, and data according to a pre-defined company policy, i.e. with the pre-determined "WHO can access WHAT document(s) and WHEN". This inadvertently organises and manages the ad-hoc and repetitive work processes in an organisation. However, in many organisations, these processes and procedures are implemented as manual paper-based working practices. This tends to be slow, error prone, and requires a high degree of manual overhead to maintain. Furthermore, traceability, identification of bottlenecks and review of historical events can be time consuming and difficult, if not impossible in a paper-based environment.

- **Parts Classification and Management**

Part classification and management, developed using a combination of group technology and object-oriented technology, enables the derivation of part family hierarchies in the vault through the grouping of common attributes that identify the part's characteristics [Miller 1996a]. It can prevent the scenario of "re-inventing the wheel" by allowing fast and easy finding of parts and designs that have been effective in the past and which can be re-used or modified. This ultimately eliminates part design duplications and encourages utilisation of off-the-shelf components and company standard parts, which is a major cost saving to many manufacturers. Other benefits of parts classification management are reduction in purchased part count, supplier consolidation, part / process standardisation and consolidation, simplifies production scheduling, etc. [Port and Bilello 1998].

- **Product Structure Management**

Product structure arranges a component or assembly in numerous higher level assemblies via the basic parent and child relationships. It forms the complete hierarchy of the managed physical product, its relationship, and the related documentation. This is important to support and control the product definition process as it enables full impact of any proposed changes when required and also manages the product configurations [Port and Bilello 1998]. Besides tracking the hierarchy of product and the product documentation, product structure management can also represent different views of BOM representation within the different stages of the product life cycle, such as:

- "As designed" BOM, which is typically more functionally oriented, focusing on what the product does and how it is configured;
- "As manufactured" BOM, which generally define parts and how they are put together on the shop floor, so it is typically oriented towards materials, scheduling and production processes;

- **Project Management**

Project management functions include team management (which team exist, who are the team members), task scheduling and tracking (how are tasks distributed, what are the starting and ending dates of the project), and monitoring of product versions and changes as well as of resources and responsibilities [Bailey and Rucker 1998, Drisis 1995]. In short, project management is the act of assigning and controlling organisational resources, such as its people, time, budget, data, and tools, in order to generate the deliverables specified in the product structure. Project management is necessary to allow for easy co-ordination of individual tasks. It supports the distribution of new tasks to teams and individuals, the building of new teams and provides the basis for the notification and messaging services [Drisis 1995].

2.2.4 PDM Enabling Applications

A PDM-enabling application is a combination of one or more core PDM functions into an application targeted at providing a focused set of capabilities to meet specific PDM needs. The following sections present three examples of PDM-enabling applications that are important for the product definition process: Product Configuration Management, Engineering Change Control, and Product Configuration.

- **Configuration Management**

PDM systems have been recognised as a solution to overcome the requirement for multiple view of a product within NPD. The application that enables this modelling of product data and provides the required interface for product models at different part of the organisation is called configuration management. Specifically, configuration management is a continuous disciplined process applied over the product life cycle to provide visibility and control of the product. It ensures that a product performs as intended and its physical configuration is identified and documented to repeatedly produce the product and meet anticipated needs for operation, maintenance, repair and replacement [CIMdata 2001, Spaulding et al 1998].

The relationship between the components of a product such as its parts, assemblies, documents, etc. defines the composition of all the items that, when combined, constitutes the complete product definition. As a product progresses through its lifecycle from concept, design, manufacture, operations, and maintenance, the way the product configuration is controlled changes. For example, design engineers record the evolution of a product by the revision number of the drawings, parts, and documents used to define it, but once the design and BOM are released to manufacturing configuration, this effectively changes to date, lot, serial number, or as maintained. Configuration management enables product structure management and its related documentation to go through controlled changes, such as the alteration of assemblies or the creation of new assemblies, change impact, etc. It describes the relationships and constraints of parts used in the product structure and provides a valuable source of audit trials that enable traceability over the entire product structure and its development through versioning.

- **Engineering Change Control**

Product changes within the product development process are inevitable especially in today's manufacturing environment, which is dominated by high product customisation. Product changes are defined as the changes that are directly related to product designs and they can be as simple as documentary amendment, or as complicated as the redesign of the entire product and the relevant manufacturing processes [Innes 1994]. One of the major problems frequently associated with product change is that of ensuring that only current documentation is available to manufacturing areas. A lack of adequate control over documentation could mean that components and assemblies are manufactured to instructions that have become outdated due to subsequent engineering change. A recent survey by Huang and Mak showed that majority of engineering change management activities were still done manually [Huang & Mak 1999]. The major problem with this approach is the overhead required in keeping registers and logbooks, detailing who has what, and when a change takes place.

Engineering change control, build upon PDM workflow and process management capabilities, can define and control changes to product configurations, part definitions, data relationships, versions, and variants through systematic and structured engineering change requests and engineering change orders. This ensures that the latest version of product configurations and associated documentation is in the right place at the right time to the right person, in a controlled manner. Engineering change control also allows a complete impact from a change to be assessed and thus enable the determination of resources required to fully implement the changes, as well as to make aware of the implications a change may have on other products [CIMdata 2001]. These improve the engineering change process compared to the manual change control procedures that rely on a large volume of paper documents being circulated and copied during the change process.

- **Product Configuration**

Throughout the various stages of a product's lifecycle, existing knowledge is used and new knowledge is generated on how products can be designed, sold, manufactured, packaged, maintained, and disposed. However, this knowledge is usually retained in the people's head and disappears when those respective people leave the company. Building on PDM product structure management functions, product configuration allows the various constraints and dependencies that govern how a product is designed, put together, or sold, to be maintained and managed by using relationships between various product data. This can greatly improve the order entry stage where sales can determine what variants and options are available for selling.

2.2.5 Benefits of PDM Systems

The main benefit of PDM systems is to create a single repository for all product-related data, which includes the product with its components, the supporting documentation and the processes and changes that it goes through the product development process. The Computing Suppliers Federation has categorised the broad benefits of implementing PDM systems into three main groups, i.e. business, operational, and information technology [CSF 1997]:

- **Business benefits** include improved competitiveness, on time delivery of profitable high quality products, better inventory control [Port 2000], affiliation to regulatory requirements, and better communications and productivity with effective use of the people within the enterprise.

- **Operational benefits** are quick and easy access to product data [Pandhi 1998], re-use of existing designs [Jones 1998], reduction in product development lead times [Pandhi 1998], and increased ability to react to change [Pikosz et al. 1998].
- **Information technology benefits** include improved data security, consistency and integrity [Gardeen et al. 1990], overcoming system incompatibility, uniform user interface for data entry mechanism, and reducing the huge amounts of paper and/or electronic based documents [Jones 1998].

Classification of benefits obtained from implementing PDM systems as tangible and intangible are important in justifying the cost of implementation. To-date, however, many of the models for measurement of the return on investment (ROI) from PDM systems implementation have been based only on the tangible benefits because many intangible benefits are general non-quantifiable and thus cannot be accurately measured [McIntosh 1995]. However, all benefits should and could be put into quantifiable terms within the limits of accuracy with which their value can be estimated. For example, "better quality products" can be broken down into small and more quantifiable elements such as reduced scrap, reduced rework, reduced warranty and service cost, and increased sales of better quality products. Recent research carried out at Cranfield University, UK, looks into justifying the ROI in PDM implementation from the perspective of intangible benefits by converting qualitative elements into monetary terms [Meng and Sackett 2000].

2.2.6 PDM Systems Implementation

Important considerations for successful PDM implementation have been highlighted and proposed by many authors to ensure the success of PDM implementation. Only a timely and efficient structured implementation strategy will realise the benefits of PDM. This has led towards the suggestion that PDM implementation is to be carried out in several phases and in an orderly manner, with the first step being able to identify the business problems and then select the appropriate technology to solve the problems [Prygoski 1998, Pandhi 1998, McIntosh 1995]. Following that is the definition of strategies and requirements, and then obtaining solutions with those requirements in mind and take careful well-calculated steps to solutions, while measuring their successes. Seven characteristics for highly effective PDM implementation methodology are suggested by Pawl [Pawl 1995]:

- **Proactive** being that a PDM implementation should be forward active, capture the enterprise vision of its future and readily adaptable to adjust to the ebb and flow of business
- **Begin with the end in mind** by having a clear understanding of PDM implementation's destination that is based on the enterprise's principles, values, and mission.
- **Put first things first** which addresses important problems quickly and using baseline measurement systems to measure the success.
- **Think win/win** that touches different areas of business and works to define processes, functions, and data standards.
- **Seek first to understand then to be understood** basis for consensus building in order to overcome obstacles in the PDM implementation.
- **Synergy** that raises organisational issues and presents an opportunity to transform unproductive and harmful business practices.
- **Renewal** based on continuous improvement, revisiting PDM goals and objectives, and continuous measuring and adjusting implementation.

Bryan identified three main complexities that constrained the application environment for PDM implementation [Bryan 1997]:

- **Access complexity** - the result of heterogeneous computer architecture, data exchange standards, drawing conventions, and local standards that govern the product data descriptions,
- **Process complexity** - the measure of interaction, fragmentation, and control of the product development process
- **Product structure complexity** - the number and variety of product data and data types that describe a product, its relationships, and the configurations within products.

He added that the selection of a PDM system should take into consideration the organisation's efforts to reduce these three complexities.

The obstacles to successful implementation of PDM systems can be linked with the corporate and departmental cultures that adhere to the traditional psychology such as “fear of the unseen”, “fear of change”, “fear of failure”, and mostly “fear of out of job”. Fortunately, with carefully planned training and sufficient exposure to systems, the traditional psychology can be replaced with "visual reinforcement", i.e. understanding of the benefits of change and the place each individual has in the new solution. It is also important for companies to be able to recognise and differentiate what is the “should, could, musts, want, and wishes” to ensure the success of its PDM implementation. Literature has identified many causes that contributed to unsuccessful PDM systems implementation, which can be largely grouped into the following three categories:

- **Internal factors**: lack of project co-ordination; lack of up-front investigation and unclear overall business motivation; lack of realistic vision and scope of the system; poor communication; lack of high level management continuous support
- **External factors**: lack of industrial benchmarks decreases the ability to effectively compare alternatives available; uncomfortable partnership with PDM supplier; lack of examples of successful PDM implementation.
- **Internal and external factors**: shortage of PDM expertise and technical infrastructure limitation

2.2.7 PDM Integration Techniques

An early problem in the development of CAD/CAM was the transfer of graphical data between different systems. This was particularly important for large complex graphics files containing product data. Initial Graphics Exchange Specification (IGES) was developed for exchanging and archiving data between CAD/CAM systems. IGES is a US ANSI standard for the exchange of geometry, drawings, piping, and electrical information. Although IGES can graphically represent most of the information in a CAD/CAM system, there was no data management system for integrating the data that each tool contained [Medhat 1994]. Furthermore, IGES does not provide a satisfactory solution because data translation results in three versions of the same data: a version for each of the target and source applications and a version for the neutral format and therefore can result in problems of version management and access control.

To resolve this problem, the International Organisation for Standardisation (ISO) developed an internationally agreed standard called the Standard for the Representation and Exchange of Product Data (STEP). Today, many CAD/CAM and some PDM vendors support the use of the neutral data format of STEP to allow sharing of product data within the NPD process. Although an integrated CAD/CAM database could smooth the transition from design to manufacturing and eliminate expensive planning and set-up time, as shown in Figure 2.3, such integrated database can only be achieved if proprietary vendors are willing to share their application program interfaces.

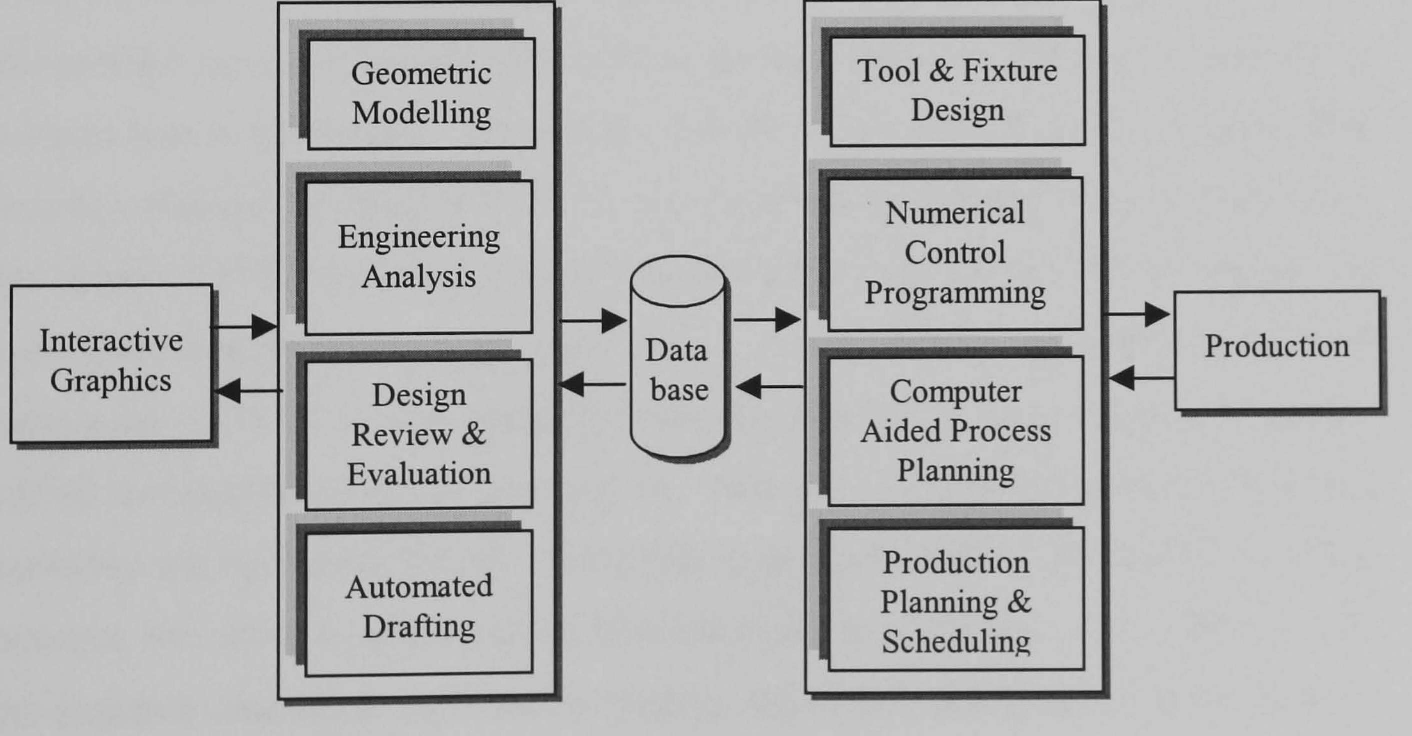


Figure 2.3 Integrated CAD/CAM Database [Groover and Zimmers 1984]

However, not until recently, many computer aided tool developers have opted to protect their customer base by introducing their own proprietary standards and were reluctant to accept industry wide standards. This has caused many frustrating problems and unnecessary expenses to manufacturing companies when it comes to sharing of product information [Chadwick 2000, Al-Timimi and Port 1997].

Interoperability is the key requirement to achieve an integrated information system in a heterogeneous environment where the product data is independent of the applications that generate and manipulate it. Successfully doing so will enable product information to outlive any proprietary system, where businesses can retain applications for as long as they deliver useful service, but with the added flexibility to change when new technology offers a more effective solution. However, to-date, data interoperability problem has yet been satisfactorily overcome and is putting severe pressure on many manufacturing enterprises. For example, Chinn reported that the potential rework required for CAD data in different downstream applications was between 50% to 70% [Chinn 2002].

STEP impacts on the performance of PDM systems by facilitating the movement of data between applications, especially in engineering related business processes [Brett 1993]. The aim is to enable access, regardless of the application or the stage within the product lifecycle, to data contained in product databases for further processing without loss in translation. According to Miller, PDM systems have been identified as a key element for integration within a heterogeneous computing environment and the values of PDM systems are largely determined by the quality of their integration with other information systems [Miller 1997a]. Today, the two most commonly used techniques of PDM system integration are the application programming interfaces (APIs) and distributed object technologies. APIs are sets of routines or protocols that build the software applications. A protocol is an agreed format for transmitting data between two devices, which can be both hardware and software. The APIs provide the required integration functionality such as associative mock-up and configuration management [Retraint 1997].

Simultaneous operation within the NPD process is no longer limited to a single organisation where use of a single PDM system may be enforced, but also across enterprise boundaries where members participate through each other's familiar and accustomed PDM systems. There is a need for platform integration. Distributed objects technologies have been identified as one solution and one of the architectures to support distributed objects is the Common Object Broker Request Architecture (COBRA) from the Object Management Group (OMG). According to OMG, COBRA is a vendor independent architecture and infrastructure that computer applications use to work together over networks [OMG 2001]. COBRA is a three-tier distributed object mechanism by which the objects transparently make requests to, and receive responses from, each other on the same machine or across a network [Siegel and Waskiewicz 1997].

2.2.8 Summary

The first introduction of PDM systems in the early 1980s responded to the need for an electronic storage facility for the voluminous product data generated by companies, focusing mainly on the design engineering area. Today, however, the functionality scope of PDM systems has been extended to aid and enhance decision making throughout the entire product development process, where its facilitates the organised electronic flow of product information while enforcing business rules and processes.

The implementation process for PDM systems is not an easy task. It is a continuous development that requires continuous measurements and monitoring, with consistent follow up, to establish the benefits that the implementation has brought to the business. Successful PDM implementation depends on a clearly defined strategy and continuous management commitment. The major benefits of implementing PDM systems are quick access and retrieval of useful relevant information and then making use of this information to aid decision-making. This ultimately allows an organisation to be more responsive to change and thus remain competitive.

2.3 PDM Systems Within the New Product Development Process

In a survey carried out between Electronic Data Systems and The Design Council within the UK, Nichols showed that industry in the UK was responding to provide better, cheaper, and faster to market products through the adoption of a concurrent engineering approach [Nichols 1992]. Concurrent engineering (CE) is an enabling technology that helps lower development and operational costs through parallel working within the product development process to reduce lead times, improve product quality, and reduce costs. Right first time approach is the common theme.

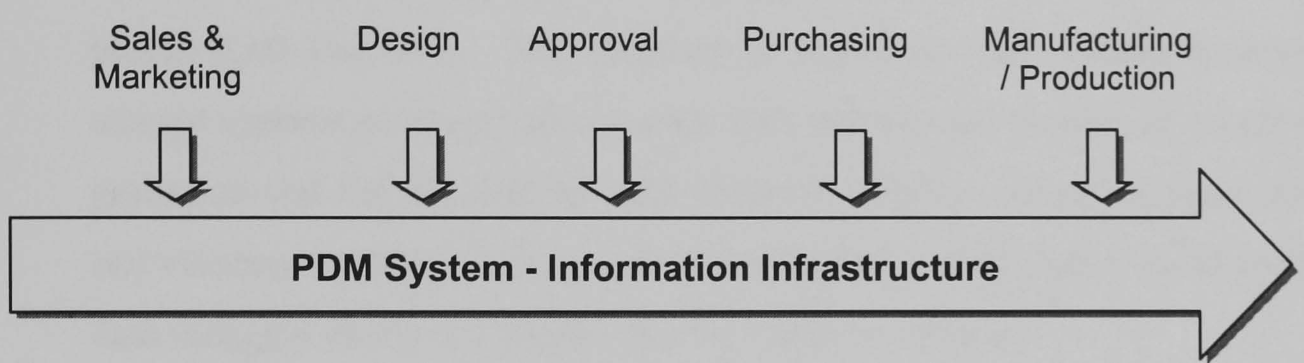
CE is made possible through the early involvement of all parties, including key suppliers and customers, by integrating people and systems across functional boundaries and performing as many activities as possible concurrently. This helps in managing the moving targets inherent in the design and production of complex products. In the past, many business processes were performed in a sequential manner that resulted in long product lead-times and costly products. The main contributing factors were high percentage of scrap and rework, inefficient use of both technologies and skills available, and this resulted in a lower profit margin. "Over the wall" was a common practice where there was no interactive activity or sharing of information between different departments.

The essence of CE is an integrated and collaborative process with a complete understanding of the product and process information that can be shared by all members of the product development team. As a consequence, CE deals with highly heterogeneous environments. Within such an environment, bi-directional information flows are necessary to allow consideration of both downstream and upstream inputs for optimum decision-making. Using conventional paper-based data management and stand-alone computers could lead to impaired communication, data loss, and redundant development. CE requires a reliable communication infrastructure, particularly within industries that deal with complex products such as automotive, aerospace, electronic and computer industries. PDM systems have been identified as an enabler for implementing CE [Miller 1197, Esebeck et al 1995]. Successful implementation of PDM systems reduces "over the wall" scenario within the product development process by facilitating effective communication channel through controlled workflow and increased sharing of accurate and up-to-date product data.

Although automation has been successfully introduced within the product development process in the past, digitisation of data within several departments of an organisation often leads to so-called islands of automation [Teeuw et al 1996]. To really benefit from the automation of individual departments, automated processes within an enterprise need to be integrated through the establishment of an integrated product database that contains a total, comprehensive, and unambiguous product model. Literature has shown the importance of having an integrated communication and information infrastructure to enable individuals and teams to rapidly interact within both the enterprise and its supply chain [Wiebe 1997, Drisis 1995].

Computer Integrated Manufacturing (CIM) is a strategy that aims to optimise the operations of an enterprise throughout the entire product development process. CIM streamlines the flow of the full product related information between divisions and allows these data to flow seamlessly through the business with a particular focus on the design and the manufacturing processes. It links islands of automation into a distributed processing system through various methodologies, tools and techniques, which help to manage all business activities in an integrated way. CIM requires an integrated architecture to provide the medium for the electronic communication of information throughout the enterprise with commonality of data to ensure that one application is able to utilise information from other applications.

The literature shows that a PDM system has been identified as a solution or an enabler to achieve an integrated information infrastructure to improve the flow and quality of information throughout the enterprise, as required within a CIM environment [Pikosz et al 1997, Pikosz and Malmqvist 1996]. This is particularly important for manufacturing enterprises involved in the design and manufacture of complex products where PDM systems help managing the voluminous data and control the flows of product information within the entire product life cycle in an effective and efficient manner, as shown in Figure 2.4.



Customer requirements received.	Design receives request and reviews similar prior designs for potential use.	New product data is sent through the approval cycle, all appropriate members review new design and automatically generated BOM using view / mark up facilities.	Manufacturing has previously been notified automatically of the new product and has sufficient lead times for component deliveries and set-ups.
Prior released products reviewed for suitability to meet customer requirements.	Suitable prior design is found quickly, product request is checked out, sales / marketing is notified of estimated time and costs.	Any changes are notified, Eros are generated, and distributed to design, management is notified of any schedule changes.	New product is manufactured at several sites as all sites can share and access product information in real time.
Product request checked-in, workflow started request sent to design.	Design is modified and checked in, system distributes new product into appropriate departments, a new bill of materials is placed under change control.	New BOM is sent to Purchasing to place orders.	Manufacturing reviews schedules and notifies Sales project is on time.
Preliminary configuration submitted to customer with costs and time estimates verified by design, purchasing, and manufacturing.			

Figure 2.4 PDM Manages Product Life Cycle [deVries 1998]

The current trends in manufacturing outlined below have also contributed to the need for PDM systems within the NPD:

- With the increasing use of today's sophisticated CAD systems in the design process, enterprises now have two major types of archive: paper-based and digital / electronic based. With most enterprises holding 60% to 70% of their archives in paper or microfilm, costly paperwork has been an unavoidable plague [CAD User 1998]. The situation is worsened with traditional manual storage systems no longer able to cope with the massive volume of documents generated and the demand for data retrieval. Today, managing paper-based and electronic product data, as well as the transition from paper-based product data to digital media is a major issue for many companies.

- The complexity of a computer system supporting the manufacturing environment can be directly related to the volume of product data processed to support decision-making. To achieve this, integration between different computer systems to enable extensive use of the product data, which exists in different sections of an enterprise, is essential. This is particularly important because widespread use of commercially available computer applications in different business areas has resulted in unmanageable proliferation of computer systems and the accompanying explosion of product data.

- All application systems have their own specific data management functionality [Wiebe 1997, Griffiths 1996, Stark 1992, Williamson 1992b]. This leads to the rise of different product data structures, formats, and definitions that represent a different description of a part. Multiple data representation relating to the same underlying product data is of great importance to accommodate the various needs of the users. For example, when a product evolves through the development process, different views of that one product will be required without consuming too much time and requiring costly manipulation of incoming data. Such representation can be made possible via a multiple data representation capability.

- Every business enterprise is faced with the challenge of constant changes and there is no guarantee of a homogeneous working environment [Hall 1997].

Introduction of new partnerships or alliances between a core manufacturer and other companies offering specialised services, merging, or take-over of businesses has restrained product data to flow only within one individual organisation. This has given rise to the need for close collaboration between the enterprises and calls for the sharing of comprehensive and up to date product data.

- The manufacturing approach in the 1990s calls for mass customisation and thus leads to a wider range of products as well as more versions of each product [Bourke 2001, Kotha 1995]. For example a survey carried out in 1995 revealed a total of 50% of the surveyed Swiss discrete manufacturing enterprises have their products specially designed to customer specifications [Scherer and Mosca 1995]. Product data on each product configuration or version has to be carefully maintained and controlled by the enterprise. Adding to this, current manufacturing companies are also faced with increased requirements to comply with both quality standards and government regulations. An audit trail, achievable with efficient document management and product configuration, is necessary to enable traceability when assisting product recalls.

2.3.1 Enhancing Product Definition Process

Product data is generated throughout every stage of the product life cycle. The first phase of the overall product realisation is the product definition, which encompasses the transition from an idea to an actual concept for a design. As a product proceeds through each stage in its life cycle, its identification becomes progressively more definite and precise. Bryan defined a product definition process as the aggregation of product data, as and when a design matures [Bryan 1997]. He stressed that product definition contains a unified body of diverse knowledge that describes the product and its work processes, and is no longer confined only to drawings and paper based engineering data. Literature also shows that critical success factors for product definition are thorough competitive analysis and good understanding of user needs and technology scenarios [Henry and Greenhalgh 1999, Cooper 1998]. A failure to define the product before development begins will result in both new product failure and serious delays in time to market. PDM systems can be used to control the product definition during the engineering stage [Walter 1996] as well as between the sales and engineering stages [Jiao and Tseng 1999].

There is a need to balance both the request for customised products and the need to ensure high responsiveness in product delivery during the product definition process. The product configuration process has been identified in recent researches to balance customisation and responsiveness [Forza and Salvador 2001, Redlein and Klinger 1999]. It is a process through which the customer's needs are translated into the product information needed for tendering and manufacturing. The product configuration process can be defined as an activity that produces a configuration, or a product instance, for a single customer order from a product configuration model. Tiihonen defined a product configuration model as a descriptive abstract of configurable or pre-designed products that are [Tiihonen et al 1996]:

- Adapted according to the requirements of the customer for each order
- Consisted of (almost) only pre-designed components
- Assigned a pre-designed product structure
- Adapted by a routine, systematic product configuration.

Recent developments in ICT have made available a new class of software tools called Product Configurators, which utilise these product configuration models. These tools enable manufacturing companies to offer a wide product variety within a short delivery time and to respond to the market with customised solutions without compromising cost structure [Jorgensen 2001, Tiihonen et al 1996]. Many of these tools require an effective generic product structure, which is a functionality that can be found in many PDM systems. Also, they are only efficient when implemented in an effective PDM environment. Product configurators are tools for rapid customer response as they provide manufacturing enterprises with the ability to configure and re-configure their products to meet specific customer requirements within a constrained time scale [Forza and Salvador 2001, Ryhmer 2000]. However, the literature shows that these tools are mainly used at the order entry stage but not at other stages within the NPD process, for example when an order has proceeded to the production shop floor.

2.3.2 Interfacing between Sales, Design and Manufacture

The ability to model product data into appropriate product structure is essential for companies that want to manage the product-related information in computer-based applications and exchange data between such applications [Männistö et al 2001]. Unfortunately, there is no single concept of a product structure because each functional area of an organisation views the product in almost entire different perspectives. For example, whilst sales requires a view that describes the products in terms of the functionality required by customer or the principles of how the product works, production requires the manufacturing view, which is usually based on the traditional bill of materials. Engineering, on the other hand, requires the design view where products are still evolving entities that are still missing their final shape and structure.

Furthermore, each part of the organisation also uses different computer applications to manage and operate its daily activities. Engineers in industry use CAx tools to focus on the actual activities of designing product for different stages of the design process, to retain the design knowledge of how a product was conceived, and also identification of the different inter-relationships in a design [Burgess and Wallace 1995]. However, without integration of the whole design process, these tools, though proven to be effective in their own fields, only push the resource bottleneck downstream. Within the engineering design stage, there is a need to manage product data used and generated by the variety of CAx systems and other automation applications.

The literature shows that while CAD excels at the capture of design knowledge and the formalisation of it for use elsewhere in the organisation, it requires a PDM system to distribute this key information [Eigner and Stelzer 1997, Wiebe 1997]. This is important because many of current CAD tools do not support a shared use of data and practically prohibit teamwork [Barber 1999, Ricciardi 1999, Benedetto et al 1998, Drisis 1995]. PDM systems have been identified to be able to capture design experience through controlled workflow that is lacking in many CAx tools

Over the last few years, ERP has established a position as the enterprise platform: the main IT solution that dictates the integration structure for the organisation [Wardle

2000, Shewchuk 1998]. However, Wardle pointed out that this needs re-consideration because within today's product development process, a more flexible tool to handle ad-hoc requirements and wide area communication and collaboration is essential [Wardle 2000]. Also, although ERP systems have been recognised to represent the explicit best-of-breed knowledge in many fields of industry [Shewchuk 1998], they are only effective with accurate and timely product data. The Croner's Manufacturing Operation Manual quoted that the BOMs should be at least 95% accurate for MRPII / ERP to be effective [Croner 2000].

Literature shows that many MRP / MRPII /ERP systems are still performing below the expected level due to unreliable and invalid input data [Wortmann 1998, Evans et al 1997, Klein 1995]. An assessment of current trends in computer-aided design and manufacturing in the furniture industry had revealed that current practice creates the bills of materials and process sheets for individual parts on MRP systems, on mainframes, while CAD drawings are produced on PCs or workstations [Wiebe 1997]. This resulted in information created in the CAD system being hand entered back into the MRP system with the prerequisite increase in error potential and time loss.

Yusuf had identified eleven candidate modules for integration with typical MRPII systems in his work on the extension of MRPII in support of integrated manufacture [Yusuf 1996]. In his survey that yielded 120 valid responses, Yusuf reported that 59% of the respondents had achieved a certain level of integration between their existing MRPII systems with the mentioned candidate modules. The survey also showed that a PDM system was been identified as one of the five most prevalent candidate modules out of the eleven that were suggested.

Integration between PDM and MRPII / ERP has been identified to provide the ability to combine manufacturing process data with design information to simulate the product manufactured in a virtual environment. This helps the integrated product team in determining the best practice in the new product introduction and allows accurate "as designed" BOM to be delivered directly to the MRPII / ERP system, and also provides up to date "as manufactured" BOMs from MRPII / ERP to the PDM system. However, full integration between MRPII / ERP and PDM is still more talked about than present in today's manufacturing enterprises [Gregory 1998]. Gregory quoted that many manufacturers are still passing the released design BOM as a flat (ASCII) file from PDM to ERP, or even more commonly, they manually re-key the information.

2.3.3 Summary

The current status of the product definition process is becoming more complex and complicated because the scope is no longer limited to just the functional or engineering data of the product. Today, a complete product definition includes in it the entire set of information that defines what is the required product, how the product is designed, manufactured, serviced, and finally disposed of, and what are the resources required to support the relevant operations throughout the product lifecycle. This set of information does not just reside within one functional area in the company, but across the entire organisation. In fact, today's working approach in the product development process requires this information to be extended across various external organisations, which include the suppliers, collaborating partners, and customers.

Today, manufacturing is thought of as not only as material transformation, but also as information and knowledge transformation. This requires an environment that can capture and manage product information effectively and efficiently, and then make this information available and accessible to relevant members within the NPD. PDM systems have been identified as a solution to provide an environment that facilitates and encourages re-use of existing product data and standardisation during the process of configuring a product. This eliminates re-inventing the wheel, reduces design errors, decreases waste, improves quality, and ultimately increases competitiveness.

With the increased demand for individualised products, formation of virtual enterprises, and the need to achieve "right first time", manufacturing enterprises require an integrated information infrastructure to improve the flow and quality of information throughout the entire organisation. However, it is still common to find some manufacturing companies where the activities around sales, design, and manufacturing are still being performed using the traditional "over the wall" approach despite successful introduction of automation within the NPD. This is due to each functional activity viewing a product in an entirely different way and there is a lack of common interface between these functional areas. PDM systems have been identified as a solution to achieve an integrated information infrastructure to improve the flow and quality of information throughout the enterprise. This can replace traditional "over the wall" approach with a concurrent working approach by enabling the sharing of information between different departments, both within local and geographically distributed enterprises.

2.4 PDM Systems and SMEs

The importance of SMEs to the UK economy is no longer questioned with recent figures from the DTI showing that SMEs are responsible for 65% of UK employment and 57% of the Gross Domestic Product [Noble and Little 2000]. This is especially the case as today's larger companies choose to concentrate on their core businesses and then outsource other activities to smaller companies. Hence, this emphasises the role of the SME, especially one with sufficient high technology and strong added value. Today, many SMEs are significant manufacturing units within UK industry.

Keeping in step with large enterprises is now the biggest challenge for many medium-sized manufacturing enterprises and SMEs. While large companies can easily afford the time and cost of integrating supply chain systems, SMEs must be sure that they get it right first time because of their limited resources. System strategies need to be based on a clear understanding of business objectives and their impact on the whole organisation. Today, the need to provide support for SMEs is a recurring theme in the literature, for example importance of government assistance [Levy 1993] and linkages with universities [Amstrong and Coyle 1999, Kelly et al 1999, Bennett et al 1998, Jones and Tang 1996].

The literature shows that there is a lack of involvement of SMEs in PDM systems [Bryan 1997, Keller-Jackson 1997]. This is not surprising because generally SMEs have a low cash flow and thus operate with minimum operating expenses. For example, in their investigation into the implementation of CIM in SMEs, Marri quoted previous work that suggested a general lack of long term investment in the

SMEs [Marri et al 1998]. He also reported that 23% of the SMEs examined suffered from insufficient working capital and that up to 60% of all SMEs in the UK were financed by overdraft. Also, Amstrong and Coyle reported in their survey that only 7.7% of the surveyed companies had an IT budget and only 2.6% had an IT manager [Amstrong and Coyle 1999].

From this aspect, it is clear that a reason why many SMEs have not invested in PDM technology is because of the relatively large costs for PDM implementation. These costs include costs for hardware, software, up-front installation, extensive user training, on going costs for system maintenance, support and upgrades, etc. For larger companies, these substantial costs can be and are spread over a large base and thus making the systems increasingly affordable. However, many SMEs with annual sales of less than £10 million typically have only a handful of managers available and a very small number of design staff. This results in an enormous cost per user and it is therefore difficult to derive the initial cost justification for PDM implementation. Also, with PDM applications becomes widespread, PDM administrators will be at least as rare as CAD managers were in the 1980s, if not potentially more expensive [Hall 1998].

Research has shown that highly formalised and structured systems are evident in the majority of large enterprises whilst information systems in SMEs are often evolutionary rather than planned [Thoburn and Winters 1998, Little et al 1997]. Little reported that many SMEs utilise ad-hoc approaches to the specification and selection of computer-based information systems [Little 1998]. He also mentioned that SMEs place very little emphasis upon how the required system will support the corporate objectives and how it will integrate with existing computer systems and business processes. Hence, it is not surprising that the literature shows that many SMEs were unable to afford the resources and specialisation required for investing into PDM systems [Mainwaring 1999b].

The other SMEs' characteristic is the nature of its business operations, where the management teams in SMEs are usually heavily involved with the daily operations of the business [Filson and Lewis 2000]. Generally, SMEs are not global, less functionally divided, and the management often has a good view of what customers wanted, influent the business improvements, and guide the NPD process. Small companies increase in size as they develop, however, they are still characterised by a few key employees attempting to carry out a wide range of tasks on their own. This can be best answered by the fact that much of their knowledge base is stored in human heads rather than in written procedures or computer systems [Jordan and Browne 1995]. This explains the lack of time available for management in SMEs to consider methods to improve their organisation structures in order to enhance business performances. Furthermore, the manufacturing environment of most SMEs is dominated by component manufacturers of simple or low volume complex products [Mainwaring 1999b]. According to Mainwaring, their BOMs tend to be relatively simple and shallow, and hence they can survive without using comprehensive and expensive tools such as a PDM system.

However, further analysis of the characteristics of SMEs proved otherwise. Firstly, although with simple products, it is important for SMEs to be able to have product traceability so that quality problems can be addressed. Therefore, it is important to have a formalised product change management system. Secondly, many SMEs practise a cross-functional type of management and hence this speaks of the importance of having the need to share accurate and timely information in assisting decision making. Thirdly, SMEs are usually under severe pressures from their large customers to produce in a shorter time and at a lower cost. This can be done by re-using existing designs, which have been approved, that are stored in a central database and made accessible to the right person. Such capability can out-perform their competitors while satisfying their customers.

The lack of SME involvement in PDM implementation can also be attributed by the PDM vendors themselves. Miller reported that in the mid 1990s, the sole source of business for PDM vendors has always been large companies with money to pay for the latest and most sophisticated technology [Miller 1996]. Miller explained that due to fierce competition in the market, PDM vendors have complied with the growing demands for increased features and capabilities, and have kept prices fairly high to recoup for their huge investment. Miller also reported that many PDM vendors recognised the huge potential of market that can be created by SMEs, however, due to the higher associated costs and risks, no PDM vendor has yet really invested in SMEs.

2.5 Conclusions

In this chapter, the literature has been reviewed against two of the research objectives mentioned in Chapter One. The first objective was to review the application and the effectiveness of PDM systems in the new product development process within manufacturing industry to enhance the product definition process. The literature has shown that PDM systems have been identified as a solution to improve the effectiveness of the NPD process. PDM functionality such as access control, workflow, process management, and product structure management provides manufacturing enterprises with the required structured and controlled information infrastructure that ensures no duplication of product data, and improves the accuracy and integrity of product data during the product definition process. Also, PDM enabling applications such as configuration management, product configuration and engineering change control can assist in speeding up the process to enable improved response to customer requirements.

The second objective was to analyse the current interfaces between sales, design, and manufacturing and the effectiveness of PDM software in improving these interfaces. The literature shows that there are still many manufacturing enterprises that practise "over the wall" approach due to each functional activity viewing a product in an entirely different way and there is a lack of common interface between these functional areas. The literature has identified the need for integrating or interfacing PDM systems with other relevant computer aided tools and manufacturing control systems to achieve an integrated information infrastructure for improved information flow and quality throughout an organisation. This can replace traditional "over the wall" approach with a concurrent working approach by enabling the sharing of information between different departments, both within local and geographically distributed enterprises.

Commercially available PDM systems are typically complex and resource intensive in implementation and this deters PDM implementations, especially the case within SMEs. The literature shows that the obstacles leading to the lack of PDM involvement from SMEs can be categorised into two groups:

- The characteristics of SMEs themselves, such as low resources availability, a lack of expertise, unawareness of ICT development, and nature of operations within the business.
- The focus by PDM vendors which targeting mainly at larger enterprises.

This chapter has also shown how PDM systems have changed from a focus on solving product data management problems within the engineering function in the early 1980s to providing an information infrastructure to support the product definition process within an extended enterprise management. The ability of PDM systems to effectively and efficiently capture and manage product data during the product definition process has created a pool of invaluable product knowledge within an organisation. Clearly, an effective PDM should be a pre-requisite in the NPD process in the manufacture of complex products, particularly where innovation and business improvement is involved. It is the author's belief that that all such businesses, despite the nature and the size of the business, would require some form of effective PDM in order to encourage concurrency of activities during the product definition process throughout the product development process.

However, a few important issues still remained unresolved. Firstly, while many PDM systems implementation methodologies have been introduced, the reported successful PDM implementation is still very much limited to large companies. Although the literature shows that the main two main obstacles to the involvement of SMEs in implementing PDM systems are lack of resources and IT skills, these are not necessarily the major stumbling block. There is a need to identify the cause for the lack of SMEs involvement in PDM implementation and then to recommend suggestions to rectify the situation, as set out in the third objective of this research mentioned in Chapter One.

Secondly, many new products are evolved from existing components or parts, therefore effective management of components is important to encourage their reusability. There is a need to introduce and improve the configuration activities during the product definition process throughout the entire product lifecycle, and not just limiting to the initial stage of the product life cycle. Incorporating the findings from the literature reviewed, it is the intention of this research to develop a specification model that will address this issue. Also, the research intends to investigate the effectiveness of PDM in creating an interface between different stages within the product development process to enhance the product definition process.

3.0 THE SURVEY OF PDM SYSTEMS USAGE

Chapter Two identified that there is a need to investigate the cause for the lack of SMEs involvement in PDM implementation and then to recommend suggestions to rectify the situation. A survey of current PDM systems usage within manufacturing companies in the UK has been identified as a means to carry out such investigation. Firstly, the results of the survey will identify the types of manufacturing industry that have implemented PDM systems, the current level of usage, and the achieved benefits. Secondly, the results of the survey will provide the percentage of SMEs and large enterprises that have not implemented PDM systems and to establish the obstacles which deter PDM implementation.

Chapter Three starts with justification for the choice of survey technique, which includes its advantages and weaknesses. This is followed by the design of the survey instrument, the survey response, and the results and analysis. The focus during the design of survey instruments was on producing an easy and simple to answer questionnaire to encourage responses. The contents of the survey instrument are discussed by providing reasons for each section of the survey instrument and the value and significance of the data expected from them.

A discussion of the survey method, survey findings, and how the objectives of the survey have been met is also presented. Following the findings from the survey, a method to encourage more SMEs involvement in PDM implementation is proposed. Chapter Three concludes by summarising on the overall implications derived from this survey.

3.1 The Survey Techniques

A survey is a procedure in which information is collected about a set of samples that have been selected from a defined population and the aim is to construct a data set from which estimates can be made and conclusions reached about this population [Thomas 1996]. For the purpose of this survey, the defined population is the manufacturing companies within the UK.

Prior to selecting the appropriate survey technique, it is important to understand the type of investigation to be carried out as every survey differs to a large extent. The intended survey requires responses from a wide range of different respondents in order to establish unbiased and generalised results. It is therefore necessary to have participation from a wide range of companies. Often these companies are located in different geographical regions. Hence, survey methods by interviews and case studies are proven to be not feasible because they would be too expensive in terms of cost, time and effort. However, a questionnaire by mail makes a good choice because it is comparatively less expensive and can cover widely spread geographical areas within a short period of time.

Other advantages of questionnaire by mail are [Yusuf 1996]:

- Unlike interviews, where contact between the interviewers and respondents must be established either facially or by voice, survey by questionnaire is not vulnerable to biasing error due to personality and behaviour of participants.
- It enhances the validity for broad-based generalisation because it is relatively standardised as its presentation and appearance does not vary from one case to another.
- Some questions in the questionnaire demand a significant length of time to answer and in some cases consultation with colleagues or other members of staff is required.
- The absence of an interviewer provides greater anonymity of respondents. Although this does not tend to increase the response rate, it can provide genuine and unbiased responses as respondents are shielded from the possibility of future reference.

Questionnaire by mail also has its weaknesses [Yusuf 1996]:

- All the questions are presented to the respondents at the same time and the investigator has no control over the sequence of questioning, as in an interview situation.
- The response rate is usually lower compared to survey by interview.

- There is room for higher inaccurate responses compared to survey by interview as some terms used on the questionnaire might not be familiar for some respondents and further clarification would be required.
- Anonymity of respondents removes the understanding of the background of respondents, which, if noted, might explain the reason behind the given responses to specific questions.
- Only simple questions can be asked. It is completely suitable for answering the "What", "When", and "Who" questions but not possible to obtain the "How" and "Why" as available if using survey by detailed case studies.

The possibility of posting the questionnaire across the Internet was also considered because while it shares the same advantages as well as the disadvantages of questionnaire by mail, it could further reduce cost and simultaneously increase coverage and response. After weighing the weaknesses against the advantages and considering the nature of the intended survey, the author decided that questionnaire by mail and posting it across the Internet will be the two adopted survey methods.

3.2 The Survey Approach

The method used during the survey approach has been based largely upon documented opinions by two authors who have been involved specifically in the area of research studies: Yin [Yin 1994] and Curran and Blackburn [Curran and Blackburn 2001]. These two authors were also recommended as good references to draw upon by the instructor from the university whom conducted a short course on the types of research work.

The first step taken during the process of carrying this survey was to identify its goal and objectives. The main purpose of this survey was to investigate the current usage of PDM systems in today's manufacturing industry within the UK. To achieve this, four objectives were set:

1. To investigate the types of manufacturing industry that have implemented PDM systems,

2. To investigate why companies have not implemented PDM systems.
3. To identify the level of PDM usage, especially in relation to interfacing / integrating PDM to other manufacturing information systems, such as MRPII and ERP,
4. To identify the achieved benefits from PDM implementation.

After identifying the purpose and nature of the survey, the justification of the survey method and technique was carried out. This was followed by the design of the survey instrument. During the design of the questionnaire, an important aspect of questionnaire by mail mentioned by Curran and Blackburn was considered:

> *"Questions should be constructed, where and when possible and appropriate, such that the answers can fall into one or other fixed categories generated in advance so that recording data for analysis is easier".*
>
> Curran and Blackburn [Curran and Blackburn 2001]

Therefore, every question was provided with a set of possible answers to choose from. An option was provided if none of the possible answers provided was appropriate.

Prior to sending out the questionnaire to the recepients, the survey instrument was sent to several PDM experts and consultants for reviewing and to improve on the questions asked and the layout of the questionnaire. Staff of the university was also approached to comment and critique on the design of the questionnaire. The main emphases were on the three maxims in constructing a questionnaire, as proposed by Gill and Johnson [Gill and Johnson 1997]:

- *Focus* - making sure that the questions will capture the data needed to test and explore the propositions and issues to address
- *Wording* - the way the question is asked has to be clear and the meaning should be unambiguous for the respondents. Also, the language or terminology used should be familiar to the respondents.
- *Structure* - the internal ordering of the questionnaire should start from the

general to the particular forming a standard sequence, with a proper instruction at the beginning.

With the intention to obtain an accurate unbiased and generalised statistical analysis, two groups of target recipient were identified. The first group was the members from the Institute of Operations Management (IOM) which represent a wide spectrum of different manufacturing sectors within the UK. It was decided to insert the questionnaire into the IOM's monthly journal, Control, to reach all its members because it is against IOM's general practice to give out the contact details of its members. An invitation to participate in the questionnaire was printed in a column in Control in a form of a short article. The article was printed in the current issue where the questionnaire was inserted as well as the previous issue before that. Specifically, the article explained the objectives of the survey and ensured the interested participants the strict confidentiality of all information provided.

The second group was the members from the PDM User Group (IPDMUG), which has members throughout the globe with the majority of them located in the USA [http://www.ipdmug.com/IPDMUG]. An invitation to participate in the survey was sent out to every IPDMUG's member separately via emails except those who were students. The decision to include participants from outside the UK was to provide the comparison between the take up of PDM within the UK with those from other countries. The contents of the email were very similar to that of the short article printed in Control, as mentioned earlier.

Next the responses were compiled and analysed. Some respondents were contacted after receiving their responses because their returned questionnaires were incomplete or contained ambiguities. The returned questionnaires were also checked for validity of response. As the original aim of the survey was to study the take up of PDM systems within the manufacturing enterprises in the UK, it is important to ensure that the responses collected were representative and sufficient for the intended population. For this purpose, the survey statistical inference was carried out.

Initially, it was intended to use SPSS computerised statistical package to analyse the responses received. However, since all information had been stored in a properly structured spreadsheet created by the author using MS Excel at the beginning of the responses collection stage, the author decided to analyse the responses using the spreadsheet created instead. The author is confident with the decision taken because for the purpose of analysing and comparing the difference of PDM usage between the UK and other places, MS Excel is capable to perform the required statistical analysis. Following the analysis of the responses, two papers were produced based on results obtained from the survey: a refereed conference paper looking at the responses received from the UK only; and a refereed journal paper looking at all the responses received.

The summarised survey approach is shown on Figure 3.1.

3.3 Questionnaire Design

Two survey instruments were produced where one was used for the questionnaire by mail and the second for posting across the Internet. The contents for both instruments were the same with the only difference being the presentation layouts. Here, the design of the two survey instruments is discussed separately.

3.3.1 Survey Instrument Design - Questionnaire by Mail

The survey instrument was a printed questionnaire on an A4 paper on both sides. A copy of the survey instrument can be found in Appendix A. It was decided to limit the survey instrument to only one sheet of A4 paper in order to encourage more participation.

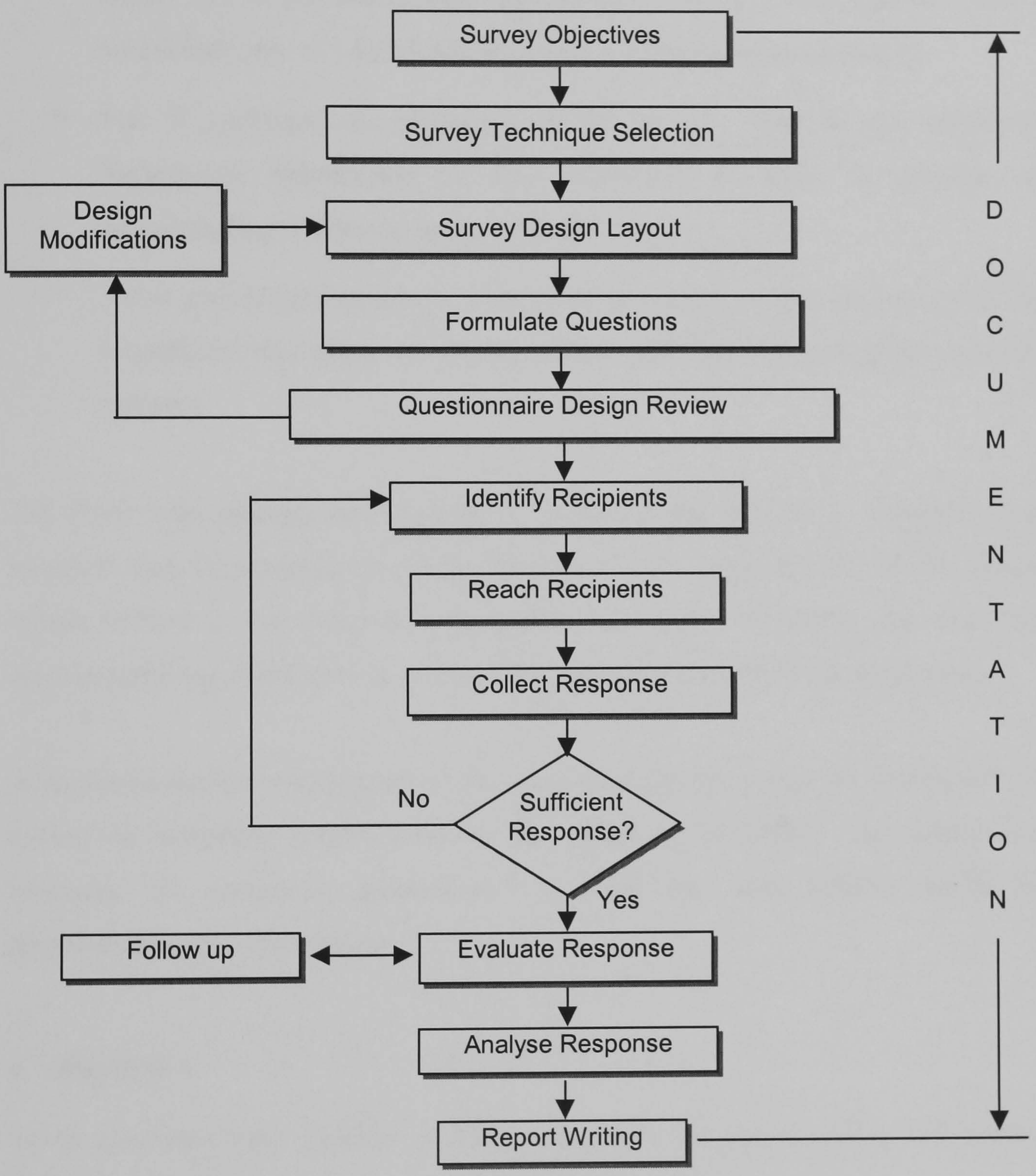


Figure 3.1 Survey Approach Adopted

The survey instrument was divided into three main sections with an introduction on the front page. The introduction section was made of three parts:

- It was envisaged that some companies might not have heard of PDM systems, hence, Part A provided a brief introduction to what a PDM system is and a simplified view of a PDM system within a manufacturing enterprise.
- Part B explained the objectives of the survey. Part B also asked the background information of the respondent in order to provide an understanding to the responses received.
- Three preliminary questions were asked in Part C, mainly to find out if the respondent has heard of PDM systems and his / her perception of such systems.

The three main sections were Section 1, Section 2 and Section 3. Section 1 was intended only for respondents whose companies have implemented a PDM system, whilst Section 2 was only for respondents working in companies that have not implemented any PDM system. Section 3 was to be answered by all respondents.

A facsimile number was printed on the bottom of the back page for respondents to return the completed questionnaire to the author by facsimile. The address for returning the completed questionnaire by mail was also printed should the respondents choose this option.

- **Section 1**

Seven questions were included in this section with the aim to gather information from respondents in order to satisfy the two last objectives:

- To identify the level of PDM usage, especially in relation to interfacing / integrating PDM to other manufacturing information systems, such as MRPII and ERP.
- To identify the achieved benefits of PDM implementation.

The first question asked about the implemented PDM system. The purpose of this question was to relate the type of company to choice of the PDM system. The length of the implemented system in operation was also asked to determine the degree of maturity of PDM users in the UK. The main purpose of implementing a PDM system in a company was asked prior to asking if the company have integrated or interfaced its PDM system to other computerised application in the company and the gained benefits. This allowed for checking of contradiction of answers from respondents, if any, and to find out what the company did to meet the intended purpose. The last question in this section asked the perceived competitive advantage to the business from the PDM implementation. This was a very important question because the answer provided will indicate the success or failure of PDM implementation in the company.

- **Section 2**

Section 2 aimed to investigate the reasons why some companies have not implemented any PDM systems. This section also questioned how the company manages its product data, the performance of its existing product information systems and the difficulties, if any. Other questions were whether the company is thinking of implementing a PDM system and the factors that would encourage PDM system implementation.

- **Section 3**

This section was intended to provide better understanding of the profile and the demographic characteristics of the company where the respondent is attached. Initially, this section was to be printed on the front page, however due to space constraint, it was later decided to place this section at the back page. Ten questions were asked in this section. From this section, four aspects of the company can be determined:

- The type of industrial sector which the company belongs to
- The size of the company - whether an SME or a large enterprise
- The type of production system employed by the company
- The computing hardware and applications available in the company

The type of industrial sector was asked to determine if PDM systems could be used in a wide range of industry, as claimed by many PDM vendors. The same reasoning also applied in asking the size of company and the type of the production system employed. These questions aimed to satisfy the first objective of this survey: to investigate the types of manufacturing industry that have implemented PDM systems. The computing supports, both in hardware and software, and tools available were asked in order to determine the readiness of the company in implementing a PDM system.

3.3.2 Survey Instrument Design - Questionnaire across the Internet

The main difference between questionnaire by mail and posting it across the Internet is that the latter was an interactive type of survey instrument. Hence, the aspect of human computer interaction (HCI) was also taken into consideration during the design of the survey instrument. HCI is a computer science discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them. Without going into in-depth of HCI, the author's main concerns were on the design method that emphasised on a user-friendly interface, easy to read, and the page can be displayed on the computer monitor screen within seconds.

The survey instrument was not posted across the Internet using the university web-site because the author was not granted full administrator right to amend the particular site whenever the need arises. This proved to be very inconvenient and inflexible. Hence, it was posted using one of the free web space providers found on the Internet. The survey instrument, though no longer accepts any responses, can still be viewed at the following uniform resource locator (URL):

http://www.geocities.com/ResearchTriangle/Thinktank/3911/

The design of the web page used the concept of frames. Specifically, frames divide web pages into multiple, scrollable regions, so that information can be presented in a more flexible and useful fashion. The main advantage of using frames is the elements that users should always see, such as control bars, copyright notices, and table of contents can be placed in a static, individual frame. When the user navigates the site in the "live" frames, which display the details, the static frame's contents remain fixed even though adjoining frames redraw.

Upon selecting the hyperlink for the survey, the respondents will be taken to an introduction page, which provided a brief introduction to PDM systems and the objectives of the survey. The survey instrument was divided into four sections:

Section 1 - provides further introduction to a PDM system
Section 2 - obtains details of the company background
Section 3 - identifies the level of PDM usage within manufacturing industry
Section 4 - investigates why a PDM system has not been implemented

As mentioned earlier, the contents of both the survey instruments are the same and it is only the layout presentation which is different. Hence, shown here is the similarity between the two survey instruments:

By Mail		On the Internet
Introduction	=	Section 1
Section 1	=	Section 3
Section 2	=	Section 4
Section 3	=	Section 2

3.4 Survey Response

A total of 5,000 copies of the questionnaire were distributed to the members of the IOM, however only 8 completed questionnaires were returned. This very poor response may be an indicative of the low relevance of PDM to the IOM's members or, perhaps, the intense work pressures imposed on most of the members today. However, it was definite that the adopted method to distribute the questionnaire was highly inappropriate.

Responses from the questionnaire posted across the Internet were encouraging. A total of 76 responses were received from the members of IPDMUG of the 350 invited participants. The respondents were made of 56 from the USA; 2 each from Israel, Korea, and Sweden; 1 each from the UK, Africa, Canada, Finland, Taiwan; and 9 unknown. Further analysis of the then 496 IPDMUG members explained the poor response from the UK compared to the high responses received from the USA:

- 353 members were from the USA, which were either academia or industrialists
- Only 4 members were from the UK (out of a total of 11 members) were from companies.

The poor response received from the UK suggested the need for a different approach in distributing the questionnaire. Next, the author approached some PDM vendors to invite their clients to participate in the survey. A lot of ten questionnaires with cover letters were sent to each PDM vendor, who had agreed to help out, for distribution to its clients because they were not allowed to release name of their clients without the client's prior consents. The cover letter explained the objectives of the survey, provided the estimated time to complete the questionnaire, requested brochures of the company's main products if possible, and ensured the recipient of the questionnaire the strict confidentiality of all information provided. However, no response was received from this approach. The vendors were later contacted to investigate what went wrong. The author was told that the questionnaires were sent to randomly selected name lists from the vendors' databases and that they were not able to give out the name lists.

The next identified approach was to distribute the questionnaire to companies that attended the University's SME Support Network Workshops and other activities, and also those identified and selected from a search on the Kompass website (http://www.kompass. com). All questionnaires sent out by the author herself had the recipient's name printed on both the envelope and the cover letter as a measure to increase response. The author also acquired assistance from Ms Zoê Dann, a researcher from the Liverpool John Moores University, UK, for distributing the questionnaire to their industry contacts.

Overall, this approach yielded an average response of 30%, i.e. 35 were returned from a total of 115 questionnaires sent out. However, after careful analysis of the responses received, 4 respondents were found not suitable because the questionnaires returned were incomplete and contained contradictory responses and the author was unable to contact them for further clarification.

In total, 40 responses were received from the UK: 39 from questionnaire by mail and 1 from the Internet.

3.5 Survey Statistical Inference

To perform the statistical inference, the statistics found in the DTI's website entitled "Small and medium enterprises (SME) statistics for the UK 2000", prepared by Small Business Service [http://www.sbs.gov.uk] will be used to represent the intended population for this survey. Table 1 presents an extract of this statistics showing only the number of enterprises, employment and turnover in the UK manufacturing industry for the year 2000. For this exercise, one sample t-test of the population and sample means was used to determine the difference between the two means relative to the spread or variability of their scores. Using the normal rules of thumb, if the t-test statistic is greater than 0.05 (5%), then there is no difference between the two means.

Before performing the test, it was deemed necessary impose two assumptions. Firstly, as the responses received from the survey were biased to medium and large sized manufacturing companies, it was deemed necessary to exclude companies with employees less than 50 from the population data. Secondly, 50 was taken to be the minimum value for the range "Less than 100" for the Sample Data. These are accepted assumptions as it is not possible for any companies smaller than that size to be able to justify for implementing a PDM system. Table 2 shows the calculation for the test and clearly shows that the sample mean is of no difference from the population mean. Therefore, the author is confident that results obtained from the survey will be significant and valid.

UK, number, thousands, £million and percent

	Number			Percent		
	enterprises	employment ('000)	turnover (£ million)	*enterprises*	*employment*	*turnover*
All enterprises	332,085	4,191	482,927	*100.0*	*100.0*	*100.0*
Employees	125,455	3,939	474,052	*37.8*	*94.0*	*98.2*
1-4	59,240	180	14,412	*17.8*	*4.3*	*3.0*
5-9	26,470	187	14,836	*8.0*	*4.5*	*3.1*
10-19	17,705	247	18,348	*5.3*	*5.9*	*3.8*
20-49	11,235	353	27,206	*3.4*	*8.4*	*5.6*
50-99	4,925	347	27,744	*1.5*	*8.3*	*5.7*
100-199	2,870	402	38,505	*0.9*	*9.6*	*8.0*
200-249	610	137	12,941	*0.2*	*3.3*	*2.7*
SMEs	**123,055**	**1,855**	**153,991**	***37.1***	***44.3***	***31.9***
250-499	1,325	462	46,418	*0.4*	*11.0*	*9.6*
500 or more	1,075	1,623	273,642	*0.3*	*38.7*	*56.7*
LEs	**2,400**	**2,084**	**320,060**	***0.7***	***49.7***	***66.3***

Source: Small Business Service.

1. Sole proprietorships and partnerships comprising only the self-employed owner-manager(s) and companies comprising only an employee director.

Table 1 Number of Enterprises, Employment and Turnover in the Manufacturing Industry

Population Data							
Range	min	max	f	xmid	f*(xmid)	μ	σ
Less than 100	50	99	4,925	75	347,375		
100-199	100	199	2,870	150	401,800		
200-249	200	249	610	225	137,275		
250-499	250	499	1,325	375	461,650		
More than 500	500	799	1,075	650	1,622,760		
			10,805		**2,970,860**	**274**	**194**

Sample Data							
Range	min	max	f	xmid	f*(xmid)	x	s
Less than 100	50	99	11	75	820		
100-249	100	249	15	175	2,618		
More than 250	250	799	13	525	6,819		
			39		**10,256**	**262**	**160**

Summarised Results:

Population Data		**Sample Data**	
Size, N	10,805	Size, n	39
Mean, μ	274	Mean, x	262
Standard deviation, σ	194	Standard deviation, s	160

Test statistics based on population studied:

Standard error of mean	31.06
Test statistic	0.39

Table 2 T-Test for Sample Collected

3.6 Survey Results and Analysis

The results from this survey are important as they could provide an insight to the rate of the take up of PDM systems in the manufacturing industry within the UK compared to other places. Here, the results of the survey are discussed and analysed in details. For ease of the discussion, the results are divided into three sections, namely profile of respondents, level of PDM usage, and why no PDM implementation. Also, the respondents are categorised into two main groups: UK and Non-UK.

3.6.1 Profile of Respondents

Of the total 115 responses received, 51 were from the SMEs and 64 from the large enterprises. Further breakdown of the responses showed that 27 SMEs and 13 large enterprises were from the UK. The questionnaires were mainly completed by middle managers involve in engineering design, manufacturing, and production. This is particularly important because people in these areas must be conversant with issues that were addressed in the survey.

Responses from UK industry showed that all respondents from large enterprises have heard of PDM whilst only 15 from the SMEs, i.e. 56% of the respondents from the UK's SMEs. Table 3.1 shows the percentage of respondents that have implemented, or invested, in PDM systems. Here, it is important to note that although non-UK respondents have a higher percentage than those from the UK, it does not necessary reflect that there is a higher density of PDM users outside the UK. This biased result is due to the fact that majority of IPDMUG members, where 98% of them were non-UK, were predominantly from companies that were already using PDM systems.

	Respondents - % [No.]	
Grouping	**UK**	**Non-UK**
Implemented/invested in PDM	28% [11]	81% [61]
Have not implemented/invested in PDM	72% [29]	19% [14]

Table 3.1 PDM and Non-PDM Grouping

Further analysis of the respondents from the UK showed that 2 SMEs and 9 large enterprises have implemented PDM systems. This verifies that most of PDM users are from large scale manufacturing companies. Various reasons come to mind but three reasons are of the most significance. First, the cost of a typical PDM system does not justify its full implementation by most SMEs. Secondly, the elaborate planning and maintaining procedure required by a PDM system often requires a full time PDM administrator. However, in most cases, it is a high possibility that SMEs would only resort to the use of certain segment of the total PDM system and this certainly does not justify the employment of a full time PDM administrator. Thirdly, many of these PDM systems can take six to nine months to implement and are difficult to understand due to their highly complex and involved nature. Expensive project-based implementation and business consulting is often unaffordable for many SMEs, with little or no continuous post-implementation support.

When asked about the benefits of PDM implementation to a company, different responses were received from companies that have implemented such system and those that have not, as shown in Table 3.2. Further analysis showed that out of the 27 UK's SMEs, only 2 perceived the benefits as of critical importance, 1 as of very important and 7 as of useful. This shows that there is a need to educate companies, which have not implemented PDM systems and particularly SMEs, on the functionality of PDM systems and how such systems can support them to ultimately achieve competitive edge.

	Respondents - % [No.]					
	UK			Non-UK		
Rate of benefit	**PDM**	**Non PDM**	**Over-all**	**PDM**	**Non PDM**	**Over-all**
Critical	55% [6]	7% [2]	20% [8]	54% [33]	36% [5]	51% [38]
Very important	36% [4]	7% [2]	15% [6]	32% [20]	29% [4]	32% [24]
Useful	-	31% [9]	22% [9]	3% [2]	7% [1]	4% [3]
Marginal	9% [1]	10% [3]	10% [4]	-	7% [1]	1% [1]
No importance	-	7% [2]	5% [2]	-	-	-
Not sure	-	38% [11]	28% [11]	-	7% [1]	1% [1]
Not stated	-	-	-	10% [6]	14% [2]	11% [8]

Table 3.2 Responses on the Beneficial of PDM Systems

Company size refers to the number of employees and the annual sales turnover, as shown in Table 3.3 and Table 3.4 respectively. The two tables show, as expected, that PDM systems implementations are related to the size of the company. Also, both tables show that an average of 82% of the respondents from the UK that have not implemented any PDM systems were SMEs compared to only 25% from non-UK's. Thus, this shows that there might be commercially available PDM systems that are suitable for the SMEs. The next question arises: why are the UK's SMEs lagging behind and not benefiting such technology? It is the intention of this survey to investigate and to provide an answer to this question.

	Respondents - % [No.]					
	UK			Non-UK		
Number of employees	PDM	Non PDM	Over-all	PDM	Non PDM	Over-all
Less than 100	9% [1]	35% [10]	27.5% [11]	3% [2]	7% [1]	4% [3]
101 - 250	18% [2]	45% [13]	37.5% [15]	10% [6]	22% [3]	12% [9]
More than 250	73% [8]	17% [5]	32.5% [13]	77% [47]	57% [8]	73% [55]
Not stated	-	3% [1]	2.5% [1]	10% [6]	14% [2]	11% [8]

Table 3.3 Company Size - Number of Employees

	Respondents - % [No.]					
	UK			Non-UK		
Annual Turnover	PDM	Non PDM	Over-all	PDM	Non PDM	Over-all
Less than £3m	-	24% [7]	17.5% [7]	3% [2]	-	3% [2]
£3m - £10m	-	28% [8]	20% [8]	3% [2]	7% [1]	4% [3]
£11m - £20m	18% [2]	17% [5]	17.5% [7]	2% [1]	-	1% [1]
£21m - £30m	18% [2]	14% [4]	15% [6]	5% [3]	14% [2]	7% [5]
More than £30m	64% [7]	14% [4]	27.5% [11]	66% [40]	36% [5]	60% [45]
Not stated	-	3% [1]	2.5% [1]	21% [13]	43% [6]	25% [19]

Table 3.4 Company Size - Annual Turnover

Table 3.3 shows that there is one respondent with its number of employees less than 100 that claimed to have implemented a PDM system. Further investigation by the author showed that the implemented PDM system referred to was an in-house built spreadsheet using MS Excel that showed both the bill of materials and the revision control of its products. The company is a caravan manufacturer. The response was considered valid based on the following three arguments:

- The goal of the survey did not exclude in-house built PDM systems.
- The respondent was aware of PDM system.
- The implemented in-house built PDM system has two important functionality of a commercially available PDM system.

Table 3.5 shows the various industry sectors represented by the respondents. The "Others" includes responses from foods and beverages, defence, textiles, and pharmaceuticals. This is in agreement with the longitudinal extension of the use of PDM systems as found in the literature.

	Respondents - % [No.]					
	UK			Non-UK		
Industrial Sector	**PDM**	**Non PDM**	**Over-all**	**PDM**	**Non PDM**	**Over-all**
Aerospace	55% [6]	3% [1]	17.5% [7]	10% [6]	7% [1]	9% [7]
Automotive	18% [2]	21% [6]	20% [8]	10% [6]	-	8% [6]
Electrical/Electronic	-	3% [1]	2.5% [1]	25% [15]	14% [2]	23% [17]
Comp. & Peripherals	-	-	-	6% [4]	14% [2]	8% [6]
Mechanical/Machinery	27% [3]	35% [10]	32.5% [13]	8% [5]	21% [3]	11% [8]
Household Appliances	-	3% [1]	2.5% [1]	2% [1]	-	1% [1]
Others	-	35% [10]	25% [10]	39% [24]	43% [6]	40% [30]

Table 3.5 Type of Industrial Sector

Many of the respondents came from companies that have been in business for a long time. Table 3.6 shows the years of business establishment of the respondents and it also shows that there was an inclination to the implementation of PDM systems based on the maturation of the business establishment. It is important not to be misled by the results from the UK's respondents and draw upon the conclusion that only companies that have been established for more than 10 years have implemented PDM systems. This result is due to the fact that out of all the respondents from the UK, 81% of the SMEs and all those from large enterprises have been operating for more than 10 years. Still, this could be a possible case because a new company would not revert to an expensive tool like a PDM system unless its method of product information system is no longer able to cope with the increased amount of product data generated. One factor that can lead to the increased in the product data generated is the increased in the varieties and complexities of product produced, which usually is very dependant on the maturity of a company.

	Respondents - % [No.]					
	UK			Non-UK		
Years of Establishment	PDM	Non PDM	Over-all	PDM	Non PDM	Over-all
Less than 2 years	-	-	-	2% [1]	-	1% [1]
2 - 10 years	-	14% [4]	10% [4]	11% [7]	14% [2]	12% [9]
More than 10 years	100% [11]	83% [24]	87.5% [35]	77% [47]	72% [10]	76% [57]
Not stated	-	3% [1]	2.5% [1]	10% [6]	14% [2]	11% [8]

Table 3.6 Years of Business Establishment

Table 3.7 shows that all respondents use some sort of computer support systems for the operations of their businesses. This confirms that today ICT is no longer just a luxury tool for many companies. Table 3.7 also shows that there are high percentages of respondents who have had implemented PDM systems were also using some sort of CAx solutions, MRP / MRPII, networks of CNC / DNC machines, and / or project management tools: 80% to 100% from the UK's respondents. This shows that if the PDM systems were successfully integrated with these applications, there would be a high degree of timely transfer and sharing of accurate product data to the right person at the right time. The next section will find out about the level of integration between PDM systems and these applications.

Note the following acronyms used in Table 3.7:

CAx	CAD/CAM/CAE/CAPP	QAS	Quality Assurance System
FS	Finite Scheduling	WM	Workflow Management
EDI	Electronic Data Interchange	PM	Project Management
EDM	Electronic Document Manager		

	Respondents - % [No.]					
	UK			Non-UK		
Computerised Applications	PDM	Non PDM	Over-all	PDM	Non PDM	Over-all
CAx	100% [10]	93% [27]	95% [37]	89% [55]	79% [11]	87% [66]
MRP / MRPII / ERP	80% [8]	55% [16]	62% [24]	66% [41]	50% [7]	63% [48]
CNC / DNC	90% [9]	48% [14]	59% [23]	55% [34]	43% [6]	53% [40]
QAS	60% [6]	14% [4]	26% [10]	53% [33]	21% [3]	47% [36]
FS	30% [3]	7% [2]	13% [5]	13% [8]	-	11% [8]
EDMS	60% [6]	17% [5]	28% [11]	53% [33]	43% [6]	51% [39]
EDI	70% [7]	21% [6]	33% [13]	47% [29]	36% [5]	45% [34]
PM	100% [10]	59% [17]	69% [27]	63% [39]	36% [5]	58% [44]
WM	50% [5]	-	13% [5]	40% [25]	7% [1]	34% [26]
Others	20% [2]	17% [5]	18% [7]	13% [8]	21% [3]	14% [11]

Table 3.7 Computerised Applications In Use

Table 3.8 shows that the majority of the respondents that have implemented PDM systems were practising make-to-order approach. This result confirms the author's claim that PDM is profound in manufacturing companies that practise make-to-order. The survey also discovered that many enterprises employed more than one type of production approach depending on the types of product in production. For example, the 3 respondents from the UK that are practising make-to-stock also claimed to be practising make-to-order. Further analysis showed that 84% of the UK's SMEs practised make-to-order compared to only 31% of the UK's large enterprises. This result agrees with the literatures reviewed: the majority of SMEs are commonly categorised to be component manufacturers for larger companies where they operate in the make-to-order approach.

	Respondents - % [No.]					
	UK			Non-UK		
Production systems	PDM	Non PDM	Over-all	PDM	Non PDM	Over-all
Make to Order	73% [8]	69% [20]	64% [25]	42% [26]	43% [6]	42%[32]
Assemble to Order	30% [3]	17% [5]	21% [8]	39% [24]	29% [4]	37%[28]
Make to Stock	30% [3]	21% [6]	23%[9]	32% [20]	21% [3]	30% [23]
Others	-	14% [4]	10% [4]	24% [15]	29% [1]	21%[16]

Table 3.8 Production Systems

Also, Table 3.8 shows that none of the UK's respondents who have implemented PDM systems quoted the option "Others" for the type of production system employed. However, visits to three of the respondents' sites made by the author after compiling the survey results showed that some of them who quoted make-to-order actually also practised engineer to order approach for their project-based products. It is therefore safe to assume that those respondents that quoted make-to-order could also be practising engineer-to-order approach.

3.6.2 Level of PDM Systems Usage

One section of the questionnaire was intended only for companies that have implemented PDM systems. Table 3.9 shows the differences between the maturity of PDM implementation between the UK's and non-UK's respondents. It shows that there is a variation of time spans of PDM implementation within both groups. It also shows that many respondents have been using PDM systems for less than 2 years: 54% from the UK and 56% from non-UK. Table 3.9 also shows that there is a significant percentage of respondents from non-UK that have implemented their PDM systems for more than 3 years. However, based on the results tabulated in Table 3.9, it is safe to conclude that the maturity of PDM systems within the manufacturing enterprises from both UK and non-UK in terms of years of implementation is still very much in its infant stage.

	Respondents - % [No.]	
PDM Maturity	**UK**	**Non-UK**
Less than 6 months	36% [4]	20% [12]
6-12 months	9% [1]	21% [13]
13 - 24 months	9% [1]	15% [9]
2 - 3 years	9% [1]	16% [10]
More than 3 years	36% [4]	28% [17]

Table 3.9 Maturation of PDM Implementation

Literature showed that every enterprise has it own purposes for implementing PDM systems. Table 3.10 shows that there are basically three similar objectives that stood out from both the UK's and non-UK's respondents, with slight differences in terms of emphasis. Here the results show that the purposes of using PDM systems in many companies are still very much the same as those that were first introduced in the early 1980s, i.e. when PDM systems were used mainly to manage the engineering design offices. However, today there is an added emphasis on managing product configuration.

Purpose of Implementing PDM Systems	Respondents - % [No.]	
	UK	Non-UK
To control part proliferation and establish standards	40% [4]	60% [37]
To manage engineering drawing system, search and retrieval	60% [6]	90% [56]
To control engineering release and change management	60% [6]	90% [56]
To manage product configuration	70% [7]	77% [48]
Others	30% [3]	21% [13]

Table 3.10 Purpose of Implementing PDM Systems

When asked whether any PDM integration has taken place, majority of the respondents which responded "Yes" already have their PDM systems in operation for more than 3 years, as shown in Table 3.11. Table 3.11 also shows that only 54% of the UK's respondents have integrated their PDM systems with other information systems, compared to a huge 74% from the non-UK's respondents. This huge difference is expected because as shown in Table 3.9: 36% of the respondents from the UK have only implemented their PDM systems for less than 6 months. The slow adoption of PDM integration within the UK's respondents can also suggest that they might be less ambitious in their PDM implementation strategies compared to those from non-UK. This can be contributed by factors such as a lack of expertise, insufficient preliminary research, or simply the fear for failures as a result from having too ambitious milestones.

Table 3.12 shows the type of computerised applications that have been integrated or interfaced to the implemented PDM system. The survey showed that the majority of respondents, those that have started PDM integration, have integration with their CAx tools, i.e. 60% and 61% from the UK and non-UK respectively, compared to the integration with PDM and MRP / MRPII / ERP systems: 20% from the UK and 42%

from non-UK. Results shown in Table 3.12 should be taken seriously because despite the high percentage of other computerised applications used by the PDM users, as shown in Table 3.7, the level of integration between these applications and PDM systems is very low. For example, out of the 80% of PDM users in the UK who have MRP / MRPII / ERP systems, only 20% of them have theirs integrated with their PDM systems. Table 3.12 shows that there is a high possibility of inaccurate product data and also duplication due to the inability to share information between different applications.

	Respondents - % [No.]	
PDM Systems in Operations	**UK**	**Non-UK**
Less than 6 months	-	11.5% [7]
6-12 months	9% [1]	11.5% [7]
13 - 24 months	9% [1]	13% [8]
2 - 3 years	9% [1]	11.5% [7]
More than 3 years	27% [3]	26% [16]

Table 3.11 Integration of PDM in terms of Length of Operation

	Respondents - % [No.]	
Integrated with PDM Systems	**UK**	**Non-UK**
CAD/CAM/CAE	60% [6]	61% [38]
MRP / MRPII / ERP	20% [2]	42% [26]
CNC/DNC Machines	10% [1]	5% [3]
Quality Assurance Systems	-	8% [5]
Project Management	10% [1]	3% [2]
Office Administration Tools	20% [2]	8% [5]
Document Management	30% [3]	16% [10]
Workflow Management	20% [2]	16% [10]
Others	-	13% [8]

Table 3.12 Integration with PDM Systems

The survey also discovered that integration with CAx solutions took place within the first 2 years of implementation, whereas integration with MRP / MRPII / ERP only took place at least after 2 years of the PDM implementation. The obtained results come as no surprise because many of today's PDM vendors were originally CAx solutions providers as PDM was evolved from the needs to improve engineering functions by enabling sharing of product data between various CAx applications. The late start of PDM integration with MRP / MRPII / ERP systems can be explained by one possibility: perhaps only through some costly experiences that enterprises realised that MRP / MRPII / ERP systems will only perform their best with accurate data supplied from applications used during design and engineering process.

Although it has been claimed that one of the main benefits of implementing a PDM system is to reduce product lead times, results in Table 3.13 shows otherwise. Many PDM users, respondents from both the UK and non-UK, opt for better quality and control of information and faster access and retrieval of information as the major benefits. This is because these benefits are immediate benefits that can be measured from an effective PDM implementation. Perhaps effective PDM implementation is seen by the respondents as an indirect factor to shorten product lead times as it is the immediate benefits gained that consequently resulted in shorter product lead times. Whatever the reasons could be, the survey showed that there is a need for the respondents to carry out performance measurement to fully appreciate all the benefits achieved.

	Respondents - % [No.]	
Benefits Gained	**UK**	**Non-UK**
Shorter product lead times	20% [2]	42% [26]
Better quality and control of information	70% [7]	85% [53]
Faster access and retrieval of information	60% [6]	87%[54]
Better visibility of product development status	50% [5]	55% [34]
Reduced unproductive engineering time	10% [1]	52% [32]
Others	10% [1]	13% [8]

Table 3.13 Benefits Gained from Implementing PDM Systems

Table 3.14 and Table 3.15 show the responses from UK and Non-UK respectively when asked how much a PDM system has helped them to achieve competitive advantages. The two tables clearly show that there is a difference in the perception from these two groups of respondents and this difference can be explained by the maturation of PDM systems implementation as shown in Table 3.9.

	UK's Respondents - % [No.]				
PDM helped to achieve competitive edge	**Less than 6 months**	**6 - 12 months**	**13 - 24 months**	**2 - 3 years**	**More than 3 years**
Considerably	-	-	-	-	-
Moderately	-	10% [1]	10% [1]	10% [1]	20% [2]
None	-	-	-	-	10% [1]
Too soon to comment	40% [4]	-	-	-	-

Table 3.14 PDM Helped to Achieve Competitive Edge [UK]

	Non-UK's Respondents - % [No.]				
PDM helped to achieve competitive edge	**Less than 6 months**	**6 - 12 months**	**13 - 24 months**	**2 - 3 years**	**More than 3 years**
Considerably	5% [3]	2% [1]	2% [1]	3% [2]	5% [3]
Moderately	3% [2]	3% [2]	8% [5]	8% [5]	13% [8]
None	-	-	-	-	-
Too soon to comment	11% [7]	16% [10]	5% [3]	5% [3]	10% [6]

Table 3.15 PDM Helped to Achieve Competitive Edge [Non-UK]

It can be concluded from the results shown in both tables that to-date many have yet to tap the full potential of PDM capability: 40% of the UK's respondents and 47% from non-UK quoted it is still too soon to comment on the effectiveness of PDM in achieving competitive edge. Also, Table 3.14 shows that none of the UK's respondents quoted that PDM implementation have helped considerably to achieve competitive edge. These results show that there is an urgent need for strategic methods that will ensure successful and effective PDM implementation. This is especially the case as shown in Table 3.14 where one UK's respondent that has implemented a PDM system for more than 3 years quoted that the implementation has not helped the company to achieve any competitive edge! Clearly the cause behind this lay within the adopted PDM implementation strategy.

3.6.3 Why No PDM Implementation

One of the sections on the questionnaire was intended to investigate the reasons why some companies have yet to implement any PDM systems. Again, it is important to remember that the analysis for the respondents from non-UK has been based on respondents that were predominantly from companies that have already using PDM systems.

Table 3.16 shows the responses received when respondents were asked why their companies have not implemented such a system. As shown in Table 3.16, unawareness of PDM system's existence is the main reason why many of the UK's respondents have not implemented such systems, followed by not able to cost justify the implementation. The responses received from the UK's respondents as shown in Table 3.16 come as expected because they were made of 25 SMEs and only 4 large enterprises. Further analysis of the UK's respondents showed that out of the 93% of SMEs that have not implemented PDM systems, 40% of them were not aware of their existence. This also explains why only 16% of them were looking into the possibility of implementing the system in the near future whilst 84% have no plan for it, comparing with 50% and 50% respectively from large enterprises.

	Respondents - % [No.]	
Reasons	**UK**	**Non-UK**
Unaware of its existence	34% [10]	7% [1]
Lack of computing expertise within the organisation	14% [4]	7% [1]
Unable to find a suitable commercial PDM system	14% [4]	36% [5]
Unable to justify the cost of implementation	28% [8]	36% [5]
Do not have the need for such system	7% [2]	14% [2]
Others	10% [3]	14% [2]

Table 3.16 Reasons for Not Implementing PDM Systems

As expected in companies that have not implemented a PDM system, the majority of them were either using their own in-house developed information system to manage their product data or were doing it manually, as shown in Table 3.17. Further analysis showed that out of the 15 UK's respondents that managed their product information manually, 90% of them were SMEs. This shows that there is a potential market for PDM systems within the UK's SMEs, however SMEs have to be made aware of such technology, especially its capability and the potential benefits that can be gained from it.

When asked whether they have any difficulties with their current existing system, 70% from the UK and 86% from non-UK responded to "Yes". Further analysis showed that out of the 25 UK's SMEs that have not implemented PDM systems, 64% of them were having difficulties with their exisiting systems. Table 3.18 shows the difficulties faced.

	Respondents - % [No.]	
Current Product information systems	**UK**	**Non-UK**
Manually	51% [15]	36% [5]
Information system developed in-house	59% [17]	71% [10]
A commercial package	3% [1]	14%[2]

Table 3.17 Current Product Information Management In Use

	Respondents - % [No.]	
Difficulties with current system	**UK**	**Non-UK**
Too many duplications	17% [5]	14% [2]
Too much clerical work	38% [11]	43% [6]
Unproductive time spent in searching for the right information	45% [13]	36% [5]
Unable to re-use existing information	10% [3]	21% [3]
Difficulties in locating required information	38% [11]	29% [4]
Difficulties in controlling the revision or version of information	34% [10]	43% [6]
Poor quality of information	17% [5]	21% [3]
Others	17% [5]	29% [4]

Table 3.18 Difficulties of Current Product Information System

Table 3.18 also shows that many of the respondents were not aware of the "causes and consequences" type of relations in all the difficulties they faced. For an example in the case of "causes", although 17% of the UK's respondents quoted too many duplications, only 10% of them realised that they were not able to re-use existing information! As for an example in the case of "consequences", while 29% from non-UK's respondents quoted difficulties in locating the required information, only 14% quoted that they have too many duplications!

Lack of awareness of PDM existence and its capability within UK's respondents suggests the need to introduce and educate UK's industry on the functionality and potential benefits of PDM systems. This need is of great importance as the survey also showed that none of the UK's respondents who have not implemented any PDM systems quoted their existing product information management system as outstanding, as shown in Table 3.19. Further analysis showed that out of all the UK's respondents that have not implemented any PDM systems, the responses for rating "Not acceptable" were made from 24% SMEs and 33% large enterprises.

	Respondents - % [No.]	
Rating	**UK**	**Non-UK**
Outstanding	-	7% [1]
Acceptable	72%[21]	36% [5]
Not acceptable	28%[8]	57% [8]

Table 3.19 Rating of Current Product Information System

Although many admitted that they have difficulties with their current product information management system, 24 of the UK's respondents were yet ready to consider implementing PDM systems out of a total of 29 that have not implemented any PDM systems. And out of the 5 that were considering in implementing one, 4 quoted the time frame for such implementation to be between 1 - 2 years. There is a need to identify why these companies were reluctant to speed their PDM implementations besides the negative perceptions of PDM capability.

Table 3.20 shows the responses received when respondents were asked under what condition would they consider implementing a PDM system. With the high percentage of respondents from the UK not aware of the existence of PDM systems, it is expected that examples of successful companies from a similar industry became the main driving factor. It can also be deduced from Table 3.20 that the reluctance of implementing PDM systems within the UK's respondents was mainly due to the difficulties in identifying a suitable system and a lack of successful examples of companies from similar category. Further analysis of the UK's respondents showed that these two factors were the prime considerations quoted by the SMEs and not reduction in PDM cost as anticipated. However, for the UK's respondents that were from large enterprises, their considerations for implementing PDM systems are slightly different: 75% of them quoted successful examples from similar industry and 50% quoted reduction in PDM cost.

	Respondents - % [No.]	
Considerations	**UK**	**Non-UK**
A suitable system can be identified	31% [9]	79% [11]
Improved existing computing expertise within the company	3% [1]	21%[3]
Examples of successful companies from similar industry/category	38%[11]	29%[4]
Increased sales	24%[7]	29% [4]
Reduction in PDM cost	28% [8]	36% [5]
Others	31% [9]	7%[1]

Table 3.20 PDM Implementation Consideration

3.7 Discussions

This section discusses the issues that emerged from the survey analysis. In particular, two topics have been emphasised: the survey method and survey findings.

3.7.1 Survey Method

Although the questionnaire was simple to answer and would require not more than 20 minutes for completion, the survey, which was carried out over a period of six months in 1999, managed to attract only a small number of respondents from the UK. Despite all the mentioned approaches to improve the number of respondents from the UK, in the end the response was still quite poor. The most disappointing responses were from PDM vendors who had agreed to help out in the survey but no actual help was received. It is important to examine the reasons for this poor response. The possibilities can be grouped into two categories: the survey approach and respondents' requirements.

In terms of the survey approach, firstly, the design of the survey instrument itself was reviewed. The use of small font size in order to limit the questionnaire to two pages was not a wise decision as it makes reading the questionnaire difficult. Also, there was no motivation to encourage respondents to spend their time to complete and return the questionnaire. For example, a colleague of the author received a satisfactory level of responses for her survey by offering a chance to win a Marks & Spencer's voucher worth £20 if the questionnaire was completed and returned.

Secondly, the use of a mail shot to reach recipients is perhaps no longer an effective means of carrying out a survey these days because companies are receiving far too many non-business related mails which are treated as time wasting. To avoid the questionnaire mailed to the recipients being treated in this way, it is essential that the specific name of an individual was printed on the envelope rather than just a title or position. Also addressing a specific person on the cover letter rather than using "Dear Sir" would have been an improvement. This has been proven in this survey where a higher percentage of responses were received from this approach. However, this could only be the case if known recipients were to be targeted for the survey.

The author has since learnt that questionnaires by mail, though the most frequently used of all research instruments, will not yield a good response if sent out to randomly selected recipients. Good responses will only be obtained if sent to known contacts. The author received a high percentage of responses from identified recipients who were approached initially via telephone and had agreed to participate, although not from all of them. Personally the author felt that pre-identified recipients could result in a biased analysis and this would defeat the initial purpose of conducting a survey, i.e. to draw out estimates and conclusions from a randomly selected but within a defined population. Thus, the author feels that there is a need to investigate a new approach or a better and effective approach for performing survey on a wide sample of a population.

In terms of respondents' requirements, firstly, perhaps during the time of the survey, PDM system implementation was not a major concern to many UK's manufacturers compared to other manufacturing information systems such as MRPII / ERP systems. Secondly, the survey was perhaps irrelevant to them in what they were trying to achieve in improving their daily business operations and they felt that the entire exercise of the survey was mainly for the benefit of academia. It is difficult to address the respondents' requirement because it is a very subjective issue and is not within the scope of this research. Nonetheless, this is an important aspect to consider in order to guarantee a more successful and effective survey.

3.7.2 Survey Findings

This section discusses the comparison of the take up of PDM systems within the UK against other countries. The findings from this survey show the followings:

1. The characteristics of SMEs are the prime obstacles to why the UK's SMEs are lagging behind and not benefiting from PDM implementation as compared to other countries such as the USA.

The literature reviewed in Chapter 2 showed that obstacles leading to the lack of PDM involvement from SMEs could be categorised into two groups:

- The characteristics of SMEs themselves, such as low resources availability, a lack of expertise, unawareness of ICT development, and nature of operations within the business.
- The focus by PDM vendors which targeting mainly at larger enterprises.

However, results from this survey show that there are PDM systems that are suitable for SMEs, as shown in Table 3.3 and Table 3.4, where there was, on average, a huge 75% from the non-UK's SMEs that have implemented PDM systems compared to only 18% from the UK. This confirms the claims made by some PDM vendors that they have products that are suitable for SMEs and that they are also beginning to aim their products at SMEs.

This leaves the characteristics of SMEs as the prime and perhaps the only obstacle.

The results from the survey showed that the characterictics of SMEs are more profound in the UK's companies compared to the non-UK's:

- SMEs were unaware of PDM's existence: 15 out of 27 UK's SMEs that responded to the survey have not heard of PDM systems.
- SMEs held with them negative perceptions of the capability within PDM systems: 10 out of 27 UK's SMEs perceived the benefits of PDM implementations as ranging from of critical importance to useful.
- The management teams in SMEs are heavily involved with the daily operations of their businesses that they sometimes overlooked secondary issues: while 64% of the UK's SMEs quoted having difficulties with their existing product information systems, only 24% of them quoted that the performance of their systems was not acceptable.

The survey also verified that financial factors, such as the lack of money for capital purchases, is not always the prime consideration for many SMEs. Instead, for SMEs that have heard of PDM systems, the two main obstacles preventing PDM implementation were difficulties in justifying a suitable system and a lack of successful examples of companies from the similar category.

2. There is an urgent need for more collaboration from manufacturing enterprises in research that aims to introduce strategic methodologies that will ensure successful and effective PDM implementation.

The literature reviewed in Chapter 2 showed that currently there are many research projects, carried out either separately or jointly between the government, academia, consultants, and PDM vendors, which emphasise on strategic methodologies to ensure effective and successful PDM implementations. The results from this survey showed that there is a need for manufacturing enterprises in the UK to be made aware and participate in these projects:

- None of the UK's respondents that have not implemented PDM systems quoted that their existing product information system as outstanding.
- Many UK's respondents that have implemented PDM systems have yet to tap

the full potential capability offered by these commercially available systems: none of them was convinced that PDM systems have considerably helped them to achieve competitive edge.

- The level of PDM usage within the UK's respondents is still far from being used as a tool to realise the goal of a computer integrated manufacturing environment: only 54% of the UK respondents have integrated their PDM systems with other information systems, and to which only 20% have integrated with MRP/MRPII applications.
- There was a lack of examples of successful companies from similar industries: a high percentage of respondents quoted identification of a suitable system and examples of successful PDM sites from similar industry as the considerations.

3.8 Meeting Survey Objectives

Although responses from other countries were also collected and analysed as a means of comparison, only responses received from the UK will be discussed in this section for addressing the four objectives set forward in the survey. This aligns with the initial purpose of this survey, which was to investigate the current usage of PDM systems in today's manufacturing industry within the UK.

Despite the low response from the UK's respondents, the 40 responses received came from a wide range of manufacturing companies within the UK, in terms of size, location, nature of business, and industry sector. Furthermore, the statistical inference showed that the sample collected does represent the intended population for this survey. Therefore, the responses received were sufficient to draw up valid conclusions on the level of PDM usage within the manufacturing industry in the UK. The results from the survey carried out showed that:

1. To investigate the types of manufacturing industry which have implemented PDM systems.

In terms of size and type of industry, there is no limitation for implementing PDM systems. However, the survey showed that manufacturing companies that have implemented PDM systems are from larger scale manufacturers, such as aerospace and automotive. As to the types of production systems employed, the survey showed that the majority of PDM users are companies that practise make-to-order or assemble-to-order manufacturing strategies. Some of the respondents who practise make-to-order also do make-to-stock, depending on the types of product in production. Although none responded to use other production approach like engineer-to-order, some of the respondents do employ this approach. In terms of the type of IT infrastructure available within an organisation, commercially available PDM systems are found to be in use by companies that generate massive volumes of product data from the various computerised applications they use in supporting their daily business operations. These companies would have the required IT skills and expertise necessary for implementing PDM systems.

2. To investigate why companies have not implemented PDM systems.

The survey showed that the obstacles preventing the involvement of UK's SMEs in implementing PDM systems are not just limited to the lack of financial resources and IT skills. The survey identified that the lack of awareness, coupled with negative perceptions of the capability of PDM systems, is a more serious factor that needs to be considered and addressed. More attentions have to be focused on how to promote this awareness effectively to SMEs.

As for the large manufacturing enterprises, the survey showed that they were well aware of PDM existence, however the obstacles preventing their involvement were the inability to both identify a suitable PDM system and to justify the cost of implementation. Their considerations for PDM implementation were more successful examples of companies from similar industry and reduction in PDM cost.

Clearly, the results of the survey showed that the obstacles to PDM implementation for SMEs and large enterprises are of two different categories:

- For SMEs, the obstacles can be classified as resistance to change and fear of unfamiliar or new technology.

- For large enterprises, the obstacles were more related to the decision to implement the technology.

3. To identify the level of PDM usage, especially in relation to interfacing PDM to other manufacturing information systems, such as MRPII and ERP.

The survey showed that a high percentage of PDM users within the UK were still at an early stage in their PDM implementation process. The majority of the PDM users have integrated their PDM systems with their CAx tools and the integration process usually took place in the first two of years of the PDM implementation. This perhaps could be contributed by the purpose of implementing PDM systems the first place. The survey has shown that many of the UK's respondents implemented their PDM systems with the aim to optimise their engineering processes: to manage and control the voluminous product data generated from the various CAx applications during the engineering process.

There were not many PDM users that have integrated their PDM system with other manufacturing information systems such as MRPII or ERP and those who have, did so only after two years of running their PDM systems. Clearly this shows that the level of PDM integration with other manufacturing information systems is still in an infant stage. This requires serious attention if PDM systems were to be used as a link between CAx and MRPII or ERP.

4. To identify the benefits achieved from PDM implementation.

The survey showed that many of the identified benefits achieved from PDM implementation were direct or immediate benefits related to the management and handling of product data and not extended to those benefits that could result from PDM implementation. The results from the survey indicated that there is a need for performance measurement to be carried out to fully justify the cause and effect that have been obtained from PDM implementation.

Also, the survey showed that it is still not possible to conclude on the effectiveness of the PDM in helping a company to achieve competitive edge.

3.9 Promoting PDM Awareness

From the discussions of the survey findings in Section 3.7.2, it is clear that there is a need to identify a method to promote PDM awareness to many manufacturing companies in the UK, particularly SMEs. This need is of utmost importance as during the literature review process, the author only came across one research work that included the raising awareness to both management and engineers in PDM functions as the first stage to any PDM implementation [MacKrell and Mandemaker 1998]. The model suggested several ways to promote to PDM, such as strategic vision workshops, conferences, education, and publications.

A practical approach should be adopted to successfully promote the awareness of PDM without having the need to invest in a commercial available PDM system. This will greatly benefit many manufacturing companies, especially SMEs. The author proposes the use of industrial case studies aimed to solve specific problems faced by a company through applying the concept of PDM. This will provide a means to address the "what", "why", and "how" of PDM, as shown in Figure 3.2, and will prepare the company for the next stage of PDM, "Readiness" as depicted in the model developed by MacKrell and Mandemaker. The proposed method will not suffer from lack of co-operation from the collaborating companies as it is to their benefit to solve the identified problems. Although this method does not guarantee a quick approach to promote PDM awareness, the success of this method will guarantee an effective approach.

3.10 Conclusions

The response received from the UK has been low despite the several approaches tried. While the poor response received questioned both the quality of the questionnaire design and the approaches adopted, it also indicated the low relevance of the subject to manufacturing companies within the UK at the time the survey was carried out.

Overall, two implications can be drawn from the survey which need to be considered before any studies on the appropriateness of PDM systems to manufacturing companies can be conducted, be it a commercially available PDM system or an in house built PDM system. Firstly, there is a need to promote and cultivate the awareness of the concept and importance of PDM to manufacturing enterprises that have not implemented PDM systems, especially the SMEs. Secondly, for enterprises that have already implemented PDM systems, there is a need to revisit and review the existing implementation strategy, especially if the implemented PDM systems have yet contributed any business competitive advantages.

A practical method to promote PDM awareness has been proposed without the need to invest in a commercially available PDM system. The next stage of the research intends to validate this method and its impacts through a series of industrial case study.

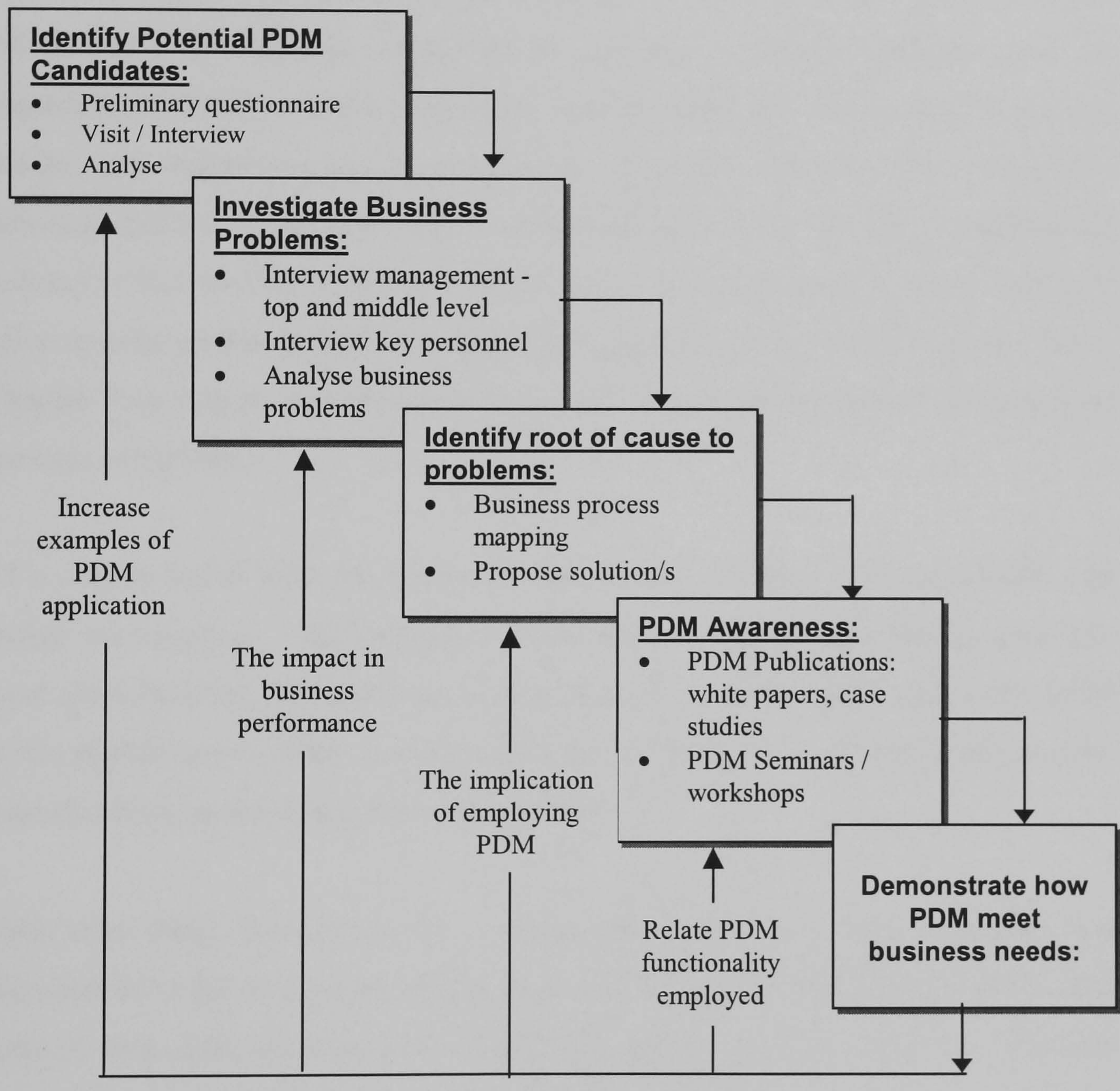


Figure 3.2 An Approach to PDM Introduction

4.0 APPLICATION OF PDM WITHIN THE PRODUCT DEVELOPMENT PROCESS

The objectives of Chapter Four are twofold. Firstly, to validate two of the points drawn in Chapter Two through the use of industrial case studies: the applications and effectiveness of PDM in enhancing the product definition process; and the importance of PDM to create an interface between sales and design; engineering and design; and engineering and manufacturing. Secondly, Chapter Three proposed a practical method to promote PDM awareness effectively to the manufacturing industry within the UK, particularly SMEs, which is through industrial case studies to solve specific problems faced by companies by applying the concept of PDM. Here, Chapter Four intends to validate the proposed method and to measure its impact on the case companies.

This chapter starts with the choice of case study technique, its justifications and design methodology. Following that, three action research case studies with two local manufacturing companies are presented in this chapter. Each case study looks at the application of PDM in a different stage of the product development process: manufacturing, engineering, and sales / marketing.

Each case study investigates the current practices in the case companies and discusses how the companies, on the basis of their real and pressing needs at that point of time, defined the need for PDM. The approaches taken, the results obtained and, where appropriate, the project implications are mentioned in each case study following the problem identification. A summary is provided at the end of each case study. The main issues identified from the three case studies, which lead to the need for an improved method for product specification at the order acceptance stage is also discussed.

Chapter Four concludes on how the two mentioned objectives are validated and the effectiveness of chosen approach to promote PDM awareness.

4.1 Case Study Technique

As mentioned in Chapter Three, a detailed case study can provide answers for the "How" and "Why" questions, which are usually not obtainable by means of other survey techniques. For the purpose of this research work, three case studies were carried out to investigate the importance of PDM in enhancing the product definition process and to create an interface between three different functional areas in an organisation. Besides that, the case studies also aimed to demonstrate the effectiveness of the chosen approach to promote PDM awareness. Therefore the choice of case study technique required have to be able to bring about action in the form of change, and at the same time develop a understanding which informs the change and is an addition to what is known. It also requires involvement of people from the organisation to plan for the appropriate actions, such as what information is required, what outcome to pursue and what method to use. For this reason, participatory action research technique was employed.

> *"Participatory action research is the way groups of people can organise the conditions under which they can learn from their own experiences and make this experience accessible to others."*
>
> McTaggart [McTaggart 1991]

During a participatory action research process, changes happen throughout the entire research process. According to Wadworth, a hallmark of a genuine participatory action research process is that it may change shape and focus over time as participants focus and refocus their understandings about what is really happening and what is really important to them [Wadworth 1998]. This nature of participatory action research process is indeed what is required to carry out the intended case studies because any introductions introduced during the period of the case study should address the needs of the company.

4.2 Case Study Design and Approach

The design of the case study method followed the concept of Yin's [Yin 1994], where appropriate. The theory development was based on the need to validate the two points addressed in the literature reviewed and the effectiveness of the proposed method to promote PDM awareness by studying the differences of the organisations on the before and after each case study implementation. The choice of the two discrete and local manufacturing companies producing complex products that are highly customised to customer requirements will enable this examination possible as their products require an effective PDM environment to ensure "right first time", which the two case companies did not have before the case study commenced. Although the two case companies are both parts of larger groups, they operate as distinct profit centres. Also, because of their distinct geographic location from the parent company, their actual plant size, and their fragmented IT infrastructure, they exhibit most of the characteristics of a larger SME.

Contact for the first case company was through a Research Fellow, employed by the university and based full time at the company, whilst contact for the second, then the Operational Engineering Manager, was made at a meeting on the first visit to the company. To understand the background of each of the companies, its products, the design and manufacturing processes employed, and the IT infrastructure available, a simple questionnaire (see Appendix B - Case Study Questionnaire) was designed and sent to each contact for providing the required information. The results from the questionnaire for each case company are presented in each case study under the section "Company Background".

The case study implementation started with each case company defining its problems and pressing needs for PDM. This is followed by the setting up of a project team where a top management from each case company participated and contributed to the smooth running of the project, along with the contact from each case company as the initiator and the research supervisor as the advisor. Before the actual investigation started, familiarisation with the organisation structure and working process of each case company was carried out to provide the author an understanding to the operations of each case company. The investigation started with discussions with relevant personnel to understand their needs and to review and analyse relevant existing operational systems and methods against the needs identified. This satisfied the design data collection to identify the relevant data for the case study implementation. From the problem identification, investigations were carried out to establish appropriate approaches and methods needed to address the problems. Throughout the process of each case study, all observations and implications from each project were documented and presented in this chapter.

The first two case studies involved software engineering and development with each of the case company after the preliminary investigations. This was due to the unavailability of appropriate tool within each case company that can be used to address the problems identified for each respective case study. The software developments and implementations constituted about two third of each of the two case studies. The third case study involved carrying out a review and feasibility study of introducing a common system from three existing systems that were in use. It proposed to the case company the product data that could and should be considered within the common system without actually developing one, aligning with the requirements from the case company. Majority of the time during the third case study was spent on understanding the product definition process and studying the system used within the case company.

Results and conclusions derived from the three case studies were disseminated to industrialists through three conferences papers, where each of these conferences emphasised on a different theme of the product development process: manufacturing, production and operations management, and logistics.

Figure 4.1 shows the approaches taken for the case study implementation.

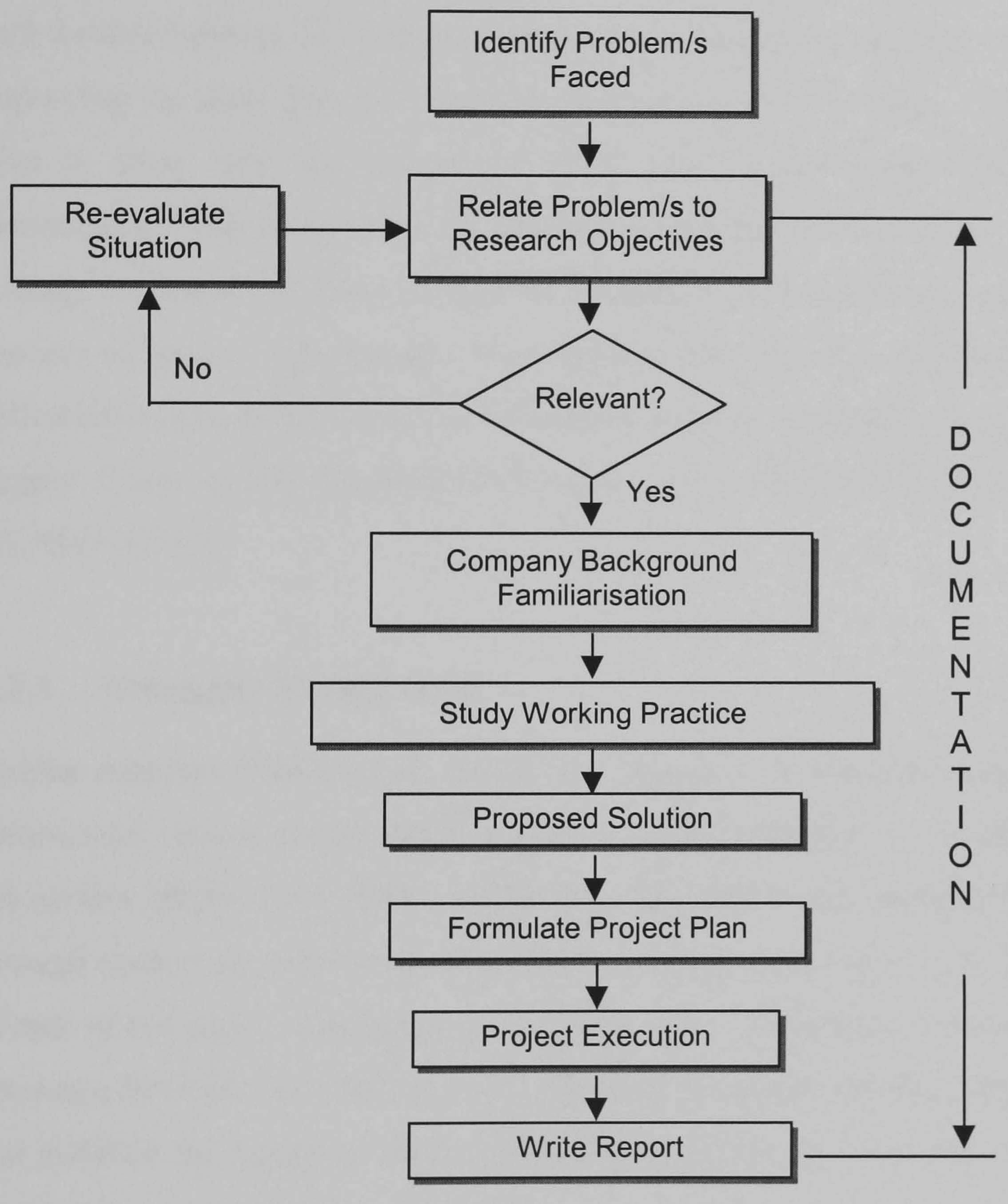


Figure 4.1 Case Study Method

4.3 Case Study #1: Application of PDM in the Manufacturing Stage

This section presents the first case study of the research project: the application of PDM during the manufacturing stage within a commercial vehicle manufacturer with a high proportion of customer defined vehicle configurations. The study is concerned with the development of a prototype production tracking and shortage control tool for improving the shop floor performance of a vehicle manufacturer. This case study aims to show how the concept of PDM aids in facilitating effective vehicle manufacture, both in terms of the production process and inventory management, through improved information flow from design to manufacture, and continuous analysis of updated information. The output of this case study formed a part of the deliverables to an EPSRC IMI Land Transport project: Development of a Responsive Supply Chain in the Commercial Vehicle Sector, RESCOVS (Grant Reference GR/M43081/01).

4.3.1 Company Background

Seddon Atkinson Vehicles Ltd., located in Oldham, near Manchester, operates in the commercial vehicle sector and is a wholly owned subsidiary of a major European automotive player, Iveco SPA. Established since 1970, the company has had gone through several up and downs. The 200 series truck, launched in 1975, was voted "Truck of the year". The company was then sold to a Spanish government holding company, ENASA, for US$1 in 1984. The Fiat Group bought the company in 1991, and installed the company within its Heavy Truck Division with Iveco, its growing commercial vehicle company, in 1999.

Today, there are approximately 212 people employed at this plant with 19% of them in the Engineering / Design department and 66% on the production shop floor. Its annual sales revenue is in the range of £30 - £50 millions and is also certified with ISO 9001. The company designs, assembles and tests its finished products, which are mainly commercial vehicles ranging from 17 to 44 tonnes for the municipal and commercial markets. All of the components for the vehicles are bought in, which explains the large supply chain supporting the company. Analysis showed that at the time of this case study, they had about 400 active suppliers.

The manufacturing approach adopted is make-to-order with a high proportion of customer defined vehicle configurations: 75% of its trucks are customer specific. The level of complexity in the manufacturing process is considered medium where it requires an average of 10 - 15 operations to assemble a finished truck. During the assembly process, the company uses in-house built applications from Iveco as well as commercially available systems, such as Cummins' Set-up Parameters Software for truck engines.

The company estimated that customised trucks orders make more than 50% of its total sales value per year, while standard trucks are less than 25%. Spare component sales make up the remaining 25%. There are more than 50 variants produced for its commercial trucks and each is made of more than 50 distinct components with high level of complexity. Over the last three years, the company has introduced more than 20 modified versions from its existing trucks and about 5 to 10 completely new trucks.

Design modularity is an adopted practice in the design process with more than ten weeks of design lead-time required. The company uses AutoCAD as its CAD tool. The level of complexity in the design process is considered medium and the company claimed that it adopts a concurrent engineering approach in all its new truck introductions. However, there is, on average, more than five iterations between engineering and production concerning engineering changes for each new truck introduced. Accurate product definition at the order capture stage is a key issue for the company. Whilst inter-group synergies are gradually being developed, particularly in the areas of design and the supply chain, the company operates as a relatively independent business unit.

The company is particularly strong in the domestic municipal market for refuse collection trucks partly due to the use of Cummins diesel engines. Currently the company's annual sales represent 1.3% of the total UK truck market [Ryhmer 2000]. This expertise is gradually being developed for the European 'municipal' markets where trucks are being manufactured in the UK but sold under the parent company brand name, Iveco, which has a greater market acceptance in Europe.

In the commercial market, competition with large mass producers is increasingly limited to 'niche' sectors where established expertise, coupled with design specification, flexibility and responsiveness, enable it to compete with less flexible mass producers. The level of market uncertainty is conceived to be medium, and the company perceives itself in the lower half of the sector for competitive performance among its competitors. The company has identified that speed of delivery, product variety and functionality, speed of response to customer, and focus on specific markets as the most important factors in enabling it to compete successfully in the commercial vehicles market. This is followed by other factors such as product quality and cost.

4.3.2 Development of a Prototype Production Tracking and Shortage Control Tool

The recent history of the company has been one of decline in the face of strong competition and a difficult and fluctuating market. Many core IT systems in use, whilst functional, are old batch update process systems with no management reporting and limited development opportunities due to the resources available and skills required. The consequence has been the emergence of a fire fighting culture and crisis management. The situation is worsened by recent company decisions to have significant cutbacks in manpower.

In the past, the company used several methods, both electronic and manual, in monitoring the production process. The manual systems such as the Kardex system and vehicle in / out logbooks involved extensive clerical effort, whilst the old electronic tracking system was developed using Lotus Notes, an application which was not widely used within the organisation as the company's IT department uses and supports only Microsoft applications. Furthermore, the old system was not year 2000 compliant. It was therefore necessary to replace the old system before the end of the year 1999.

The company had identified the urgency of replacing the old tracking system. During the initial take up of the project, it was agreed to develop a new truck assembly tracking system that mimicked the old tracking system. However, results from the investigation of the work practice within the company showed that the major problem was a lack of accurate and visible product data and thus resulted in producing many duplicated product data. For example, the old tracking system was found to be producing information that could be found in the company in house built MRP system, within its AS/400 mainframe system. While the company claimed that all relevant product and production data are stored in the database and material and suppliers in the MRP system, management had to go through piles of printed reports and performed additional data manipulations in order to obtain the required information. The exercise was manually intensive and time consuming.

The company was later convinced that an improved interface for manufacturing based on effective PDM allied to improved shortage identification and control was the key to overcoming their problems and accepted the approach proposed by the author for the design of the prototype tracking system.

Five objectives were set up for this project:

- Capture and re-use of existing product data to avoid duplication of data.
- Manipulation of existing and new product data and its relationships to allow the organisation to re-define how and where the data is used.
- Use of currently available computing facilities within the organisation to avoid unnecessary additional expenditure.
- Enable sharing of data across the organisation through a user-friendly interface.
- Create reporting facilities to provide a basic management information system for senior management.

The benefits envisaged from the project are particularly improved communication throughout the organisation to allow for:

- Better management focus on problem solving.
- Better and more accurate materials management as well as measuring supplier performances.
- Quicker customer response on product availability and order delivery status.
- Efficient and effective production process on the shop floor.

4.3.3 Project Approach

Because of the nature of the project, which required a quick and fast solution to address the then pressing needs, rapid software prototyping was adopted as the methodology to develop the required solution, instead of the conventional software development. The project also intended to introduce PDM to the case company, which at the time of the case study was not aware of PDM existence, by showing how effective PDM could solve its problems through the use of the prototype.

The project started off by gaining an understanding of the vehicle order tracking process on the shop floor and the old electronic tracking system that was in use. The author learnt that the case company scheduled different vehicle orders for production depending on the required week for delivery of the order. The exercise was carried out manually by an experienced production planner who knew the average time required to assemble the particular vehicle, which included the lead-time for all bought in parts required for that vehicle. The project aimed to capture this knowledge and to make it available to all relevant parties.

Prior to the development of the prototype system specifications, discussions with the end users and the developer of the old system were held to identify the strengths and weaknesses of the system design and functionality. During the process of deriving the system specification for the new prototype system, several discussions were also held with members from the company to identify potential end users. The exercise was deemed necessary in order to collect necessary information for the prototype specifications.

In order to avoid duplication of data entry and hence possible errors from human intervention, the company IT Department was consulted during the development stage to discuss methods of sharing information between the MRP and the database in company mainframe system with the prototype system. Also, due to the cost of a major system and the level of company expenditure on new product development, the company had decided to address identified problems of data visibility using MS Access, which was already networked on a recently introduced Intranet using a Windows NT server.

Initially, the targeted end-users were mainly those involved in the production process namely the production managers, material managers and controllers, shop floor supervisors and line leaders. However, it was then decided to provide the viewing facility to other functions within the organisation. Therefore, issues of access control, data security and integrity were also considered during the development stage.

A series of training sessions were provided to the company to show the system functionality, system behaviour, and most importantly to emphasise the need for a new way of working within the organisation through the availability and visibility of accurate product data. This was carried out by the Research Fellow, the initiator of the project, who had participated throughout the development of the prototype.

4.3.4 Project Results

The new prototype system was developed to improve data visibility and reporting in the production control, tracking, and materials management areas, and hence named **Pro**duction **T**racking and **S**hortage **C**ontrol, ProTSC. Much of the core product data was transferred from the company mainframe to ProTSC whereas the production status data was from ProTSC to the mainframe. This two-way file transfer was performed through an American National Standard Incorporation (ANSI) formatted text file. Direct linking of the mainframe to ProTSC was suggested but the company opted for the two-way file transfer method because of the fear for losing data integrity. It was by far much simpler to implement and deemed suitable in this situation because the company was not very confident with its then IT skills available.

A list of relevant product data was established based on the system specification derived, which were from both the existing data identified from the old system and some newly introduced data. The relationships between these data were then defined and created to meet the required specification. Figure 4.2 shows the database schema for ProTSC using MS Access as the development platform. A system architecture manual was produced during the hand-over of ProTSC to allow the company to do any future modifications when required.

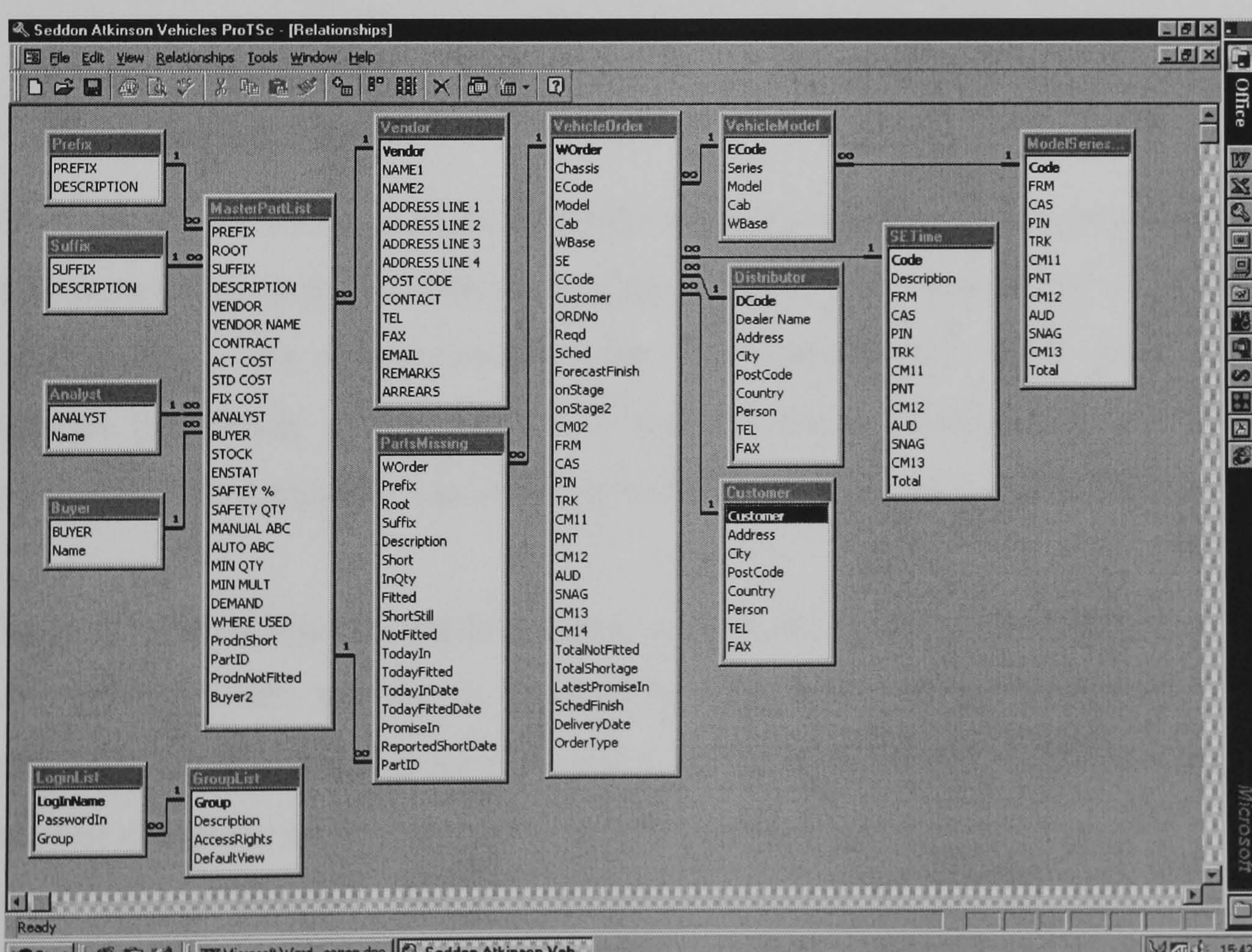


Figure 4.2 ProTSC Prototype Architecture

The development and implementation of ProTSC was a success and it is now installed as one of the company core systems. ProTSC interacts with the various end users through three main screens: a management screen for production tracking and performance monitoring; a material control screen for materials management; and a production control screen for production status tracking and materials shortages reporting.

To address the issue of access control, every member from the case company was pre-assigned to a specific group with different access right for each screen. This prevents unauthorised changes to the product data stored in ProTSC. Also, those who have the right to modify the product data will be more careful with updating ProTSC because they will be held responsible for every change they made. This inadvertently increases the accuracy of the product data held in ProTSC.

A user instruction manual was also provided to the case company upon the hand over of the project, see Appendix C. The main features of ProTSC are set out below.

- **Management Screen**

The management screen is made available to the management with a host of search options provided on the left-hand side of the screen to allow fast find of the required vehicle order. The screen provides them the summary of a truck order, which includes the details of both the order and the truck specifications, and where appropriate, parts missing from a vehicle and the progress tracking of a vehicle.

Figure 4.3 shows the management screen of a particular vehicle order showing its parts missing. Parts missing are distinguished into two types: parts not fitted to the truck and parts not available for production use. This allows the identification of the cause of disruption on the shop floor. It also shows the promised delivery date given by the material planner. This is important as decision can then be taken to avoid bottlenecks on the shop floor.

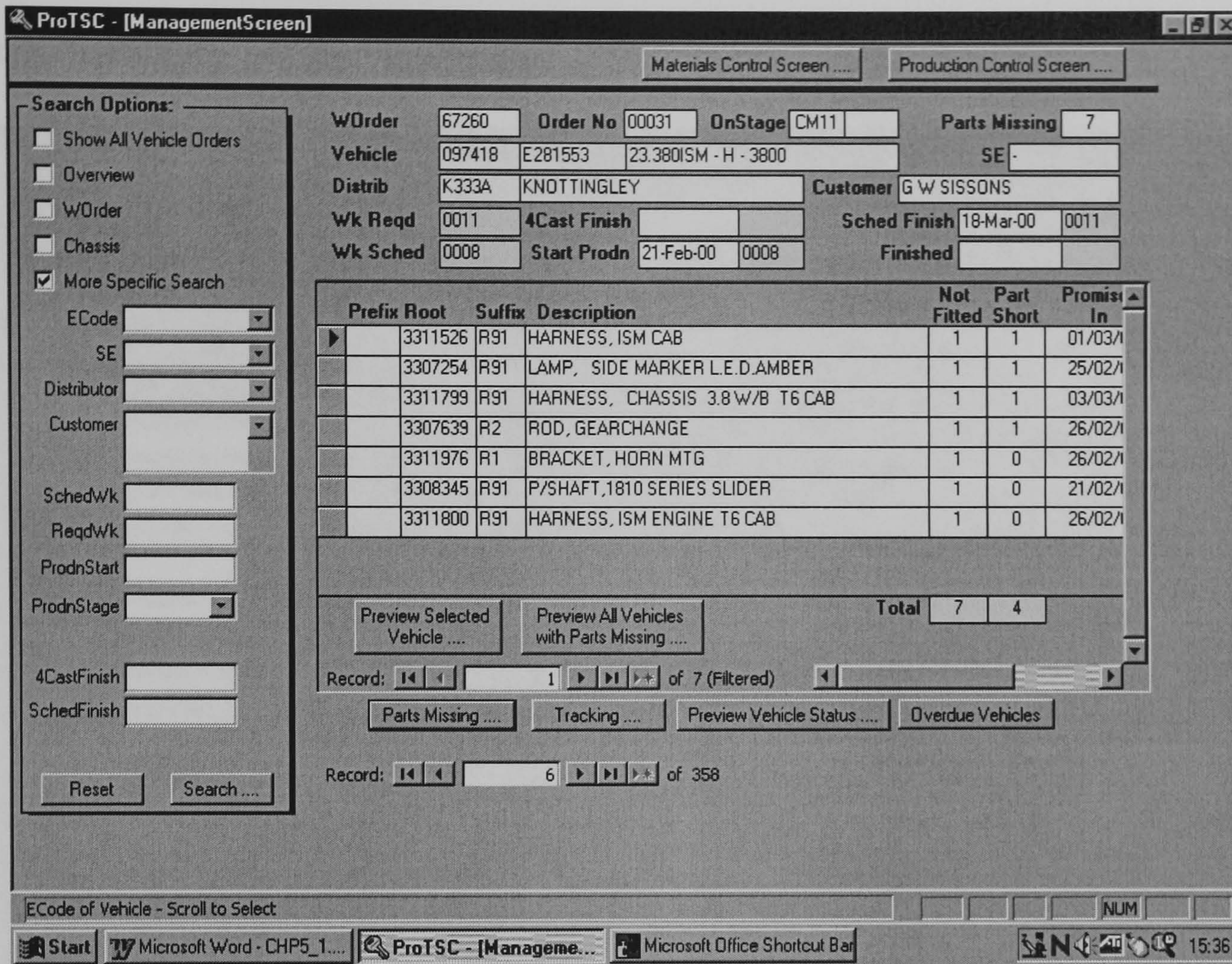


Figure 4.3 Management Control Screen - Parts Missing Display

Figure 4.4 shows the progress tracking of a vehicle order. Colour coded "traffic lights" is used to allow identification of the truck progress at a glance as well as providing the details of the performance of each production stage:

- Red identifies the specific stage has taken up far more time than the standard time set;
- Yellow signifies more time has also been consumed but still within an acceptable ratio; and
- Green means that the specific stage was executed within the standard time or has taken up lesser time than the standard time.

Also provided in the Management Control Screen is an overview of the weekly loading on the shop floor, which can be viewed on a yearly basis. Refer Appendix C, ProTSC User Manual Guide, for the screen snapshot. This quick on screen display enables management to identify any possible capacity overloading and to rectify the problems before they obstruct the shop floor progress.

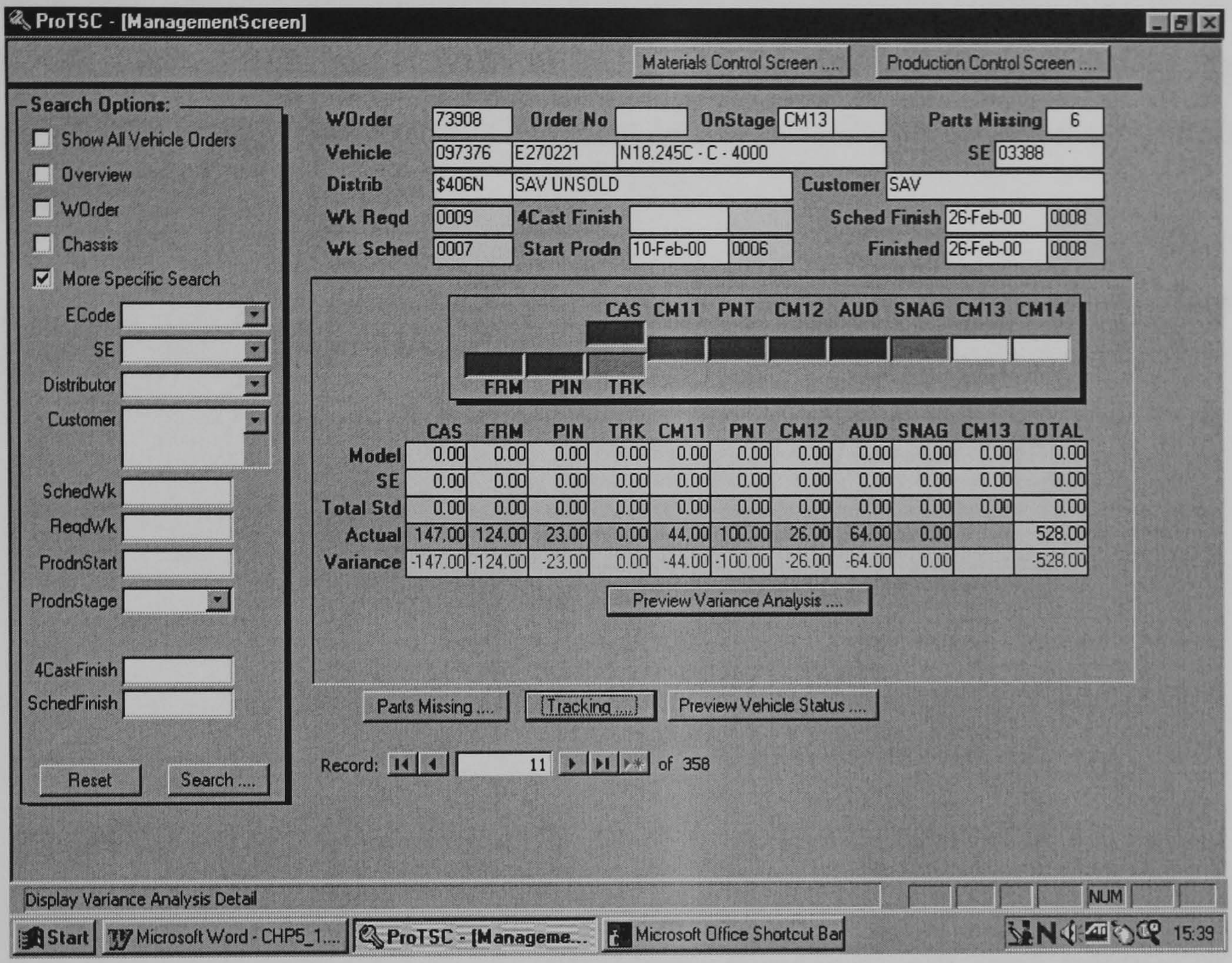


Figure 4.4 Management Control Screen - Progress Tracking Display

- **Materials Control Screen**

The material control screen aims to aid the materials planners in their daily material procurement and management activities. Refer to Appendix C, ProTSC User Manual Guide, for the complete screen displays available for the purpose of material control. Here, Figure 4.5 shows the screen display of a specific part with shortages reported. A search option is provided for easy finding of the required part. It shows the details of the shortage; the date the shortage was reported; the shortage quantity; and the promised delivery date given by the material planner for a specific truck order.

Also included in the Materials Control Screen is information on vendors such as the details, order schedule, arrears and over deliveries. This information is important to the company in managing its materials procurement activities more efficiently and to be able to identify and analyse the effectiveness of its vendors in terms of prompt delivery. It is worth noting here that information on vendors' delivery performance was added in after the hand over of the project and was developed by the IT department from the case company with the assistance from the author. The efforts by the case company have clearly demonstrated that the management within the company has started appreciating the values and benefits that could be obtained from effective PDM.

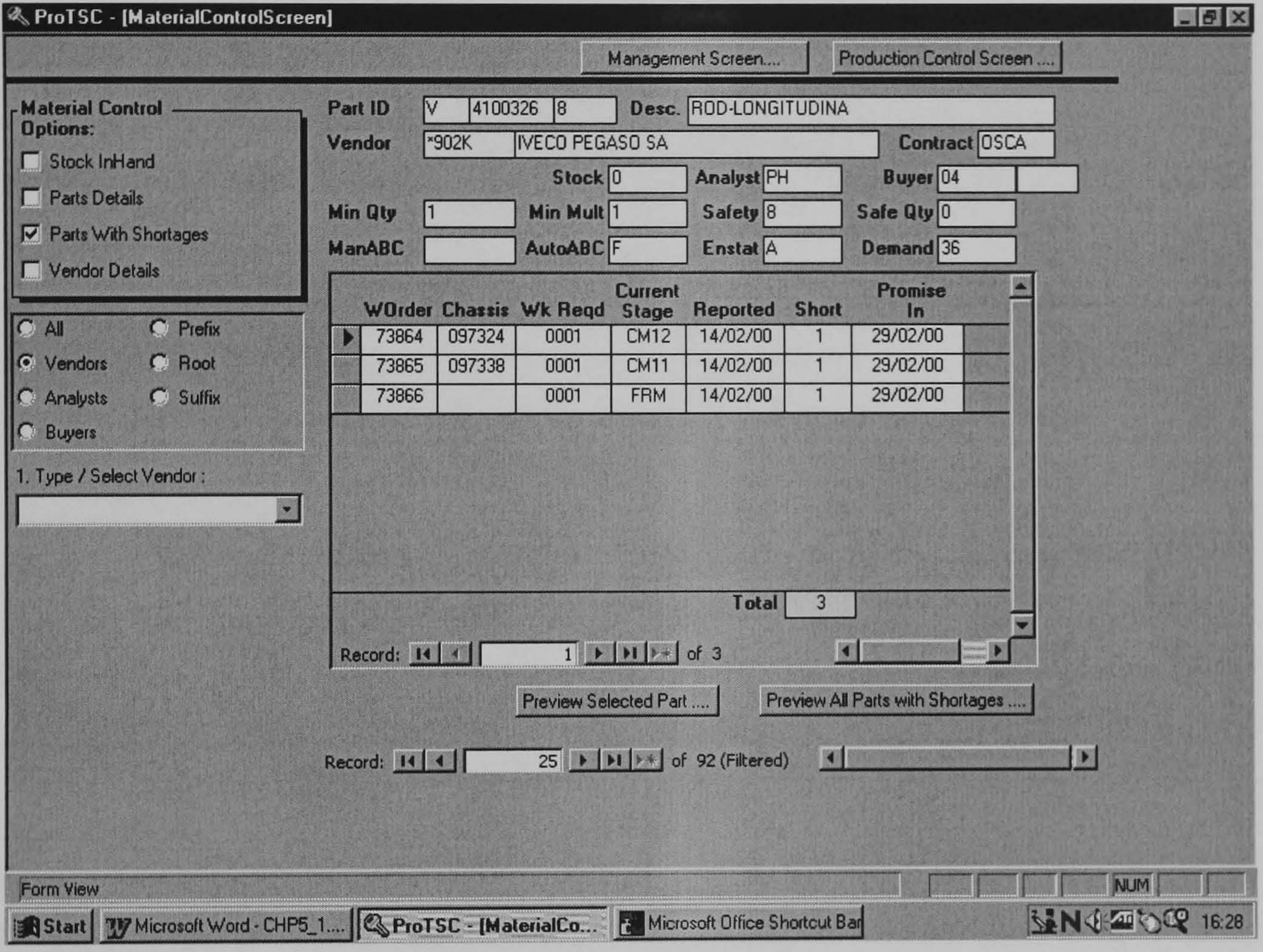


Figure 4.5 Material Control Screen - Part Shortage Display

- **Production Control Screen**

The production control screen aims to help the production supervisors to plan the shop floor operations by providing them the production status of all vehicle orders and their materials shortages, if any. Refer to Appendix C, ProTSC User Manual Guide, for the complete screen displays available for the purpose of production control.

The status and details of all truck orders available on the shop floor are grouped according to their current production stages as shown in Figure 4.6. This provides the production supervisor a quick identification of what are available on the shop floor. An automatic moving mechanism is built into ProTSC to move a truck on the shop floor according to the pre-defined assembly process. The actual production time spent for completing a specific assembly stage on the shop floor is then calculated automatically.

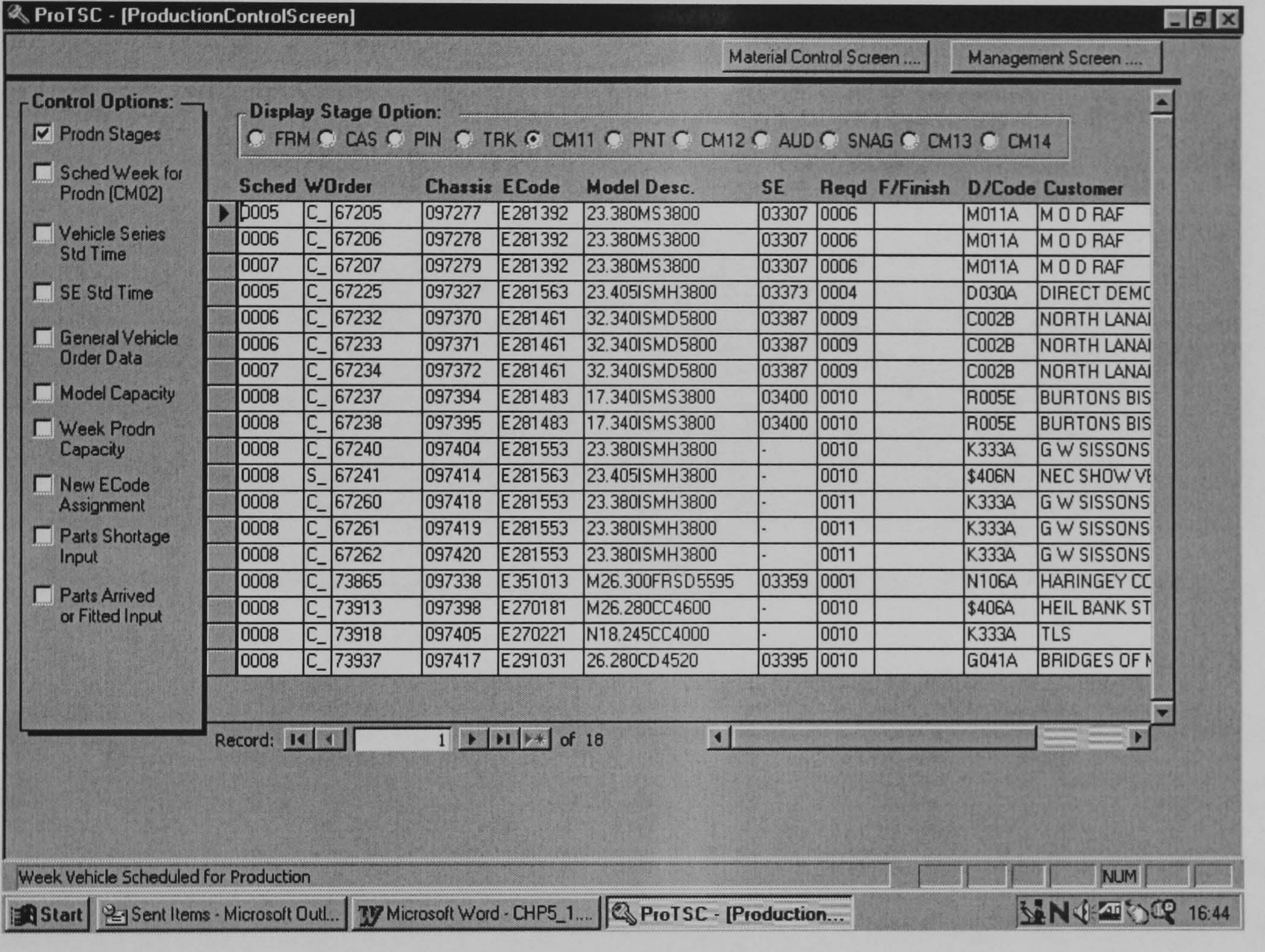
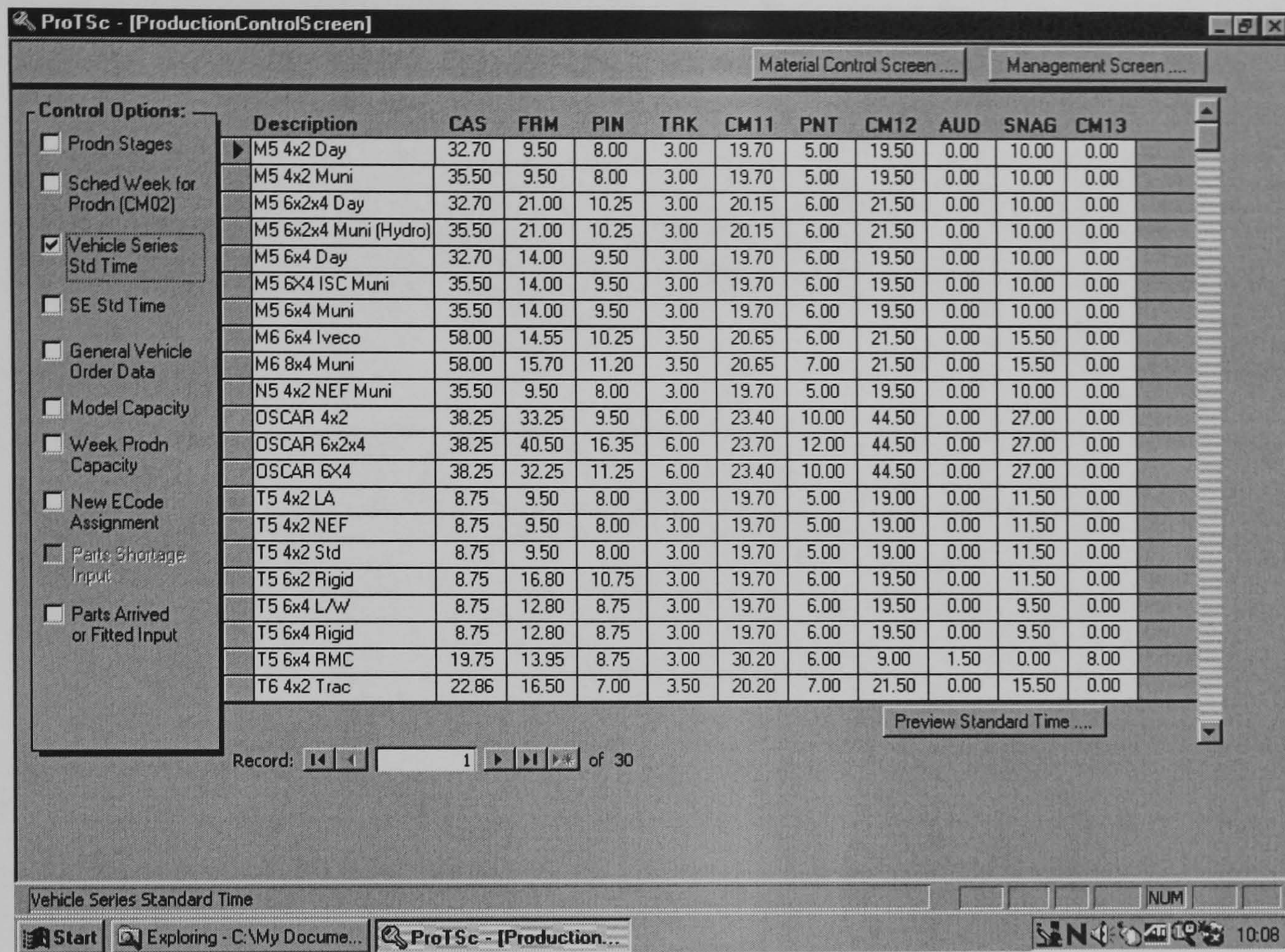


Figure 4.6 Production Control Screen - Production Status Display

It is also important to be able to record the standard production time set by the company for each range of truck and the special equipment (SE) needed respectively, for comparison against the actual production time. Here SE refers to specific alterations made from a standard truck based on customer's request that requires engineering input. Figure 4.7 shows the screen display for the standard production time for some of the ranges of truck produced by the company. This information is also displayed in the management screen under the tracking of truck progress, see Figure 4.4. The visibility of this information enables the company to adjust the standard production time and hence achieve a more accurate cost.



Description	CAS	FRM	PIN	TRK	CM11	PNT	CM12	AUD	SNAG	CM13
M5 4x2 Day	32.70	9.50	8.00	3.00	19.70	5.00	19.50	0.00	10.00	0.00
M5 4x2 Muni	35.50	9.50	8.00	3.00	19.70	5.00	19.50	0.00	10.00	0.00
M5 6x2x4 Day	32.70	21.00	10.25	3.00	20.15	6.00	21.50	0.00	10.00	0.00
M5 6x2x4 Muni (Hydro)	35.50	21.00	10.25	3.00	20.15	6.00	21.50	0.00	10.00	0.00
M5 6x4 Day	32.70	14.00	9.50	3.00	19.70	6.00	19.50	0.00	10.00	0.00
M5 6X4 ISC Muni	35.50	14.00	9.50	3.00	19.70	6.00	19.50	0.00	10.00	0.00
M5 6x4 Muni	35.50	14.00	9.50	3.00	19.70	6.00	19.50	0.00	10.00	0.00
M6 6x4 Iveco	58.00	14.55	10.25	3.50	20.65	6.00	21.50	0.00	15.50	0.00
M6 8x4 Muni	58.00	15.70	11.20	3.50	20.65	7.00	21.50	0.00	15.50	0.00
N5 4x2 NEF Muni	35.50	9.50	8.00	3.00	19.70	5.00	19.50	0.00	10.00	0.00
OSCAR 4x2	38.25	33.25	9.50	6.00	23.40	10.00	44.50	0.00	27.00	0.00
OSCAR 6x2x4	38.25	40.50	16.35	6.00	23.70	12.00	44.50	0.00	27.00	0.00
OSCAR 6X4	38.25	32.25	11.25	6.00	23.40	10.00	44.50	0.00	27.00	0.00
T5 4x2 LA	8.75	9.50	8.00	3.00	19.70	5.00	19.00	0.00	11.50	0.00
T5 4x2 NEF	8.75	9.50	8.00	3.00	19.70	5.00	19.00	0.00	11.50	0.00
T5 4x2 Std	8.75	9.50	8.00	3.00	19.70	5.00	19.00	0.00	11.50	0.00
T5 6x2 Rigid	8.75	16.80	10.75	3.00	19.70	6.00	19.50	0.00	11.50	0.00
T5 6x4 L/W	8.75	12.80	8.75	3.00	19.70	6.00	19.50	0.00	9.50	0.00
T5 6x4 Rigid	8.75	12.80	8.75	3.00	19.70	6.00	19.50	0.00	9.50	0.00
T5 6x4 RMC	19.75	13.95	8.75	3.00	30.20	6.00	9.00	1.50	0.00	8.00
T6 4x2 Trac	22.86	16.50	7.00	3.50	20.20	7.00	21.50	0.00	15.50	0.00

Figure 4.7 Production Control Screen - Truck Standard Time Display

The shop floor supervisors record all parts not available for production for each truck order. Figure 4.8 shows the screen for part shortages reporting. ProTSC automatically provides the dates when the shortages are reported, which are also displayed in the material control screen and thus enabling the materials planners to take necessary action to prevent further disruption on the shop floor.

When a reported missing part is delivered to the shop floor, the supervisor updates the part shortage information by checking in the quantity received. Similarly when a missing part is fitted to a truck, the supervisor also updates the part fitted information by recording the quantity fitted. Two screen designs were provided for this exercise, which clearly marked the missing parts as parts not fitted to truck and parts reported not available for production use: one is based on the truck work order number and the other is based on part number. Refer to Appendix C for the two screen displays.

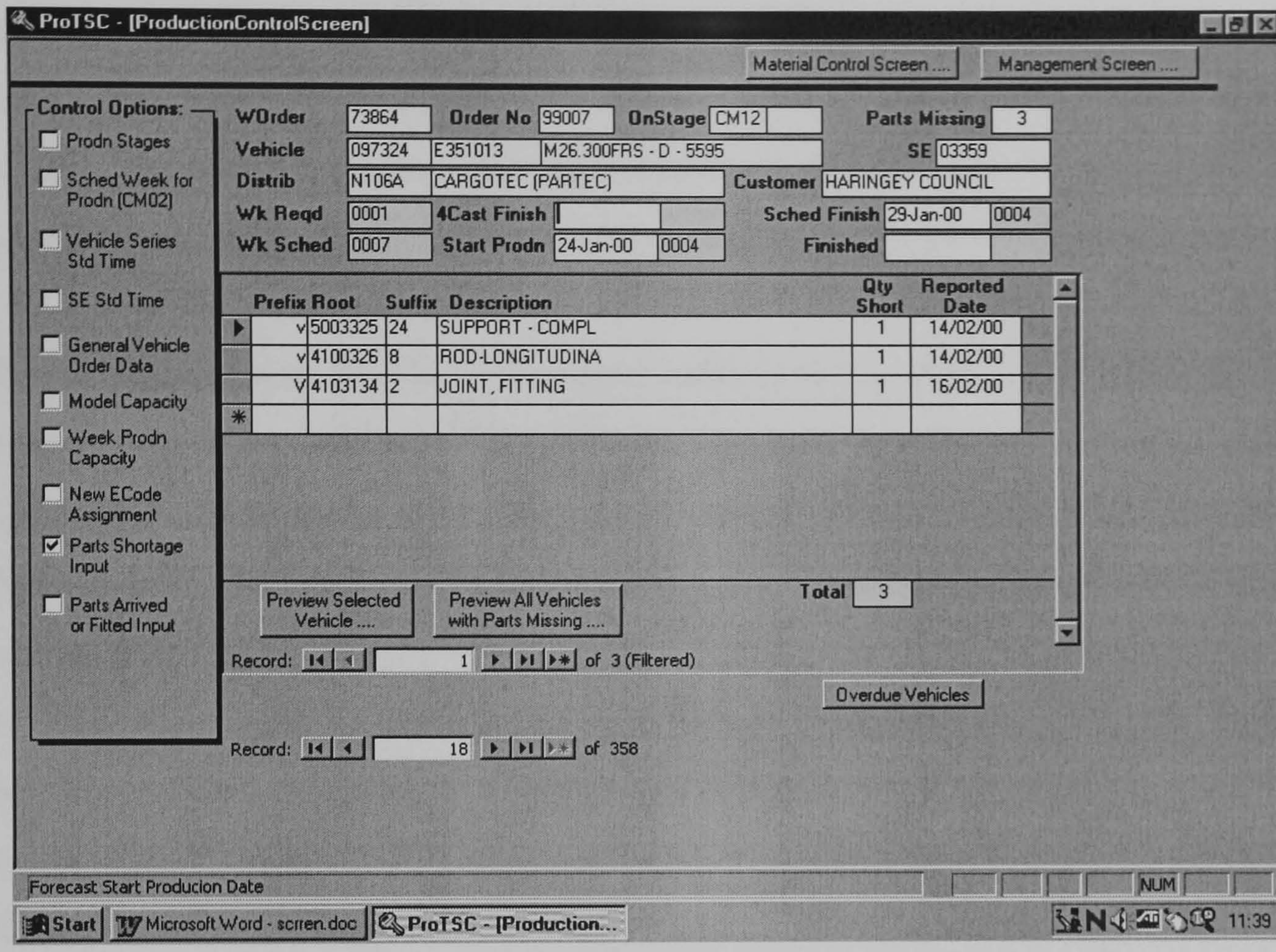


Figure 4.8 Production Control Screen - Reported Parts Shortage Display

4.3.5 Project Implications

During the implementation process, effective PDM was introduced as a means to achieve the three aspects to an improved production control, which were emphasised and monitored: materials management for controlling inventory level and flow, assembly line tracking for maintaining visibility of production status, and shop floor performance.

- **Materials Management**

The company has nearly 17,000 records of parts and components used for production. The company had an old shortage reporting system, however it was clerically intensive, inaccurate, and did not command the respect of those involved in addressing shortage issues. Without an effective reporting facility that showed what is in stock and what is missing from the production shop floor, it was difficult for material planners to respond to manufacturing needs accurately. ProTSC provided the required product data visibility. It displayed full details of the missing parts together with details of the vehicle requiring the part and their promised delivery dates. The company used ProTSC to enter all part shortages, which either would disrupt or were disrupting the manufacturing process due to unavailability. Consequently, this reduced administration cost and possible production bottlenecks.

Before implementing ProTSC, information relating to materials procurement was not readily available. Although the company has and uses an in-house built MRP system, no information on vendor arrears or over-deliveries was made available. Resources to determine the 'big picture' were not available and the company could only concentrate on dealing with the latest problem. ProTSC included the current weekly vendor schedule order requirement showing demanded requirements together with forecast requirements. An opportunity to directly email or fax these schedules to appropriate suppliers was being considered to handle material procurement more efficiently and effectively.

- **Assembly Line Tracking**

Prior to implementing ProTSC, vehicle production status could only be determined by checking the assembly line physically or by asking manufacturing staff. As a result, a significant amount of time was consumed on the telephone or in person finding out about information held or owned by another department. ProTSC allowed vehicle data to be sorted by production process. A mnemonic display of the production line process allowed a summarised view for each vehicle of its progress in the production process.

In addition, ProTSC also provided comprehensive data relating to each vehicle including vehicle specification, engineering and sales designated names, customer data, and delivery requirement details. A key benefit from implementing ProTSC was that all this information is made available throughout the organisation and authorised users can easily appraise themselves of the current vehicle position without the need for further communication. This has inadvertently increased productivity and realised improved truck build qualities.

- **Shop Floor Performance**

A system of standard vehicle production times was used by finance for pricing. However, this standard time was not checked against the actual time spent on the shop floor, as the latter was not retained for analysis. ProTSC enabled an automated data capture of actual production times for the various production stages and thus allowing comparison to standard times set by the company. A colour coded 'traffic light' system was incorporated to signify progress and to show at a glance whether the vehicle was being built according the pre-defined standard production time. This task is now conducted with the minimum of effort.

The linkage between the order taking function and manufacturing was poor leading to unrealistic customer promises and additional pressures on manufacturing. Furthermore, in some cases, the sales specifications were incomplete or inconsistent. This usually resulted on more working time spent on managing order changes and errors. The company used to have a vehicle order forecasting system, however it was no longer in use at the time of the case study due to unavailable resources. ProTSC provided the production planner with the ability to distinguish the type of order currently in production as well as those scheduled for production. This information enabled the production planner to effectively manage the workflow in the shop floor. Time previously consumed in producing data has now been redirected to analysis and problem solving.

4.3.6 Project Key Performance Measures

The key performance measures, as set out in the proposal of RESCOVS, along with a statement of achievement at the end of September 2000 before the significant market downturn and the launch of the Euromover, a new truck model introduced by the case company are listed below. The list is also presented in the final RESCOVS report submitted to the EPSRC IMI research council.

- *40% reduction in inventory to £4.4m* - 24% manufacturing inventory reduction from £7.9m to £6.0m and over last 48 weeks the inventory for major items has fallen by 35.6 % (£516,542).

- *30% reduction in lead-times for standard vehicles from 10 to 5 weeks* - Standard vehicles now produced in 6 weeks (40%).
- *30% reduction in lead-times for SE vehicles from 26 to 13 weeks* - Majority of special vehicles now produced in 16 weeks (39%).
- *20% reduction in work in process* - WIP reduced from £3.1m to £2.4m (23%).

In addition to the above, over the forty weeks to end of September 2000, an improvement in on-time delivery reduced late deliveries from 45% to 15%.

4.3.7 Summary

This case study demonstrated the importance of product data visibility and availability to aid decision-making during the production monitoring process. The use of a familiar user-friendly tool to facilitate this proved to be invaluable. The objective was to make the various processes more transparent as a first stage in problem identification and solving in order to achieve a more effective and efficient shop floor control. The functionality of PDM incorporated in ProTSC includes the product structure, workflow (for the production operations), and data security.

The case study showed how ProTSC empowered employees through improved information flow and continuous analysis of updated information. Also demonstrated was the importance of creating an effective interface between management from various departments, material control, and production control. The case study identified that it is important to be able to capture the correct vehicle specification at the order processing stage to avoid bottlenecks at the downstream of the product development process.

The case study also showed how the case company was introduced to the concept of PDM in providing the required product data visibility and availability without actually implementing a PDM system. The case study was deemed successful and the case company has begun to appreciate the importance of effective PDM in managing its product data within its daily shop floor operations. This was clearly shown by the case company in their effort to improve its suppliers' delivery performance.

4.4 Case Study #2: Application of PDM in the Engineering Stage

This section presents the second case study, the application of effective product data management during the engineering design and planning stage within an industrial pump manufacturer. This study discusses the development of a prototype pattern database for the second case company with products that are heavily customised and with a high degree of design content. This case study emphasised the importance of the availability of accurate and up to date product data to facilitate re-use of existing designs to aid engineering design and planning. The case study also aimed to encourage the case company to invest more resources to its existing PDM system by demonstrating the potential benefits of effective PDM through the developed prototype pattern database.

4.4.1 Company Background

Sulzer Pumps (UK) Ltd., located in Leeds, is a division of Sulzer Pumps. Sulzer Pumps is a subsidiary of Sulzer Corporation, a multi-billion dollar globally active Swiss technology corporation, and it primarily supplies engineered and pre-engineered centrifugal pumps for consumption by end users in various industries on a global basis. Applications include power generation, oil and gas, hydrocarbon processing, water and sewage. Here, engineered pumps refer to those that are heavily customised with a high design content, whereas pre-engineered pumps refer to those fairly standard ranges with little customisation required.

The main types of pumps produced are barrel pumps, ring section pumps, horizontal split casing pumps, vertical pumps and a complete range of single stage pumps. The company's emphasis is on engineered pump packages where it designs, manufactures, assembles, and tests its pumps against a particular specification. The company also provides after-sales services to meet its customers' changing needs through a network of service centres throughout the UK. Many of its pumps are compliant with the standard set out by the American Petroleum Institute, API 610, which covers the minimum requirements for centrifugal pumps, including pumps running in reverse as hydraulic power recovery turbines, for use in petroleum, heavy-duty chemical, and gas industry services.

There are approximately 260 people employed at this site with 15% of them in the Engineering department and 54% on the production shop floor. Established in the 1930s, the company has grown from a small engineering company to an international supplier of pumping equipment. Currently it dominates about 25% - 50% of the market share for pumps and pumping equipment within the UK.

With a purpose-built factory and offices opened in 1981 for the dedicated production of centrifugal pumps, some of the world's largest and most powerful pumps have been designed and manufactured at Leeds for customers on all continents. For example, in the 1980s, the company supplied the world's largest water injection pump, rated at about 18.5 MW, to British Petroleum (BP) Amoco in North Slope.
The company's annual sales revenue is more than £50 million and its managerial systems comply with the requirements of BS 5750 Part 1 - 1987 (ISO 9001 - 1987) which have been assessed and proved by Lloyds Register of Quality Assurance. The level of market uncertainty is medium and the company perceives itself in the top 30% among its competitors on a global scale. To compete successfully with its competitors, the company has identified speed of delivery, product functionality, and product cost as the most important enabling factors, followed by product quality, variety, and speed of response to customers.

The manufacturing approach adopted is engineer-to-order (ETO) with 80% of its pumps specifically made according to customer specifications. For example, from the total sales value per year, more than 50% is made of customised pumps, while standard pumps is less than 25%. Spare parts formed the remaining 25%. In general, the production system of the company, like many ETO manufacturers, is of medium variability, low volume, and low inventory.

The company uses commercially available computer-aided tools to aid its manufacturing process: Unigraphics CAM for supporting off-line tools programming for complex models used in milling machines; and Graphcam and GNC for the simpler tool paths required in the turning machines. The majority of its finished pump components require an average of 5 - 10 operations for conversion from raw materials. A complete pump package takes more than 10 weeks of manufacturing lead-time for completion. The level of complexity in the manufacturing process is low.

Re-use of existing designs is a common practice. There are about 30 - 50 variants produced from its main pumps of which each is made of more than 50 distinct components with high level of complexity. Over the last three years, the company has introduced more than 20 modified versions from its existing range of pumps and less than 2 completely new pumps. Design modularity approach is the adopted practice in the design process with an average of 5 - 10 weeks of design lead-time before approving a new design for production.

Computer-aided tools used to aid the design process are mainly CAD systems: AutoCAD CADPipe for the piping arrangement, Unigraphics SDRC for 3-D modelling, and Medusa for all 2D design works. While the company has a commercial PDM system, Unigraphics' IMAN, installed for the past three years, it has yet to explore the full functionality offered in that PDM system. At the time of the case study, the company was using IMAN as a document manager to manage all the 3-D models generated from SDRC. Better quality and control of information were the reported benefits gained since the implementation.

Although the literature has shown that concurrent engineering (CE) is a pre-requisite to achieve the 'right first time' approach in many new product introductions, the company has not adopted this practice to all its new pump introductions: only 5% - 10% involved the use of CE. This explained why, on average, more than five iterations between engineering and manufacturing, which concerned engineering changes, were made after a design had been approved and released for production although the level of complexity in the design process is low.

With an average of 5 - 10 different types of pump data generated for every new pump introduced, the company has identified the importance of an effective PDM method to allow access to and sharing of correct relevant pump data within the organisation. Aligned with this, the company had defined two projects as a means to introduce effective product data definition and management:

Project One - Development of a prototype pattern database for the tracking of the casting equipment and the linking of patterns to pump orders.

Project Two - Feasibility study of a common order set system within the three European pumps divisions: Sulzer Pumps (UK) Ltd., Sulzer Pompes, France, and Sulzer Pompen Germany.

This section discusses Project One that involved the use of product data management method during the engineering and planning process. Project Two is mentioned in Section 4.5 where it involved the use of product data management in the order entry aspect of the sales process.

4.4.2 Development of a Prototype Pattern Database

Prior to the implementation of the prototype pattern database, the majority of the casting equipment was maintained manually using pattern cards. Here, casting equipment refers to the patterns and core boxes used in making castings. The pattern making and control process was outsource to the company's primary pattern maker in Leeds. There were over 10,000 items of casting equipment located all over the factory, at its contracted pattern makers and in various foundries. The pattern cards were the only controlling mechanism for all the casting equipment and were stored at the primary pattern maker's place. The company had neither information on the logistics and development of its casting equipment nor what had been recorded on the cards.

During the initial investigation, several issues were identified and pointed out the need to control all relevant information of the casting equipment electronically. Firstly, the company had no control over its casting equipment since all the pattern cards were stored at the pattern maker's place. Secondly, the paper-based pattern card system did not provide sufficient information on the components of the casting equipment. Thirdly, the existing paper-based system had no back up and was at risk of damage by fire, flood, malice etc. Fourthly, discussions with the supply chain manager suggested a need for the company to have a record keeping system where pumps information and their associated components from the European manufacturing plants can be easily transferred to other controlling locations, say India or China. This was aligned with the company business plans of expanding its manufacturing plants to Asia in order to be more cost competitive.

Initially, it was intended to use the pattern database developed by its sister company, Sulzer Pompes, France. However, review of the French system showed that it was not suitable for the working approach within the case company. The French system only allowed the retrieval of information based on pattern details such as pattern number, pattern order number, pattern location, and casting drawing number. It was impossible to retrieve any information based on other means, for example pump details such as pump sales number, pump type, or pump size, which was important to the case company at the engineering planning stage. Furthermore, business opportunities with its American counterpart, Bingham Corporation, had also put forward an urgent need to re-structure the management of the casting equipment data and its relationship to finished pumps.

Three objectives were identified and defined during the take up of the project:

1. To maintain the pattern history, i.e. modifications, of the casting equipment
2. To track the location of the various elements of casting equipment
3. To be able to know what casting equipment is used in which castings for which pump orders and vice versa

The envisaged benefits obtainable from the project:

- Full awareness of casting equipment logistics by both the company and its pattern maker

- Ability to re-use existing casting equipment
- Faster and more accurate initial (pre sales) price quotation by the Sales staff
- Better after sales customer service

4.4.3 Project Approach

Similar to case study #1, case study #2 also utilised the rapid software prototyping approach. Although it was a possibility to configure IMAN to include the management of the casting equipment, time and resources allocated for this case study did not permit it. Firstly, the author has no knowledge of IMAN and there was no available expertise within the case company or from the university to assist the author. Secondly, given the time frame of three months to complete the project, it was not possible for the author to be capable to reconfigure the system settings of IMAN. Thirdly, the company has yet to extent the application of IMAN beyond engineering. This proved to be not suitable for the purpose of this case study because it was envisaged that all data manipulations for the casting equipment were to be performed at the pattern maker's site.

The project started off by gaining an understanding of the French pattern database system. A review report was produced which included the system architecture design and functionality. The report was distributed to members of the company who were involved in the project to provide an explanation of the inappropriateness of the French system and to emphasis a need to develop a new one. Visits to a pattern making shop and a foundry were also arranged by the case company to allow the author to understand the terminology used and process associated with the production of castings.

Discussions were held with potential users in the company and its primary pattern maker to derive the required specification for the prototype database. Both the French system and the pattern card were used as the basis for discussions. A proposed user interface, system architecture, and system functionality were demonstrated to the potential users upon the acceptance of the system specifications before the actual development took place. During the development stage, the company IT Department was also consulted to discuss the arrangement for extending access of the prototype to the company's primary pattern maker where all the data entry to the prototype database will be carried out. The IT people later decided that dial-in method would be used.

Similar as Case Study #1, the case company in-house built MRP system was used to provide all the new pump orders to the prototype to avoid any data duplication. The IT department has agreed to provide a weekly text download from the MRP system to update the pump orders recorded in the prototype. Since the French system was found to be inappropriate for the use within the case company, it was necessary to transfer all information stored in the French system to the prototype. Furthermore, it was envisaged that the French could use the prototype in the future instead of their existing one. An additional MS Access application was created to automatically transfer all information from the French system using SQL (Standard Query Language), a standard language to perform data manipulations within any relational database systems.

The agreed functionality of the prototype system was mainly to control three main items: pump order, pattern set-up, and casting equipment. Figure 4.9 shows the relationship between these three controlled items. The pump, an end product, is constructed from several pattern set-ups. A pattern set-up is a casting equipment arrangement used to produce a specific casting and consists of one or several casting elements.

MS Access 97 was selected as the development tool because it was available in the company and furthermore the author was sufficiently familiar, from the experience gained in the previous case study, with the application to confidently develop the prototype within the given time frame of the project. Another important factor is the relatively easy to use database management capabilities within MS Access 97 [Coles 1996]. Also, the French system was developed using MS Access 97, therefore if the use of the pattern database were to be extended to the French division, it would be accepted and could be easily maintained by them.

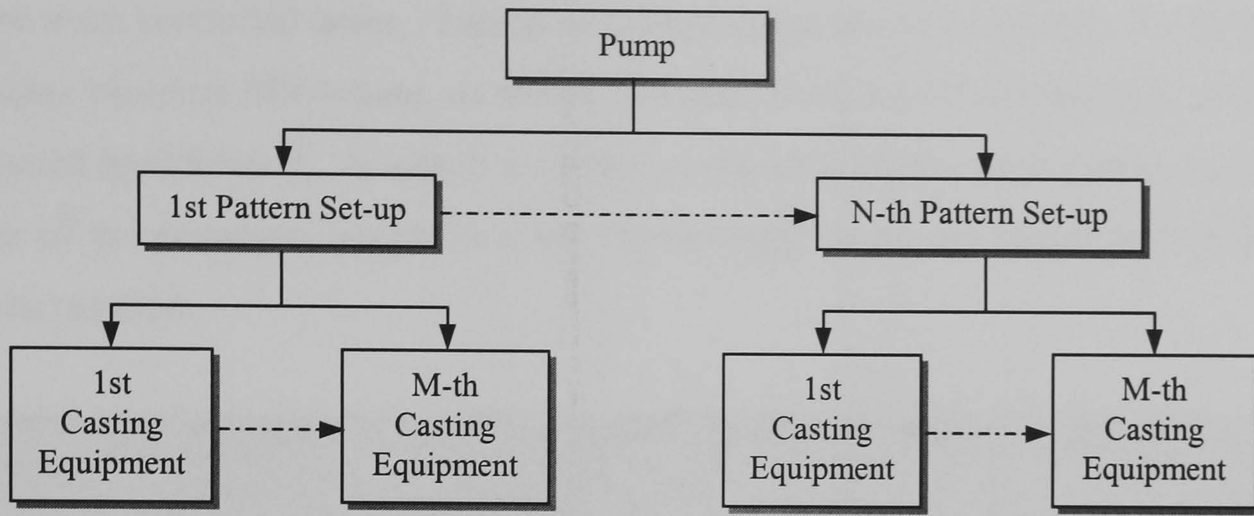


Figure 4.9 Pump, Pattern Set-up and Casting Equipment - Relationship

As the prototype was to be installed in the company local network, everyone in the company has access to the system. At the time of the case study, the case company decided that all data manipulations and entries would be carried out at the pattern maker's site. Therefore it was decided to restrict all access right of the prototype to everyone in the organisation to read only, whereby no modifications to the product data stored in the prototype would be possible.

A demonstration of the developed prototype was provided to the company to validate the system meeting the agreed specification. This was followed by a series of training to all potential users in the company and its main pattern maker. This was carried out by the author with the help from the initiator of the project, then the Operational Engineering Manager.

4.4.4 Project Results

The development of the prototype pattern database emphasised the importance of structured product data management. Existing product data, specifically the pump data, pattern set-up data and casting equipment data, were identified and collected from both the pattern cards and the French system. New product data and attributes, where appropriate, were introduced and irrelevant existing product data were removed, and valid relationships between all relevant product data were re-established and distinguished to provide an unambiguous relationship between the three main controlled items. Taking this relationship into consideration, the database schema based on MS Access, as shown in Figure 4.10, was then created to meet the required specification. A system architecture manual was produced during the hand-over of the prototype system to allow the company to do any future modifications when required.

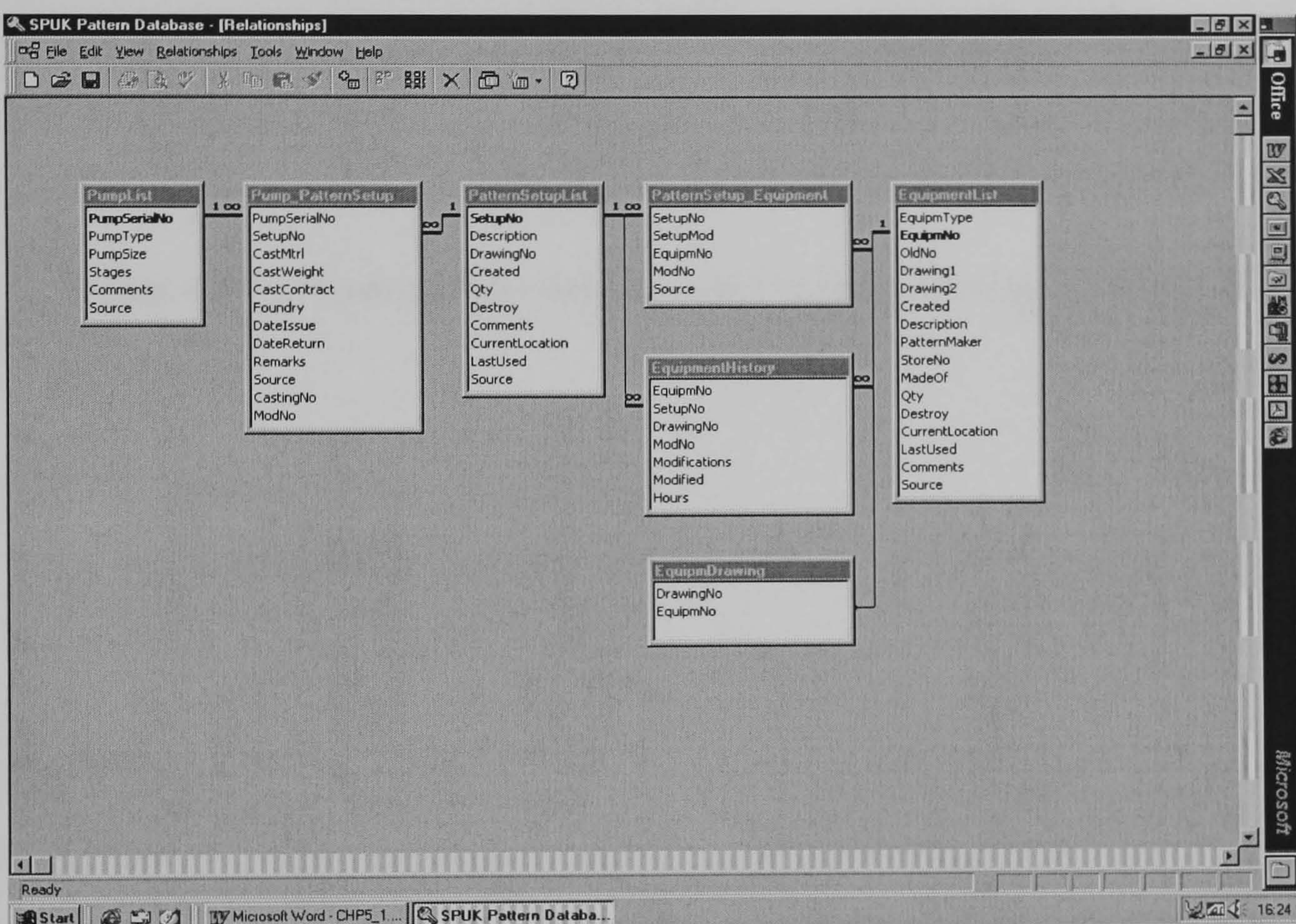


Figure 4.10 Pattern Database Prototype Schema

To allow the easy use of the prototype, two process flow diagrams were produced and included in the user instruction manual. Figure 4.11 shows the process flow diagram for assisting the Sales Engineers from the case company to locate the necessary components for a specific pump order. For maintaining the casting equipment, Figure 4.12 shows the process flow diagram for assisting the pattern maker in updating the logistics of the casting equipment.

Now the prototype is fully operational and is generating key on-line business information to sales, cost estimating, design, purchasing, and scheduling and production departments.

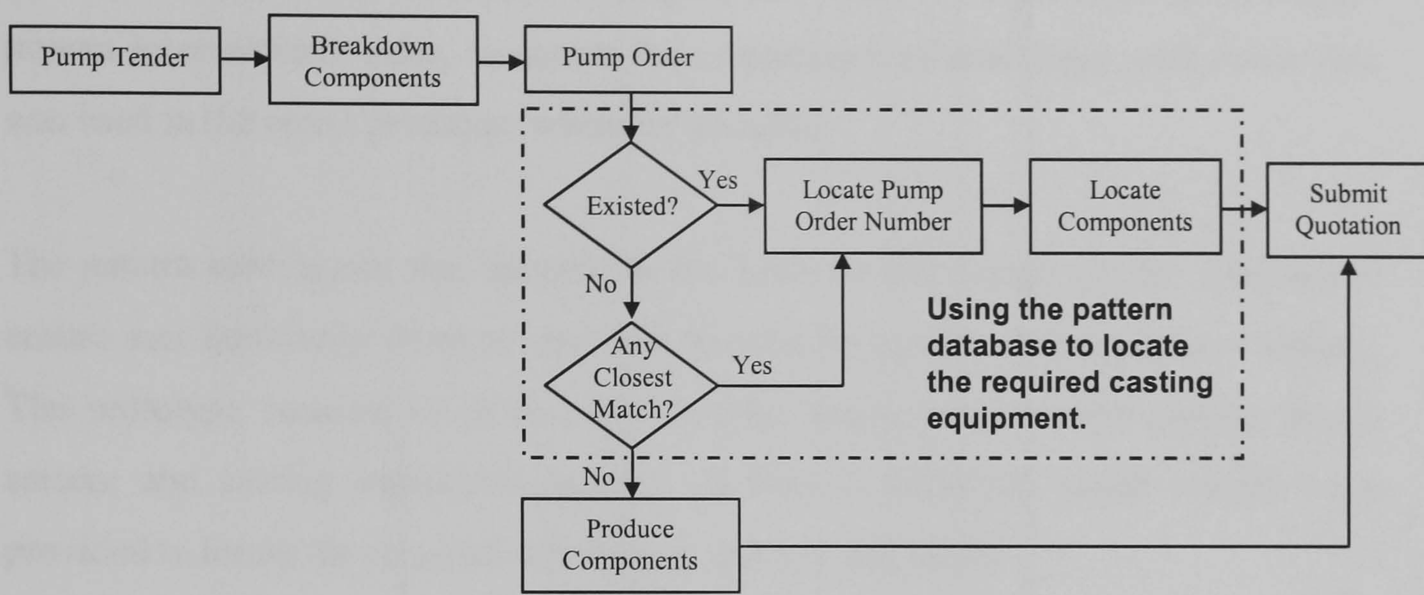


Figure 4.11 Process Flow Diagram for Locating Casting Equipment

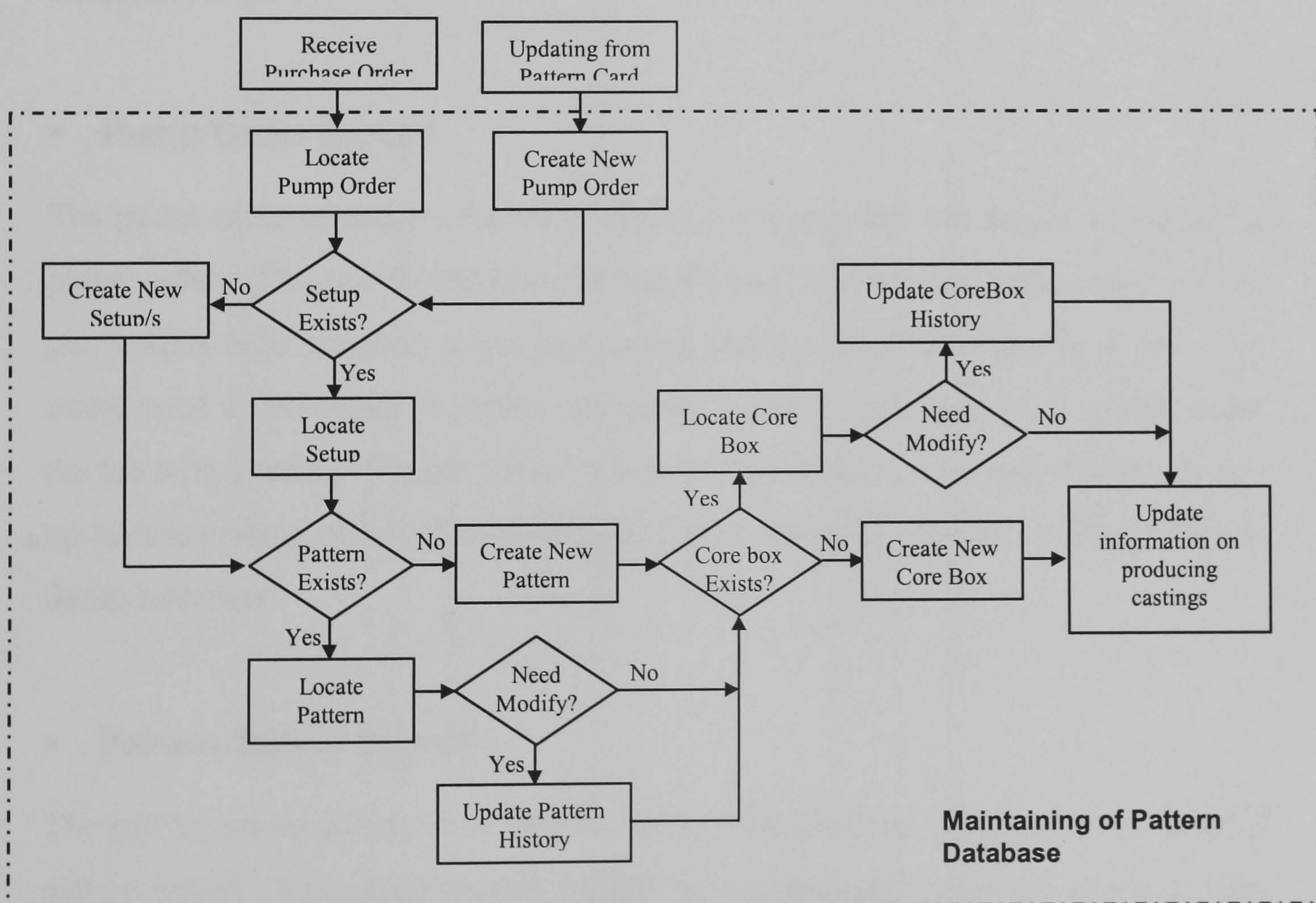


Figure 4.12 Process Flow Diagram for Maintaining Casting Equipment

The key feature built into the prototype was an automatic mechanism to assign the last location and the date of last used of each pattern set-up and its respective casting equipment whenever it is assigned to or removed from a specific pump order. This provided an automatic control for the logistics of these two controlled items without human intervention. Also, to ensure the consistency of data input, pull down lists was used in the entire prototype wherever possible.

The pattern card layout was adopted as the basis for the design of user interface to ensure user familiarity when maintaining the casting equipment logistics and history. The prototype consists of three main screens: pump order screen; pattern set-up screen; and casting equipment screen. A host of different search criteria were provided to locate the required information quickly and easily.

A user instruction manual, refer to Appendix D, was also provided to the case company upon the hand over of the project. The designs of the three main screens are set out below.

- **Pump Order Screen**

The pump order screen, as shown in Figure 4.13, provides the details of a specific pump order. The search criterion for fast finding the required pump order are the pump sales order number, pump type, pump size and number of pump stages. The assignment of the required pattern set-ups to a specific pump order is shown under the tab with heading "Pattern Setup" whereas the allocation of a specific pattern set-up for the making of a specific casting is shown under the tab with heading "Pattern Setup Location".

- **Pattern Set-up Screen**

The pattern set-up screen, as shown in Figure 4.14, provides the details of a specific pattern set-up. The search criteria for fast finding the required pattern set-up are the set-up number, set-up drawing number, set-up description, set-up current location, years set-up not in use, and set-up status, i.e. destroyed or not. The assignment of pump orders that use a specific pattern set-up is shown under the tab with heading "Pump Designation" whereas the allocation of a specific pump order and its required castings is shown under the tab with heading "Pattern Setup Location". The construction of a specific pattern set-up is shown under the tab "Setup Equipment" and its modification history is shown under the tab with heading "Setup History".

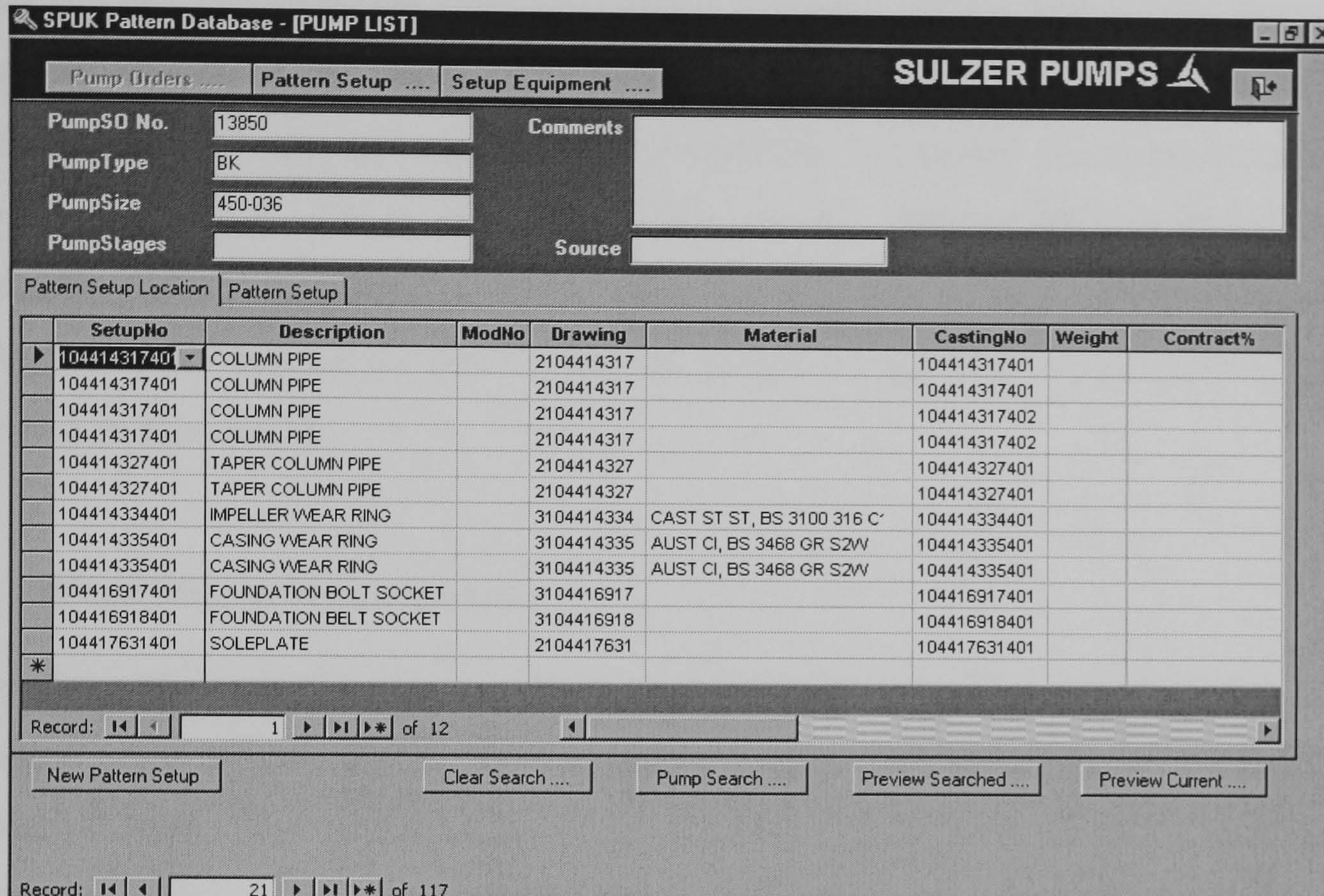


Figure 4.13 Pump Order Screen Display

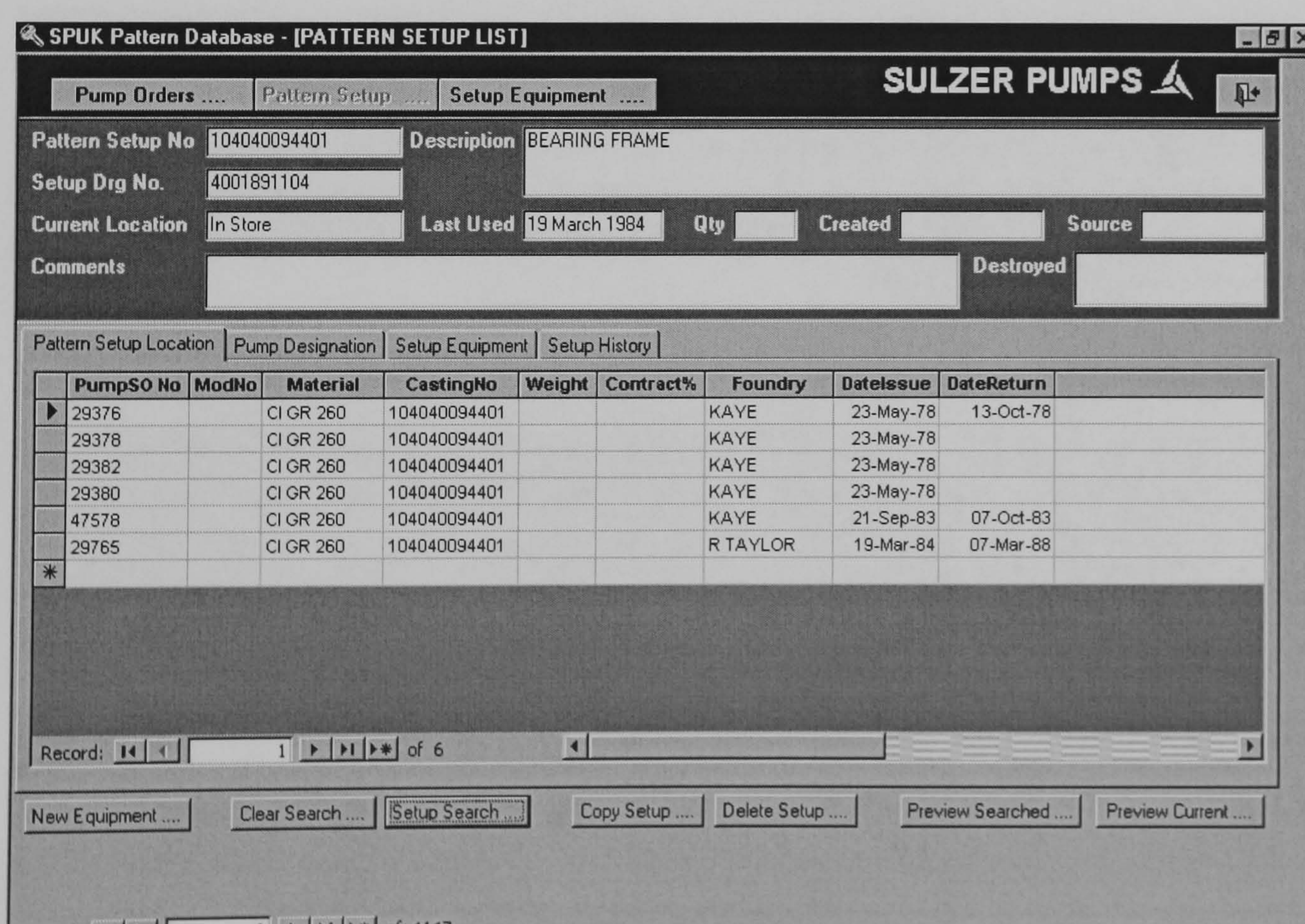


Figure 4.14 Pattern Set-up Screen Display

- **Casting Equipment Screen**

The casting equipment screen, as shown in Figure 4.15, provides the details of specific casting equipment. The assignment of pattern set-ups that use the specific casting equipment and its correspond version is shown under the tab with heading "Pattern Setup". The tab with heading "Where Use / Location" shows pump orders and the allocation of their respective pattern set-ups. The modification history of specific casting equipment is shown under the tab with heading "Setup History". Twelve search criteria for fast finding the required pattern set-up are provided, as shown in Figure 4.16.

- **What Where When Screen**

To allow for a glance of all the three controlled items from one screen display, the "what where when" screen was provided. Figure 4.17 shows the "What Where When" screen. The search criteria for this screen was made of all the three controlled items in order to allow fast finding of the required item was provided, as shown in Figure 4.18.

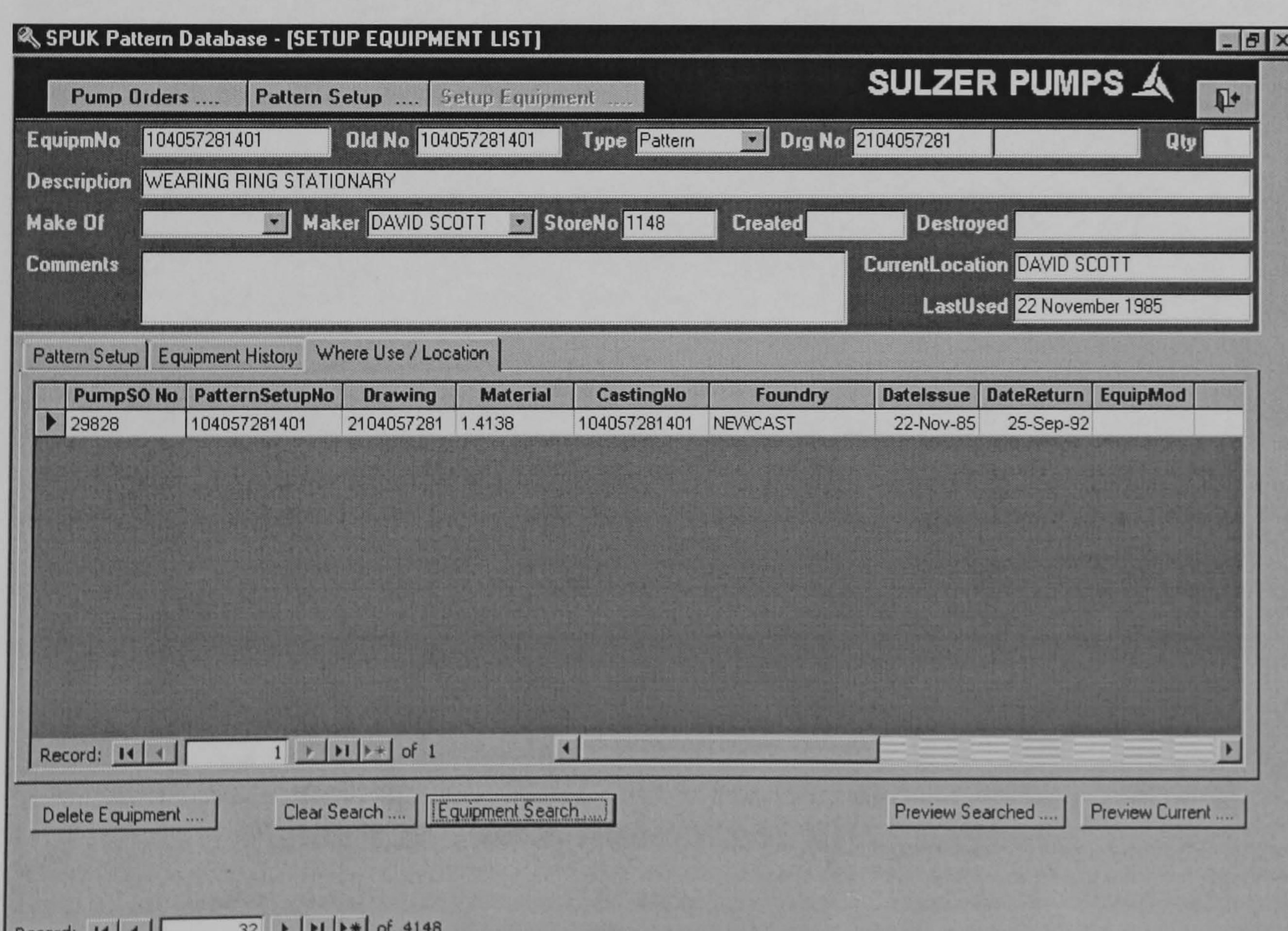


Figure 4.15 Casting Equipment Screen Display

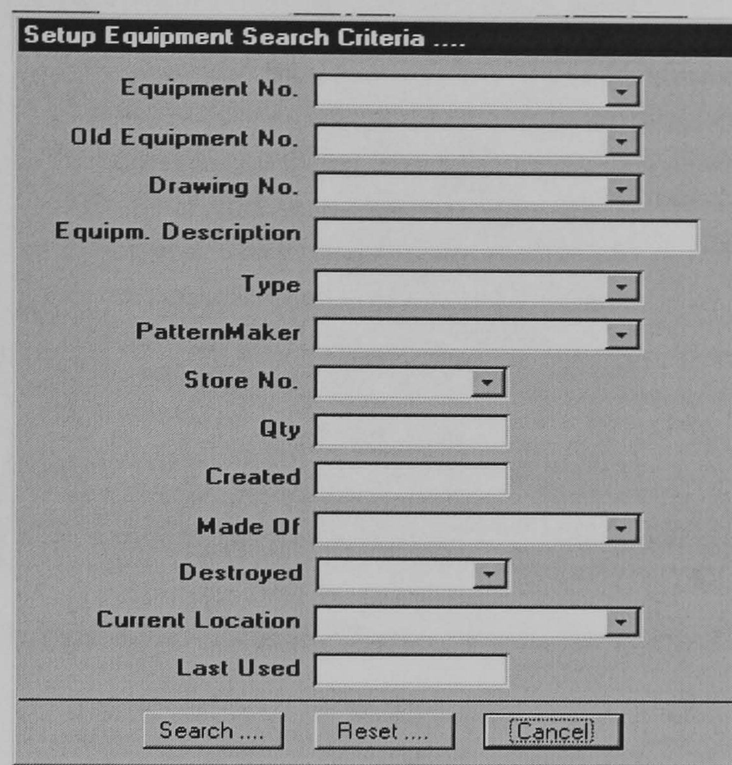


Figure 4.16 Casting Equipment Search Criteria

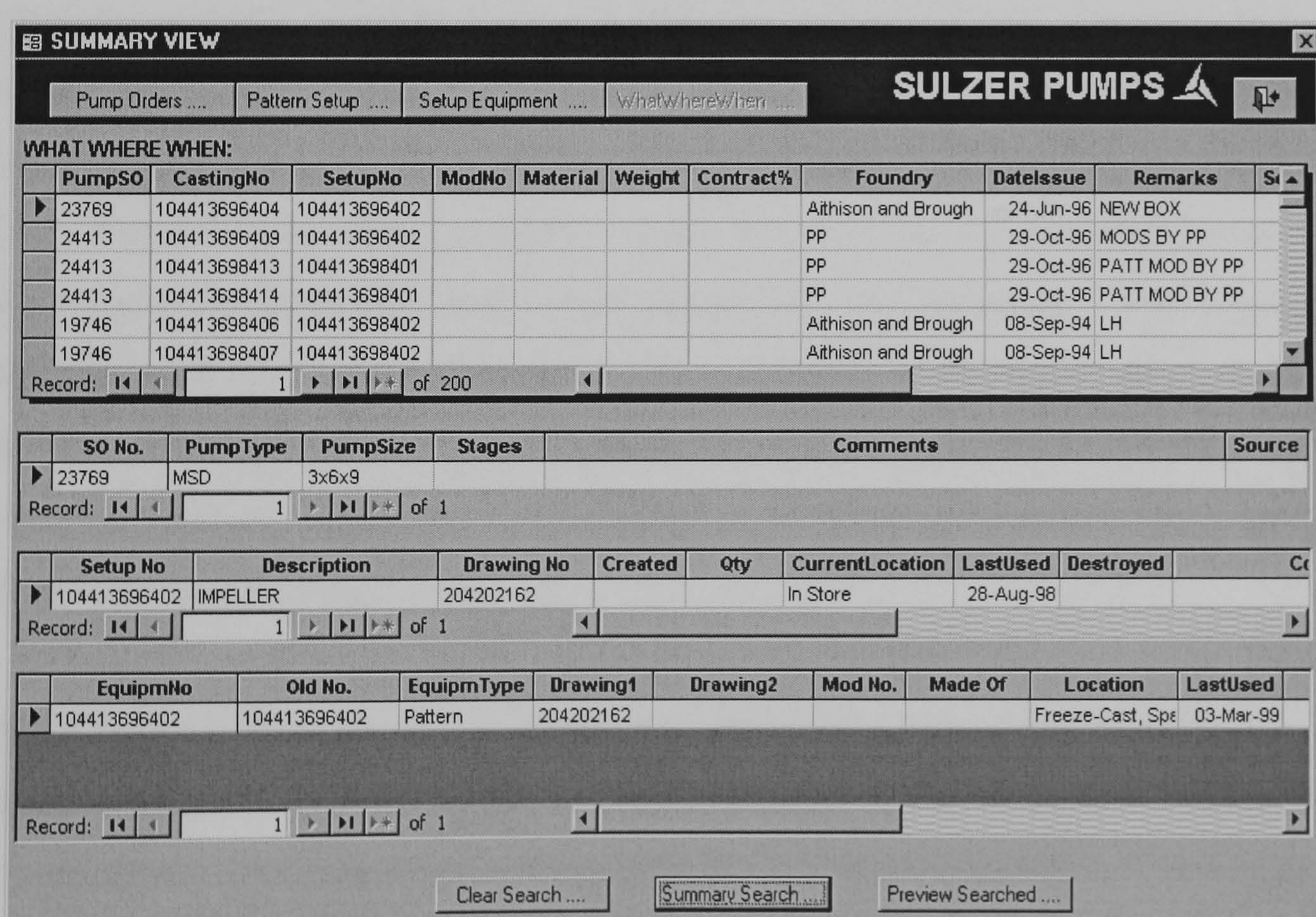


Figure 4.17 What Where When Screen Display

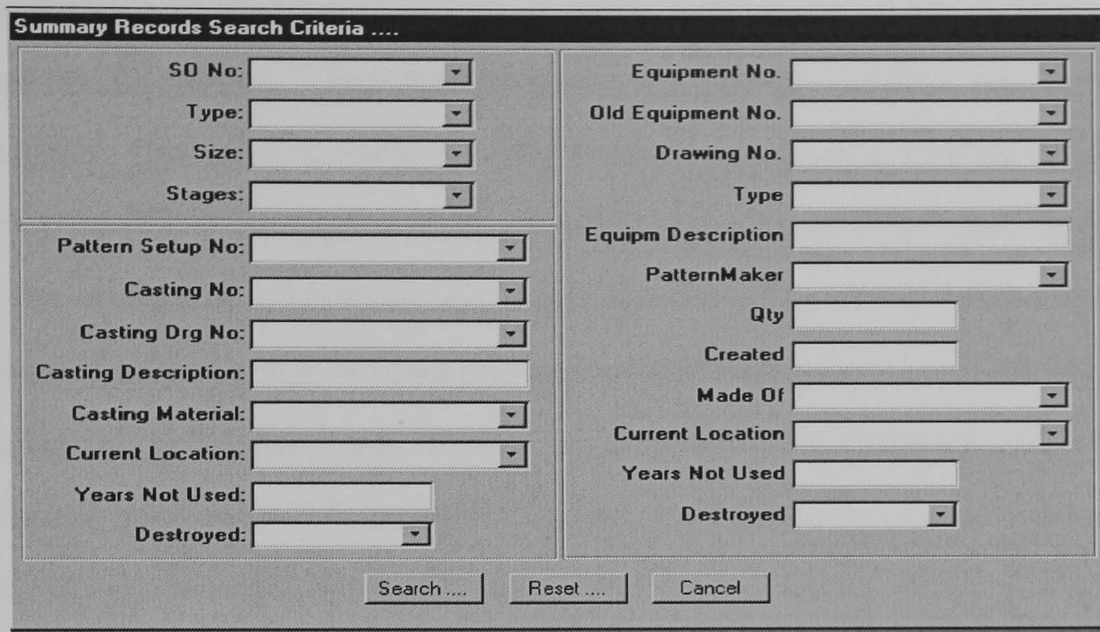


Figure 4.18 What Where When Search Criteria

4.4.5 Project Implications

At the time of the case study, the case company has only two or three people who were actually using SDRC and one or two using IMAN. The case study aimed to encourage the case company to invest more resources into IMAN, however this was not achieved at the end of the case study. The case company has no intention to further extend the application of PDM beyond its existing function in managing all the 3-D models generated from SDRC, which were not really used during production but merely for marketing and virtual production trial purposes. The company believed that 2-D was sufficient for the working environment they required. However, they implemented SDRC and IMAN several years ago due to instructions from the company head office in Switzerland to synchronise the use of computer aided tools for the pump production.

Three PDM related aspects to improving engineering design and planning were emphasised and monitored during the implementation: re-use of existing designs, the planning and scheduling of the casting equipment, and the logistics and maintenance of the casting equipment.

- **Re-use of Existing Designs**

The company has fulfilled more than 1,200 pump orders since 1975. Whilst the majority of these pumps were configured differently, many of the components used were similar in design. For the purpose of this case study, the definition of components is restricted to refer to only pattern set-ups and casting equipment to produce the required castings used in a pump construction. The company has good systems for searching information on a pump order basis and a pump size and type basis, but very little data was arranged on a component basis. As a result, duplicate components were designed and made. For example, the company had in the past designed and produced two patterns for the same impeller casting but used for constructing two different types of pump.

The prototype database allowed the company to search for the required information on a component basis independent of pump range, as well as on a pump basis. Once the required component or a close match component has been found, its drawings can be quickly traced and retrieved by the engineering designers. This has reduced the design lead-time, eliminated the scenario of re-inventing the wheel, prevented repetition of past design errors, and ultimately enabled the designers to produce better and cheaper designs.

- **Planning and Scheduling of Casting Equipment**

The company has casting equipment that worth over £10 millions located at various places, with some outside the UK. It is important for the company to be able to manage this valuable inventory to allow effective planning and scheduling on a European base rather than separately. For example, its sister company, Sulzer Pompes, in France, held about at least 2,900 items of casting equipment at its site at the beginning of the case study. However, due to downsizing of the operations at the French division, it is now no longer producing pumps and many of the casting equipment items are being moved to elsewhere. Unfortunately this information was stored only in the French pattern database.

The prototype pattern database has incorporated the casting equipment from the French pattern database. Therefore, whilst it allows the company to manage the UK casting equipment more effectively, it also gives the company the ability to bring the casting equipment inventories in France and in the UK together. This enables the company to effectively pool the resources of the two divisions. Using the prototype database, the company can now easily monitor casting equipment usage and rationalise their inventory as and when required. Casting equipment clashes can also be managed in a more effective way since the checking of clashes can be done up front by the scheduling department.

- **Casting Equipment Logistics and Maintenance**

In the past, the only control tools for the casting equipment were the pattern cards which were located at the company's primary pattern maker's place and the company had no information on the logistics and development of its casting equipment. Whenever required, the company had to fax or phone the pattern shop to enquire the necessary information. This was very time consuming and did not guarantee an immediate feedback from the source of information.

Using the developed prototype pattern database, the company can now easily monitor patterns by foundry location, determine casting equipment condition and set-up configuration, and thereby estimate costs for any changes that may be required. All these can be incorporated into the tender much quicker and more accurately compared to the traditional process, i.e. faxing or phoning the primary pattern maker. The prototype also enables the company to estimate when a pattern may require replacement and ensure the cost of this is incorporated into the costing for the next order.

4.4.6 Summary

This case study demonstrated the importance of effective PDM to enable product data visibility and availability to aid decision-making during the engineering design and planning stages. The objective was to encourage the re-use of existing designs to produce better and cheaper products. The case study has shown that whilst the product definition process is an exhausting and time consuming practice, the ability to re-use existing designs enhances and produces the required product definition accurately and on the first few instances. The developed prototype has enabled the company to identify the correct casting equipment to construct a particular pump order, and to be fully aware of the casting equipment logistics and conditions. Also demonstrated from the case study was the importance of on-line business information to improve business performance.

Although the case company has a commercial PDM system in operation for more than three years at the time of the case study, the potential benefits of effective PDM were not fully utilised perhaps due to the lack of strategic planning at the initial implementation stage. This case study, without involving the use of the available PDM system, has demonstrated some of the significant benefits that can be achieved within an effective PDM environment. The functionality of PDM demonstrated in the prototype includes the product structure, engineering change management, configuration management, and data security and consistency.

Although no performance measure was carried out to establish the improvements resulted from the implementation of the prototype, verbal feedback from several people in the company a few weeks after the project showed that the case study too was a success. The case company has now begun to appreciate and emphasise the need for effective PDM to improve business performance. This was evident where the case company later proposed a second case study looking at the effectiveness of PDM during the initial order entry stage. However, the case company had clearly stated throughout the case study that it has no intention to invest further in IMAN until the design process is 3D orientated.

4.5 Case Study #3: Application of PDM in the Sales Stage

This section presents the third case study, the application of effective PDM in the order entry aspect of the sales process with the same case company in case study #2. Unlike the other two case studies, where each involved the development of a prototype system, this case study reviewed the feasibility of using one common order set system between the case company and its two sister companies by studying and analysing the order set systems used within each company. An order set is a pump order definition that includes all relevant information to produce the pump package required by customers, i.e. the pump technical data and documentation, commercial data, scope of supply, quality, and necessary ancillary equipment. It is important that the order set system produces accurate pump order information to avoid unnecessary bottlenecks and problems later at the product development process. The emphasis is to enable the sharing of product data through reduced data duplication and incompatibility at the initial stage of the product development process.

4.5.1 Feasibility Study of a Common Order Set System

Over the years, three of the Sulzer Pumps European groups have been unable to share information due to the different information systems used by each division. The three divisions were the case company, Sulzer Pumps (UK) Ltd., and its two sister companies: Sulzer Pompes, in France, and Sulzer Weise GmbH, in Germany. As a result from this, manual re-entry works had to be performed to translate information received from other divisions into an appropriate form recognised by the system employed at the recipient division. The case company had identified a need to overcome this situation. This was in line with the "Europe 17" project that aimed to re-structure the organisation of these three divisions. The company had proposed that a common order set system would be a solution to reduce the duplication and incompatibility of pump data between the three divisions.

The advantages of a common order set can be seen from two perspectives: internal and external. Internally, within each division, a common order set enables all involved members, from the initial tendering stage to the final delivery of the pump package, to share and access the latest updated and accurate pump data. Externally, between the three divisions, a common order set allows a common method of communicating relevant pump data within the network. The perceived benefits were greater clarity of order specification, speedier order definition and distribution, and reduction of data duplication between the systems. Three objectives were identified for this project:

1. To assess the feasibility of using a common order set across the European pump operations.

2. To investigate the opportunities for sharing product specification data between the various tendering, order specification, and order engineering systems.
3. To recommend the take up of one of the three systems in use, if appropriate, as the basic model for the common order set or to establish the requirements for a common order set.

At the time of the case study, the company has an in-house built application that addressed pump data required during the tendering process, SPOS, which was in its refinement stage. Originally there was a paper-based system, which survived until about 1990. This system used pre-printed forms and was written on typewriters. It was then replaced by a computerised version that ran on AS/400. The latter system was absolutely reliable, but it was very slow to use, both in terms of writing data to it and finding data from it. Also, the system was written by an individual who has left the company, in an obsolete programming language, Synon II, which none of the present programmers knows well. Over the years there had been a few attempts to improve the AS/400 version, but it was roundly criticised by everyone in the company. There were also interests in having a PC portable and email-able order set which could be completed at every individual sales office that did not have access to the AS/400. Orders won in Singapore, for example, had to be re-entered in the UK by people in the company or by the tendering engineer from Singapore.

It was envisaged that SPOS could be transmitted electronically, once compressed, to respective tendering engineer/s for a particular pump order, and hence SPOS has been designed as a one-off application, i.e. a file that stores all the relevant details for one particular order. For this reason, MS Excel has been selected as the development tool for SPOS. A user form / screen has been designed to enable quick find of the required pump data to work with. This eliminates the unnecessary effort and time of having to go through a long list within the spreadsheet, which at the time of the case study contained about 2,700 lines. In order for the form and worksheet to work synchronously, the entire system is driven using MS Visual Basic on a run time basis.

SPOS does not rely on the AS/400 for the purposes of data entry, although it does have to refer to the latter for a few specific fields of a confirmed order: Customer, Pump Type and Size, Quantity, Job Title and Project Engineer. For a non-confirmed or non-released order, SPOS works as a stand-alone system. Specifically, SPOS aims to enable fast searching of relevant information, reduce reliance on paper distribution, and control a revision messaging service. For this reason, a few requirements stand out as critical to the success of SPOS: email facility, change control mechanisms and audit trail facility, company wide accessibility, and also user friendliness.

4.5.2 Project Approach

The project started off by gaining an understanding of the pump definition process in the case company through identifying the processes and documents used during the tendering process, as shown in Figure 4.19.

The author discovered that some of the documents used during the tendering process varied depending on the areas of application for the pump. Further investigation showed that the difference was caused by the working practice within the tendering department: as every tendering engineer is assigned to a specific type of pump produced by the company, each of them has his own set of documents that were produced by himself. Discussions with two Tendering Engineers at SPUK dealing with two different types of pump enquiry have verified that although each uses his own set of tendering documents, the contents of these document are very similar.

During the case study, the author learnt that the case company had specific criteria for selecting the pump type, size and material. Some of these criteria influence the decision making during the selection of the other criteria. For example, the criteria for selecting the pump type are based on the duty requirements of its client. Here duty requirements refer to the capacity of the pump, the corresponding head to be generated, the type of application used, the operating temperatures, the locations, or the type of liquid to be pumped. While the criteria for selecting pump materials are based on the compatibility with the liquid to be pumped, they are also influenced by the application where the pump is to be used because the type of application also determines the type of liquid to be pumped.

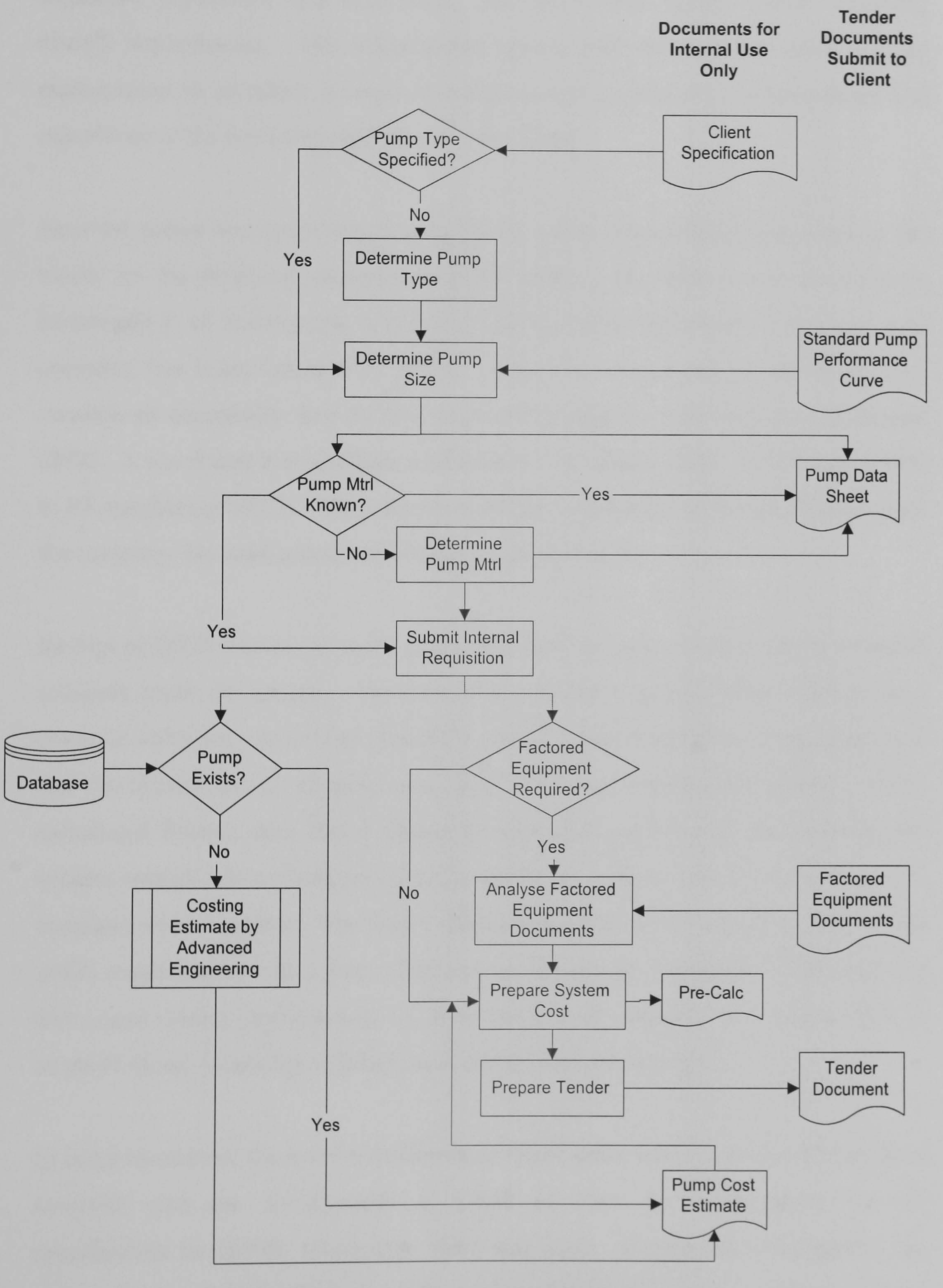


Figure 4.19 Pump Definition Process

At the time of the case study, this exercise was carried out manually. The decision made, most of the time, was very subjective and mainly influenced by the tendering engineer's experience and knowledge, and economical factors whilst satisfying client's requirements. The investigation agreed with the decision taken by the management to introduce a common order set system whereby the knowledge and experience of the tendering engineers can be stored.

Next the author was given access to SPOS to review its suitability to be used as the model for the proposed common order set system. But first, it was necessary to investigate if all information required during the tendering process within the case company has been included in SPOS. This was carried out by comparing the contents of documents used by two engineers during the tendering process against SPOS. It was found that SPOS accommodates their requirements. SPOS is available to all members of SPUK. Write access to SPOS is restricted to certain groups within the company, but read access is available to all personnel.

Review of SPOS was based on the requirements of the case company for the intended common order set system. The two most important criteria when considering a common order set system were that there should be no duplication of data entry and that the system should support some form of change and revision control. Other considered criteria were that it should be easy and quick to use, user friendly, be useable outside sales offices, be largely in data sheet format (report / printout), and be company wide viewable. The review found that whilst SPOS satisfied many of the initial requirements with a few refinement on the system functions, it was suffering from poor system performance, i.e. how the system responds to a user's input in terms of speed, reliability, robustness, accuracy, and consistency.

In order to address the system performance issue, there was a need for all members involved with the development of SPOS to come to an agreement on the specification for SPOS, which then there was none. During the investigation, the author found out that all previous discussions between the case company and the hired software developer for SPOS were performed verbally with no written evidence of what the delivery supposed to be. Upon the agreement with all members involved and the software developer, the author produced the "as then" and "as wish" design specification for SPOS, which was later used as the foundation for discussion for SPOS development.

4.5.3 Project Results

A total of five reports have been produced for this project. The first three reports document the pump data recorded and used within each division. The forth report provides the results from analysing the earlier three reports. The final report concludes on the feasibility of using a common order set across the three European pump companies:

- Report 1 Sulzer Pumps (UK) Ltd
- Report 2 Sulzer Pompen Germany
- Report 3 Sulzer Pompes France
- Report 4 Results of Analysis
- Report 5 Feasibility Review

▪ Report 1 - Sulzer Pumps (UK) Order Set, SPOS

Specifically SPOS has thirteen main sections. Report 1 was made up of twelve parts, which covered in details all the product data considered in each respective section, except for the last section because there were only lines for notes or comments with no specific product data considered.

There were approximately 1,336 pump data considered in SPOS. The analysis showed that the German division included 28% of all these pump data, where it was only 6% with the French. Excluding sections which both the German and French did not include, out of the 877 pump data, the German covered 42% and the French 9%. Obviously, the order set system used by the French division was the least comprehensive.

- **Report 2 - Sulzer Pompes (France) Order Set**

At the time of the case study, the order set used at Sulzer Pompes France, SPF, was made of three MS Word files, where each file looked a specific pump information. Report 2 is made of three parts; each covered a respective section of the pump information. There were approximately 290 pump data considered by SPF. The analysis showed that SPOS included 47% of all these pump data and the German division looked at 54% of them. Discussions with a French tendering engineer showed that although SPF did consider certain sections of a pump order that were also available in the other two divisions, the pump data considered within each section were not always the same. It also found that the order set was designed such that any new or more specific information can be added up wherever and whenever required. This created a situation where not the same pump data will be considered all the times.

Report 2 concluded that the order set used by the French division was non-explicit and not standardised. A decision was taken to exclude the French order set system from the analysis based on the following reasons:

- The contents were not always consistent or standardised. For example, additional fields were added in and obsolete fields were deleted as part of their documentation wherever appropriate and whenever required.
- As the contents were not standardised, there was no standard layout design available.
- There were some repeated fields and since data was entered manually in each section, inconsistency of data due to duplication of data entry would impose a major problem.
- There was no evidence to suggest that there was any form of change and revision control.

- **Report 3 - Sulzer Weise GmbH (Germany) Order Set, OES**

At the time of the case study, Sulzer Weise GmbH (Germany) has its order entry set documentation, OES, in the form of seven MS Excel files. Each file was designed to document a specific part of the pump order using a form format that does not allow changes to the form design to ensure that the outputs from OES were always the same. Report 3 only considered five out of the seven sections that formed OES because the other two were just for notes or comments.

For the purpose of analysis, a decision was taken to exclude the French division based on the conclusion in Report 2. There were approximately 1,061 pump data considered in OES. The analysis showed that out of these pump data, SPOS considered 33%. Out of the five sections considered in Report 3, SPOS only looked at three of them. Therefore, excluding those sections not considered by the case company, out of the 877 pump data used in OES, SPOS included 42% of them.

- **Report 4 - Results of Analysis**

Report 1, 2, and 3 showed that there was a significant difference between the three order-set systems and suggested that it would be difficult to introduce a common order set between all three divisions. Report 4, however, concluded that it was possible to have a common order set between the three mentioned divisions, but with the condition that all three divisions pre-established an agreed set of pump data and the level of detail of each pump data required. Report 4 provided the results of the further detailed analysis, i.e. the comparison between SPOS and OES.

Report 4 also proposed fourteen generalised sections of a pump order, which can be introduced in the common order set system. Further analysis showed that when considering these fourteen generalised sections, SPOS is slightly more comprehensive in terms of identifying the necessary detailed information in defining a pump order as compared to OES. Without considering the aspect of system performance, Report 4 recommended the SPOS could be taken up as the basic model for developing the common order set system for the three mentioned divisions.

- **Report 5 - Feasibility Review**

The objective of Report 5 was to conclude on the feasibility study of using a common pump order set between the case company and its two sister companies. Specifically, Report 5 looked at the feasibility of a common order set system between the three mentioned divisions, the recommendation for the design of a common order set system, and finally proposed a generalised pump definition data that would satisfy the requirements of all three divisions.

In terms of the feasibility of using a common order set system between the three mentioned division, Report 5 repeated the conclusion made in Report 4 that it was possible to introduce one but all three divisions have to put efforts in establishing the necessary pump data first. As for the recommendation for the design issue, Report 5 pointed out that four aspects of system design must be considered which were system design, user and system interaction, system functionality, and system performance. Report 5 also proposed a list of considerations that should be looked into if a common order set system is desired. Report 5 concluded that although each division had it own order set system that seemed to work satisfactorily to each division requirements, it was difficult to recommend that any of the these systems be used as the basic model for the common order set. This was because none had satisfied all the four aspects mentioned without further modification work:

- Sulzer Pompes, France:

  The system used is not explicit as the pump data considered was not comprehensive and it was neither standardised nor consistent when compared to the systems used by the other two divisions.
- Sulzer Pumps (UK) Ltd.:

  Although pump data was comprehensive and standard, the degree of detailed data still needed consideration. Whilst the requirements for system design and user and system interaction were satisfactory, work was needed to be done in terms of system functionality and system performance.

- Sulzer Weise GmbH, Germany:

  Although pump data was comprehensive and standard, the degree of detailed data still needed consideration. Whilst the requirements for system performance and system design were satisfactory, work was needed to be done in terms of user and system interaction and system functionality.

Extending the fourteen generalised sections for pump definition mentioned in Report 4, Report 5 proposed a further detailed pump data that could be considered as the basis information of pump definition for the common order set system.

At the time of the case study, each division proposed its own order set to be adopted as the basic model for the common order set should the idea be taken seriously. The foreseen solution for this scenario would then be to transfer the order set file, or files, between divisions emphasising document control. Report 5, however, recommended whilst traditional file transference has its own advantages in terms of simplicity, it could also result in many unforeseen difficulties. For example, the amount of electronic documents travelling between divisions every time a change is introduced would require a strict electronic document control within each division to ensure all divisions are referring to the latest documents. The situation would be worsened especially when a pump order is transferred from OES, which is made of seven files!

Report 5 suggested that with the advent of today's web technology, it would be worthwhile to use the web technology when considering the development of the common order set system. By having a central database, where access is made available to all the three divisions, it is without doubt that information available is always up to date and accurate. The advantage of using the web technology would become even more evident if and when access to other networks within the Sulzer Pumps Groups is considered. Furthermore, the project noted that the implementation time would be short because of the familiarity of web technology by the end users at the case company.

4.5.4 Summary

The case company and its two European sister companies have had in the past avoided the need for a common order set system between them. The contributing factor was that each division is dealing with different types of pump and hence would require different set of pump data. For example, whilst the case company deals with engineered pump packages that involves high degree of customisation and with a high design content, the German division mainly produces pre-engineered pump packages that are those fairly standard ranges with little customisation required.

This case study looked at the importance of sharing product data in an organisation and between organisations to reduce data duplication and incompatibility at the order entry aspect of the sales / marketing, the initial stage of the product development process. The case study also looked at the importance of product data change and revision control in order to maintain product data integrity and consistency. Results from the case study showed that despite the differences in types of pump produced by each division, it is possible to introduce to a common order set system between the three mentioned divisions.

A set of general pump data was proposed, established from analysing the three different order set systems used by the three divisions, which could be introduced and could be used as the starting point for the development of the common order set. The proposed generalised pump data was derived from studying and analysing the product data requirements and taking into consideration the flexibility and possibility of changes in the requirements in the future by the three divisions involved.

4.6 Discussions

Throughout the three case studies, the author discovered that although there are various good practices which are obvious and well accepted and widely published in the literature, the two case companies were definitely not carrying out some of these good practices. For example, although it is commonly accepted that re-use of existing designs should be incorporated within NPD to eliminate the scenario of "re-inventing the wheel", Case Study #2 showed that the case company had in the past re-designed and reproduced similar products because of its inability to re-use existing designs. Also, while product data visibility is important in aiding decision making, Case Study #1 showed this was not made available and as a result, fire fighting and crisis management was a common scenario within the case company.

There are various possible explanations to this situation, such as a lack of strategic planning approach or simply a resistance to change from current working approach. The three case studies carried out have identified that a lack of effective PDM as a major factor and have demonstrated to both case companies how to manage their product data and make them available to the right person at the right time. Case Study #1 and Case Study #2 showed the importance of data visibility and effective data presentation as the first stage in identifying both problems and solutions. Case Study #3 showed the importance to share product data contained in a common product data system with built in change and revision control, which can prevent duplication of data entry and also maintain product data consistency, accuracy, and integrity.

The literature shows that today's modern product development is versatile and rapidly developing with highly customised products which requires concurrency approach throughout the organisation, mainly sales, engineering, and manufacturing, during the initial product development process. However, in reality, mass customisation has caused much alienation of the sales function from the rest of the product development process. For example, the linkage between the order taking function and manufacturing in the case company in Case Study #1 was poor and thus resulted in unrealistic customer promises. The best solution would be if each Sales person would have his or her own product expert as an assistant, but unfortunately this is too expensive.

The three case studies have shown that the key solution to overcome this is the ability to achieve a one-time order capture, which requires accurate first time product definition from the order bidding stage, and sharing of and maintaining this accurate product data throughout the product development process. This presented a strong case for the need for an effective late product configuration tool. The need for this has also been shown in the PDM systems usage survey carried out by the author: 70% from the UK respondents and 77% from the non-UK respondents quoted managing product configuration as one of the three top priorities in implementing PDM systems. The formulation of this late product configuration tool would require inputs from all relevant members throughout the NPD process.

The author foresees the importance of using a late product configuration tool, a computerised product expert, as the alternative to an actual product expert. A late product configuration tool, using the concept of effective PDM and configuration management, can be developed to assist the organisation of customers, design, and manufacturing information such that marketing, design engineering, and manufacturing are all involved in the product definition phase. It will incorporate the product expert's knowledge and can be made accessible throughout the entire product development process.

Specifically, the development of a late product configuration tool can be based on two perspectives: the product data and their inter-relationships. The first looks at the use of a generic product structure including its process definition and details of its documentation, which covers all of the product ranges requirements and match specifically the component already designed and those require design works. The second governs the inter-relationships within the generic product structure using information gathered from customers at the initial stage of the product development process, and history from both design constraints and the production problem encountered on shop floor.

The literature has shown how dispersed non-interconnected systems used throughout the product development process, coupled by the traditional "over the wall" approach, have had caused tremendous loss to manufacturers in terms of re-work, scrap, and materials and labour wastage. This is also shown in three case studies carried out. Findings from the three case studies showed that the two case companies were more interested on bespoke point solutions to address their specific problems rather than investing into commercially available best of breed solutions that offer various functionality which attempt to solve their every need. The case studies demonstrated how these bespoke micro solutions can be used to bridge the gap between different functional areas within an organisation by enabling the sharing of information with the main data vault without duplicating existing product data and thus prevented unnecessary errors from manual data re-entry.

The case studies carried out also presented two important findings. Firstly, the case studies have successfully proved that micro computerised applications could be used to effectively raise PDM awareness and demonstrate the concepts of and needs for PDM. Secondly, the literature has shown that there is no fully integrated enterprise wide information system and the case studies confirmed this. The case studies opened a new window of possibility that the investment in computer technology by manufacturing companies is moving back to islands of automation. The need for effective PDM is more profound in this situation to provide an environment that allows the sharing of relevant product data between these islands of automation.

Finally, the two prototype systems developed in Case study #1 and Case Study #2 have shown that MS Access, a widely available and affordable database application can be used to develop a moderately sophisticated product data management system. This would benefit many SMEs as most of them already have MS Access. This is important because the focus of the literature on PDM is upon large, relatively expensive PDM packages that are beyond the means of the majority of SMEs.

4.7 Conclusions

This chapter has presented the results of three industrial action case studies, emphasising the importance of effective product data management application within three different stages of the product development process: sales, engineering, and manufacturing. Table 4.1 provides the summary of the three case studies.

All three case studies met the objectives set during the specification phase of the projects in an effective and structured manner. Both companies considered the development and implementation of the respective prototype systems as particularly successful. While the project implications from each case study are different, all three case studies clearly showed that employee empowerment and better way of working within the organisation could be achieved through improved accurate and up-to-date product data management and information flow.

The three case studies carried out have also validated the three objectives mentioned in Chapter Two:

- **The effectiveness of PDM in improving the configuration activities during the product definition process:**
  The results from the three case studies have shown how effective PDM enhances the product definition process. Case Study #1 and Case Study #3 showed how the ability to share product data at the initial order entry stage prevented unnecessary bottlenecks at the downstream of the product development process. Case Study #2 demonstrated that effective PDM enables the re-use of existing designs, which reduces the repetition of past design errors and eliminates the "re-inventing the wheel" scenario. Also, the results have also shown that all involved parties within the product development process are made aware of and able to contribute to the development status of the particular product, i.e. the changes, the approval, and the release of the end product to be manufactured on the shop floor.

- **The importance of PDM to create an interface between sales and engineering, engineering and manufacturing:**
  The three case studies have shown that an interface between the sales, engineering, and manufacturing functions allows a company to control the three stages of the product definitions process, i.e. from the "as requested" to the "as designed" and finally to the "as built" view of a product.

- **The effectiveness of the proposed method for PDM operations within SMEs:**
  The three case studies carried out have successfully proven that the method chosen to promote PDM awareness to companies is effective. Although the two case companies are both parts of larger groups, they exhibited most of the characteristics of a larger SME. Both case companies are now more conscious minded in terms of how the product data is generated, used, and maintained. Issues such as data visibility, availability, and accessibility are major concerns to these two companies, as expressed by them during a brief follow-up after the completion of each case study.

This chapter has also discussed the importance of a late product configuration tool, based on the concept of effective PDM and configuration management, to provide manufacturing enterprises the collaborative and innovative business environment needed through two structured approaches:

- Better understanding of the market and its needs through information gathered at the initial stage of the product development process,
- Organising this gathered information to provide a knowledge base that is accessible to all involved parties and thus enable them to contribute throughout the entire product development process.

The author has developed the specification model for a late product configuration and an envisaged configure-to-order environment for use of this tool, see Appendix E. A prototype was also developed based on this specification and was demonstrated to the first case company. Three refereed conference papers on the design of the late product configuration tool produced and presented. However, due to time constraint, it was not possible to implement the prototype at the case company. Hence, for this reason, the design and development of the late product configuration is appended to Appendix E.

	Case Study #1	Case Study #2	Case Study #3
Product Development Stage	Manufacturing / Production Process	Engineering Design and Planning	Sales Order Entry
Product View	"As built" view of an end product manufactured on the shop floor	"As designed" view of the end product to be manufactured on the shop floor	"As requested" view of a product required by the customer
Objective	To make the various processes on the shop floor more transparent as a first stage in problem identification and solution to ensure smooth workflow on the production shop floor.	To enable the re-use of existing designs during the engineering design stage to produce better and cheaper new products.	To review the importance of sharing product data in an organisation and between organisations to reduce and eliminate data duplication, inaccuracy, inconsistency, and incompatibility.
Project Output	A prototype production tracking and shortage control system for the case company.	A prototype pattern database system for the case company.	Reports on the study of feasibility of adopting a common product order definition system within the case company and its two sister companies.
Implications	Reduces manufacturing lead-time and assists in meeting customer delivery requirements	Aids in the engineering planning and scheduling processes, and subsequently the manufacturing process.	Emphasises how effective data definition and management would enable the company to achieve "Right First Time" approach.
Results	Employees' empowerment through improved information flow and continuous analysis of updated information.	Identification of correct casting equipment to construct the required pump, and to be fully aware of the casting equipment logistics and conditions.	

Table 4.1 Case Studies Summary

5.0 RESEARCH DISCUSSIONS

The research work started off with an intensive literature review on NPD and PDM in order to gain an understanding of what PDM systems are in terms of the functionality offered by commercial PDM vendors and the significant roles played by these systems on today's NPD process. From the literature review, the author felt it is vital that manufacturing companies involved in the NPD process should have some form of PDM system in their organisations. This is particularly profound with discrete high value capital goods manufacturers where their products are highly customised according to customer requirements, for example those in the make-to-order environment. These manufacturing companies require PDM systems to allow them the access to accurate and up-to-date product data to facilitate the re-use existing designs since many of their new products are likely to evolved from existing or old products. These PDM systems can be either commercially available or in-house built.

However, these commercially available systems are not always affordable by all, especially SMEs that have limited resources in terms of financial capability, staff time, and ICT skills. The survey carried out during the research confirmed that up to the year 1999, there was still a lack of SME involvement in PDM systems: 82% of the UK's respondents that have not implemented PDM systems were SMEs. The survey also showed that 56% of the UK's respondents that have not heard of PDM systems were from SMEs. The survey concluded that one of the main obstacles to the lack of SMEs involvement in PDM systems is the unawareness of the existence of PDM systems. This also explains why many SMEs don't have an effective in-house built PDM system.

Also, the results from the survey showed that even SMEs that have heard of PDM systems held with them negative perceptions of the capabilities these systems would bring to their businesses. The survey showed that these negative perceptions were mainly due to lack of relevant successful examples of PDM implementation in companies of a similar size and from a similar sector. The survey also showed that the penetration of PDM systems and the level of maturity of PDM systems implementation in the UK are still in their infancy where 60% of the surveyed companies, which have implemented PDM systems, have less than two years of experience in the implementation.

The survey concluded that there is an urgent need to promote PDM awareness to manufacturing companies and one suggestion identified from the survey is by demonstrating examples of successful PDM implementation within SMEs. A transfer of know-how or technology from large manufacturing enterprises to SMEs, perhaps to suppliers, would also increase awareness and examples of good practice. However, during the course of this project, the author had difficulty in locating companies that have successfully implemented PDM systems. Discussions with experts and PDM consultants verified that many companies, even large companies, are still having problems with their PDM system implementation. Some of these companies had changed their vendors and even found the PDM system incompatible with a new computer implementation. Therefore, the initial intention of the research to focus on the transfer of technology from companies that have successfully implemented PDM systems to promote PDM awareness in SMEs was not seen to be feasible.

This was then replaced by a series of industrial case studies with local discrete product companies that manufacture to customer specifications, emphasising on the importance of PDM concept within the product development process. The decision to introduce the concept of PDM to solve the then identified problems faced by each case company rather than using a commercially available PDM system for these case studies was based on the ground that it is far more important to understand the concept of PDM and how it can help to address the identified problems. The case studies intended to promote the awareness for PDM and to encourage its implementation. It is not within the scope of this research to investigate methods for effective implementation of PDM systems.

Two companies were identified where both companies produce complex products that are highly customised to their customers' requirements. Although the two case companies are both parts of larger groups, because of their distinct geographic location from the parent company, their actual plant size, and their fragmented IT infrastructure, they exhibited most of the characteristics of a larger SME. Initial meetings with the companies provided the author with a clear view of the then pressing problems within each company. Whilst assisting in the solution of current problems, the author successfully promoted the importance of PDM in meeting business objectives of both companies. Altogether, three case studies were carried out with the two collaborating companies. Each case study looked at the application of PDM at three different stages in the product development process. Results from the three case studies have addressed and validated the first two objectives of this research: the effectiveness of PDM in enhancing the product definition process and in creating an interface between different functional areas within an organisation.

The first case study looked at the manufacturing process stage and demonstrated the effectiveness of PDM to make all relevant accurate and up to date product data available throughout the organisation, replacing unproductive activities and thereby increased productivity and improved product build qualities. The case study also demonstrated how interfacing the manufacturing process and materials planning with the order taking function has reduced the unrealistic order delivery promises to customers, enabled a better and more accurate order forecasting, and improved the efficiency of the shop floor control.

The second case study looked at the design and engineering planning stage and emphasised the importance of PDM to enable the re-use of existing designs and to enhance the product definition process. The case study demonstrated how extending the product information within the engineering planning stage has enabled the production of a more precise cost estimate of the required product and its delivery date at the order entry stage. The case study also showed how having no control of the product information has led to delays in the planning and scheduling processes and consequently hindered pump production and ultimately impaired business performance.

The third case study exemplified the importance of the ability to share standardised product data in an organisation as well as between organisations to reduce both data duplication and incompatibility at the order entry aspect of the sales function. The case study showed how unnecessary work was required to translate information received from different departments to enable its usability due to the lack of product data standardisation.

During the implementation of the three case studies, the author discovered that the two case companies use their own in house built MRP system and also a few other micro applications that address specific needs in their daily business operations. However, investigations of these micro applications revealed that they do not allow sharing of product data and some were duplicating existing product data. The two developed prototypes successfully demonstrated the concept of effective PDM to the case companies and, where appropriate, provided the means for sharing of relevant product data between these micro applications without duplicating any existing product data.

Findings from the case studies, especially Case Study #2, have also validated a conclusion drawn from the PDM survey performed, i.e. the level of PDM system usage is still at the infant stage. This explains why it was difficult to locate companies that have successful implemented PDM systems. These findings have also presented a favourable case to the focus of this research in that attention should be emphasised on the importance of understanding the concept of PDM and how it can help to address business needs. The proposed method to introduce PDM awareness, which emphasises on understanding the business needs and then only employing the suitable technology to realise these business needs, has proven to be effective and after the case studies, both companies have begun to appreciate the importance of PDM. Aligned with the third objective of this research, the method introduced is highly practical and would benefit many SMEs.

Outcomes from the three case studies have identified the needs for an effective one-time order capture at the order entry stage to further enhance the product definition process. On the departure of a Research Fellow employed by the university, the author was offered a research position to develop a generic prototype late product configuration tool for responsive manufacturing. The project was part of a 27 months project funded by the Innovative Manufacturing Initiative (IMI) within the EPSRC and in collaboration with case study #1. The collaborating company has often failed to make profit on some customer orders because of promises made by sales people without consultation with other company functions. Inaccurate vehicle specifications have to be reverted back to engineering for re-engineering and ratification due to an ineffective order capture process. This invariably caused delay in delivery of vehicles. Ultimately, this results in customer dissatisfaction. Investigation by the previous researcher into the working procedures at the collaborating company emphasised the urgent need for all departments in the company to have access to relevant required information to cut down wasted time and cost [Rhymer 2000]:

- Information for the engineering department was often late, sometimes lost and misinterpreted by both purchasing and industrial engineering
- The historical database of product information was not kept up to date or recorded efficiently.
- Special requirements on vehicles that have been made before, or were similar to another one, had to be sorted out manually through the company "special equipment" procedure, if member of staff did recognise similarities, or re-created if not.

Results from case study #1 coupled with Rhymer's investigation have confirmed the need for a computerised solution to aid the initial order capture process. The project provided an opportunity for the author to demonstrate how an effective PDM environment can realise one-time order capture. The author was responsible to improve the late configuration ability for the collaborating company using tools appropriate to the SME sector leading to the development and documentation of a generic late configuration methodology for vehicle manufacture. It was envisaged that the solution would provide an interface between the sales, engineering, and as well as the manufacturing departments and thus overcome the unavailability and inaccuracy of product information between the three functional areas. The result from the project was a model specification of a generic late product configuration tool. The tool intended to act as an alternative to an actual product expert to assist sales at the initial order bidding stage and to provide the visibility of all processes related to a product and its documentation. The objective was to enable a manufacturing company to provide quick response to changing customer requirements, where and when required.

Although commercial product configuration tools exist in the market, many of them are not easily affordable by SMEs. Also, many of these commercially tools are targeted only at the initial order taking stage. The developed late product configuration specification aimed to extend this by enabling the tracking of customer orders that have proceeded to the shop floor. The specifications developed allow the creation of a PDM system and a configuration tool that is platform independent. A prototype was developed based on the mentioned specifications using MS Access, which is widely available to many SMEs. The prototype was demonstrated to the company and an interest has been shown by the company to proceed with the next stage necessary to implement the prototype. Due to the insufficient resources from the collaborating company as well as the time constraints of the research, it was not possible to implement the prototype at the company. An extension to this project mainly looking at the validity of the developed specification and envisaged late product configuration process has been considered as future work recommendation and is mentioned in the next chapter.

6.0 CONCLUSIONS

While much of PDM related research carried out by academia in recent years involved the use of commercially available PDM systems, the approach adopted for this research is slightly different. This research emphasises on the importance of the understanding and the capability to employ the concept of PDM without necessarily having to actually implement a commercial PDM system to demonstrate its objectives. Specifically, this research focuses upon how the concept of PDM can be applied in practice to define and configure products and to provide an interface between other business areas within an organisation, mainly sales, design, and manufacturing. The author defined PDM as:

> *"The management of all product and process related data within the product lifecycle to define, configure, produce and maintain the end product."*

Although the chosen definition is broad, it aligns with and best describes the focus of this research work.

This adopted approach allows the study of the effectiveness of PDM within the product development process without investing in a commercially available PDM system. This research would be of interest to manufacturing companies that are searching for effective ways of introducing PDM to solve their business needs without requiring a huge initial investment, particularly SMEs that are not aware of PDM.

Included within this thesis is a comprehensive literature review giving an introduction to NPD, emphasising the main changes in the methods of product definition and the management of product data that have occurred with the advent of computer support. The evolution of product data management methods and software tools such as PDM systems within a modern integrated manufacturing system for NPD has been a particular focus in the literature review. A brief introduction to the functionality and applications of PDM systems has also been included, as has a survey of the level of current PDM systems usage. The descriptions of the three industrial case studies have been provided, and the design and development of a late product configuration tool has also been outlined. However, since the effectiveness of tool was not validated during this research, due to time constraints, its design and development has not been included in the main thesis but instead has been appended to the end of this thesis as Appendix E.

The key issues arising from the literature review, the survey and the three case studies have been discussed in Chapter 5. This chapter presents the issues drawn from the work undertaken to address the research objectives and hypotheses. The summarised findings from the research and their contributions to current knowledge are also discussed. Two future research projects are also proposed at the end of this chapter.

6.1 Meeting Research Objectives

The research methodology mentioned in Chapter One has successfully addressed the three objectives that were put forward in this research.

Objective 1: To review the applications and effectiveness of PDM systems in the new product development process within manufacturing industry to enhance the product definition process.

The literature reviewed showed that the scope of the product definition process is no longer limited to the functional or engineering data of the product. The literature reviewed also showed that product configuration process has been identified in recent researches to balance both the request for customised products and the need to ensure high responsiveness in product delivery during the product definition process. The author has demonstrated the need for an effective one-time order capture at the initial order entry stage through the three case studies. The author has produced a model specification for a late product configuration tool and developed a prototype based on this specification, which was later demonstrated to a collaborating company. The prototype demonstrated how an effective PDM environment can capture, manage, and facilitate the sharing of product information to enable product configuration at the initial order entry stage as well as when the order has proceeded to the production stage.

Objective 2: To analyse the current interfaces between sales and design, design and manufacturing and the effectiveness of PDM software in improving these interfaces.

The literature has shown that there is no fully integrated enterprise wide information system and the case studies confirmed this. The three case studies showed that "over the wall" approach was a common practice in the two case companies due to the lack of the ability to share product data between different functional areas, especially between sales, design and manufacturing. Results from the implementations of the two prototype systems during the first two case studies showed that effective PDM systems could improve these interfaces. The model specification for the late product configuration tool was developed to provide the required product data representation to interface the sales, design, and manufacturing functional areas.

Objective 3: To identify appropriate models for PDM operations within SMEs.

The proposed method to promote PDM awareness has been proven effective and the two case companies have begun to appreciate the importance of effective PDM. Both case companies are now more conscious minded in terms of how the product data is generated, used, and maintained. Issues such as data visibility, availability, and accessibility are major concerns to these two companies, as expressed by them during a brief follow-up after the completion of each case study. The case studies have demonstrated how micro computerised solutions can be used to bridge the gap between different functional areas within an organisation by enabling the sharing of information with the main data vault without duplicating existing product data and thus prevented unnecessary errors from manual data re-entry. These solutions are easily affordable by many SMEs.

6.2 Validating Research Hypotheses

The first hypothesis underlying this research work is that a high level of integration, or an effective interface, between PDM and relevant manufacturing control systems is essential to effective manufacturing performance, especially for the make-to-order manufacturing sector, particularly SMEs. This has been demonstrated by the achievement of the three research objectives discussed above and supported by the case study work.

Manufacturers are generating massive and complex product data everyday with the aid of today's advanced ICT. A business strategy that uses advanced ICT to ensure that the accuracy of product data is maintained and made available and accessible to all parties to facilitate the sharing of information was shown to be essential within each of the case study companies. This was also supported by the results of the survey.

The two prototypes implemented, ProTSC and the pattern database, were developed to address the identified problem areas and both are currently operating as live systems within the respective companies. The main objective of the three case studies was to show that the importance of applying the concept of PDM in the three functional areas during NPD. The case studies were effective and very successful. They have shown that providing PDM functionality within those areas had provided significant benefits to the respective areas as well as influencing and improving the effectiveness of manufacture by providing some degree of sharing of product data with other manufacturing systems. Therefore, the three case studies have validated the importance of PDM integration with other manufacturing control systems in each case.

The second hypothesis states that PDM is applicable and can be as beneficial to the SME as it is to the larger enterprise when implemented from the right perspective and using the right methodology. The survey results showed that unawareness and negative perceptions are the two main reasons to why many SMEs have not implemented PDM systems, contrary to just a lack of financial resource and IT skills as found in many literature. This research work has adopted an approach where the "what, why, and how" of PDM systems were introduced to an SME in two sequential phases. Through the three case studies, this research has shown that SMEs respond more positively to systems that address specifically their business needs, and are bespoke, affordable, and simple to install.

During the initial stage of implementing the case studies, it was confirmed that both collaborating companies are potential PDM candidates. Through the case studies, the companies were introduced to the concept of PDM and its importance, which addressed the "What" and "Why". Next, demonstration of the developed prototype, LPCon, to one of the collaborating companies showed how a bespoke and affordable PDM application can be utilised to meet the business objectives. This addressed the "How". The demonstration had generated considerable interest from the senior management level.

6.3 Research Findings

The research findings from this research are summarised as below:

- Although the literature reviewed indicated that the functionality scope of PDM systems has been extended to aid and enhance decision making throughout the entire product development process, results from the survey carried out showed that the use of PDM systems in the manufacturing industry within the UK is still very much in its infant stage. This was also confirmed in the case studies where one of the case companies was only using its PDM system as a document manager after three years of implementation.
- The literature has shown that there is no fully integrated enterprise wide information system and the case studies confirmed this. The three case studies showed that the two case companies were more interested on bespoke point solutions to address their specific problems rather than investing into commercially available best of breed solutions that offer various functionality which attempt to solve their every need. The case studies demonstrated how these bespoke micro solutions can be used to bridge the gap between different functional areas within an organisation by enabling the sharing of information with the main data vault without duplicating existing product data and thus prevented unnecessary errors from manual data re-entry.
- Also, the case studies opened a new window of possibility that the investment in computer technology by manufacturing companies is moving back to islands of automation, which emphasises the need for effective PDM to provide an environment that allows the sharing of relevant product data

between these islands of automation.

- The survey showed that there are PDM systems that are suitable for SMEs, however there is still a lack of SMEs involvement in PDM system implementations within the UK. The survey identified that the lack of awareness and negative perceptions to the capability of PDM systems are the major obstacles to SMEs involvement in PDM systems, besides the general lack of financial resources and IT skills.
- The two prototypes developed and implemented during the case studies and the prototype late product configuration tool have demonstrated that MS Access, supported by MS Visual Basic, has proven to be an effective approach to PDM system development.

6.4 Research Contributions to Knowledge

The research contributions to knowledge are:

- The proposed method to introduce the concept and importance of PDM in addressing business needs has proven to be an effective means to promote PDM awareness to manufacturing companies.
- The prototype system developed in the first case study, ProTSC, provided a novel approach to the monitoring of vehicle build progress and shortage control.
- The developed specification for the late product configuration tool has created a PDM environment affordable to many manufacturing companies. It allowed the configuration of product based on customer requirements at the initial order entry stage, as well as when the order as proceeded to the shop floor.

6.5 Future Research

Two future research programmes have been identified towards the end of this research work. The objective is to further strengthen the work that has been undertaken in this research.

6.5.1 Research #1 - Best Practice of Product data Management

A key output from this research work has been the development of the generic late product configuration tool. However, the research has come to its end before the author was able to implement and validate its effectiveness as a full working system. Specifically, the aim of the proposed research is to identify a benchmarking tool for best practice in PDM. The objectives contributing to this aim are:

- To identify current practice of PDM to formulate best practice through analysing and methods, approaches and strategies employed and results or achievement obtained.
- To further enhance and then validate the effectiveness of the developed late product configuration tool as a means of PDM solutions to improve the product development process.

The proposed research would require involvement of various manufacturing companies that have implemented PDM systems, both large enterprises and SMEs. Collaborations from members such as those from the IPDMUG discussion group, which is made world-wide PDM users from various commercial PDM systems, would provide an ideal solution.

6.5.2 Research #2 - Classification of PDM Systems

Currently, there are many commercially available PDM systems in the market. However, from the literature reviewed, the author has not come across any attempts that categorise PDM systems based on functionality, usage, client base, and cost for implementation. The author perceives that the four mentioned categorisations of PDM systems can be used as a generic indicator for manufacturing enterprises to quickly identify the suitable PDM system based on their requirements. This is especially the case for the SMEs where, as concluded in Chapter Four, the two main reasons why many SMEs in the UK have yet to implement a PDM system are:

- The unawareness of such system existence and negative perceptions of the system capability

- The inability to find a suitable commercial PDM system and unable to justify the cost of implementation

Furthermore, this generic indicator can provide useful information to PDM vendors as a means for improving and upgrading both their products and services. The four categorisations can be summarised as follows:

- **Functionality**

  The CIMdata collaborative Product Definition Management (cPDM) model, as shown in Figure 6.1, can be used as a reference model for the functionality categorisation. The emphasis will be the foundation technologies and the core functions. This categorisation distinguishes the type of support and capability offered by a specific PDM system and is important to manufacturing enterprises where they are able to identify the suitable PDM system or systems in order to support the type of operating environment required.

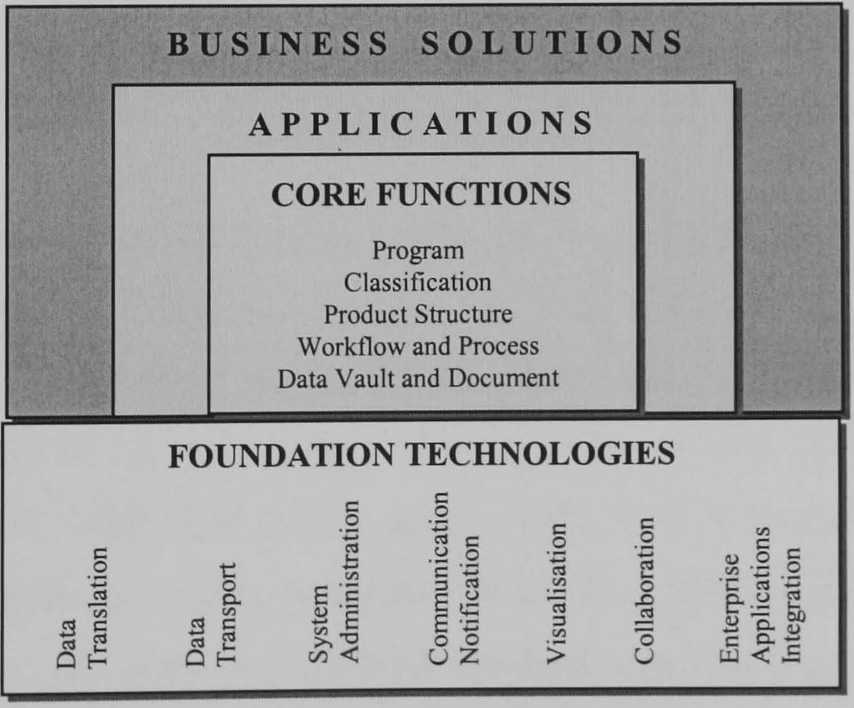


Figure 6.1 CIMdata's cPDM Model [CIMdata 2001]

- **Usage**

  Combination of the four classes of MRP users by Oliver Wight [Wight 1984] and the applications and business solutions from the CIMdata's cPDM model can be referred to for the usage categorisation. This categorisation identifies the main requirements of implementing a PDM system in order to achieve business goal and can also be used as a means for calculating return of investment.

- **Client base**

  Many PDM providers have claimed that their products are suitable for SMEs, however examples of PDM implementations within SMEs are scarce. This categorisation will help future potential PDM investors to quickly identify the suitable PDM systems based on mainly its strength, focus, and commitments in the areas of applications and the type of users and industry sectors it supports.

- **Cost for implementation**

  The complete cost of implementation should include direct cost as well as hidden costs that need considering when deciding on implementing a PDM system. Direct costs are such as the cost for software licensing, add-ons modules, hardware requirements, training, etc., whereas hidden costs are such as maintenance and support, customisations, length of implementation, etc. This categorisation is important for a potential PDM investor to quickly identify the suitable as well as affordable PDM systems that are available.

The proposed research would require a thorough investigation of a wide range of PDM systems, ranging from matured systems to those that just starting to penetrate the PDM market. Currently available PDM guides, such as the one produced by CIMdata Ltd., can be used to provide an initial view of the available systems. Collaboration with PDM consultants and several PDM providers can help to establish and enhance the generic indicator. A survey instrument can be created to aid data collection. An example of such survey instrument is appended to Appendix F. The established indicator can then be validated through the use of case study with potential manufacturing companies.

REFERENCES

Groover and Zimmers 1984	**Groover, M.P. and Zimmers, E.W. Jr.** *CAD / CAM: Computer Aided Design and Manufacturing.* Prentice Hall, Inc., Eaglewood, Cliffs, NJ, USA, 1984.
Gardeen et al. 1990	**Gardeen, J.W. and Hansen, P.E.** *Engineering Data Management - The Technology for Integration.* Proceedings of 1990 ASME International Computers in Engineering Conference and Exhibition, pp. 31 - 35.
McTaggart 1991	**McTaggart, R.** *Principles of Participatory Action Research* Adult Education Quarterly, Vol. 41, No. 3, 1991, pp. 170
Rangan and Fulton 1991	**Rangan, R. M. and Fulton, R.E.** *A Data Management Strategy to Control Design and Manufacturing Information.* Engineering with Computers, 1991, No. 7, pp. 63 - 78.
Fitzgerald 1992	**Fitzgerald, A.** *Enterprise Resource Planning (ERP) – Breakthrough or Buzzword?* The 3rd International Conference on Factory 2000: Competitive Performance Through Advanced Technology, 1992, pp. 291 - 297.
Nichols 1992	**Nichols, K** *Better, Cheaper, Faster Product - by Design* Journal of Engineering Design, Vol. 3, 1992, pp. 217 - 228
Stark 1992	**Stark, J.** *Engineering Information Management Systems - Beyond CAD/CAM to Concurrent Engineering Support.* Van Nostrand Reinhold, NY, USA, 1992.
Williamson 1992b	**Wiliamson, I.P.** *The Struggle for Data Management in the Manufacturing Enterprise.* Proceedings to the 3rd International Conference on Factory 2000: Competitive Performance Through Advanced Technology, July 1992.
Brett 1993	**Brett, S.** *Take a STEP Inside* CADCAM, April 1993, Vol. 13, no. 4, pp. 27 - 31.
Levy 1993	**Levy, J.** *Small and Medium Sized Enterprises: A Recipe for Success.* Manufacturing Engineer, 1993, Vol. 72, No. 6, pp. 258 - 259.

Urban et al 1993

Urban, S.D.; Shah, J.J.; and Rogers, M.T.
Engineering Data Management: Achieving Integration Through Database Technology.
Computing & Control Engineering Journal, June 1993, pp. 119 - 126.

Beckert 1994

Beckert, B.A.
Destination: Integration
Computer Aided Engineering, 1994, Vol. 13, No. 7, pp. 6 - 12.

Innes 1994

Innes, J.G.
Achieving Successful Product Change.
Pitman Publishing, London, 1994.

Kidd 1994

Kidd, P.T.
Agile Manufacturing: Forging New Frontiers.
Addison Wesley Publishing Company, 1994.

Little and Gavin 1994

Little, D. and Gavin, C.J.
Application of CASE within Manufacturing Industry.
Software Engineering Journal, July 1994

Medhat 1994

Medhat, S.
Engineering Data Management – from Electronic Design Automation to Concurrent Engineering.
Proceedings of the International Conference on Concurrent Engineering and Electronic Design Automation (CEEDA '94), pp. 519 - 532.

Mortimer 1994

Lee-Mortimer, A.
Implementing Simultaneous Engineering.
World Class Design to Manufacture, 1994, Vol. 1, No. 1, pp. 43 - 47.

Scheer 1994

Scheer, A.W.
CIM - Towards The Factory of The Future.
Springer-Verlag: 3rd Edition, 1994.

Sullivan et al 1994

Sullivan, W.G.; Lee, P.; Luxhoj, J. and Thannirpalli, R.
A Survey of Engineering Design Literature: Methodology, Education, Economics, and Management Aspects.
The Engineering Economist, 1994, Vol. 40, pp. 7 - 40.

Vroom 1994

Vroom, R.W.
From Databases to Data Management within Product Development.
Proceedings of the Advances in Computer Aided Engineering, Delft University, The Netherlands, June 1996, pp. 187 - 194.

Yin 1994

Yin, R.K.
Case Study Research: Design and Methods
SAGE Publications, 2nd Edition, 1994

Ackers et al 1995	**Ackers, A.; Edwards, K. and Roozenburg, N.** *Design Guidelines Support of Decision Making During The Early Stages of The Design Process.* Proceeding of The 10th International Conference on Engineering Design, ICED 1995, Praha, August 22 - 24, Vol. 4, pp. 1477 - 1482.
Bayliss et al. 1995	**Bayliss, D.C.; Akueson, R.; Parkin, R. and Knight, J.A.G..** *Concurrent Engineering Philosophy Implemented Using Optimised Design.* Proceeding of the Institution of Mechanical Engineers, Vol. 209, 1995, pp. 193 - 199.
Burgess and Wallace 1995	**Burgess, S.C. and Wallace, K.M.** *An Overview of The Functionality Needed in CAD Tools.* International Conference on Engineering Design, ICED 1995, Praha, Czech, August 22 - 24, 1995, Vol. 4, pp. 1296 - 1301.
Cheraghvandi 1995	**Cheraghvandi, M.** *Interoperable Design and Engineering Systems.* MSc Thesis - University of Cranfield, UK, 1995.
Chung et al 1995	**Chung, W.C.; Li, K.C. and Chick, K.O.** *Smart Use of Decision Support Technology for Concurrent Operations.* IFIP WG5.7 Working Conference on Managing Concurrent Manufacturing to Improve Industrial Performance, Washington, USA, September 1995, pp. 160 - 171
Court et al 1995	**Court, A.W.; Culley, S.J. and McMahon, C.A.** *A Methodology for Analysing The Information Accessing Methods of Engineering Designers.* Proceeding of The 10th International Conference on Engineering Design, ICED 1995, Praha, Czech, August 22 -24, Vol. 2
Drisis 1995	**Drisis, L.** *Computer Aided Team Work in Design.* Proceeding of The 10th International Conference on Engineering Design, ICED 1995, Praha, Czech, August 22 - 24, 1995, Vol. 4, pp. 1314 - 1315.
Esebeck et al 1995	**Esebeck, G.V.; Tegel,O.; Grote, K.H.; Miller, J.L.** *Combination of Management Methods and Information Technologies for Product Development Process.* Proceedings of the Computers in Engineering Conference and the Engineering Database Symposium, ASME 1995, pp. 1155 - 1164.
Gascoigne 1995	**Gascoigne, B.** *PDM: The Essential Technology for Concurrent Engineering* World Class Design to Manufacture, No. 2, 1995, pp. 38 - 42
Jordan and Browne 1995	**Jordan, P. and Browne, J.** *A Production Planning and Control Architecture for Small Manufacturing Enterprises.* IFIP WG5.7 Working Conference on Managing Concurrent Manufacturing to

Improve Industrial Performance, Washington USA., Sept 1995, pp. 228 - 240.

Khadilkar and Stauffer 1995 — **Khadilkar, D. and Stauffer, L.**
Evaluating The Re-Use of Design Information: An Experimental Case Study.
Proceeding of The 10th International Conference on Engineering Design, ICED 1995, Praha, August 22 - 24

Klein 1995 — **Klein, L.R.**
Product Data Management and MRPII Systems for Cleveland Electronic Commerce Resource Center.
Proceedings to AUTOFACT'95 Conference, pp. 148 - 158.

Kotha 1995 — **Kotha, S.**
Mass Customisation: Implementing the Emerging Paradigm for Competitive Advantage.
Strategic Management Journal, 1995, No. 16, pp. 21 - 42

Marsh and Wallace 1995 — **Marsh, R. and Wallace, K.**
Integrity of Design Information.
Proceeding of The 10th International Conference on Engineering Design, ICED 1995, Praha, August 22 -24, Vol. 4, pp. 1449 - 1454.

McIntosh 1995 — **McIntosh, K.G.**
Engineering Data Management - A Guide to Successful Implementation.
McGraw Hill Book Company, UK, 1995.

Rangan 1995 — **Rangan, R.M.**
Engineering Data Management: Information Infrastructure to Support Engineering Processes in the 21st Century.
Proceedings of the Computers in Engineering Conference and the Engineering Database Symposium, ASME 1995, pp. 1067 - 1068.

Scherer and Mosca 1995 — **Scherer, E.; Frigo-Mosca, F.**
Business Processes in Product Engineering: A Survey on Organisation and Information Systems in Switzerland 1995.
IFIP WG5.7 Working Conference on Managing Concurrent Manufacturing to Improve Industrisl Performance, Washington USA, September 1995, pp. 255 - 264.

Vroom 1995 — **Vroom, R.W.**
Aspects and Dimensions of Product Data Management (PDM).
Proceeding of The 10th International Conference on Engineering Design, ICED 1995, Praha, August 22 -24, Vol.4, pp. 1425 - 1429.

Araujo et al 1996 — **Araujo, C.; Benedetto-Neto, H.; Campello, A.C.; Segre, F.M. and Wright, I.C.**
The Utilisation of Product Development Methods.
Journal of Engineering Design, 1996, Vol. 7, No. 3, pp. 265 - 277

CIMdata 1996 — **CIMdata**
Product Data Management: The Definition (An Introduction to Concepts, Benefits,

and Terminology).
CIMdata, Inc (http://www.CIMdata.com), Feb. 1996.

Gavin 1996 — **Gavin, C.J.**
The Application of Computer-Aided Software Engineering Within Manufacturing Industry.
PhD Thesis - University of Liverpool, UK, 1996

Griffiths 1996 — **Griffiths, A.**
IIC's Engineering Information Management Survey
Engineering Data Management Newsletter, June 1996, Vol. 5, No. 9, pp. 3 - 5.

Harris 1996 — **Harris, S.B.**
Business Strategy and The Role of Engineering Product Data Management: A Literature Review and Summary of The Emerging Research Questions.
Proceedings of The Institution of Mechanical Engineers, Part B [Journal of Engineering Manufacture], Vol. 210, No: B3, pp. 207 - 220.

Jardim-Gonçales et al 1996 — **Jardim-Gonçales, R.; Barata, M.M.; Sousa, P.C.; Steiger-Garçao, A. and Pamiés-Teixeira, J.**
Manufacturing Information Systems Integration: A Proposal Using SIP.
MED, Manufacturing Science and Engineering, ASME, Vol. 4, 1996, pp. 675 - 685

Jones and Tang 1996 — **Jones, O. and Tang, N.**
Networks for Technology Transfer: Linking HEIS and SMFs.
International Journal of Technology Management, 1996, Vol. 12, No. 7/8, pp. 820 - 829.

Lee and Chen 1996 — **Lee, D.L. and Chen, Y.M.**
Integrated Product and Process Data Management.
Integrated Computer Aided Engineering, 1996, Vol. 3, No. 1, pp. 1 - 4.

Miller 1996 — **Miller, E.**
The Plight of Small Companies
Computer-Aided Engineering Magazine, March 1996

Miller 1996a — **Miller, E.**
The Value of Parts Management.
Computer Aided Engineering Magazine, January 1996

Pikosz and Malmqvist 1996 — **Pikosz, P. and Malmqvist, J.**
Possibilities and Limitations When Introducing PDM Systems To Support The Product Development Process.
Proceedings of the NordDesign'96, Espoo, Finland, pp. 165 - 175,

Surlis 1996 — **Surlis, P.**
Chaos Theory.
CAMCAM Magazine, June 1996 pp. 27

Teeuw et al 1996	**Teeuw, W.; Liefting, J.; Demkes, R. and Houtsma, M.** *Experience with Product Data Interchange: On Product Models, Integration, and Standardisation.* Computers in Industry, 1996, Vol. 11, No. 3, pp. 205 - 211
Thomas 1996	**Thomas, R.** *Research Methods - Guidance for Postgraduates. [Edited by Tony Greenfield]* John Wiley & Sons, NY, USA, pp. 115 - 124
Tiihonen et al 1996	**Tiihonen, J.; Soininen, T.; Männistö, T. and Sulonen, R.** *State of the Practice in Product Configuration - A Survey of 10 Cases in the Finnish Industry* Knowledge Intensive CAD, 1996, Vol. 1, pp. 95 - 114
Waters 1996	**Waters, G.D.** *The Management of Product Data: The Missing Link* MSc Thesis - University of Cranfield, UK, September 1996.
Yusuf 1996	**Yusuf, Y.Y.** *The Extension of MRPII In Support of Integrated Manufacture* PhD Thesis - University of Liverpool, UK., June 1996
Al-Timimi and Port 1997	**Al-Timimi, K. and Port, S.** *The Compelling Case for STEP.* Engineering Data Newsletter, April 1997, Vol. 5, No. 3, pp. 10 - 12.
Bourke 1997	**Bourke, R.** *Product Information Management: A Key Building Block - Product Life Cycle Definition.* Midrange ERP, July/August 1997.
Bryan 1997	**Bryan, M.G.** *An Approach Framework for Product Data Management* EngD Thesis - University of Cranfield, UK, 1997.
CSF 1997	**Computer Supplier Federation, UK.** *CSF Roadshow - PDM / EDM on the Road.* CADCAM, Vol. 16, No. 10, October 1997, pp. 43 - 44.
Eigner and Stelzer 1997	**Eigner, M. and Stelzer, R.** *PDM - The Link between CAx and MRP.* Engineering Data Newsletter, April 1997, Vol. 5, No. 1, pp. 11 - 15.
Evan et al 1997	**Evans, M.; Braggs, S.; Kleevers, T.** *Ovum Evaluates: ERP for Manufacturers.* Ovum, UK, 1997

Gill and Johnson 1997 | **Gill, J. and Johnson, P.**
Research Methods for Managers
Paul Chapman, London.

Hall 1997 | **Hall, G.**
The key to Global Success.
CADCAM, October 1997, pp. 47 - 48.

Humphries 1997 | **Humphries, C.**
Reaching Out to SMEs: The Strategic Challenge.
TEC 97 Conference, Birmingham, UK, June 1997.

Jung et al 1997 | **Jung, S.; Van Aken, E.M.**
Joint Action And Shared Results: New Measurement Dimensions of Customer-Supplier Partnership.
Proceedings of The 6th Industrial Engineering Research Conference (IERC), Florida, USA., May 1997, pp. 867 - 872.

Keller-Jackson. 1997 | **Keller-Jackson, C.**
Product Data Management, Its Emergence and the Small and Medium Enterprise.
MSc Thesis - University of Huddersfield, UK, September 1997

Koonce et al 1997 | **Koonce, D.; Dhmija, D. and Judd, R.**
An Integrated Model for Manufacturing Information Exchange.
Proceedings of The 6th Industrial Engineering Research Conference (IERC), Florida, USA., May 1997, pp. 531 - 536

Little et al 1997 | **Little, D., Guenaoui, D., Hodgson, N. and Gavin, C.J.**
Requirements for The Increased Use of Software Engineering Methods and Tools Within Manufacturing Industry - The Final Report.
University of Huddersfield (EPSRC/DIP Grant Ref: GR/K40901), Nov 1997.

Miller 1997 | **Miller, E.**
The Synergy between PDM and Business Process Re-Engineering.
Computer-Aided Engineering Magazine, March 1997

Miller 1997a | **Miller, E.**
Successful Strategies for Integrating PDM and CAD.
Engineering Data Newsletter, Jan/Feb 1997, Vol. 5, No. 1, pp. 15 - 18.

Ostwald and Muñoz 1997 | **Ostwald,P.F. and Muñoz, J.**
Manufacturing Processes and Systems - Ninth Edition.
John Wiley & Sons, 1997.

Pikosz et al 1997 | **Pikosz, P.; Malmstrom, J. and Malmqvist, J.**
Strategies For Introducing PDM Systems in Engineering Companies.
Presented at the ISPE CE'97 Rochester, Michigan, USA.

Prasad
1997

Prasad, B.

Concurrent Engineering as an Integrator for Managing Product Development / Delivery Process.

International Journal of Materials and Product Technology, Vol. 12, Nos. 4 - 6, 1997, pp. 279 - 287

Retraint
1997

Retraint, E.

CATIA / CDM - ProductManager.Integration

Engineering Data Newsletter, April 1997, Vol. 5, No. 1, pp. 10 - 11.

Siegel and Waskiewicz
1997

Siegel, J. and Waskiewicz, F.

Establishing a Common Foundation for PDM Software Interoperability.

Engineering Data Newsletter, June 1997, Vol. 5, No. 6, pp.7 - 19.

Thirupathi and Roy
1997

Thirupathi, D. and Roy, R.

Warwick Manufacturing Group. Concurrent Engineering in Product Introduction: Some Requirements for Information Management

The Proceedings of the First International Conference: Managing Enterprises – Stakeholders, Engineering Logistics & Achievements (ME-SELA'97), Loughborough University, UK, July 1997, pp. 561-566.

Thuraisingham
1997

Thuraisingham, B.M.

Data Management Systems: Evolution and Interoperation.

CRC Press, Boca Raton, New York, 1997.

Wiebe
1997

Wiebe, E.N.

Adding Agility to CAD: Integrating Product Data Management Tools Into An Organisation.

Human Factors and Ergonomics in Manufacturing, Winter 1997, Vol. 7, No. 1, pp. 21 - 35.

Williams
1997

Williams, L.T.

Planning and Managing The Information Systems - A Manager's Guide.

Industrial Management & Data Systems, No. 5, 1997, pp. 187 - 191

Wright
1997

Wright, I.C.

A Review of Research into Engineering Change Management: Implication for Product Design.

Design Studies, January 1997, Vol. 18, No.1, pp. 33 - 42.

Bailey and Rucker
1998

Bailey, J.E. and Rucker, R.H.

Automated Management of Design Data: Product, Process, and Resource Structures.

International Journal of Industrial Engineering, Vol. 15, No. 1, March 1998, pp. 7 - 16.

Barclay and Dann
1998

Barclay, I. And Dann, Z.

Improving New Product Development Performance.

The Institute of Operations Management Seminar: New Product Realisation - Dreams to Reality Seminar, 1st October 1998.

Barclay et al. 1998 — **Barclay, I.; Dann, Z. and Holroyd, P.**
Improving Product Development Performance.
Woodhead Publishing Limited, 1998.

Barry and Duffill 1998 — **Barry, S.P. and Duffill, A.W.**
Organisation Culture for World Class Manufacturing.
Proceedings of the 14th National Conference on Manufacturing Research, UK - Advances in Manufacturing Technology XII, September 1998, pp. 441 - 446

Benedetto et al 1998 — **Benedetto-Neto, H.; Campello, A.C., Segre, F.M. and Wright, I.C.**
A Comparison of Differing Perceptions of the Benefits of Design Methods in Europe and North America.
Proceedings of Engineering Design Conference, Brunel, UK, 1998, pp. 419 - 425

Bennett et al 1998 — **Bennett, J.; Polkinghorne, M. and Pearce, J.**
Teaching Company Scheme: Technology Transfer for SMEs.
Manufacturing Engineer, 1998, Vol. 77, No. 3, pp. 139 - 143.

Boyle et al. 1998 — **Boyle, A.; Cottam, C.; and Kaldos, A.**
Requirements of a Tool Management System for High Variety, High Volume, Multi-Process Manufacture.
Proceedings of the 14th National Conference on Manufacturing Research, UK - Advances in Manufacturing Technology XII, September 1998, pp. 113 - 118.

CAD User 1998 — *The S.E.A.'s Wave*
CAD User - The UK & Ireland AutoCAD Design Computing Magazine, Vol. 11, No. 7, July/August 1998, pp. 42 - 43.

Carroll 1998 — **Carroll, B.**
Product Data Management Update
The Kalthoff Spring '98 Conference on March 24, 1998. (http://www.pdmic.com/presenting/index.html#a)

Cooper 1998 — **Cooper, R.**
Benchmarking New Product Performance: Results of the Best Practices Study.
European Management Journal, Vol. 16, No. 1, 1998, pp. 1 - 17.

deVries 1998 — **deVries, P.**
Integrating Applications and Data.
Proceedings to the 1998 CIMdata PDM Conference, Florida, USA, 7- 9 April.

Gregory 1998 — **Gregory, A.**
Linking PDM Systems to Manufacturing.
Manufacturing Computer Solutions, April 1998, pp. 34 - 36.

Hall 1998 — **Hall, G.**
Surfing with PDM
http://www.cadcam-magazine.co.uk/htm/cad/features/nov02.htm

Hall et al. 1998 — **Hall, D., Mavromihales, M; Ubbi, K.; Mason, J.; Kitsell, E; Little, D.**
Manufacturing Workshops For Managers & Engineers - Fast Track Product Development
University of Huddersfield, 1998.

Hough 1998 — **Hough, D.A.**
Bridging the Functionality Gap - Configurable Interoperability for ERP Execution.
Integrated Design & Manufacturing, May 1998, Vol. 2, No. 4.

Johnson et al. 1998 — **Johnson, K. and Coll, F.**
Industrial and Academic Collaboration: Adding to Britain's Value Chain.
Proceedings of the 1998 International Conference of Manufacturing Value-Chain, pp. 25 - 34.

Jones 1998 — **Jones, L.**
A Full Integration of CSM, PDM and ERP.
Proceedings to the 1998 CIMdata PDM Conference, Florida, USA, 7- 9 April.

Little 1998 — **Little, D.**
Development of A Package Selection Method and Tool for Small and Medium Sized Enterprises (SMEs).
Computer Integrated Manufacturing Systems, 1998, Vol. 11, No. 4, pp. 351 - 355.

Manning and Wight 1998 — **Manning, D. and Wight, O..**
Sales and Operation Planning Hits the Sweet Spot.
Control (The Institute of Operations Management), Vol. 24, No. 8, October 1998, pp. 25 - 26.

Marri et al 1998 — **Marri, H.B.; Gunasekaran, A. and Grieve, R.J.**
An Investigation into the Implementation of Computer Integrated Manufacturing in Small and Medium Enterprises
The International Journal of Advanced Manufacturing Technology, No. 14, 1998, pp. 935 - 942

McMahon and Browne 1998 — **McMahon, C. and Browne, J.**
CADCAM - Priciples, Practice, and Manufacturing Management.
Addison-Wesley, 1998.

McMillan 1998 — **McMillan, D.**
Managing An Avalanche of New Product Launches.
The Institute of Operations Management Seminar: New Product Realisation - Dreams to Reality Seminar, 1st October 1998.

Pandhi 1998 — **Pandhi, Y.**
Achieving Best Business Results from PDM.
Proceedings to the 1998 CIMdata PDM Conference, Florida, USA, 7- 9 April.

Pikosz et al. 1998

Pikosz, P. and Malmqvist, J.

A Comparative Study of Engineering Change Management in 3 Swedish Engineering Companies.

Chalmers University of Technology, Sweden -Report, 1998.

Port 1998

Port, S.

DM and Beyond for Engineering

Document Manager, Jan/Feb 1998, pp. 29 - 31.

Port and Bilello 1998

Port, S. and Bilello, P.

PDM Overview and Benefits.

Proceedings to the 1998 CIMdata PDM Conference, Florida, USA, 7- 9 April.

Prygoski 1998

Prygoski, S.

Selecting Your PDM Vendor: A Methodology with Lessons Learned.

Proceedings to the 1998 CIMdata PDM Conference, Florida, USA, 7- 9 April.

Sackett and Martin 1998

Sackett, P.; Martin,V.R.

Information Resources Management for Customer Focus in Small Manufacturing Companies.

Proceedings of the 1998 International Conference of Manufacturing Value-Chain, pp. 481 - 488.

Shewchuk 1998

Shewchuk, J.P

Agile Manufacturing: One Size Does Not Fit All.

Proceedings of the 1998 International Conference of Manufacturing Value-Chain, pp. 143 - 150.

Taylor 1998

Taylor, J.

Engineering the Information Age.

IEE Review, Vol. 44, No. 6, Nov. 1998, pp. 250 - 252.

Thoburn and Winters 1998

Thoburn, J.G. and Winters, C.N.

Data Management - An Overview of Information Requirements for SMEs.

Proceedings of the 14th National Conference on Manufacturing Research, UK - Advances in Manufacturing Technology XII, September 1998, pp. 523 - 528.

Tinham 1998

Tinham, B.

The MCS Survey - Where to now with PDM?

Manufacturing Control Solution, March 1998, pp. 31 - 37.

Trott 1998

Trott, P.

Innovation Management and New Product Development.

Financial Times Management, Pitman Publishing.

Vokurka and Fliedner 1998

Vokurka, R.J. and Fliedner, G.

The Journey Towards Agility.

Industrial Management and Data System, 1998, No. 4, pp. 165 - 171.

Wadworth 1998 | **Wadsworth, Y.**
What is Participatory Action Research?
Action Research International (Refereed On Line Journal of Action Research), Paper 2, November 1998
[http://www.scu.edu.au/schools/gcm/ar/ari/p-ywadsworth98.html]

Willis 1998 | **Willis, T.H.**
Operational Competitive Requirements for The 21st Century.
Industrial Management & Data Systems, No. 2, 1998, pp. 83 - 86

Wortmann 1998 | **Wortmann, J.C.**
Evolution of ERP Systems.
Proceedings of the 1998 International Conference of Manufacturing Value-Chain, pp. 11 - 23.

Amstrong and Coyle 1999 | **Amstrong, P.J. and Coyle, P.J.**
The Relevance of Enterprise Resource Planning to Manufacturing SMEs.
Proceedings to the 15th International Conference on Production Research, Limerick, Ireland, 9th - 13th August 1999, Vol. 1, pp. 721 - 724

Barber 1999 | **Barber, M.**
Concurrent Engineering Acts As A Catalyst in Companies.
Proceedings to the 15th International Conference on Production Research, Limerick, Ireland, 9th - 13th August 1999, Vol. 1, pp. 223 - 226.

Belecheanu et al 1999 | **Belecheanu, R.; Pawar, K.S.; Barson, R. and Haque, B.**
A Framework for Supporting Decision Making in Early Phases of Product Development in Concurrent Engineering.
Proceedings to the 15th International Conference on Production Research, Limerick, Ireland, 9th - 13th August 1999, Vol. 1, pp. 201 - 204.

Chu and Fan 1999 | **Chu, X. and Fan, Y.**
Product Data Management based on Web Technology.
Integrated Manufacturing Systems, Vol. 10, No. 2, 1999, pp. 84 - 88.

Elzen et al 1999 | **Elzen, R.V.D., Pels, H.J., Helms, R., Mandemaker, D., Meng, L., Sackett, P. and Primavera, J.**
A Practical Approach for Rapid Implementation of PDM in SME's
Proceedings to the 5th International Conference on Concurrent Engineering, The Hague, 17 - 17 March 1999, pp. 157 - 165.

Gunasekaran et al 1999 | **Gunasekaran, A.; Miele, R. and Rahimi, F.**
Investment Justification of Information Technology Projects: A Case Study.
Proceedings to the 15th International Conference on Production Research, Limerick, Ireland, 9th - 13th August 1999, Vol. 1, pp. 695 - 698.

Henry and Greenhalgh 1999 | **Henry, M. and Greenhalgh, S.**
Fast Track Product Development: Linking Time Comnpression Technologies to Voices of The Customers and Competitive Analysis.

Time Compression Technologies, October 1999, Vol. 7, No. 5, pp. 20 - 24.

Huang and Mak 1999 — **Huang, G.Q. and Mak, K.L.**
Current Practices of Engineering Change Management in UK Manufacturing Industries.
International Journal of Operations & Production Management, 1998, Vol. 19, No. 1, pp. 21 - 37.

Jiao and Tseng 1999 — **Jiao, J. and Tseng, M.M.**
A Requirement Management Database System for Product Definition.
Integrated Manufacturing Systems, 1999, Vol. 10, No. 3, pp. 146 - 153.

Kelly et al 1999 — **Kelly, P.F.; Dickinson, M. and Gourd, T.**
Re-Structuring of Facilities and Systems in a Specialised SME.
Proceedings to the 15th International Conference on Production Research, Limerick, Ireland, 9th - 13th August 1999, Vol. 2, pp. 1201 - 1204.

Kruse 1999 — **Kruse, G.**
Advance Planning and Scheduling: Beyond MRPII.
The 1999 Institute of Operations Management Annual Conference: "Making The Difference", 16th - 17th November, UK.

Mainwaring 1999 — **Mainwaring, J.**
Concurrent Engineering: Where To Now?
Manufacturing Computer Solutions, Vol. 5, No. 3, March 1999, pp. 31 - 34.

Mainwaring 1999b — **Mainwaring, J.**
PDM - Slotting into the Jigsaw?
Manufacturing Computer Solutions, Vol. 5, No. 4, April 1999, pp. 36 - 38.

Orr 1999 — **Orr, S.**
The Role of Technology in Manufacturing Strategy: Experiences from the Australian Wine Industry.
Integrated Manufacturing Systems, 1999, Vol. 10, Issue 1, pp.45 - 55.

Pham et al 1999 — **Pham, D.T.; Dimov, S.S. and Setchi, R.M.**
Intelligent Product Manuals.
Proceedings of Institution of Mechanical Engineers, 1999, Vol. 213, No. 1, pp. 65 - 76.

Ratchev et al 1999 — **Ratchev, S.M.; Shiau, J. and Valtchanov, G.**
Distributed Product and Facility Prototyping in Extended Manufacturing Enterprises.
Proceedings to the 15th International Conference on Production Research, Limerick, Ireland, 9th - 13th August 1999, Vol. 1, pp. 233 - 236.

Redlein and Klinger 1999 — **Redlein, A. and Klinger, K.**
Fulfilling Customer's Needs by the Use of a Variant Configurator for Dynamic Product Definition
Proceedings to the 15th International Conference on Production Research, Limerick,

Ireland, 9th - 13th August 1999, Vol. 1, pp. 301 - 304.

Ricciardi 1999 | **Ricciardi, M.C.M.**
Individual and Organisational Efficiency in Cross Functional Product Development Teams.
Proceedings to the 15th International Conference on Production Research, Limerick, Ireland, 9th - 13th August 1999, Vol. 1, pp. 205 - 208.

Ritchie and Black 1999 | **Ritchie, J. and Black, I.**
Customer and Process Influence in Product Manufacturing.
Proceedings to the 15th International Conference on Production Research, Limerick, Ireland, 9 - 13 August 1999, Vol. 1, pp. 285 - 288.

Rowell 1999 | **Rowell, T.**
Workflow Survives the Web.
Conspectus - Workflow and Document Management Technology, September 1999, pp. 1 - 4.

Bibb et al 2000 | **Bibb, R.; Brown, R. and Wright, D.**
A Rapid Prototyping Product Design & Development Advice System for SMEs.
Proceedings of the 3rd International Conference on Stimulating Manufacturing Excellence in Small and Medium Enterprises (SMESME), 17-19 April 2000, Coventry, UK, pp. 40 - 53.

Bolmqvist et al 2000 | **Blomqvist, M.; Karjalainen, J. and Suolanen, O.**
Supply Chain Management Tools for Small and Medium Sized Enterprises.
Proceedings of the 3rd International Conference on Stimulating Manufacturing Excellence in Small and Medium Enterprises (SMESME), 17-19 April 2000, Coventry, UK., pp. 237 - 247

Chadwick 2000 | **Chadwick, D.**
Healing the Wounds of Data Conversion
CAD User, March 2000, Vol. 13, No. 3, pp. 44 - 47.

Croner 2000 | *Croner's Manufacturing Operations*
Croner Publication, 2000

Filson and Lewis 2000 | **Filson, A. and Lewis, A.**
New Product Development Strategy Linked to Business Performance: An Empirical Investigation of UK SMEs.
Proceedings of the 3rd International Conference on Stimulating Manufacturing Excellence in Small and Medium Enterprises (SMESME), 17-19 April 2000, Coventry, UK, pp. 495 - 503.

Meng and Sackett 2000 | **Meng, L.Y. and Sackett, P.**
A Model for Cost Justifying Investment in Product Data Management
Proceedings of the PDT Europe 2K, 2000, The Netherlands, pp. 27- 34

Noble and Little | **Noble, C. and Little, D.**
A Survey of the Approach to Training Needs and Staff Development by

2000 *Manufacturing SMEs in West Yorkshire.*

Proceedings of the 3rd International Conference on Stimulating Manufacturing Excellence in Small and Medium Enterprises (SMESME), 17-19 April 2000, Coventry, UK, pp. 535 – 541.

Pendrous 2000 **Pendrous, R.**

Virtual Future

Manufacturing Management, Vol. 9, No. 3, March 2000, pp. 33 - 34

Port 2000 **Port, S.**

Business and PDM

IT Solutions (Supplement to Manufacturing Management, Vol.9, No. 3, March 2000), Spring 2000, pp. 26 - 27.

Rigby et al. 2000 **Rigby, C.; Forrester, P. and Burnett, J.**

The Agile Enterprise - Opportunities for SMEs.

Proceedings of the 3rd International Conference on Stimulating Manufacturing Excellence in Small and Medium Enterprises (SMESME), 17-19 April 2000, Coventry, UK, pp. 96 - 105.

Rhymer 2000 **Rhymer, S.J.**

An investigation into Special Equipment Procedures at Seddon Atkinson Vehicles

MSc dissertation, University of Huddersfield, April 2000.

Wardle 2000 **Wardle, R.**

The Importance of Document Management in ERP.

IT Solutions (Supplement to Manufacturing Management, Vol.9, No. 3, March 2000), Spring 2000, pp. 14 - 15.

Woodcock et al 2000 **Woodcock, D.J.; Mosey, S.P. and Wood, T.B.W**

New Product Development in British SMEs

European Journal of Innovation Management, Vol. 3, No. 4, pp. 212 - 221

Bourke 2001 **Bourke, D.**

Product Development for Mass Customisation - Part 1.

Engineering Data Management Newsletter, June 2001, Vol. 10, No. 9, pp. 1 - 3

CIMdata 2001 **CIMdata**

Collaborative Product Definition Management (cPDM): An Overview

http://www.cimdata.com.

Curran and Blackburn 2001 **Curran, J. and Blackburn. R.A.**

Researching the Small Enterprise

Sage Publications Ltd., London.

Forza and Salvador 2001 **Forza, C. and Salvador, F.**

Product Configuration and Inter-Firm Co-ordination: An Innovative Solution from a Small Manufacturing Enterprise

Proceedings of the 4th International Conference on Stimulating Manufacturing

Excellence in Small and Medium Enterprises (SMESME), 14-16 May 2001, Aalborg, Denmark, pp. 323 - 330.

Jorgensen 2001 | **Jorgensen, K.A.**
Product Configuration - Concepts and Methodology
Proceedings of the 4th International Conference on Stimulating Manufacturing Excellence in Small and Medium Enterprises (SMESME), 14-16 May 2001, Aalborg, Denmark, pp. 314 - 322.

Kemp et al 2001 | **Kemp, J.L.C.; Albiez, A.; Wagner, F. and Roth, N.**
A Knowledge Management Solution for Improving Corporate Product Development
Proceedings of the 7th International Conference on Concurrent Enterprising (ICE), 27-29 June 2001, Bremen, Germany, pp. 277 - 280.

Kidd 2001 | **Kidd, C.**
The Case for Configuration Management
IEE Review, September 2001, pp. 37 - 41

Männistö et al 2001 | **Männistö, T.; Peltonen, H.; Soininen, T. and Sulonen, R.**
Multiple Abstraction Levels in Modelling Product Structures
Data & Knowledge Engineering Journal, 2001, No. 36, pp. 55 - 78

OMG 2001 | **OMG**
COBRA Basics
http://www.omg.com/gettingstarted/cobrafaq.htm

Porter 2001 | **Porter, P.**
Cyber Space Keeps Product Design Soaring.
Global Design News, October 2001, pp. 64 - 66

Chinn 2002 | **Chinn, A.**
It Won't Work!.
CAD User, April 2002, Vol. 15, No. 4, pp. 16 - 17

APPENDIX A - PDM Systems Usage Survey Instrument

University of HUDDERSFIELD

PDM Survey Questionnaire

A. Introduction:

Today, large volumes of data are generated during the lifecycle of a product. Data can be of multiple formats and are stored in various different media. There is a need to employ an efficient and effective data management system to achieve competitive advantage in a business. Product Data Management (PDM) system has been identified as one solution.

PDM system provides the underlying database technology for managing data such as collection, storage, access, control, dissemination, and archiving. It imposes rigid disciplines in defining and categorising the relationships of parts and processes and their lifecycles via an appropriate product structure. It is also an IT base for integration within a heterogeneous computing environment. It is an integral part of concurrent engineering.

When implemented successfully within the organisation, a PDM system can help to reduce time to market; reduce product cost; provide a better product and/or service quality; remove islands of automation; and enhance cross departmental communications.

The architecture of a PDM system within a manufacturing enterprise is shown in Figure 1.

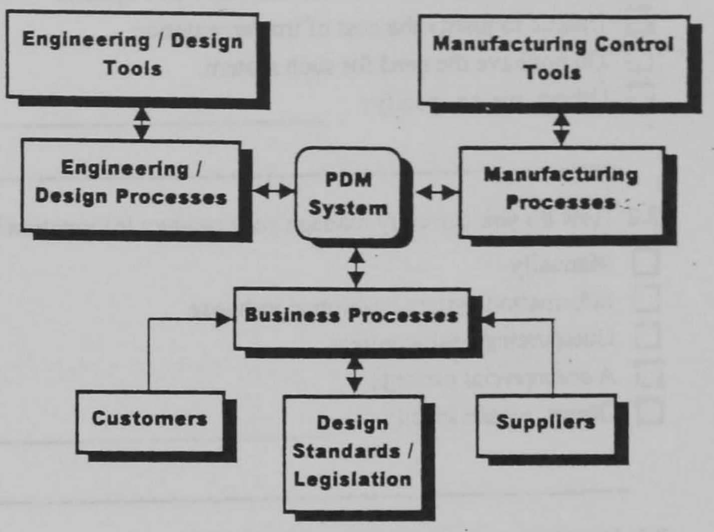


Figure 1 - PDM System within a manufacturing enterprise

B. Objective of Questionnaire.

The objective of this questionnaire is to survey the current usage of PDM in today's UK manufacturing industry. **Section 1** aims to identify the level of PDM usage within the manufacturing industry. **Section 2** investigates the reasons why a PDM system has not been implemented. **Section 3** aims to provide a better understanding of the company's background.

Please complete the blanks below or attach your business name card.

Name: ____________

Position held: ____________

Company's name: ____________

Address: ____________

____

Tel. No: ____________

C. Preliminary questionnaire.

C1. Have you heard of PDM or other similar software ?

☐ Yes ☐ No

C2. Has your company invested in a commercial PDM system ?

☐ Yes ☐ No

C3. How beneficial is / would be a PDM system to your company ?

☐ Of critical importance ☐ Very important
☐ Useful ☐ Marginal
☐ Of no importance ☐ Not sure
☐ Others, please comment : ____________

____

Note : *Please tick at the appropriate box/es.*

SECTION 1 - Only for companies that have implemented a PDM System

For the purpose of this questionnaire, the word "information" is taken as either data and/or documents.

1.1 What is your implemented PDM system ?

☐ CoCreate's WorkManager ☐ Unigraphic's IMAN
☐ Metaphase's Metaphase 3.0 ☐ Sherpa's SherpaWorks
☐ Eigner & Partner's CADIM ☐ MatrixOne's Matrix
☐ IBM's ProductManager ☐ Altris'es Pro-CM
☐ Others, please specify : ____________

1.2 How long has the system been in operation ?

☐ Less than 6 months ☐ 6-12 months ☐ 13 - 24 months
☐ 2 - 3 years ☐ More than 3 years

1.3 What is/are your purpose of implementing a PDM system ?

☐ To control part proliferation and establish standards
☐ To manage engineering drawing system, search and retrieval
☐ To control engineering release and change management
☐ To manage product configuration management
☐ Others, please specify : ____________

____

1.4 Have you integrated/interfaced any computerised applications used in your company with the current PDM system ?

☐ Yes ☐ No

1.5 If Yes, which systems are they ?

☐ CAD / CAE / CAM ☐ MRP / MRPII
☐ CNC / DNC Machines ☐ Quality Assurance System
☐ Project Management ☐ Office Administration Tools
☐ Document Management ☐ Workflow Management
☐ Others, please specify : ____________

____

16. What are the benefits gained from implementing PDM ?

☐ Shorter product lead times.
☐ Better quality and control of information.
☐ Faster access and retrieval of correct information.
☐ Better visibility of product development status.
☐ Reduced unproductive engineering time.
☐ Others, please specify : ____________

____

1.7 How much has the system helped to achieve the competitive advantage for your business ?

☐ Considerably ☐ Moderately
☐ None ☐ Too soon to comment

For the purpose of this questionnaire, the word "information" is taken as either data and/or documents.

SECTION 2 - only for companies that have not implemented a PDM System

2.1 Why has your company not implemented a PDM system ?

- ☐ Unaware of its existence.
- ☐ Lack of computing expertise within the organisation.
- ☐ Unable to find a suitable commercial PDM system.
- ☐ Unable to justify the cost of implementation.
- ☐ Do not have the need for such system.
- ☐ Others, please specify : ____________

2.2 How do you currently manage your product information?

- ☐ Manually
- ☐ Information system developed in-house
- ☐ Outsourcing / sub-contract
- ☐ A commercial package
- ☐ Others, please specify : ____________

2.3 How is your current product information management system ?

☐ Outstanding ☐ Acceptable ☐ Not acceptable

2.4 Do you have any difficulties with your current product information management system ?

☐ Yes ☐ No

2.5. Is your company considering investing in PDM ?

☐ Yes ☐ No ☐ Too soon to decide

2.6 If yes, what is the expected time frame for the implementation ?

☐ Less than 6 months ☐ 6 - 12 months
☐ 1 - 2 years ☐ More than 2 years

2.7. If "Yes" to question 2.4, what are the difficulties?

- ☐ Too many duplications
- ☐ Too much clerical work
- ☐ Unproductive time spent in searching for the right information
- ☐ Unable to re-use existing information
- ☐ Difficulties in locating required information
- ☐ Difficulties in controlling the revision or version of information
- ☐ Poor quality of information
- ☐ Others, please specify : ____________

2.8 In what circumstances would your company consider implementing a PDM system ?

- ☐ A suitable system can be identified.
- ☐ Improved existing computing expertise within the company.
- ☐ Examples of successful companies from similar industry / category.
- ☐ Increased sales.
- ☐ Reduction in PDM costs.
- ☐ Others, please specify : ____________

SECTION 3 (To be answered by ALL)

3.1 Types of industrial sector in:

☐ Aerospace ☐ Automotive
☐ Electrical/Electronic ☐ Computer & Peripherals
☐ Mechanical/Machinery ☐ Household Appliances
☐ Others, please specify : ____________

3.2 Number of employees :

☐ Less than 100 ☐ 101 - 250 ☐ More than 250

3.3 Years of business establishment :

☐ Less than 2 years ☐ 2 - 10 years ☐ More than 10 years

3.4 Annual sales turnover (m = million) :

☐ Less than £ 3m ☐ £ 3m - £ 10m ☐ £ 11m - £ 20m
☐ £ 21m - £ 30m ☐ More than £ 30m

3.5 Computing support system :

☐ None ☐ Mainframe ☐ Mini
☐ Workstation ☐ Client-Server ☐ Stand-alone PCs

3.6 Operating system :

☐ Unix ☐ MS DOS ☐ MS Windows
☐ Others, please specify : ____________

3.7 Networking system :

- ☐ LAN (local distribution within one site)
- ☐ WAN (wide distribution for more than one site)
- ☐ None ☐ Others, please specify : ____________

3.8 Production system :

- ☐ Make to order (High variability, low volume, low inventory)
- ☐ Assemble to order (High variability, low volume, med inventory)
- ☐ Make to stock (Low variability, high volume, high.inventory)
- ☐ Others, please specify : ____________

3.9 Manufacturing control system :

☐ Manual ☐ Finite Scheduling Tools
☐ JIT (Just In Time) / Kanban ☐ MRP/ MRPII
☐ ERP (Enterprise Resource Planning) ☐ OPT (Optimised Production Technology)
☐ Others, please specify : ____________

3.10 Computerised applications used in the company:

☐ CAD / CAE / CAM ☐ MRP / MRPII
☐ CNC / DNC Machines ☐ Quality Assurance System
☐ Product Data Management ☐ Finite Scheduler
☐ Electronic Document Management ☐ Electronic Data Interchange (EDI)
☐ Project Management ☐ Workflow Management
☐ Others, please specify : ____________

Note : *Please tick at the appropriate box/es.*

Thank you for taking the time to complete this questionnaire, please return the completed questionnaire to:

Fax: 01484 - 472340

Ms HL Lee
Manufacturing System Research Group
The University of Huddersfield
Room Z3/04, West Building (Z Block)
Queensgate, Huddersfield HD1 3DH

APPENDIX B - Case Study Questionnaire

BACKGROUND INFORMATION

The Respondent:

Name ______________________

Position ______________________

Years of employment ______________________

Tel. ______________________

The Company:

Name ______________________

Address ______________________

____

Post Code ______________________

1.0 COMPANY INFORMATION

1.1 UK owned?

☐ Fully ☐ Partially

☐ No. Please state the nationality:

____

1.2 Multi sites?

☐ Yes ☐ No

1.3 Is the company a subsidiary of a larger company?

☐ No

☐ Yes. Please state the parent company and origin:

____

1.4 Type of industry classification:

☐ Mechanical Power Transmission

☐ Pumps & Pumping Equipment

☐ Measuring/Testing/Precision - Equipment & Apparatus

☐ Household Appliances

☐ Aircraft & Parts

☐ Computer & Office Equipment

☐ Motor Vehicles - Parts & Equipment

☐ Industrial/Commercial Machinery & Equipment

☐ Others. Please specify:

____

____

____

1.5 Years of establishment of this site:

☐ Less than 2 years ☐ 2 - 5 years

☐ 2 - 10 years ☐ More than 10 years

1.6 Annual sales revenue of this site (m = million):

☐ Less than £ 3m ☐ £ 3m - £ 10m

☐ £ 11m - £ 20m ☐ £ 20m - £ 30m

☐ £ 30m - £ 50m ☐ More than £ 50m

1.7 Number of people employed at this site:

☐ Less than 50 ☐ 50 - 100

☐ 101 - 250 ☐ 251 - 500

☐ 501 - 1,000 ☐ More than 1,000

1.8 Type of permanent employees (not trainees) employed in this site in terms of years of employment:

Longest; _______years Shortest: _______years

1.9 Approximate number of people employed in each department at this site:

Marketing / Sales ________ People

Engineering / Design ________ People

Manufacturing / Production ________ People

Purchasing ________ People

Others ________ People

1.10 Is this site ISO 9000 compliant?

☐ Yes. Please specify the series:

☐ ISO 9001 ☐ ISO 9002 ☐ ISO 9003

☐ Others ______________________

☐ No. Intend to apply for one?

☐ No

☐ Yes. Please specify the approximate when:

☐ Less than 2 years

☐ More than 2 years

1.11 Capacity of this site:

Note: Enter the approximate quantity in brackets

Customer order per month [ ]

Manufacturing order per month [ ]

Shippable end items per month [ ]

Others. Please specify:

______________________[ ]

______________________[ ]

______________________[ ]

1.12 What position do you perceive your company among your competitors?

Top

☐ 10%

☐ 30%

☐ 50%

Bottom

☐ 10%

☐ 30%

☐ 50%

☐ Others. Please specify:

____

2.0 PRODUCT INFORMATION

2.1 Main product(s) produced at this site:

____

____

____

2.2 Number of variant / range of main product(s):

- ☐ Less than 5 ☐ 5 - 10
- ☐ 10 - 20 ☐ 20 - 50
- ☐ 50 - 100 ☐ More than 100

2.3 Number of other products produced at this site:

- ☐ None ☐ Less than 2
- ☐ 2 - 5 ☐ More than 5

2.4 The level of complexity in assembly (in respect of the number of bill of materials levels) for the majority (~80%) of the end products:

- ☐ 1 -2 levels ☐ 3 -4 levels
- ☐ 5 - 8 levels ☐ More than 8 levels

2.5 Number of distinct components in the majority (~80%) of the end products:

- ☐ Less than 5 ☐ 5 - 10
- ☐ 10 - 20 ☐ 20 - 30
- ☐ 30 - 50 ☐ More than 50

2.6 Level of customisation in majority (~80%) of the end products:

- ☐ None. Totally standard (catalogue type)
- ☐ Slight customisation (e.g. labelling)
- ☐ Moderate customisation (e.g. aesthetic)
- ☐ Specific for customer
- ☐ Highly specialised - one off
- ☐ Others. Please specify:

____

2.7 Level of complexity in majority (~80%) of the end products:

☐ High ☐ Medium ☐ Low

2.8 Average lifecycle of the majority (~80%) of the end products:

- ☐ Less than 2 years ☐ 2 - 5 years
- ☐ 5 - 10 years ☐ 10 - 15 years
- ☐ 15 - 20 years ☐ More than 20 years

3.0 MARKET INFORMATION

3.1 Average market share within the UK for the majority (~80%) of the end products:

- ☐ 100% - no competition ☐ 75% - 100%
- ☐ 50% - 75% ☐ 25% - 50%
- ☐ Less than 25%

3.2 Average frequency of introducing new product into the market from this site:

Note: A new product in this context is one that has design implications, might require testing and need a bill of materials that is not a near copy of an existing version.

- ☐ One in every 3 months
- ☐ One in every 6 months
- ☐ One in every 12 months
- ☐ One in every 18 months
- ☐ Others. Please specify:

____

3.3 Level of market uncertainty:

☐ High ☐ Medium ☐ Low

☐ Others. Please specify:

____

3.4 Level of market uncertainty:

Note: 1 being most important and 5 least important

Requirements:	1	2	3	4	5
Quality	☐	☐	☐	☐	☐
Speed of delivery	☐	☐	☐	☐	☐
Cost	☐	☐	☐	☐	☐
Variety	☐	☐	☐	☐	☐
Functionality	☐	☐	☐	☐	☐
Aesthetic	☐	☐	☐	☐	☐
Others. Please specify:					
______________	☐	☐	☐	☐	☐
______________	☐	☐	☐	☐	☐
______________	☐	☐	☐	☐	☐

4.0 ENGINEERING/DESIGN PROCESS

4.1 Using computer tools to aid design process?

- ☐ No
- ☐ Yes. Please specify the type of computer tools and the name of system/s:
  - ☐ Computer-aided design - CAD
    System ______________________
  - ☐ Knowledge Based System - KBS
    System ______________________
  - ☐ Rapid prototyping - RT
    System ______________________
  - ☐ Others. Please specify:
    ____
    ____

4.2 Average engineering/design lead time for a new product:

Note: Engineering / design lead time in this context refers to the total time to produce an approved design ready for production.

☐ Less than 1 week ☐ 1 - 5 weeks
☐ 5 - 10 weeks ☐ More than 10 weeks

4.3 Is design modularity approach an adopted practice when designing new products?

☐ Yes ☐ No

4.4 Is concurrent engineering approach adopted in ALL new product introductions?

- ☐ Yes.
- ☐ No. Please specify the frequency it is applied on new product introduction:
  - ☐ Never ☐ Less than 5%
  - ☐ 5% - 10% ☐ 10% - 20%
  - ☐ 20% - 50% ☐ More than 50%

4.5 Average frequency of engineering changes for a new product introduced:

Note: Engineering changes here refer to changes made after the design has been approved and released for production.

☐ None ☐ Less than 2 times
☐ 2 - 5 times ☐ More than 5 times

4.6 Average type of product data generated to accommodate new product:

Note: Examples of product data are 3D models, 2D drawings, specification, manuals, CNC programs, etc.

☐ Less than 5 types ☐ 5 - 10 types
☐ 10 - 20 types ☐ More than 20 types

4.7 Level of complexity in the design process

☐ High ☐ Medium ☐ Low

5.0 PROCESS PLANNING

5.1 Using computer tools to aid process planning?

- ☐ No
- ☐ Yes. Please specify the type::
  - ☐ Built In-house
  - ☐ Commercially available system. Please specify the name of the system:
    ____
    ____

5.2 Average lead time in process planning for a new product:

Note: Lead time in this context refers to the total time to produce an approved work instruction sheet for production.

☐ Less than 1 week ☐ 1 - 5 weeks
☐ 5 - 10 weeks ☐ More than 10 weeks

5.3 Level of complexity in the process planning:

☐ High ☐ Medium ☐ Low

6.0 MANUFACTURING PROCESS

6.1

Production system:	*High*	*Medium*	*Low*
Variability	☐	☐	☐
Volume	☐	☐	☐
Inventory	☐	☐	☐

6.2 Using computer tools to aid manufacturing process?

- ☐ No
- ☐ Yes. Please specify the type::
  - ☐ Built In-house
  - ☐ Commercially available system. Please specify the name of the system:
    ____
    ____

6.3 Number of operations required in the majority (~80%) of instances to convert a raw material into a finished product:

☐ Less than 5 ☐ 5 - 10
☐ 10 - 15 ☐ More than 15

6.4 Average manufacturing lead time for a new product:

Note: Manufacturing lead time in this context refers to the total time to produce a product while in production / shop floor.

☐ Less than 1 week ☐ 1 - 5 weeks
☐ 5 - 10 weeks ☐ More than 10 weeks

6.5 Level of complexity in the manufacturing process

☐ High ☐ Medium ☐ Low

6.0 PDM IMPLEMENTATION

6.1 PDM system(s) implemented:

- ☐ IBM's ProductManager
- ☐ Metaphase's Metaphase 3.0
- ☐ Eigner & Partner's CADIM
- ☐ MatrixOne's Matrix
- ☐ Sherpa's SherpaWorks
- ☐ Unigraphic's IMAN
- ☐ Others, please specify :

____

6.2 How long has the system been in operation?

- ☐ Less than 6 months
- ☐ 6 - 12 months
- ☐ 13 - 24 months
- ☐ 2- 3 years
- ☐ 3 - 5 years
- ☐ More than 5 years

6.3 Purpose(s) of implementing PDM system(s):

- ☐ To control engineering release and change management
- ☐ To manage engineering drawing system, search and retrieval
- ☐ To manage product configuration management
- ☐ To provide a platform for integration
- ☐ Others, please specify :

____

____

____

____

____

____

1.4 Have you integrated/interfaced any computerised applications used in your company with the current PDM system ?

- ☐ Yes
- ☐ No

1.5 If Yes, which systems are they ?

- ☐ CAD / CAE / CAM
- ☐ MRP / MRPII
- ☐ CNC / DNC Machines
- ☐ Quality Assurance System
- ☐ Project Management
- ☐ Office Administration Tools
- ☐ Document Management
- ☐ Workflow Management
- ☐ Others, please specify : ______________________________

____

16. What are the benefits gained from implementing PDM ?

- ☐ Shorter product lead times.
- ☐ Better quality and control of information.
- ☐ Faster access and retrieval of correct information.
- ☐ Better visibility of product development status.
- ☐ Reduced unproductive engineering time.
- ☐ Others, please specify : ______________________________

____

1.7 How much has the system helped to achieve the competitive advantage for your business ?

- ☐ Considerably
- ☐ Moderately
- ☐ None
- ☐ Too soon to comment

APPENDIX C - Production Tracking and Shortage Control [ProTSC] User Instruction Manual

USER INSTRUCTION MANUAL

FOR THE

SEDDON ATKINSON VEHICLES'
PRODUCTION TRACKING AND SHORTAGE CONTROL (ProTSC)
PROTOTYPE SYSTEM

7.0 APPENDIX B

1.0 OVERVIEW

There are three main screens available: the ***Management Screen***, the ***Production Control Screen***, and the ***Material Control Screen***. To ensure data integrity, **ProTSC** is designed in a way where some screens and their sub-screens are for viewing only whilst some are editable. The ***Management Screen*** is available for viewing only, no editing can be done in this screen and any of its sub-screens. The ***Production Control Screen*** and its sub-screens are all editable screens. The ***Material Control Screen*** has only one editable sub-screen whilst the rest are for viewing only. Appendix A shows the snapshots for all the screen displays for **ProTSC** and examples of all reports available are provided in Appendix B.

2.0 TO START

When entering the system, the user will be prompted to enter his/her login name and password. The correct combination of login name and password determines which screens the user has access right to.

3.0 MANAGEMENT SCREEN

Upon entering the ***Management Screen***, the user will be shown the details of all the records of vehicle orders available in the system. The user can browse through each record by using the navigation button which is located at the centre bottom of the screen. A query box with five (5) options, called the *Search Options*, is provided at the left hand side of the screen for specific query (see Figure 1, pp. A1).

To narrow down the search, option "More Specific Search" should be chosen. Once this option is selected, a list of search criteria is displayed (see Figure 3, pp. A2). Figure 3, pp. A2, shows the results of a search based on two criteria: *Distributor Code* and *Production Stage*. Note that if no record is found, the right hand side of the screen will be blank and the navigation button disabled.

Above the navigation button, at the right most corner, is the *Preview Vehicle Status* button which allows the user to preview the "Vehicle Status Report" before printing. The report is based on the query option selected by the user. For example, if option "Distributors" is selected and the distributor code is set to *S406A*, then the report will only display all records with distributor code of *$406A*. If the default option is selected, "Show All Vehicle Orders", then all records available will be displayed in the "Vehicle Status Report". For a printout example of the "Vehicle Status Report" for Distributor Code $406A, see Report 1, pp. B1

3.1 Parts Missing Details

If there is a part missing from the selected record, the user can click on the *Part Missing* button, located slightly above the navigation button, to view the details. Note that the *Part Missing* button is only enabled when there is at least one part missing from the vehicle, i.e. not fitted to the vehicle. When this button is clicked, the *Parts Missing* sub-screen will be displayed, as shown in Figure 2, pp. A1. There are two buttons provided in this sub-screen: *Preview Selected Vehicle* and *Preview All Vehicles with Parts Not Fitted.* These buttons are used to display the report "Vehicle's Part Shortage and Not Fitted List". The difference between these two buttons is that *Preview Selected Vehicle* displays the "Vehicle's Part Shortage and Not Fitted List" for one particular vehicle, whereas the other button displays all records of vehicles which have parts missing. Report 2, pp. B2, shows a printout example of the report entitled "Vehicle's Part Shortage and Not Fitted List" for all vehicles which have parts missing.

3.2 Vehicle Tracking Details

Next to the *Parts Missing* button is the *Tracking* button which is only enabled when the vehicle has started production. When the user clicks this button, the *Vehicle Tracking Details* sub-screen will be displayed, see Figure 3, pp. A2. The *Preview Variance Analysis* button can be used to preview the report "Variance Analysis" for the selected model of vehicle, i.e. the E-Code of a vehicle. See Report 3, pp. B3, for an example printout of this report for model E270191.

3.3 Overview Option

Within the *Search Options*, there is an option called *Overview*. When this option is selected, the user has to enter the year for the weekly overview, e.g. 1999. Once the year has been entered, *Overview* sub-screen will be displayed. This sub-screen shows the weekly loading of the production stages, as shown in Figure 4, pp. A2.

4.0 PRODUCTION CONTROL SCREEN

Similar to the ***Management Screen***, the ***Production Control Screen*** has a query box, called *Control Options*, which has nine (9) operations that can be performed by authorised users, see Figure 5, pp. A3. The default for this Control Option is the *Production Stages*. The following sub-sections discuss each of the nine options available.

4.1 Production Stages

When this option is selected, the *Production Stages* sub-screen will be displayed, see Figure 5, pp. A3. This sub-screen shows where all vehicles are currently available in the shop floor. A Display Stage Option is provided for selecting the required production stage. If the display is not sorted, an ascending/descending sorting options are available by right clicking the mouse button, as shown in Figure 9, pp. A5. Note that the vehicle's work order number is prefixed with either "C_" or "S_" to show the type of order of that vehicle. Refer to the next sub-section, 4.2, for the types of prefix used.

A "moving" mechanism is built into the system to move a vehicle to its next production stage when it has completed its current stage. To activate the "moving" mechanism, move the mouse pointer to the required vehicle's work order number and double click on the left button mouse. Note that the moving mechanism is only available when the cursor is on the "WOrder" column. A confirmation message dialogue window will appear before the moving mechanism takes place. To confirm that the current operation is completed, click on the *OK* button. Once the *OK* button has been clicked, the selected vehicle will be moved to the next appropriate stage. If a wrong vehicle is moved, then the mistake has to be corrected manually. Refer to sub-section 4.4 for details on how to rectify the mistake.

When option "CM14" is chosen from the *Display Stage Option*, an additional field, *Delivered*, will be displayed. When performing the "moving" mechanism for vehicles that are in the "CM14" stage, the user has to take note of the Delivered date – the moving mechanism will not work if the vehicle selected is delivered only a month ago.

To print the list of vehicle in a particular Production Stage, the user has to go to the Management Screen and use the "More Specific Search" option to display the required stage. Refer to sub-section 3.0 for more details.

4.2 Scheduled Week for Production (CM02)

When this option is selected, the *Scheduled Week for Production* sub-screen will be displayed. Note that this sub-screen is similar to the *Production Stage* sub-screen, see Figure 6, pp. A3. Note that all vehicles' work order numbers are prefixed with an alphabet to show the type of order. The prefixes used are:

- F - for a forecast order
- C - for a confirmed customer order
- S - for a make to stock order
- R - for a refurbished order

A 'Production week' filter is provided to select a required production week. This is selected by entering (YY/MM) e.g. 0005. When this filter is used, only the filtered records are displayed. ProTSC also displays the maximum capacity per week as entered by manufacturing in the Weekly capacity table.

A "moving" mechanism is also provided in this sub-screen for moving a vehicle from scheduled for production to start production, i.e. moving from *CM02* to both *FRM* and *CAS*. Note that the moving mechanism is only available for vehicles with prefixes "C" or "S", and it will only be activated if the cursor is on the "WOrder" column. Refer to sub-section 4.1 for details on how to activate the "moving" mechanism. If a mistake is made when moving a vehicle from *CM02* to *FRM* and *CAS*, then the mistake has to be corrected manually. Refer to sub-section 4.4 for details on how to rectify the mistake.

To print the list of CM02 vehicle, the user has to go to the Management Screen and use the "More Specific Search" option. Set the *Production Stage* to "CM02" and then enter the *Scheduled Week*, if required. Refer to sub-section 3.0 for more details.

4.3 Standard Time for Vehicle Series and SE

When new standard time is established for the vehicle series, the necessary information can be entered to **ProTSC** by selecting the *Vehicle Series Std Time*. Figure 7, pp. A4, shows the display of the sub-screen for *Standard Time for Vehicle Series*. To enter a newly established standard time for a certain vehicle range, scroll along the vertical scroll bar to reach the last record line. Note that there can not be two identical vehicle series description.

SE standard time is obtained through the download from the mainframe and thus the field *Description*, when option *SE Std Time* is selected, is not editable. However, the standard hours for each operation can be modified. Figure 8, pp. A4, shows the *SE's Standard Time* sub-screen. Note that both the *Standard Time for Vehicle Series* and *Standard Time for SE* sub-screens have a *Preview Standard Time* button.

Hence, if there is a change in the existing standard time for both SE and Vehicle Series, use the ***Find*** option to locate the required vehicle range. The ***Find*** option is available in the pop up menu, as shown in Figure 9, pp. A5, when the right-hand mouse button is clicked. Note, only click the right-hand mouse button when the mouse pointer is at the "Description" column. When this option is selected, a standard MS Access *Find* dialogue window will appear for finding the required vehicle series or SE, see Figure 10, pp. A5. Enter the vehicle series required at the text box for *Find What*. Before selecting the *Find First* or *Find Next* button, the user can refine his/her search by selecting the type of *Search* and *Match* options required.

There are three (3) types of *Search* options: *Up* for upward searching, *Down* for downward searching, and *All* to search all records. It is recommended to use the *All* option unless the user is very sure of the position of the required record relative to the current record. Similar to the type of *Search* option, *Match* has also three (3) options: *Whole Field* for a complete match of what is entered, *Any Part of Field* for partial match of what is entered, and *Start of Field* for matching the beginning with what is entered. In the *Standard Time for Vehicle Series* sub-screen, it is recommended to use the *Any Part of Field* option to avoid entering the complete vehicle series description. If *Match Case* is checked, then the user has to make sure that appropriate capital letters and small letters are entered correctly. Failing to do so will result in zero record found. Thus, it is recommended not check this option.

As the *Find* dialogue window is called when the mouse pointer is at the "Description" column, the option *Search Only Current Field* will be checked. It is recommended to leave this option checked to enable a faster search. However, if the *Find* dialogue window is called when the mouse pointer is not at the "Description" column, do not check this option even if it is enabled. This option is only useful if the mouse pointer is located at the correct column where the ***Find*** option is needed. A standard MS Access error message window will be displayed if no record is found. To proceed, close this error message window by clicking the ***OK*** button.

The *Preview Standard Time* button allows the user to preview the corresponding "Standard Time Report", e.g. if Control Option is *Standard Time for Vehicle Series*, then the report will be "Vehicle Series Standard Time". Examples of printout report for the "Vehicle Series Standard Time" and the "SE Standard Time" can be found in Report 6, pp. B6, and 7, pp. B7, respectively.

4.4 General Vehicle Order Data

When this option is selected, the *General Vehicle Order Information* sub-screen will be displayed, as shown in Figure 11, pp. A6. The purposes of having this sub-screen are of twofold:

1. to correct the mistake made as mentioned in sub-section 4.1 and 4.2;
2. to enter the forecast start date and completion date of a vehicle.

Note that all information on this sub-screen, except those under the heading of *Production Data*, is not editable.

To rectify the mistake made as mentioned in sub-section 4.1 and 4.2, delete the date and time for the particular stage which the vehicle had been wrongly moved. To fast find a specific vehicle record, for example based on the chassis number, move the mouse pointer to the text box for Chassis Number, then right click the mouse button and choose the *Find* option. When option is selected, the MS Access standard *Find* dialogue window will be displayed. Refer to sub-section 4.3 for more information on how to use the *Find* dialogue window.

4.5 Model Production Capacity

This option is provided for the purpose of recording the maximum production capacity per week based on the vehicle model type or model groups. When this option is selected, the ***Production Capacity*** sub-screen will be displayed, as shown in Figure 12, pp. A6.

4.6 New ECode Assignment

When a new ECode is introduced during the download, there is a need to assign its vehicle series type as the download does not provide such information. This option is provided to allow such task to be carried out. When this option is selected, the *E-Code Assignment* sub-screen will be displayed, see Figure 13, pp. A7. Select the correct vehicle series by scrolling down the combo box. Alternatively, the user can also type in the correct vehicle series. An error message window will be displayed if the entered vehicle series does not already exist in the system.

Hence, if there is a new vehicle series introduced, it is necessary to enter the information in the option ***Vehicle Series Standard Time*** before an E-Code can be assigned to it.

4.7 Parts Shortage Input

When a part is reported missing from a vehicle, the *Part Shortage Input* sub-screen can be used to record the shortage. Figure 14, pp. A7, shows the display of the *Part Shortage Input* sub-screen. To find the required vehicle, move the mouse pointer to either the "WOrder" text box or the "Chassis" text box, and then click the right hand mouse button to activate the ***Find*** option. Once the required vehicle is found, enter the correct combination of "Prefix", "Part Root Number" and "Suffix" to retrieve the correct part reported short from the selected vehicle. When entering the "Part Root Number", it is not necessary to type in the leading zeros if the part root number has less than seven (7) digits. For example, if the part root number is "0000251", enter only "251" and **ProTSC** will fill the four (4) leading zeros automatically.

Only with a correct combination of Prefix, Root and Suffix will the description of the part be displayed. If the part description is blank, check the combination again. Once the correct part has been retrieved, enter the quantity reported short from the selected vehicle. After entering the quantity for shortage, **ProTSC** will automatically assigned current date to the column "Date Reported". Note that this last column is not editable. Tab key, on the keyboard, can be used to move from one column to another instead of the mouse.

After finish entering the reported shortages, it is important to make sure that the record selector is shown as a black triangle [▸] and not a pencil [... ✎]. The record selector is located at the left-hand side of the all records. If the record selector is shown as a pencil, move the mouse pointer to the "WOrder" text box.

Two preview buttons are provided in this sub-screen for previewing the report "Vehicle Parts Shortage and Not Fitted List": *Preview Selected Vehicle* only displays the report for the selected vehicle, whereas *Preview All Vehicles with Shortages* shows report for all vehicles which have part shortages reported from them. See Report 2, pp. B2 for an example of this report. Note that the *Preview Selected Vehicle* button is only enabled when there is, at least, one part reported short from that specific vehicle.

4.8 Parts Arrived or Fitted Input

Two options are provided to record parts arrived and/or fitted to vehicles: ***WOrder*** and ***Part Number***. Figure 15, pp. A8, shows the display of *Part Arrived or Fitted Input - WOrder* sub-screen and Figure 16, pp. A8, shows the *Part Arrived or Fitted Input - Part Number* sub-screen. The user can choose to update the existing parts missing from vehicles, i.e. parts arrived and/or fitted onto the vehicles, using either one of these two options. Note that all fields, except "Today In" and "Today Fitted", are not editable.

To fast find a specific part shortage record, move the mouse pointer to required text box and then right click the mouse button to activate the *Find* option. For example, when using the option *Part Arrived or Fitted Input - WOrder*, move the mouse pointer to the "WOrder" text box, or "Chassis" text box if preferred. Refer to sub-section 4.3 for more information on how to use the *Find* dialogue window.

There are three (3) buttons designated in these two sub-screens:

- Option ***WOrder***: *Preview Selected Vehicle*, *Preview All Vehicles with Parts Missing*, and *Update Parts Missing*,
- Option ***Part Number***: *Preview Selected Part*, *Preview All Parts with Shortages*, and *Update Parts Missing*,

Once the appropriate entries have been made for parts arrived and/or fitted, use the *Update Parts* ***Missing*** button to update the status of parts missing from vehicles. However, before doing that, it is important to check that the record selector at the left-hand side is shown as a black triangle [▸] and not a pencil [... ✎].. If the record selector is shown as a pencil, move the mouse pointer to the following respective text box before clicking the ***Update Missing*** button:

- If using option ***WOrder***: "WOrder" text box
- If using option ***Part Number***: "Part Root Number" text box

If the other two buttons are clicked before the missing parts are updated, then the previewed report will not show the correct updated information. Hence, it is recommended to use these preview buttons after parts missing from vehicles have been updated. In the *Part Arrived or Fitted Input - WOrder* sub-screen, the two preview buttons are used to preview the report "Vehicle's Parts Shortage and Not Fitted List". Report 2, pp. B2 shows an example of this report. The two preview buttons in the *Part Arrived or Fitted Input - Part Number* sub-screen are used to preview the report "Production Parts Shortage List", Report 9, pp. B9 shows an example of this report.

4.9 Weekly Production Capacity

An option is provided to record the manufacturing weekly production capacity. (Total for all models). This information is entered against each 'production week' and is displayed in the Production screen (CM02 stage) when this production week filter is utilised.

5.0 MATERIALS CONTROL SCREEN

As in the ***Management Screen*** and ***Production Control Screen***, the ***Materials Control Screen*** also has a query box, called the *Materials Control Option*, which has four (4) options. As shown in Figure 17, pp. A9, the default option is the "Stock In Hand" which display the currently available stock. All sub-screens in Material Control Screen, except *Vendor Details*, *Parts With Shortages and the temporary buyer field in 'Parts Details'* are for viewing and they are non editable. The following sub-sections discuss about each of the four options available.

5.1 Stock In Hand

When this option is selected, the *Stock In Hand* sub-screen will be displayed, as shown in Figure 17, pp. A9. As mentioned, this sub-screen is for viewing only and thus no editing is possible. A *Print Preview* button is provided to preview the report "Stock In Hand". An example of the "Stock In Hand" report is shown in Report 8, pp. B8.

5.2 Parts Details

To view the details of a specific part, select the option *Part Details* from the *Material Control Option* box. When this option is selected, a query box will be displayed at the bottom of the *Material Control Option* box as well as the *Part Details* sub-screen, as shown in Figure 18, pp. A9. The default for the query box is "All" which displays all the parts available. To narrow down the search, select one of the seven (7) options from the query box and then enter, or select by scrolling the list, the search criteria in the text box provided. Note that with the exception of the 'temporary buyer' field, this sub-screen is also for viewing purposes only.

The temporary buyer field can be used to record the buyer initials/numeric code when this information is unavailable via the download.

5.3 Part with Shortages

Similar to the option *Part Details*, *Part With Shortages*, when selected, will display the query box beside the *Part With Shortage* sub-screen, as shown in Figure 19, pp. A10. Again, the default for the query box is "All" which shows all parts with shortages reported from production. Refer to sub-section 5.2 for details on using the query box. The purpose of this sub-screen is to allow the user to enter the Promise In Dates for parts reported short from production. Note that all fields in this sub-screen, except for "Promise In", are not editable.

Two buttons are provided in this sub-screen: ***Preview Selected Part*** and ***Preview All Parts with Shortages***. These preview buttons are for previewing the report "Production Parts Shortage List". See Report 9, pp. B9 for an example of this report.

5.4 Vendor Details

The last option in the *Material Control Screen* is the *Vendor Details*. When this option is selected, *the Vendor Details* sub-screen will be displayed, as shown in Figure 20, pp. A10. By right clicking the mouse button, the *Find Record*, *Sort Ascending*, and *Sort Descending* options are available for selection. Note that this sub-screen is currently editable by User Groups 'PUR', 'ISS', and 'MGT'. Under 'normal' circumstances this information should be provided by the 'Vendor details' download. When this data is imported, existing text in ProTSC will be replaced.

Figure 1 Management Screen Display

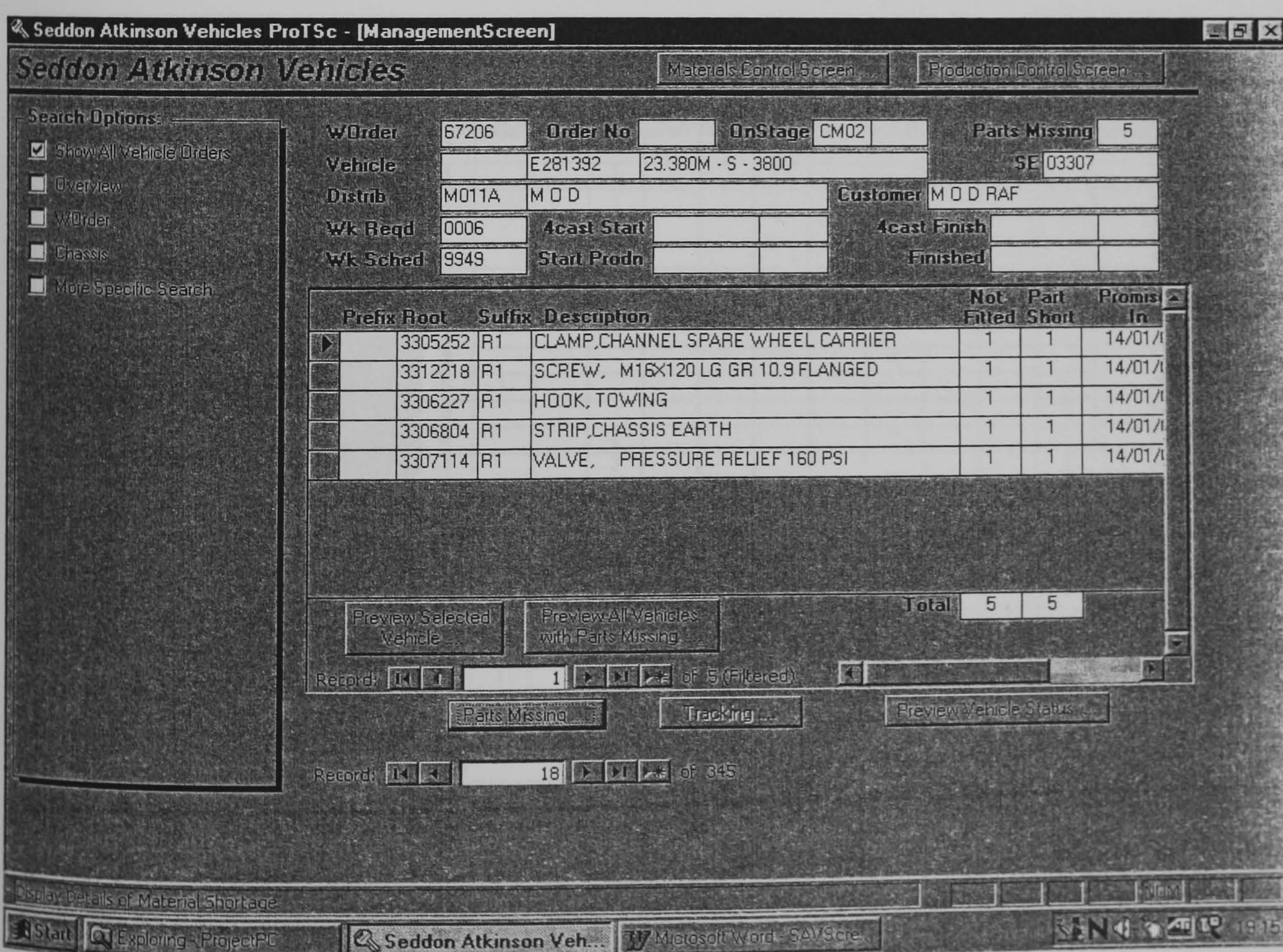


Figure 2 Management Screen showing Parts Missing

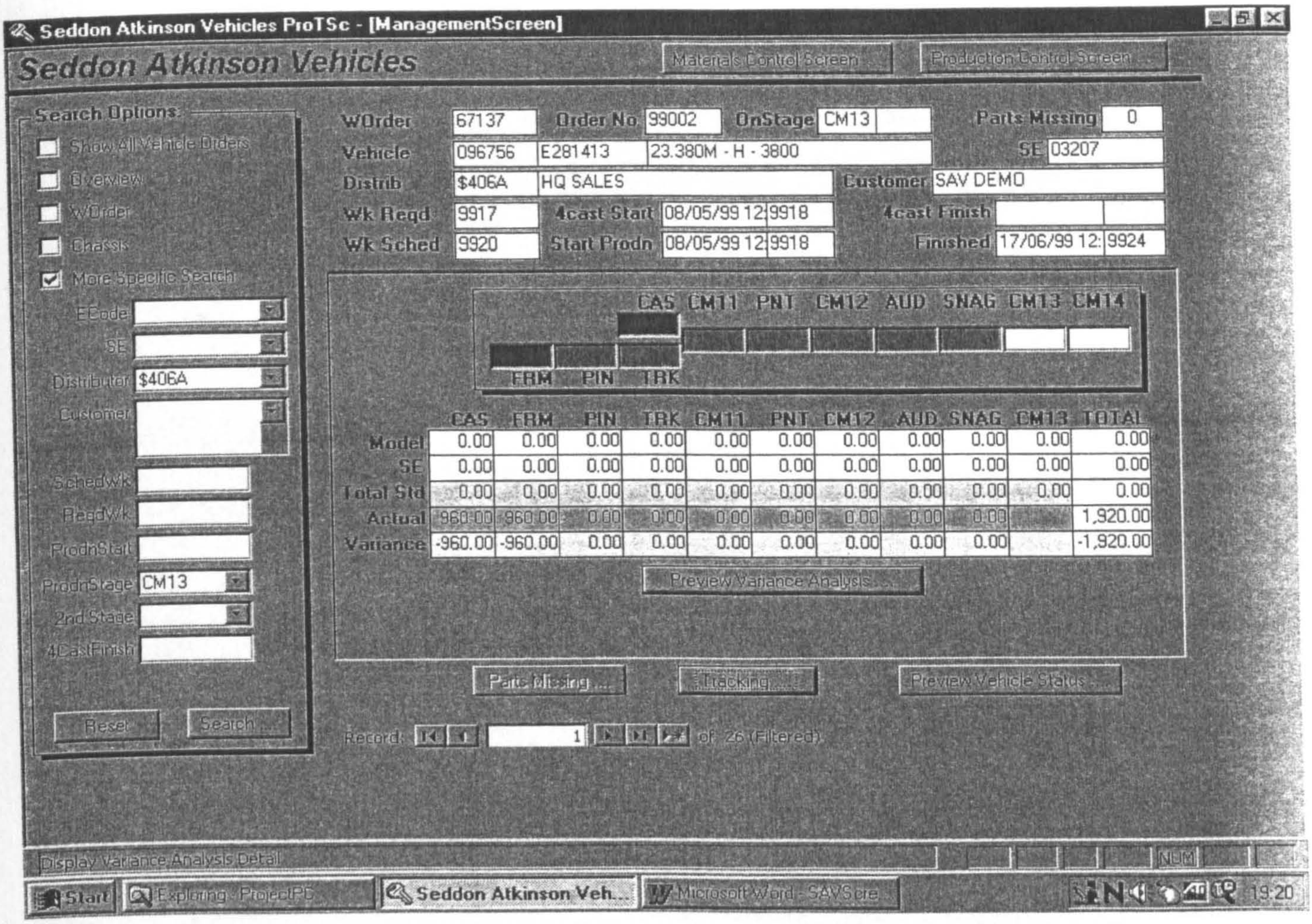


Figure 3 Management Screen showing Vehicle Tracking Details

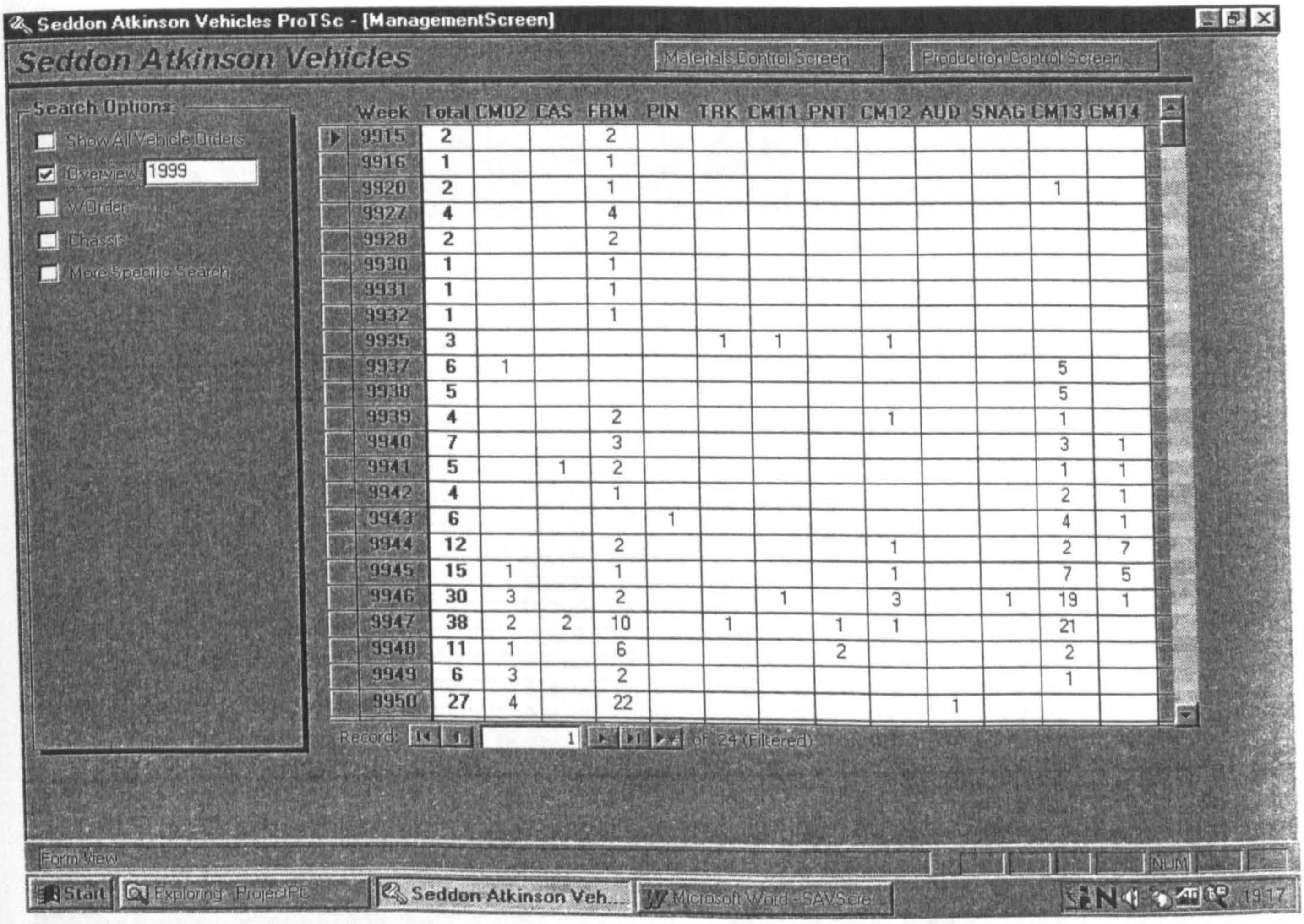
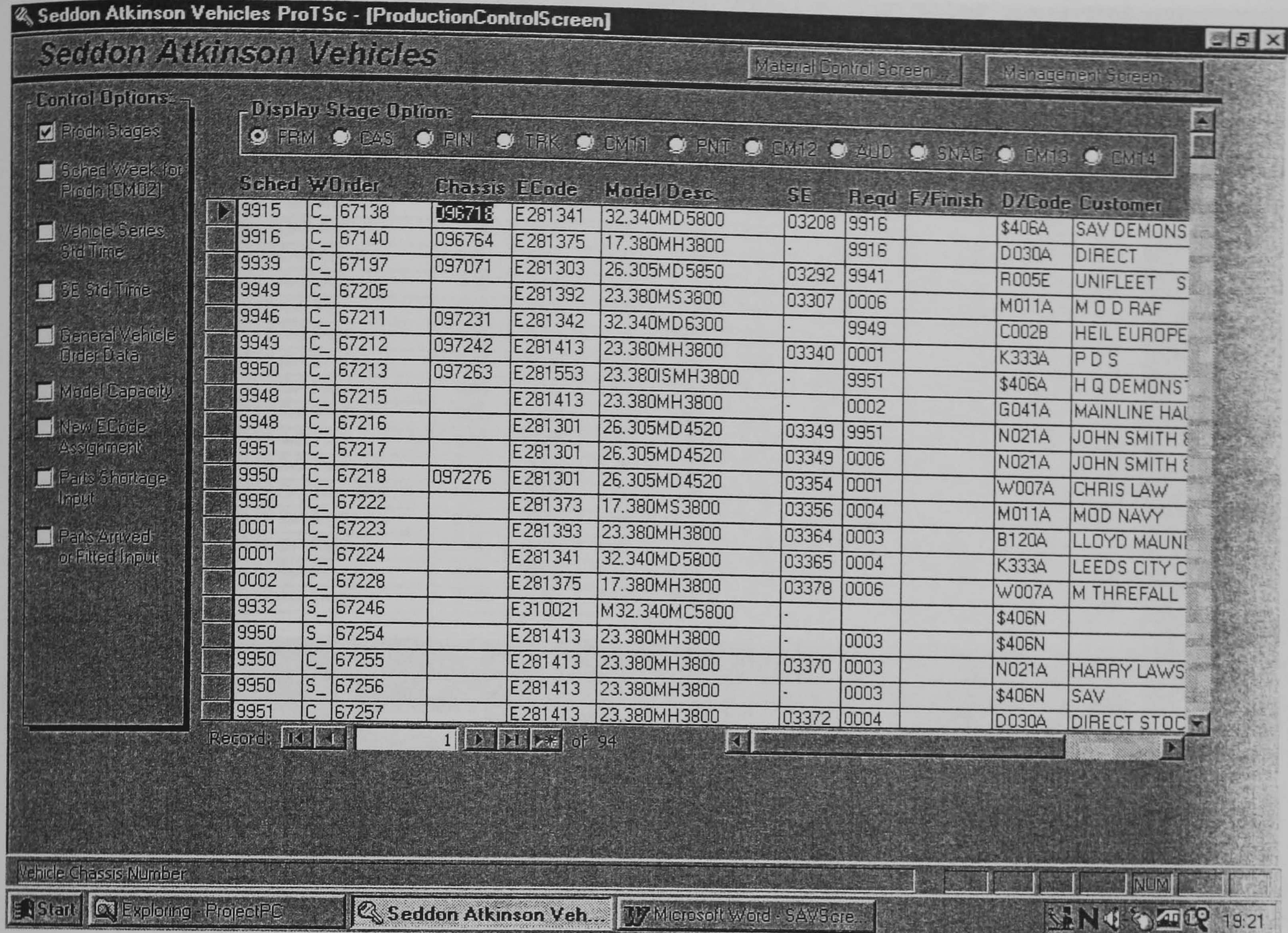


Figure 4 Management Screen showing Overview Details



Sched	WOrder		Chassis	ECode	Model Desc.	SE	Reqd	F/Finish	D/Code	Customer
9915	C_	67138	096718	E281341	32.340MD5800	03208	9916		$406A	SAV DEMONS
9916	C_	67140	096764	E281375	17.380MH3800	-	9916		D030A	DIRECT
9939	C_	67197	097071	E281303	26.305MD5850	03292	9941		R005E	UNIFLEET S
9949	C_	67205		E281392	23.380MS3800	03307	0006		M011A	M O D RAF
9946	C_	67211	097231	E281342	32.340MD6300	-	9949		C002B	HEIL EUROPE
9949	C_	67212	097242	E281413	23.380MH3800	03340	0001		K333A	P D S
9950	C_	67213	097263	E281553	23.380ISMH3800	-	9951		$406A	H Q DEMONS
9948	C_	67215		E281413	23.380MH3800	-	0002		G041A	MAINLINE HA
9948	C_	67216		E281301	26.305MD4520	03349	9951		N021A	JOHN SMITH
9951	C_	67217		E281301	26.305MD4520	03349	0006		N021A	JOHN SMITH
9950	C_	67218	097276	E281301	26.305MD4520	03354	0001		W007A	CHRIS LAW
9950	C_	67222		E281373	17.380MS3800	03356	0004		M011A	MOD NAVY
0001	C_	67223		E281393	23.380MH3800	03364	0003		B120A	LLOYD MAUN
0001	C_	67224		E281341	32.340MD5800	03365	0004		K333A	LEEDS CITY C
0002	C_	67228		E281375	17.380MH3800	03378	0006		W007A	M THREFALL
9932	S_	67246		E310021	M32.340MC5800	-			$406N	
9950	S_	67254		E281413	23.380MH3800	-	0003		$406N	
9950	C_	67255		E281413	23.380MH3800	03370	0003		N021A	HARRY LAWS
9950	S_	67256		E281413	23.380MH3800	-	0003		$406N	SAV
9951	C	67257		E281413	23.380MH3800	03372	0004		D030A	DIRECT STOC

Figure 5 Production Screen showing Production Stages of Vehicle Orders

Sched	WOrder		Chassis	ECode	Model Desc.	SE	Reqd	F/Finish	D/Code	Customer
9949	C_	67206		E281392	23.380MS3800	03307	0006		M011A	M O D RAF
9949	C_	67207		E281392	23.380MS3800	03307	0006		M011A	M O D RAF
9950	C_	67219		E281373	17.380MS3800	03355	0004		M011A	MOD RAF
9950	C_	67220		E281373	17.380MS3800	03355	0004		M011A	MOD RAF
9950	C_	67221		E281373	17.380MS3800	03355	0004		M011A	MOD RAF
0002	C_	67225		E281563	23.405ISMH3800	03373	0004		D030A	DIRECT DEMC
0002	C_	67226		E281413	23.380MH3800	03371	0005		D030A	DIRECT STOC
0003	C_	67227		E281563	23.405ISMH3800	03375	0009		D030A	K & K HAULAG
0003	C_	67229		E281375	17.380MH3800	03379	0010		W007A	M THRELFALL
0004	C_	67230		E281375	17.380MH3800	03378	0015		W007A	M THREFALL
0005	C_	67231		E281341	32.340MD5800	03384	0009		$406A	COMPANY DE
0005	C_	67232		E281341	32.340MD5800	03387	0009		C002B	NORTH LANA
0005	C_	67233		E281341	32.340MD5800	03387	0009		C002B	NORTH LANA
0005	C_	67234		E281341	32.340MD5800	03387	0009		C002B	NORTH LANA
0005	C_	67235		E281301	26.305MD4520	03390	0008		C002B	ROBERT COO
0005	S_	67236		E281341	32.340MD5800	03389	0009		$406N	SAV
0007	S_	67237		E281483	17.340ISMS3800	-	0010		$406N	
0007	S_	67238		E281483	17.340ISMS3800	-	0010		$406N	
0007	S_	67239		E281553	23.380ISMH3800	-	0010		$406N	
0007	S	67240		E281553	23.380ISMH3800	-	0010		$406N	

Figure 6 Production Screen showing Vehicle Orders Scheduled Week

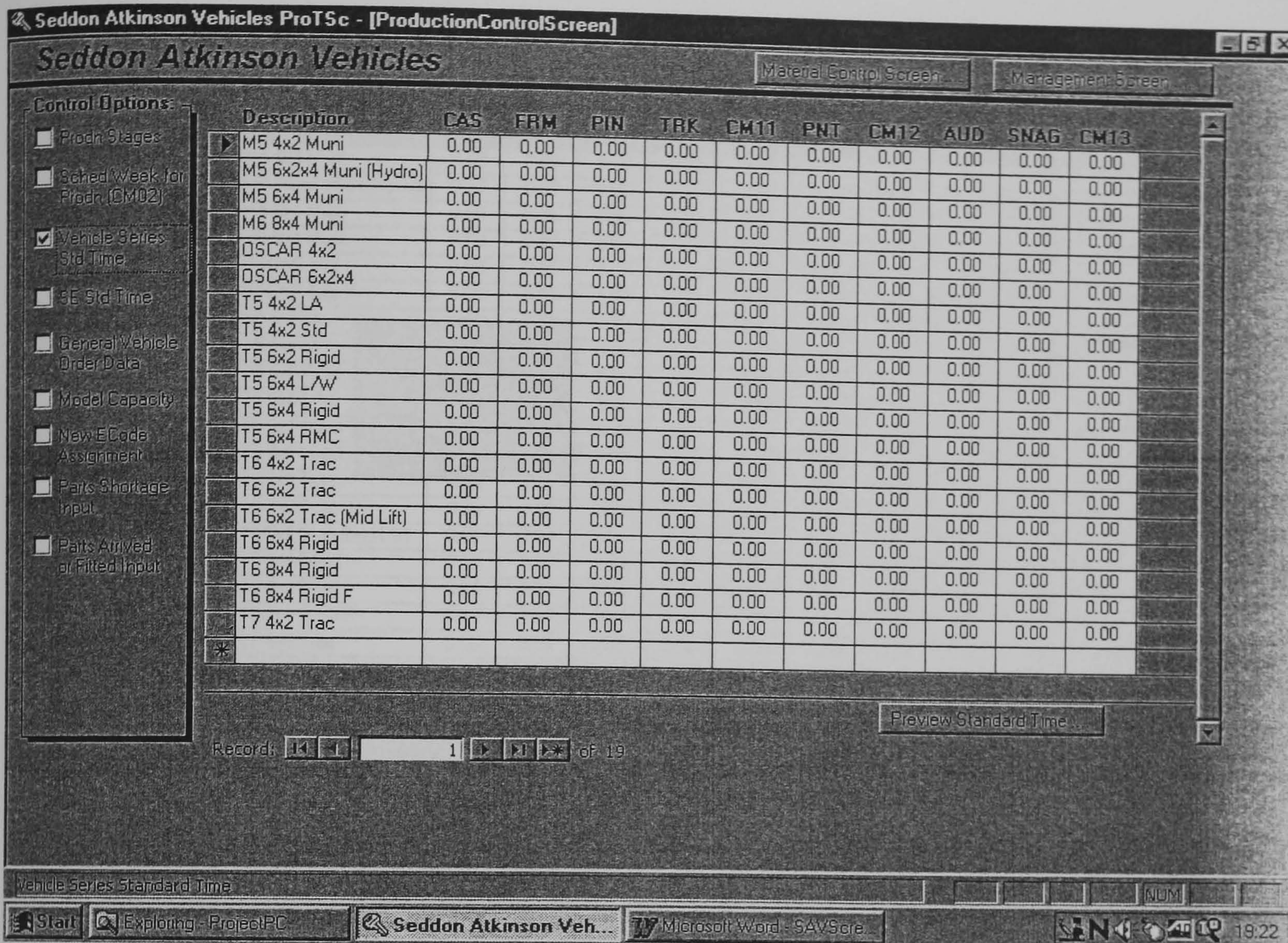


Figure 7 Production Screen showing Vehicle Series Standard Time Input

Figure 8 Production Screen showing SE Standard Time Input

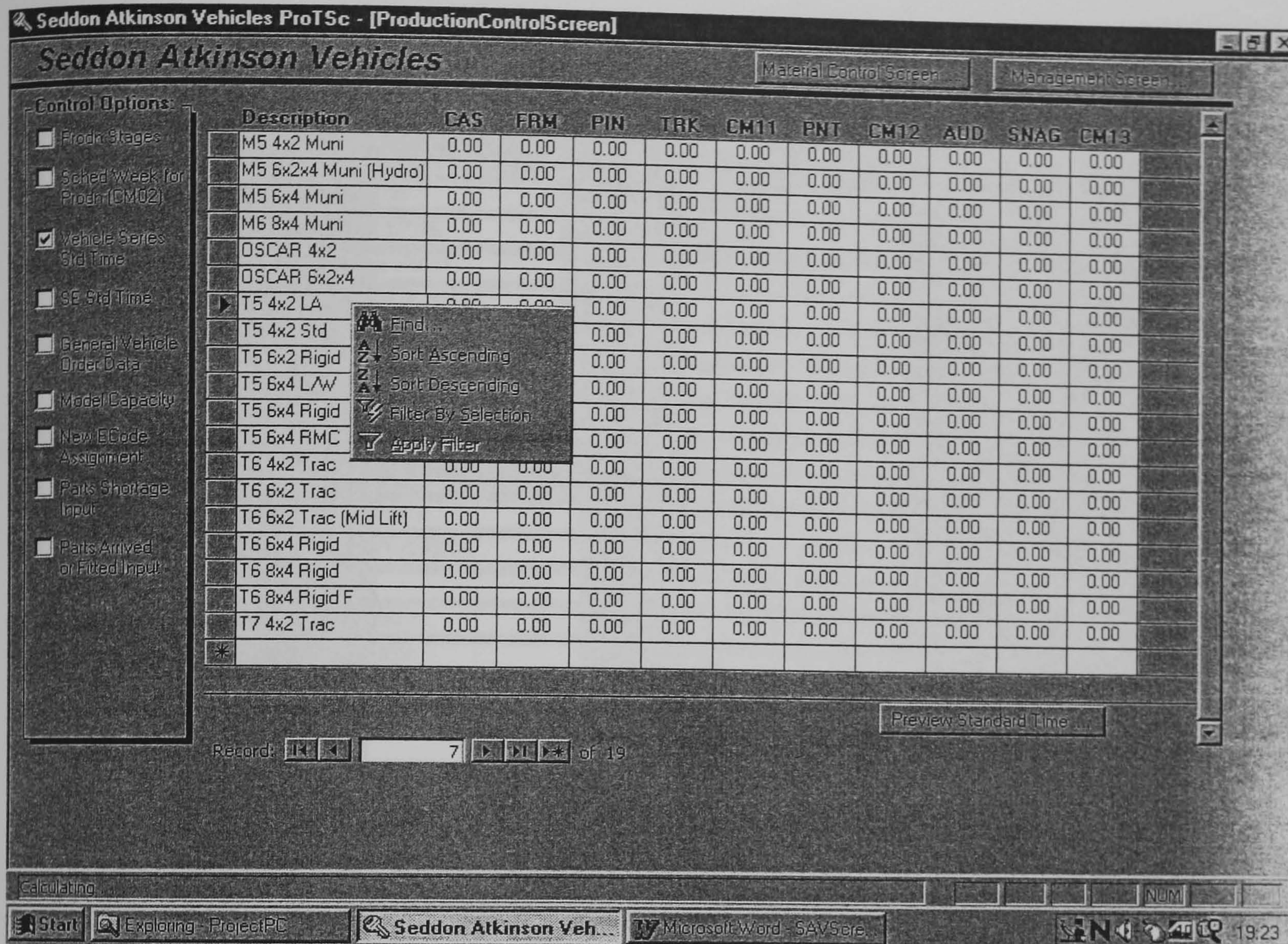


Figure 9 Production Screen showing Pop Up Menu

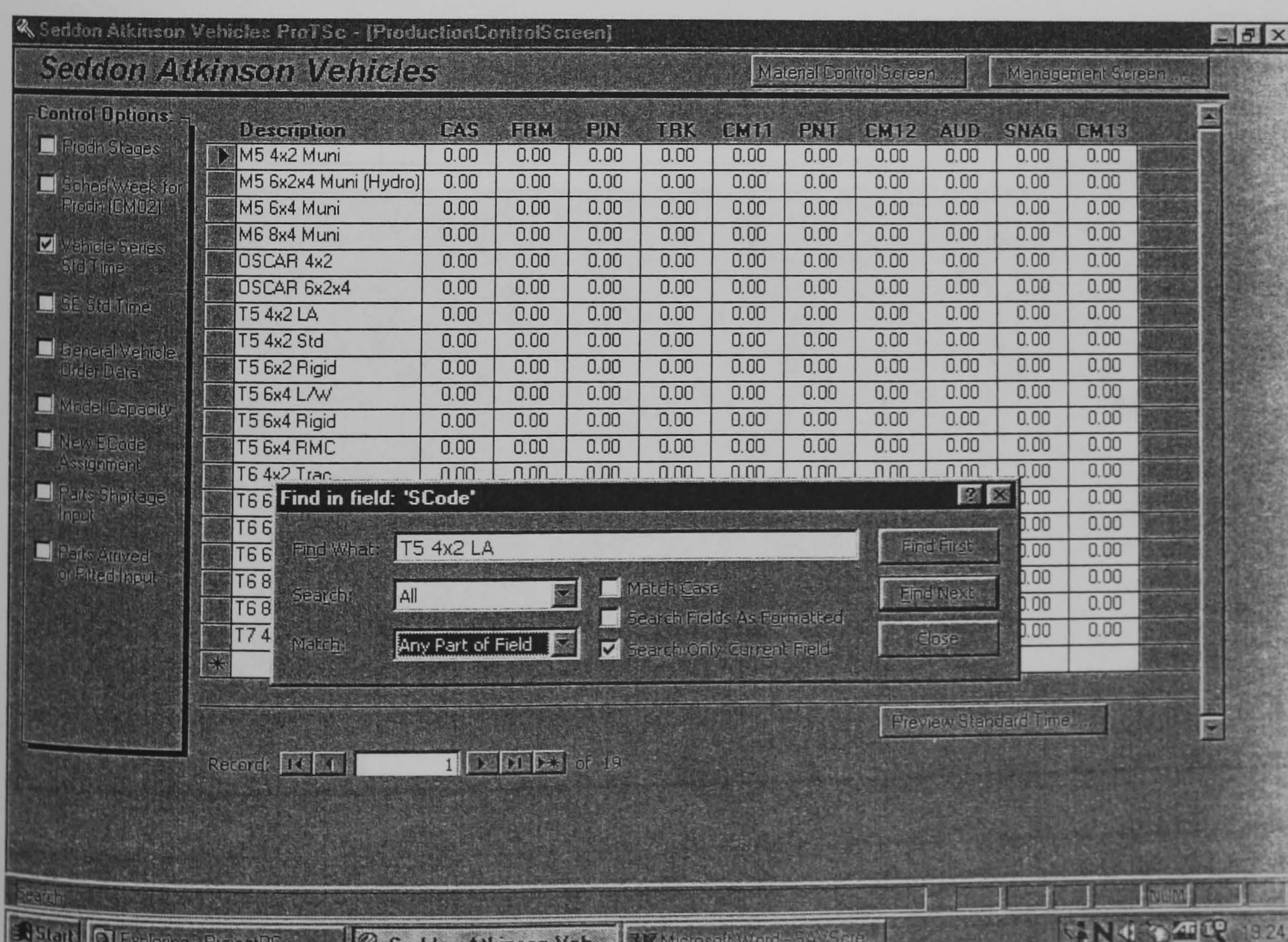


Figure 10 Production Screen showing MS Access Standard "Find" Dialogue Window

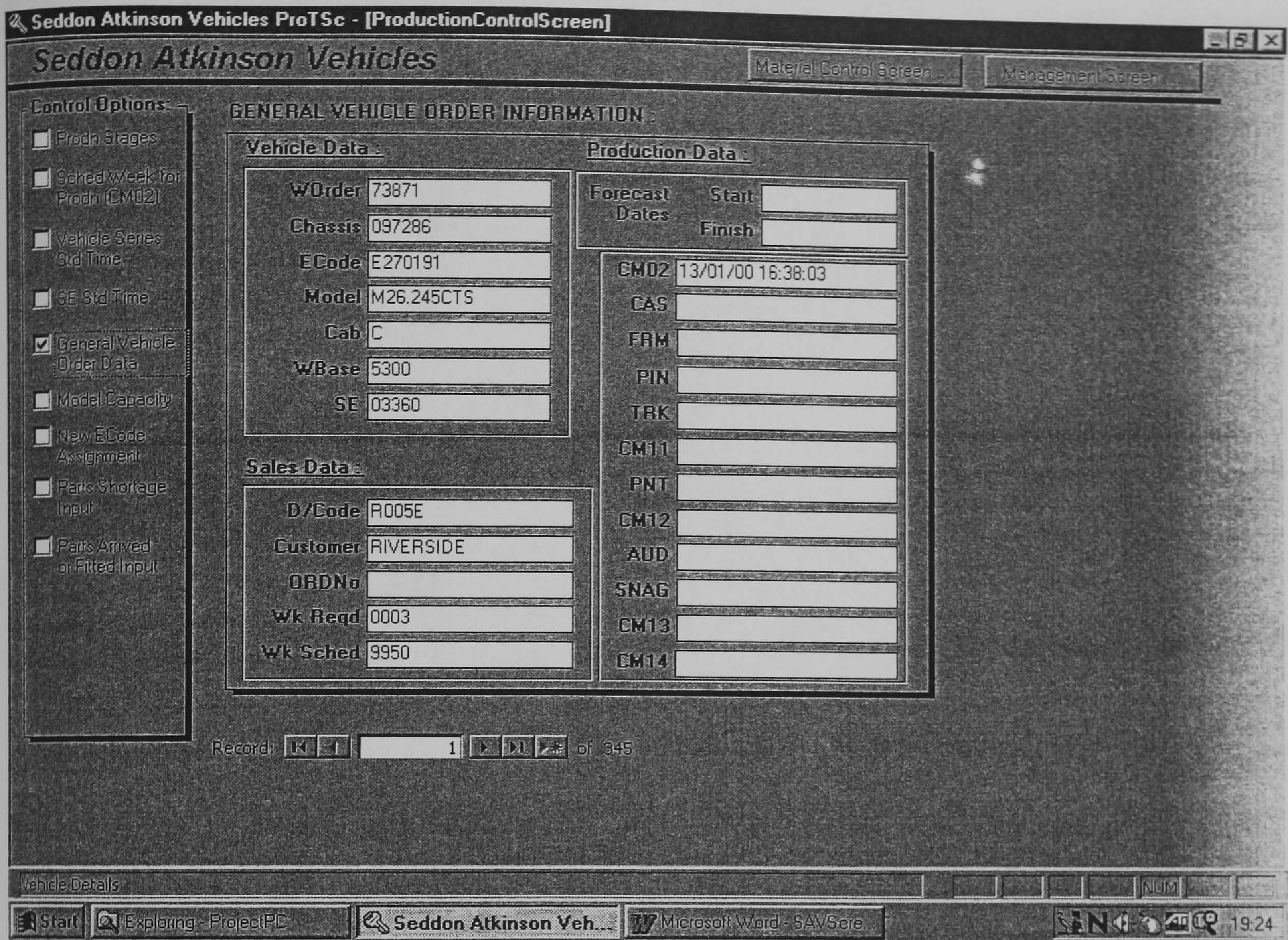


Figure 11 Production Screen showing General Vehicle Order Data

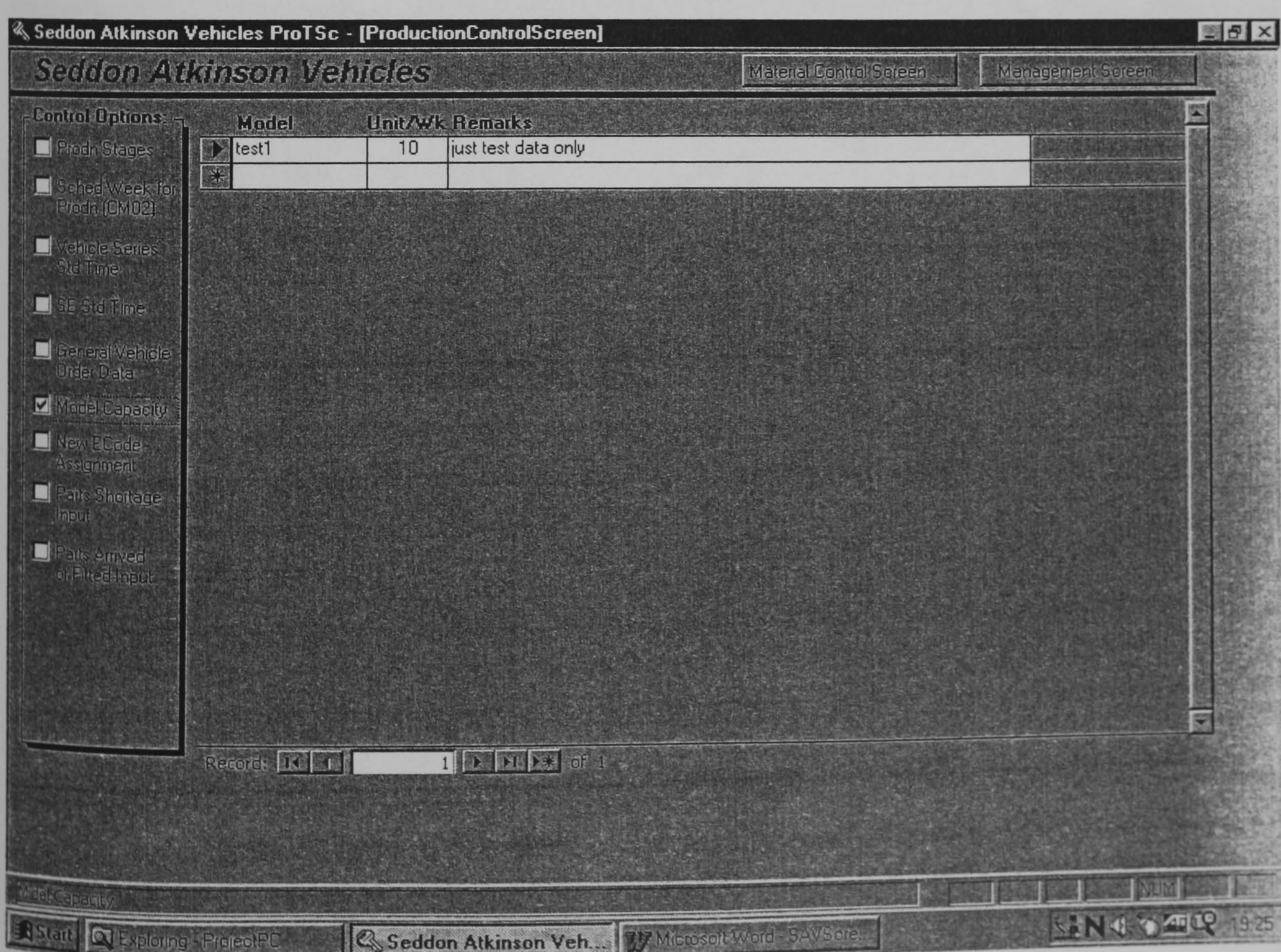


Figure 12 Production Screen showing Production Capacity Input

Figure 13 Production Screen showing New E-Code Assignment

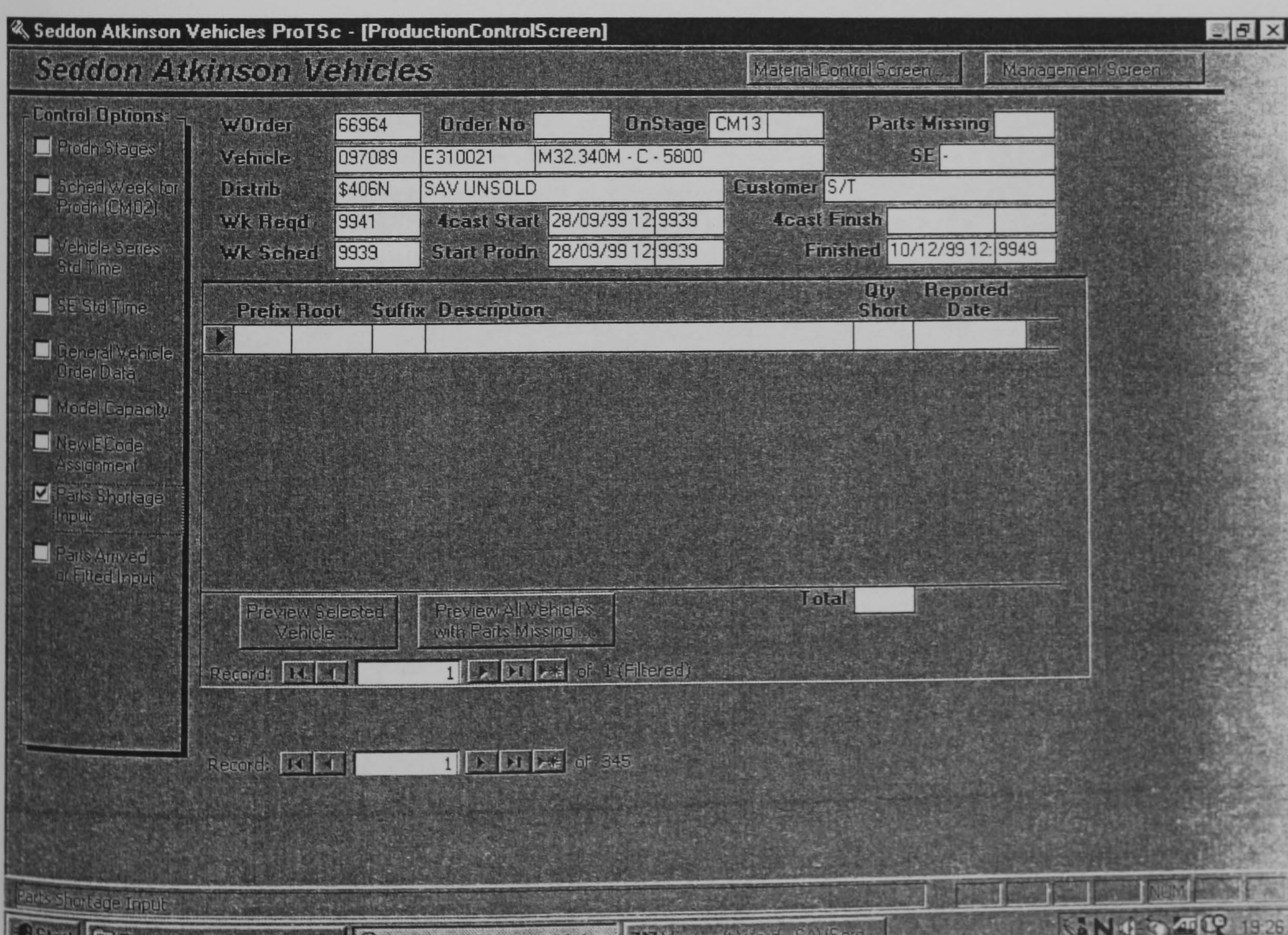


Figure 14 Production Screen showing Parts Shortage Input

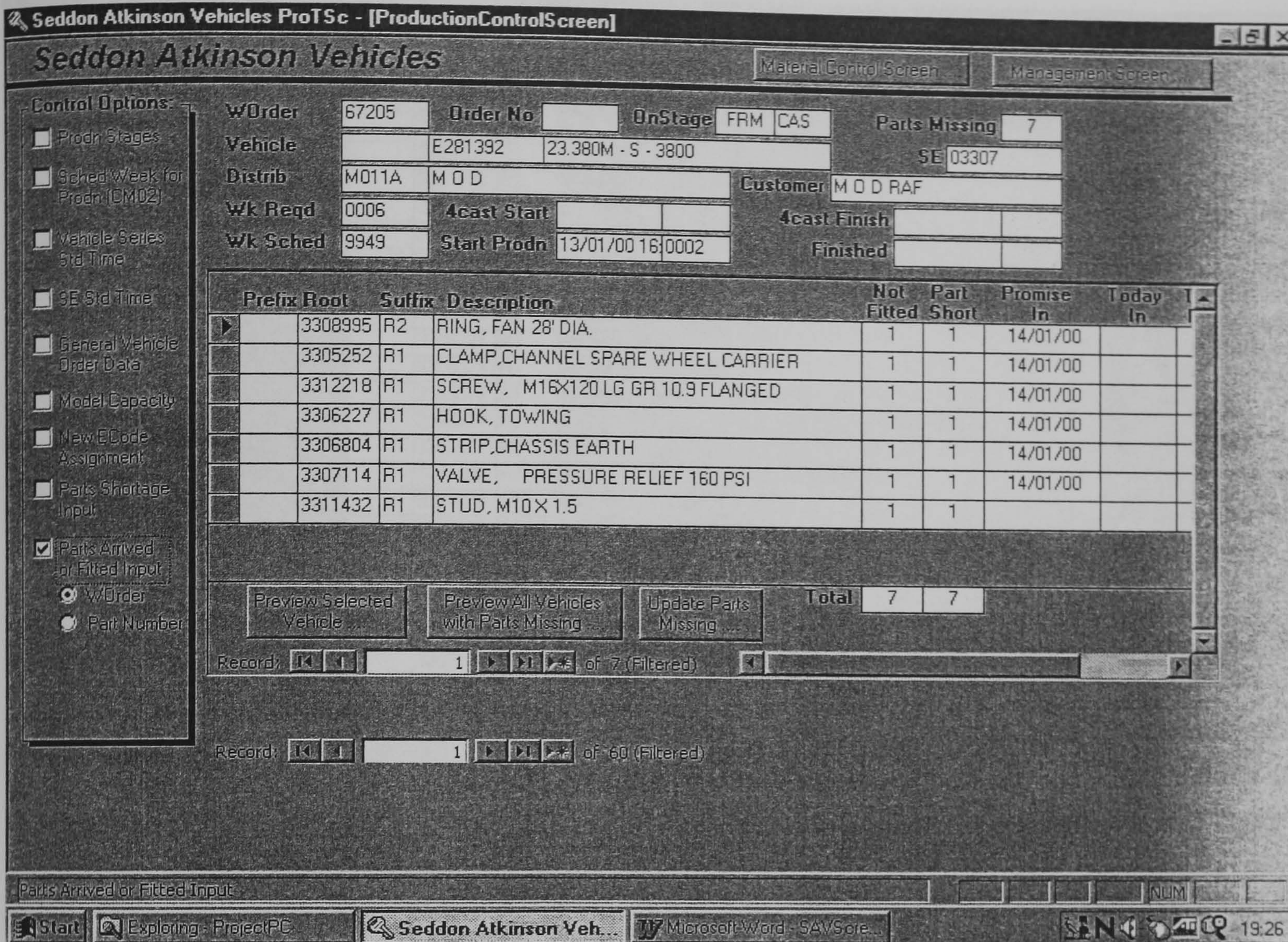


Figure 15 Production Screen showing Parts Arrived or Fitted Input - WOrder

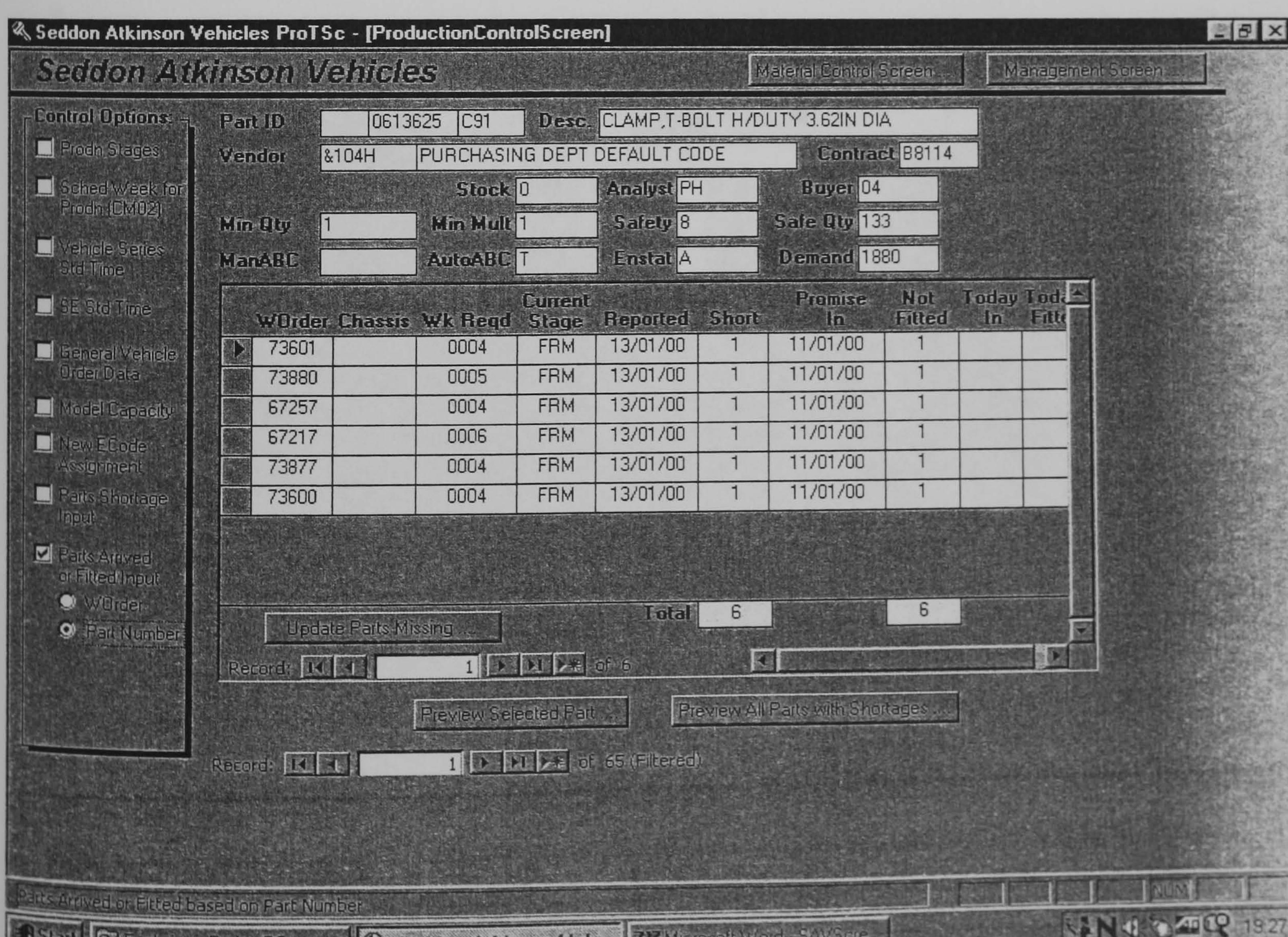


Figure 16 Production Screen showing Parts Arrived or Fitted Input - Part Number

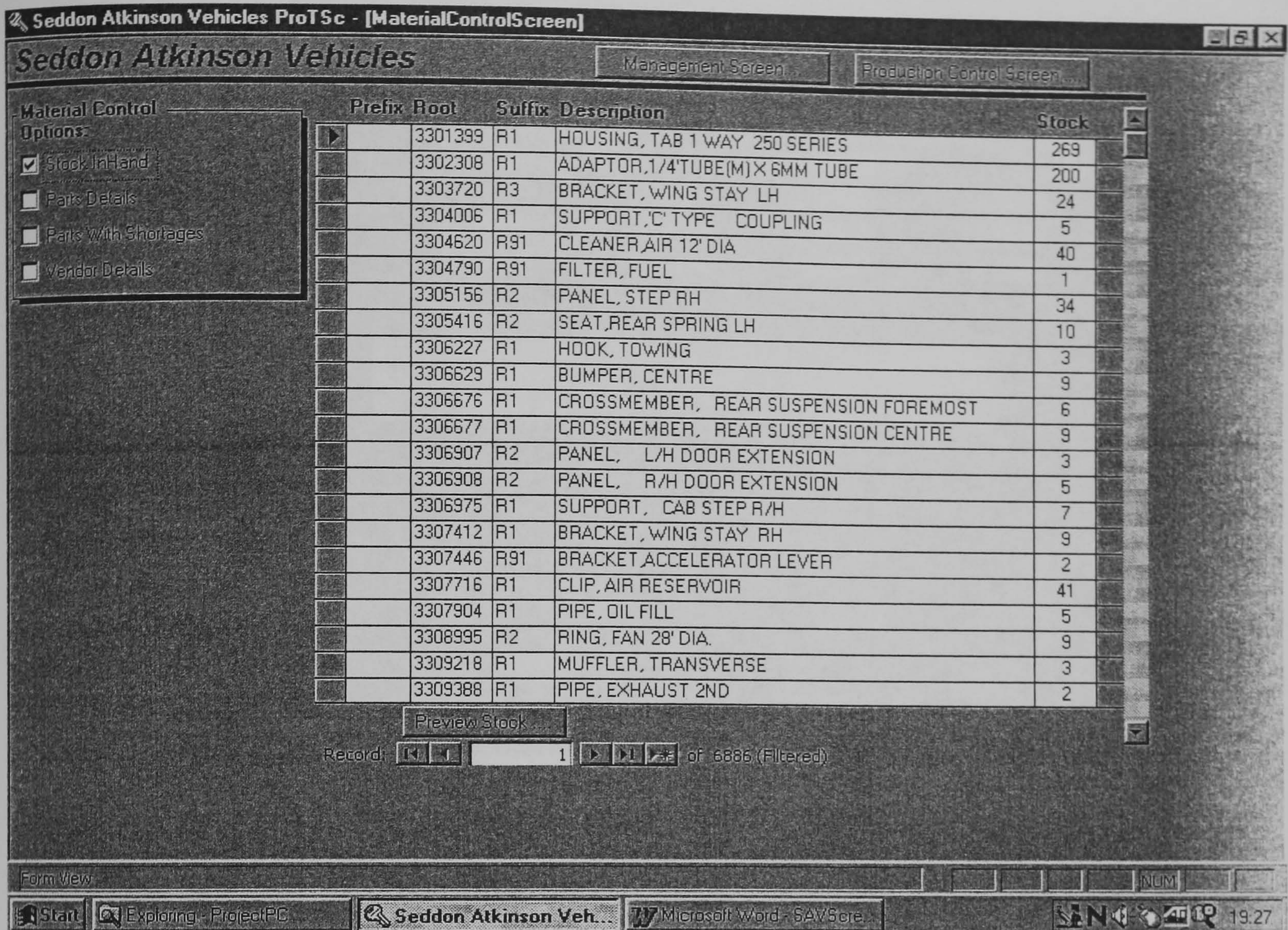


Figure 17 Material Control Screen showing Stock In Hand

Figure 18 Material Control Screen showing Parts Details

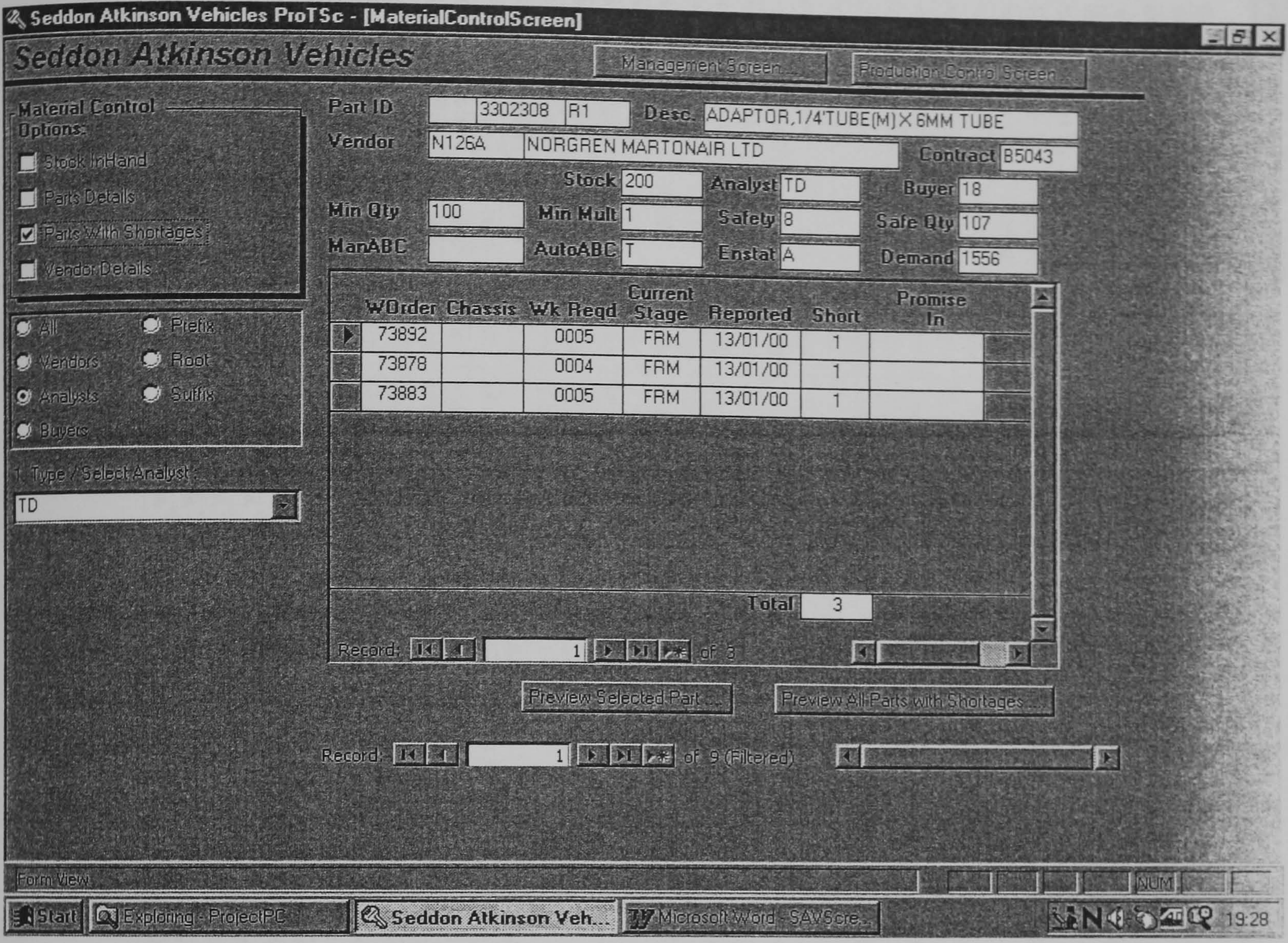


Figure 19 Material Control Screen showing Parts Shortage Details

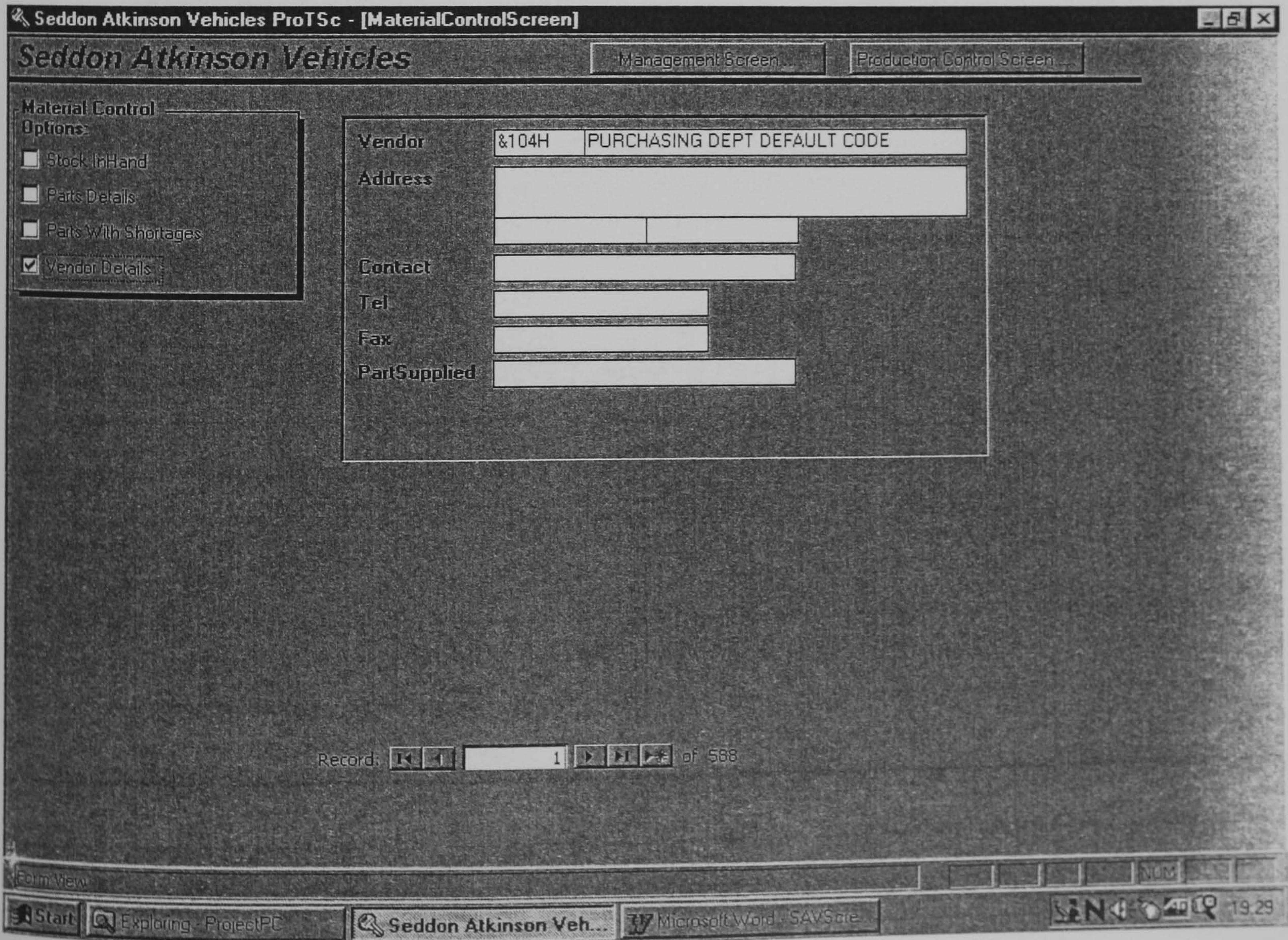


Figure 20 Material Control Screen showing Vendor Details

VEHICLES STATUS LIST

Printed: 1/22/2002 10:31:29

Work Order	Vehicle Descriptions Chassis	ECode	Model	Cab	WBase	SE	Dealer	Customer	Order No	Week Sched	Laydown Date	Laydown Week	Current Stage	Sched Finish	Forecast Finish	Actual Finish	Week Reqd	Part Not Fitted
74042	097569	E270221	N18.245C	C	4000	-	$406A	SITA MID SUSSEX		0024	6/6/2000 17	0023	CM14	6/17/2000		7/4/2000 17	0024	0
74044	097573	E231042	18.235B	D	4500	03441	$406A	BRITISH GAS		0022	5/24/2000 1	0021	CM14	6/24/2000		6/23/2000 1	0025	0
74045	097574	E231042	18.235B	D	4500	03441	$406A	BRITISH GAS		0022	5/25/2000 1	0021	CM14	6/24/2000		6/23/2000 1	0025	0
74046	097575	E231042	18.235B	D	4500	03441	$406A	BRITISH GAS		0023	5/30/2000 1	0022	CM14	6/24/2000		6/23/2000 1	0025	0
74047	097576	E231042	18.235B	D	4500	03441	$406A	BRITISH GAS		0023	5/31/2000 1	0022	CM14	6/24/2000		6/23/2000 1	0025	0
74048	097577	E231042	18.235B	D	4500	03441	$406A	BRITISH GAS		0023	5/31/2000 1	0022	CM14	6/24/2000		6/23/2000 1	0025	0
74049	097578	E231042	18.235B	D	4500	03441	$406A	BRITISH GAS		0023	6/1/2000 15	0022	CM14	6/24/2000		6/23/2000 1	0025	0
74050	097582	E291021	26.245C	D	4520	03445	$406A	RMC	00806	0024	6/6/2000 17	0023	CM14	7/15/2000		7/13/2000 1	0028	0
74051	097583	E291021	26.245C	D	4520	03445	$406A	RMC	00806	0024	6/8/2000 17	0023	CM14	7/15/2000		7/12/2000 1	0028	0
74052	097584	E291021	26.245C	D	4520	03445	$406A	RMC	00806	0024	6/12/2000 0	0024	CM14	7/15/2000		7/12/2000 1	0028	0
74053	097585	E291021	26.245C	D	4520	03445	$406A	RMC	00806	0027	6/13/2000 1	0024	CM14	7/15/2000		7/12/2000 1	0028	0
74054	097586	E291021	26.245C	D	4520	03445	$406A	RMC	00806	0027	6/14/2000 1	0024	CM14	7/15/2000		7/13/2000 1	0028	0
74067	097638	E270181	M26.280C	C	4600	-	$406A	HEIL BANK STOCK	16543	0029	7/13/2000 1	0028	CM14	8/12/2000		7/25/2000 1	0033	0
74068	097639	E270181	M26.280C	C	4600	-	$406A	HEIL BANK STOCK	16543	0029	7/13/2000 1	0028	CM14	8/12/2000		7/26/2000 1	0033	0
74078	097621	E231042	18.235B	D	4500	03441	$406A	BRITISH GAS		0028	7/11/2000 1	0028	CM14	8/5/2000		7/31/2000 1	0030	0
74079	097622	E231042	18.235B	D	4500	03441	$406A	BRITISH GAS		0028	7/11/2000 1	0028	CM14	8/5/2000		8/1/2000 17	0030	0
74080	097623	E231041	18.235B	D	3800	03452	$406A	BRITISH GAS		0030	7/21/2000 1	0029	CM14	8/5/2000		8/3/2000 17	0030	0
74083	097606	E231042	18.235B	D	4500	03441	$406A	BRITISH GAS		0028	7/5/2000 16	0027	CM14	7/29/2000		7/21/2000 1	0030	0
74084	097607	E231042	18.235B	D	4500	03441	$406A	BRITISH GAS		0028	7/6/2000 17	0027	CM14	7/29/2000		7/20/2000 1	0030	0
74085	097608	E231042	18.235B	D	4500	03441	$406A	BRITISH GAS		0028	7/6/2000 17	0027	CM14	7/29/2000		7/22/2000 0	0030	0
74086	097609	E231042	18.235B	D	4500	03441	$406A	BRITISH GAS		0028	7/8/2000 09	0027	CM14	7/29/2000		7/22/2000 0	0030	0
74087	097610	E231042	18.235B	D	4500	03441	$406A	BRITISH GAS		0028	7/8/2000 09	0027	CM14	7/29/2000		7/27/2000 1	0030	0
74088	097611	E231042	18.235B	D	4500	03441	$406A	BRITISH GAS		0028	7/10/2000 1	0028	CM14	7/29/2000		7/25/2000 1	0030	0
74094	097803	E231043	18.215B	D	5650	-	$406A	SITA LB KENSINGTON		0040	10/2/2000 1	0040	CM13	10/28/2000		10/12/2000	0036	0
74129	097799	E270181	M26.280C	C	4600	03499	$406A	HEIL BANK STOCK	17772	0040	10/2/2000 1	0040	CM14	10/28/2000		10/16/2000	0043	0
74132	097782	E270181	M26.280C	C	4600	03499	$406A	HEIL BANK STOCK	17772	0040	10/3/2000 1	0040	CM14	10/21/2000		10/12/2000	0043	0
74140	097724	E270221	N18.245C	C	4000	03476	$406A	RIVERSIDE HIRE	00071	0035	8/23/2000 1	0034	CM14	9/23/2000		9/6/2000 17	0038	0
74141	097735	E270221	N18.245C	C	4000	03508	$406A	NOBLET MUNI SERVICES	00817	0035	8/23/2000 1	0034	CM14	9/23/2000		9/6/2000 17		0
74151	097834	E270212	N18.215B	D	4000	03507	$406A	NOBLET MUNICIPAL S/T		0043	10/17/2000	0042	CM14	11/11/2000	11/14/2000	11/10/2000	0043	0
74152	097820	E270221	N18.245C	C	4000	03514	$406A	RIVERSIDE S/T		0041	10/10/2000	0041	CM14	11/4/2000		11/4/2000 1	0043	0
74153	097821	E270221	N18.245C	C	4000	03514	$406A	RIVERSIDE S/T		0042	10/11/2000	0041	CM14	11/4/2000		10/28/2000	0043	0
74154	097808	E270151	M18.245C	C	4000	-	$406A	SITA ASHFORD S/T		0041	10/3/2000 1	0040	CM14	10/28/2000		10/18/2000		0
74155	097822	E270151	M18.245C	C	4000	-	$406A	SITA ASHFORD S/T		0041	10/9/2000 1	0041	CM14	11/4/2000		10/19/2000		0
74156	097835	E270212	N18.215B	D	4000	03507	$406A	NOBLET MUNICIPAL S/T		0043	10/19/2000	0042	CM14	11/11/2000	11/14/2000	11/10/2000	0043	0
74174	097809	E270201	M26.280CTS	C	5300	-	$406A	L B OF CROYDON	19816	0042	10/16/2000	0042	CM14	10/28/2000	10/26/2000	10/28/2000		0
74175	097823	E270201	M26.280CTS	C	5300	-	$406A	NORTH TYNESIDE		0043	10/18/2000	0042	CM13	11/4/2000		10/31/2000		0

Report 1
Sample Vehicle Status Report for Distributor Code "$406A"

Vehicles' Parts Shortage And Not Fitted List

Printed : 1/22/2002 10:30:15

WOrder	Chassis	Week Reqd	Current Stage	Total Shortage	Total Not Fitted	Prefix	Root	Suffix	Description	Vendor	VCode	Analyst / Buyer		Qty Not Fitted	Qty Short	Promise In
67389		0111	TRK	1	1	V	9849521	1	FLAP, COVER FRONT	CASPLE	C332A	JR	27	1	1	3/9/2001
67451	098001	0110	PNT	1	1	V	9849521	1	FLAP, COVER FRONT	CASPLE	C332A	JR	27	1	1	3/9/2001
67452	098002	0110	CM11	1	1	V	9849521	1	FLAP, COVER FRONT	CASPLE	C332A	JR	27	1	1	3/9/2001
73944		0119	TRK	1	1		0916863	S1	SUPPORT, PIPES	FRANK RIGG LTD	R066A	JR	27	1	1	3/2/2001
73945		0111	CM02	3	3		0916863	S1	SUPPORT, PIPES	FRANK RIGG LTD	R066A	JR	27	1	1	3/2/2001
							3310161	R2	PIPE, EXHAUST FRONT 2ND	THOMSON PETTIE TUBE PROD	T323A	TD	27	1	1	
73991		0112	PIN	1	1		0916863	S1	SUPPORT, PIPES	FRANK RIGG LTD	R066A	JR	27	1	1	3/2/2001
74330		0108	FRM CAS	3	3	V	4746064		GROMMET, 40MM ID FUEL PIPES	SAV PURCHASING PERSONNE	&118G	CB	18	1	1	3/2/2001
						V	5003147	40	BUNK,MATTRESS LOWER	PURCHASING DEPT DEFAULT	&104L	CB	04	1	1	
						V	5003147	41	BUNK,MATTRESS LOWER	PURCHASING DEPT DEFAULT	&104L	CB	04	1	1	
74333		0112	CAS TRK	1	1	V	4746064		GROMMET, 40MM ID FUEL PIPES	SAV PURCHASING PERSONNE	&118G	CB	18	1	1	3/2/2001
74334		0112	CAS TRK	2	2		3312858	R91	KIT, DRUM TYPE EXH CHASSIS MOUNT	DINEX EXHAUSTS LTD	D252A	JR	19	1	1	3/2/2001
						V	4746064		GROMMET, 40MM ID FUEL PIPES	SAV PURCHASING PERSONNE	&118G	CB	18	1	1	3/2/2001
74371		0112	PIN	3	3		0916863	S1	SUPPORT, PIPES	FRANK RIGG LTD	R066A	JR	27	2	2	3/2/2001
						V	4746064		GROMMET, 40MM ID FUEL PIPES	SAV PURCHASING PERSONNE	&118G	CB	18	1	1	3/2/2001
74411		0112	CAS PIN	2	2	V	1205998	0	HOUSING, LUCAR IGNITION SWITCH	COPAT SRL	C476A	VE	26	1	1	
						V	1772227	4	CLIP, ACC. CABLE	M F U SRL	M366A	VE	29	1	1	
74412		0112	CAS PIN	2	2	V	1772227	4	CLIP, ACC. CABLE	M F U SRL	M366A	VE	29	1	1	
						V	4746064		GROMMET, 40MM ID FUEL PIPES	SAV PURCHASING PERSONNE	&118G	CB	18	1	1	3/2/2001
74413		0112	CM02	2	2	V	1772227	4	CLIP, ACC. CABLE	M F U SRL	M366A	VE	29	1	1	
						V	4746064		GROMMET, 40MM ID FUEL PIPES	SAV PURCHASING PERSONNE	&118G	CB	18	1	1	3/2/2001
74421		0112	FRM CAS	3	3		0916863	S1	SUPPORT, PIPES	FRANK RIGG LTD	R066A	JR	27	1	1	3/2/2001
						V	1772227	4	CLIP, ACC. CABLE	M F U SRL	M366A	VE	29	1	1	
						V	4746064		GROMMET, 40MM ID FUEL PIPES	SAV PURCHASING PERSONNE	&118G	CB	18	1	1	3/2/2001
74422		0112	CAS PIN	2	2		0916863	S1	SUPPORT, PIPES	FRANK RIGG LTD	R066A	JR	27	1	1	3/2/2001
						V	4746064		GROMMET, 40MM ID FUEL PIPES	SAV PURCHASING PERSONNE	&118G	CB	18	1	1	3/2/2001
74443		0112	FRM CAS	2	2		0916863	S1	SUPPORT, PIPES	FRANK RIGG LTD	R066A	JR	27	1	1	3/2/2001
						V	4746064		GROMMET, 40MM ID FUEL PIPES	SAV PURCHASING PERSONNE	&118G	CB	18	1	1	3/2/2001
74457		0114	FRM CAS	3	3	V	1205998	0	HOUSING, LUCAR IGNITION SWITCH	COPAT SRL	C476A	VE	26	1	1	
						V	1772227	4	CLIP, ACC. CABLE	M F U SRL	M366A	VE	29	1	1	
						V	4746064		GROMMET, 40MM ID FUEL PIPES	SAV PURCHASING PERSONNE	&118G	CB	18	1	1	3/2/2001
EARLY			CM02	22	22		3306699	R1	ABSORBER, SHOCK REARMOST	PURCHASING DEPT DEFAULT	&104H	CB	04	22	22	
OSCA1			CM02	16	16	V	5003980	04	STEP, DRIVERS SIDE	SAV PURCHASING PERSONNE	&133G	XX	33	7	7	
						V	5003990	56	DOOR, PANEL RHD EXTENSION	PURCHASING DEPT DEFAULT	&104L	CB	04	9	9	
PICK			CM02	3	3		3312858	R91	KIT, DRUM TYPE EXH CHASSIS MOUNT	DINEX EXHAUSTS LTD	D252A	JR	19	1	1	3/2/2001
						V	4120773	9	HARNESS	PURCHASING DEPT DEFAULT	&104L	CB	04	1	1	
						V	9716446	9	DUCT, AIR INTAKE	HAYWOOD ROTOMOULDING LT	H349A	JR	08	1	1	

Report 2
Sample Vehicles' Part Shortage and Not Fitted List

Variance Analysis Report for : E270191

Printed: 1/22/2002 10:33:06

	CAS	FRM	PIN	TRK	CM11	PNT	CM12	AUD	SNAG	CM13	Total Hrs
Standard	35.50	21.00	10.25	3.00	20.15	6.00	21.50	0.00	15.50		

WOrder	Chassis	SE	Frame Layout	Current Stage
73871	097286	03360	12/14/19	CM14

	CAS	FRM	PIN	TRK	CM11	PNT	CM12	AUD	SNAG	CM13	Total Hrs
Actual	70.00	44.00	4.00	25.00	507.00	-17.00	96.00	0.00	0.00	373.00	1,102.00
Variance	-34.50	-23.00	6.25	-22.00	-486.85	23.00	-74.50	0.00	15.50		

WOrder	Chassis	SE	Frame Layout	Current Stage
73872	097287	03360	12/15/19	CM14

	CAS	FRM	PIN	TRK	CM11	PNT	CM12	AUD	SNAG	CM13	Total Hrs
Actual	118.00	116.00	4.00	1.00	363.00	-17.00	0.00	192.00	0.00	349.00	1,126.00
Variance	-82.50	-95.00	6.25	2.00	-342.85	23.00	21.50	-192.00	15.50		

WOrder	Chassis	SE	Frame Layout	Current Stage
73873	097288	03360	12/20/19	CM14

	CAS	FRM	PIN	TRK	CM11	PNT	CM12	AUD	SNAG	CM13	Total Hrs
Actual	70.00	44.00	4.00	25.00	339.00	-17.00	288.00	0.00	0.00	336.00	1,089.00
Variance	-34.50	-23.00	6.25	-22.00	-318.85	23.00	-266.50	0.00	15.50		

WOrder	Chassis	SE	Frame Layout	Current Stage
73874	097289	03360	12/20/19	CM14

	CAS	FRM	PIN	TRK	CM11	PNT	CM12	AUD	SNAG	CM13	Total Hrs
Actual	358.00	68.00	4.00	289.00	51.00	7.00	264.00	0.00	0.00	360.00	1,401.00
Variance	-322.50	-47.00	6.25	-286.00	-30.85	-1.00	-242.50	0.00	15.50		

WOrder	Chassis	SE	Frame Layout	Current Stage
73875	097290	03360	12/22/19	CM14

	CAS	FRM	PIN	TRK	CM11	PNT	CM12	AUD	SNAG	CM13	Total Hrs
Actual	334.00	332.00	4.00	1.00	147.00	-17.00	278.00	0.00	-14.00	240.00	1,305.00
Variance	-298.50	-311.00	6.25	2.00	-126.85	23.00	-256.50	0.00	29.50		

WOrder	Chassis	SE	Frame Layout	Current Stage
73907	097374	03386	1/31/200	CM14

	CAS	FRM	PIN	TRK	CM11	PNT	CM12	AUD	SNAG	CM13	Total Hrs
Actual	75.00	51.00	4.00	20.00	193.00	69.00	176.00	0.00	15.00	994.00	1,597.00
Variance	-39.50	-30.00	6.25	-17.00	-172.85	-63.00	-154.50	0.00	-5.00		

WOrder	Chassis	SE	Frame Layout	Current Stage
73983	097542	03427	5/12/200	CM14

	CAS	FRM	PIN	TRK	CM11	PNT	CM12	AUD	SNAG	CM13	Total Hrs
Actual	99.00	99.00	0.00	0.00	167.00	529.00	480.00	0.00	0.00	3.00	1,377.00
Variance	-63.50	-78.00	10.25	3.00	-146.85	-523.00	-458.50	0.00	12.00		

WOrder	Chassis	SE	Frame Layout	Current Stage
73988	097571	-	6/1/2000	CM14

	CAS	FRM	PIN	TRK	CM11	PNT	CM12	AUD	SNAG	CM13	Total Hrs
Actual	191.00	169.00	0.00	22.00	91.00	679.00	23.00	0.00	0.00	41.00	1,216.00
Variance											

WOrder	Chassis	SE	Frame Layout	Current Stage
73989	097572	-	6/6/2000	CM14

	CAS	FRM	PIN	TRK	CM11	PNT	CM12	AUD	SNAG	CM13	Total Hrs
Actual	161.00	160.00	0.00	1.00	31.00	41.00	463.00	0.00	0.00	16.00	873.00
Variance											

WOrder	Chassis	SE	Frame Layout	Current Stage
74011	097514	03443	4/28/200	CM14

	CAS	FRM	PIN	TRK	CM11	PNT	CM12	AUD	SNAG	CM13	Total Hrs
Actual	148.00	127.00	21.00	0.00	122.00	49.00	183.00	0.00	0.00	1.00	651.00
Variance	-112.50	-106.00	-10.75	3.00	-101.85	-43.00	-161.50	0.00	10.50		

Report 3

Sample Variance Analysis Report for Model "E270191"

Vehicle Series Standard Time

Printed: 1/22/2002 10:33:42

Vehicle Series	CAS	FRM	PIN	TRK	CM11	PNT	CM12	AUD	SNAG	CM13
M5 4x2 Day	32.7	9.5	8	3	19.7	5	19.5	0	10	0
M5 4x2 Muni	35.5	9.5	8	3	19.7	5	19.5	0	10	0
M5 6x2x4 Day	32.7	21	10.25	3	20.15	6	21.5	0	10	0
M5 6x2x4 Muni (Hydro)	35.5	21	10.25	3	20.15	6	21.5	0	10	0
M5 6x4 Day	32.7	14	9.5	3	19.7	6	19.5	0	10	0
M5 6X4 ISC Muni	35.5	14	9.5	3	19.7	6	19.5	0	10	0
M5 6x4 Muni	35.5	14	9.5	3	19.7	6	19.5	0	10	0
M6 6x4 Iveco	58	14.55	10.25	3.5	20.65	6	21.5	0	15.5	0
M6 8x4 Muni	58	15.7	11.2	3.5	20.65	7	21.5	0	15.5	0
N5 4x2 NEF Muni	35.5	9.5	8	3	19.7	5	19.5	0	10	0
OSCAR 4x2	38.25	33.25	9.5	6	23.4	10	44.5	0	27	0
OSCAR 6x2x4	38.25	40.5	16.35	6	23.7	12	44.5	0	27	0
OSCAR 6X4	38.25	32.25	11.25	6	23.4	10	44.5	0	27	0
T5 4x2 LA	8.75	9.5	8	3	19.7	5	19	0	11.5	0
T5 4x2 NEF	8.75	9.5	8	3	19.7	5	19	0	11.5	0
T5 4x2 Std	8.75	9.5	8	3	19.7	5	19	0	11.5	0
T5 6x2 Rigid	8.75	16.8	10.75	3	19.7	6	19.5	0	11.5	0
T5 6x4 L/W	8.75	12.8	8.75	3	19.7	6	19.5	0	9.5	0
T5 6x4 Rigid	8.75	12.8	8.75	3	19.7	6	19.5	0	9.5	0
T5 6x4 RMC	19.75	13.95	8.75	3	30.2	6	9	1.5	0	8
T6 4x2 Trac	22.86	16.5	7	3.5	20.2	7	21.5	0	15.5	0
T6 6x2 Trac	22.86	18	9.25	3.5	30.7	7	11	7.5	0	8
T6 6x2 Trac (Mid Lift)	22.86	19.5	9.25	3.5	20.2	7	21.5	0	15.5	0
T6 6x4 CURSOR	22.86	14.25	9.75	3.5	20.2	6	21.5	0	15.5	0
T6 6x4 Rigid	22.86	14.25	9.75	3.5	20.2	6	21.5	0	15.5	0
T6 8x4 CURSOR	22.86	15.5	11.75	3.5	20.9	7	21.5	0	15.5	0
T6 8x4 Rigid	22.86	15.5	11.75	3.5	20.9	7	21.5	0	15.5	0
T6 8x4 Rigid F	22.86	16.25	11.75	3.5	20.9	7	21.5	0	13	0
T7 4x2 Trac	28.06	16.5	7.25	3.5	30.7	7	11	8	0	8
T7 6x2 Trac	28.06	17.75	8.25	3.5	30.7	7	11	8	0	8

Report 6
Sample Vehicle Series Standard Time List

SE Code	CAS	FRM	PIN	TRK	CM11	PNT	CM12	AUD	SNAG	CM13
03399	0	0	0	0	0	0	0	0	0	
03400	0	0	0	0	0	0	0	0	4	
03402	0	0	0	0	0	0	0	0	0.5	
03403	0	0	0	0	0	0	0	0	0	
03404	0	0	0	0	0	0	0	0	1.5	
03405	0	0	0	0	0	0	0	0	1	
03406	0	0	0	0	0	0	0	0	0	
03407	0	0	0	0	0	0	0	0	6	
03408	0	0	0	0	0	0	0	0	0.5	
03409	0	0	0	0	0	0	0	0	0	
03410	0	0	0	0	0	0	0	0	1	
03411	0	0	0	0	0	0	0	0	1	
03412	0	0	0	0	0	0	0	0	3.25	
03413	0	0	0	0	0	0	0	0	3.25	
03414	0	0	0	0	0	0	0	0	0.5	
03415	0	0	0	0	0	0	0	0	0	
03416	0	0	0	0	0	0	0	0	10	
03417	0	0	0	0	0	0	0	0	0	
03418	0	0	0	0	0	0	0	0	0	
03419	0	0	0	0	0	0	0	0	0.25	
03420	0	0	0	0	0	0	0	0	3.25	
03421	0	0	0	0	0	0	0	0	0	
03423	0	0	0	0	0	0	0	0	0.5	
03424	0	0	0	0	0	0	0	0	3.5	
03425	0	0	0	0	0	0	0	0	1	
03426	0	0	0	0	0	0	0	0	0	
03427	0	0	0	0	0	0	0	0	2	
03428	0	0	0	0	0	0	0	0	5	
03429	0	0	0	0	0	0	0	0	0	
03430	0	0	0	0	0	0	0	0	1	
03431	0	0	0	0	0	0	0	0	0	
03432	0	0	0	0	0	0	0	0	5	
03433	0	0	0	0	0	0	0	0	5.75	
03434	0	0	0	0	0	0	0	0	2.75	
03435	0	0	0	0	0	0	0	0	2.75	
03436	0	0	0	0	0	0	0	0	3.5	
03437	0	0	0	0	0	0	0	0	35	
03438	0	0	0	0	0	0	0	0	0	
03439	0	0	0	0	0	0	0	0	2	
03440	0	0	0	0	0	0	0	0	1	
03441	0	0	0	0	0	0	0	0	4.25	
03442	0	0	0	0	0	0	0	0	37	
03443	0	0	0	0	0	0	0	0	0.5	
03444	0	0	0	0	0	0	0	0	1.25	
03445	0	0	0	0	0	0	0	0	3.75	
03446	0	0	0	0	0	0	0	0	3	
03447	0	0	0	0	0	0	0	0	0.5	
03448	0	0	0	0	0	0	0	0	21.75	
03449	0	0	0	0	0	0	0	0	1	
03450	0	0	0	0	0	0	0	0	0	
03451	0	0	0	0	0	0	0	0	8	
03452	0	0	0	0	0	0	0	0	4.25	
03453	0	0	0	0	0	0	0	0	5	
03454	0	0	0	0	0	0	0	0	0	
03455	0	0	0	0	0	0	0	0	1	
03456	0	0	0	0	0	0	0	0	0	

Report 7
Sample SE Standard Time List

Stock In Hand

Printed: 1/22/2002 10:35:10

Prefix	Root	Suffix	Description	Stock
V	9842876	8	HANDLE	13
V	9847438	8	PLATE, STOP LH	51
	3312327	R91	PUMP,POWER STEERING	58
	3312320	R1	PLATE, BLINK CODE SWITCH	932
	3294210	R1	ANGLE, SPARE WHEEL MTG	5
	3300487	R1	PROGPH,VEHICLE DATA	60
	3301301	R1	SADDLE, SPRING RH	3
	3302169	R1	ADAPTOR, M18 X 1.5M 1/2'BSPM 60% CONEF	15
	3304444	R1	BRACKET, ENGINE MTG REAR INNER RH	27
	0613625	C91	CLAMP,T-BOLT H/DUTY 3.62IN DIA	264
	0775973	C91	CLAMP,T BOLT H/DUTY 5.50IN DIA	152
	3301399	R1	HOUSING, TAB 1 WAY 250 SERIES	100
	3302308	R1	ADAPTOR,1/4'TUBE(M) X 6MM TUBE	240
	3303720	R3	BRACKET, WING STAY LH	28
	3304006	R1	SUPPORT,'C' TYPE COUPLING	15
	3304790	R91	FILTER, FUEL	1
	3305156	R2	PANEL, STEP RH	20
	3305416	R2	SEAT,REAR SPRING LH	15
	3306629	R1	BUMPER, CENTRE	38
	3306676	R1	CROSSMEMBER, REAR SUSPENSION FOREMOST	17
	3306804	R1	STRIP,CHASSIS EARTH	1
	3306907	R2	PANEL, L/H DOOR EXTENSION	2
	3306975	R1	SUPPORT, CAB STEP R/H	10
	3312215	R1	STEP, FRONT CENTRE BUMPER	5
	3312287	R1	BRACKET, SWC	3
V	1668603	4	SCREW,HX FL/HD M20 X 80 LG 10.9 DAC 5	200
V	3798586		TREAD, WING STEP RH	90
V	4854432		SWITCH, ROCKER FOG LIGHT	8
V	9846640	2	LIGHT, HEAD R/H	70
V	9847346	5	PROTECTOR, SLP CAB	77
V	9849658	5	PROTECTOR, GRILLE	60
	3307446	R91	BRACKET,ACCELERATOR LEVER	26
	3307841	R91	HARNESS, ENGINE	11
	3307904	R1	PIPE, OIL FILL	23
	3309218	R1	MUFFLER, TRANSVERSE	21
	3309388	R1	PIPE, EXHAUST 2ND	1
	3309389	R1	PIPE, EXHAUST 1ST	1
	3309390	R91	MUFFLER, ST. STEEL	1
	3310054	R1	PIPE, AIR INTAKE	17
	3310502	R1	CONSOLE,GEAR CHANGE MD3560	40
	3310672	R1	HOSE,ASSY AIR BRAKE	50
	3311427	R1	ROD, GEARCHANGE SECOND	3
	3311432	R1	STUD, M10 X 1.5	505
	3311870	R1	BRACKET, CENTRE BRG P/SHAFT LOWER	3
	3311930	R1	ADAPTOR, 5/8 TUBE M27	39
	3312046	R91	KIT, TECALEMIT 30PT INTERLUBE XGS	2
	3312077	R1	BRACKET,SWITCH ASSY	396
	3312218	R1	BOLT,HX FL/HD M16 X 120 LG ZND 10.9 5A	70
EN	0691768		BUSH, STABILIZER BAR	66
V	4100039	0	SUPPORT	49
V	4102310	5	COVER, ABS PROTECT	126
V	8143608		CROSSMEMBER, CAB REAR SUSPENSION	28
V	9842822	7	HARNESS, SPEEDO SUB - LOOM	5
	3312362	R1	PLATE, BARRIER UNIT MOUNTING	28

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Report 8
Sample Stock in Hand List

Production Parts Shortage List

Printed: 1/22/2002 10:36:59

Vendor	VCode	Prefix	Root	Suffix	Description	Stock	Analyst/	Buyer	WOrder	Chassis	D/Code	4Cast Finish	Current Stage	Not Fitted	Short	Promise In	Short Reported
PURCHASING DEPT	&104H		3306699	R1	ABSORBER, SHOCK REARM	9	CB	04	EARLY		$406F		CM02	22	22		2/28/2001
PURCHASING DEPT	&104L	V	4120773	9	HARNESS	0	CB	04	PICK		$406F		CM02	1	1		2/15/2001
		V	5003147	40	BUNK,MATTRESS LOWER	0	CB	04	74330		$406A		FRM CAS	1	1		2/26/2001
		V	5003147	41	BUNK,MATTRESS LOWER	0	CB	04	74330		$406A		FRM CAS	1	1		2/26/2001
		V	5003990	56	DOOR, PANEL RHD EXTENSI	0	CB	04	OSCA1		$406F		CM02	9	9		2/21/2001
SAV PURCHASING P	&118G	V	4746064		GROMMET, 40MM ID FUEL PI	0	CB	18	74330		$406A		FRM CAS	1	1	3/2/2001	2/28/2001
		V	4746064		GROMMET, 40MM ID FUEL PI	0	CB	18	74333		W091A		CAS TRK	1	1	3/2/2001	2/28/2001
		V	4746064		GROMMET, 40MM ID FUEL PI	0	CB	18	74334		W091A		CAS TRK	1	1	3/2/2001	2/28/2001
		V	4746064		GROMMET, 40MM ID FUEL PI	0	CB	18	74371		K333A		PIN	1	1	3/2/2001	2/28/2001
		V	4746064		GROMMET, 40MM ID FUEL PI	0	CB	18	74412		K333A		CAS PIN	1	1	3/2/2001	2/28/2001
		V	4746064		GROMMET, 40MM ID FUEL PI	0	CB	18	74413		K333A		CM02	1	1	3/2/2001	3/1/2001
		V	4746064		GROMMET, 40MM ID FUEL PI	0	CB	18	74421		K333A		FRM CAS	1	1	3/2/2001	2/28/2001
		V	4746064		GROMMET, 40MM ID FUEL PI	0	CB	18	74422		B120A		CAS PIN	1	1	3/2/2001	2/28/2001
		V	4746064		GROMMET, 40MM ID FUEL PI	0	CB	18	74443		$406A		FRM CAS	1	1	3/2/2001	2/28/2001
		V	4746064		GROMMET, 40MM ID FUEL PI	0	CB	18	74457		L011A		FRM CAS	1	1	3/2/2001	3/1/2001
SAV PURCHASING P	&133G	V	5003980	04	STEP, DRIVERS SIDE	0	XX	33	OSCA1		$406F		CM02	7	7		2/21/2001
CASPLE	C332A	V	9849521	1	FLAP, COVER FRONT	0	JR	27	67389		$406A		TRK	1	1	3/9/2001	2/28/2001
		V	9849521	1	FLAP, COVER FRONT	0	JR	27	67451	098001	$406N		PNT	1	1	3/9/2001	2/28/2001
		V	9849521	1	FLAP, COVER FRONT	0	JR	27	67452	098002	$406N		CM11	1	1	3/9/2001	2/28/2001
COPAT SRL	C476A	V	1205998	0	HOUSING, LUCAR IGNITION	0	VE	26	74411		K333A		CAS PIN	1	1		2/28/2001
		V	1205998	0	HOUSING, LUCAR IGNITION	0	VE	26	74457		L011A		FRM CAS	1	1		2/28/2001
DINEX EXHAUSTS L	D252A		3312858	R91	KIT, DRUM TYPE EXH CHASSIS	0	JR	19	74334		W091A		CAS TRK	1	1	3/2/2001	2/21/2001
			3312858	R91	KIT, DRUM TYPE EXH CHASSIS	0	JR	19	PICK		$406F		CM02	1	1	3/2/2001	2/21/2001
HAYWOOD ROTOM	H349A	V	9716446	9	DUCT, AIR INTAKE	0	JR	08	PICK		$406F		CM02	1	1		2/28/2001
M F U SRL	M366A	V	1772227	4	CLIP, ACC. CABLE	0	VE	29	74411		K333A		CAS PIN	1	1		2/28/2001
		V	1772227	4	CLIP, ACC. CABLE	0	VE	29	74412		K333A		CAS PIN	1	1		3/1/2001
		V	1772227	4	CLIP, ACC. CABLE	0	VE	29	74413		K333A		CM02	1	1		2/28/2001
		V	1772227	4	CLIP, ACC. CABLE	0	VE	29	74421		K333A		FRM CAS	1	1		2/28/2001
		V	1772227	4	CLIP, ACC. CABLE	0	VE	29	74457		L011A		FRM CAS	1	1		3/1/2001
FRANK RIGG LTD	R066A		0916863	S1	SUPPORT, PIPES	0	JR	27	73944		G041A		TRK	1	1	3/2/2001	2/28/2001
			0916863	S1	SUPPORT, PIPES	0	JR	27	73945		C002B		CM02	1	1	3/2/2001	2/28/2001
			0916863	S1	SUPPORT, PIPES	0	JR	27	73991		A001A		PIN	1	1	3/2/2001	2/28/2001
			0916863	S1	SUPPORT, PIPES	0	JR	27	74371		K333A		PIN	2	2	3/2/2001	2/28/2001
			0916863	S1	SUPPORT, PIPES	0	JR	27	74421		K333A		FRM CAS	1	1	3/2/2001	2/28/2001

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Report 9
Sample Parts Shortage Report

APPENDIX D - Pattern Database User Instruction Manual

USER INSTRUCTION MANUAL
FOR
SULZER PUMPS (UK) LTD.
PATTERN DATABASE PROTOTYPE SYSTEM

TABLE OF CONTENTS

TABLE OF FIGURES

1.0 OBJECTIVES

The goal of SPUK Pattern Database is to allow Sulzer Pumps UK Ltd. (SPUK) to track of its casting equipment used in making castings. Specifically, the functions provided are:

- to maintain the history, i.e. modifications, of casting equipment,
- to track the location of casting equipment
- to be able to know what casting equipment are used in which castings for which pump orders and vice versa

2.0 OVERVIEW

Specifically, the pattern database is used to maintain and view its three controlled items: pump order, pattern set-up, and set-up (casting) equipment. Pattern set-up is a newly introduced controlled item to cater to the need of multi-stage pumps from Bingham. A pattern set-up is an arrangement of casting equipment to produce a certain casting required in a pump order.

Hence, there are three main screens available in the pattern database: the ***Pump Order Screen***, the ***Pattern Set-up Screen***, and the ***Set-up Equipment Screen***. All three screens have very similar design:

1. Each screen can be divided into four main areas:
   - The header with three buttons: ***Pump Order***, ***Pattern Set-up***, and ***Set-up Equipment***. These buttons allow users to switch to required screen. Note that when in one specific screen, the associated button is disabled. For example, ***Pump Order*** button is disabled in the ***Pump Order Screen***. An exit button is also provided on the right hand side of this area. The header is shaded with a blue background.
   - The controlled item details section, which shows the details of each controlled item. This area is in a green background.
   - The associated data area which shows all the associated product data of each controlled item. This data are grouped into folders:
     - Pump Orders Screen has two folders - pattern set-ups used in each specific pump order and their locations where they were sent to produce the required castings.
     - Pattern Set-ups Screen has four folders - pump order designation, pattern set-up locations where they were sent to produce the required castings, pattern set-up history, and the casting equipment used in each set-up.
     - Set-up Equipment Screen has three folders - pattern set-ups where the specific equipment is used, the set-up equipment history, and their locations where they were sent to produce the required castings for a specific pump order.
   - Function buttons area where appropriate function can be executed:
     - Search - available for all screens, it is to activate the search criteria for the respective controlled item.
     - Clear search - available for all screens, it is to re-set the search and display all records available for the respective controlled item.
     - Copy - only available in ***Pattern Set-up Screen,*** it is to copy the existing pattern set-up with its equipment but not the pump orders that use the specific set-up. **Note:** It is important to change the pattern set-up number from "Copied Pattern Setup" to the correct set-up number.
     - Delete - only available for Pattern Set-up Screen and Set-up Equipment Screen, it is to delete the existing controlled item when it becomes obsolete.

- Preview Searched - available for all screens, it is to preview print all the found records based on the search criteria for the respective controlled item.
- Preview Current - available for all screens, it is to preview print the current active record of the respective controlled item.

2. To activate the required function provided by appropriate button on each controlled item's screen, press the left mouse button ONCE. Right clicking the mouse button, where appropriate, will display a list of additional database functions:
   - Sorting Records - Ascending / Descending order
   - Filtering Records
   - Print Option
   - Print Preview Options
   - Close active Form / Screen

3. Each screen has its own set of search option that can be called out by pressing the respective search button. The objective of providing this search options is to facilitate fast retrieval of the required records. When entering the search criteria, wildcards (* and/or ?) can be used in all the search options. **Note:** It is important NOT to use " and ' as this will crash the system.

4. To delete a specific editable record, place the mouse pointer at the record selector area (indicated by the black triangle ▶) of the required record and left click the mouse button to select / highlight the selection. If the entire required record is not highlighted, left-click the mouse button again. **Note:** press the delete button (on the keyboard) only when the entire record is highlighted.

5. To add in a new record where appropriate, move the mouse pointer to the first field of the new record line (indicated by an asterisk * at the record selector area) and left click the mouse button.

6. When maintaining the pattern database, if the search results in no record found, the right hand side of the screen will display blank values in all fields in the main details' area. However, when only viewing records, the message "No record is found matching the search required" will be displayed. Upon closing this message, the pattern database will automatically reset the search and shows all records available in the database.

7. Within all folders of each screen, it is possible to go to a specific controlled item by double clicking the left mouse button at cell of the required controlled item. For example, in the ***Pump Order Screen*** under the folder Pattern Set-up, when double left click at a specific pattern set-up, the system will automatically go to the ***Pattern Set-up Screen*** with the required Pattern Set-up details.

A summarised of all records, called ***Summary Screen***, is also provided to display all records in one screen full. Refer to Section 7.0 for details. The ***Summary Screen*** is non-editable to ALL users.

3.0 TO START

Before starting the database, the user will be requested to enter his/her login password. Specific password is required if write access is required - this is to be arranged between the user and the IT department. If the user only wants to view the records in the database, then he/she can just leave the password blank and either click the Enter button provided or hit the enter (or return↵) key on the keyboard.

Upon entering the database, the Pattern Database Start Form will be displayed, as shown in Figure 1. Three options are provided on this form:

Maintain Records -	to modify or update the data for the three controlled items in the database; to update the pump records in the database
View Records -	to read or view the data in the database for the three controlled items in the database; to view the "what where when" records of all three items in one screen full.
Quit Application -	to exit from the database

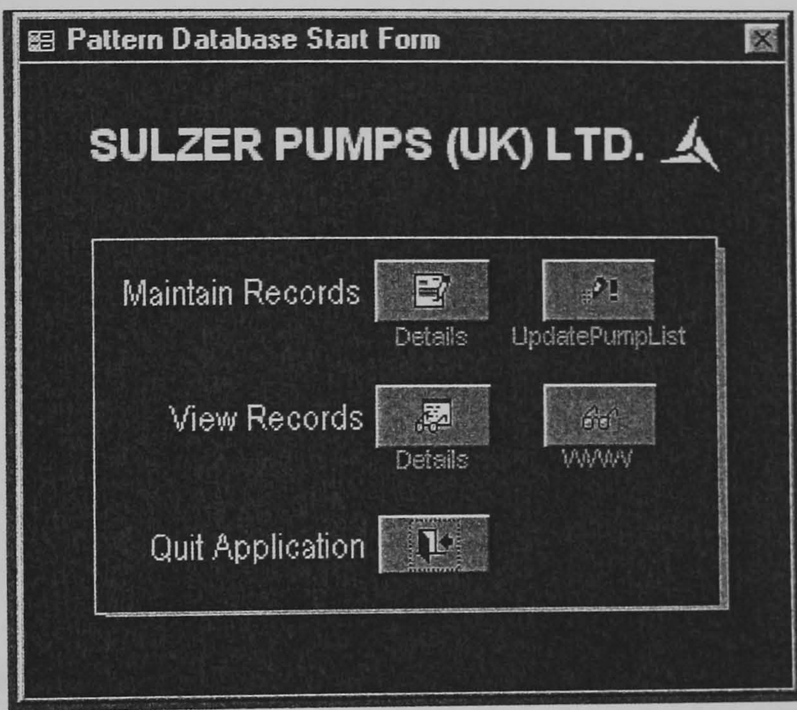


Figure 1 Pattern Database Start Up Display

Note:

- The Maintain Records options will be disabled, or greyed, if the user has no write access to modify the data the database.
- The Update Pump List is always disabled, or greyed, for all users except those who have the administration right to modify the database design.

Now, select the required option. For the purpose of this manual, all screen displays shown here will be those of Maintaining Records option. Where appropriate, the differences in screen design found in those with only viewing right will be mentioned.

4.0 PUMP ORDER SCREEN

Upon selecting the option Maintain Records - Details, the ***Pump Order Screen*** will be displayed, as shown in Figure 2. The search criterion for pump order is shown in Figure 3.

The details of a pump order include the pump sales order number, the pump type, size, and number of stages. Also provided are a text box for comment and a text box for indicating the source of that specific record, either from SPUK or SPF.

Two folders are provided under the data associated with the pump order:

- Pattern Set-up Location - to show which foundry the set-up was sent to produce what casting. When maintaining records, this is editable, therefore new records can be added in, obsolete records can be deleted, and changes can be made to every data in each row. However, when viewing records, this is non-editable.
- Pattern Set-up - to show what/which pattern set-ups are used in a specific pump order. This folder is ALWAYS non-editable for all users.

If it is necessary to remove a particular pattern set-up from a pump order or to add an existing pattern set-up to a pump order, this should be done through the Pattern Set-up Location folder. Refer to Section 2.0, note 4 for how to delete a record, and note 5 for how to add in a new record.

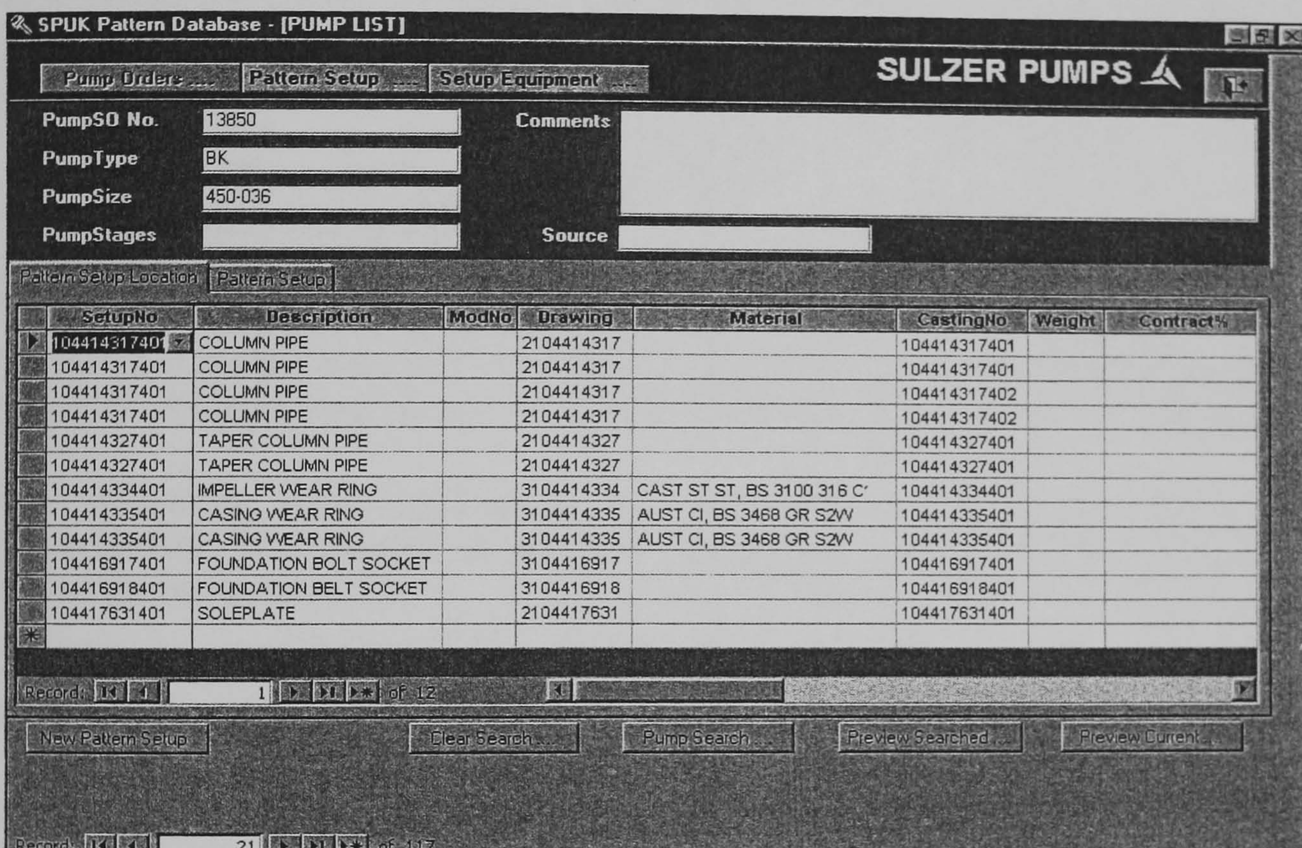


Figure 2 Pump Order Screen

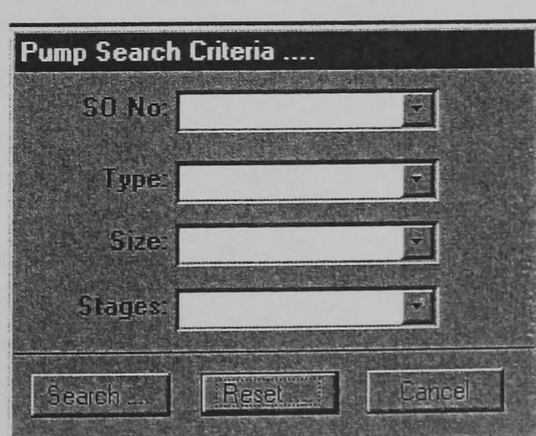


Figure 3 Pump Order Search Criteria

When adding a new record of an existing pattern set-up to a pump order, move the mouse cursor to the Set-up column, under the folder Pattern Set-up Location, and click on the scroll down icon for a list of pattern set-up available. Find and select the required pattern set-up. The details of the set-up will be automatically filled in. Remember to assign the necessary casting information, foundry to send, and date order is issued.

When maintaining records, if a new pattern set-up (i.e. one that does not exist) is required for a pump order, then the button "New Pattern Set-up", at the function button area, should be activated. **Note:** It is important NEVER to add in a new pattern set-up, one that does not exist, for a pump order using the add-in a new record method as explained in Section 2.0, note 5. Doing so will result in an error message prompting no match could be found. To overcome this, click OK on the error message and press the ESC button on the keyboard.

When "New Pattern Set-up" is activated, the user will be taken to the ***Pattern Set-up Screen***, see Figure 4 for an example of this screen snapshot. Note that the pattern set-up number, in the controlled item details section, is automatically assigned as "New Setup". **Note:** It is very important to change this to the correct new pattern set-up number - NEVER forget to change this or an error caused by duplicate pattern set-up number will occur. If an error message concerning duplicate values appear after activated the "New Pattern Set-up" button, do the following:

- Click OK on all the error messages displayed
- Go to the ***Pattern Set-up Screen***
- Search for Pattern Set-up with Pattern Set-up number = "New Setup"
- If it is a wrongly entered record, then delete the record using the delete button provided at the function button area; if it is a valid record but the pattern set-up number has not been correctly assigned, then change the pattern set-up number to its correct set-up number.

When viewing records, the "New Pattern Set-up" button does not exist, instead the "Pump Summary" is shown. When activated, the user will be taken to ***Pump Summary Screen***. Refer to Section 7.0 for more details.

5.0 PATTERN SET-UP SCREEN

Figure 4 shows a snapshot of the ***Pattern Set-up Screen*** while Figure 5 shows the search criterion for pattern set-up.

All fields, in the pattern set-up details section, are manual inputs except for Current Location and Last Used, which are automatically updated every time the particular set-up is sent to produce a specific casting for a particular pump order. Although these two are updated automatically, it is possible to change their values manually.

Four folders are provided under the data associated with the pattern set-up:

- Pattern Set-up Location - to show which foundry the set-up was sent to produce what casting. When maintaining records, this is editable, therefore new record can be added in, obsolete records can be deleted, and changes can be made to every data in each row. However, when viewing records, this is non-editable.
- Pump Designation - to show what/which pump order the particular set-up is used. This folder is ALWAYS non-editable for all users.
- Set-up Equipment - to show what/which set-up equipment the particular set-up is consisted of. This is editable when maintaining records but non-editable when viewing records.
- Set-up History – to show the history of changes the specific pattern set-up. Similar as set-up equipment folder, this folder is editable when maintaining records and non-editable when viewing records.

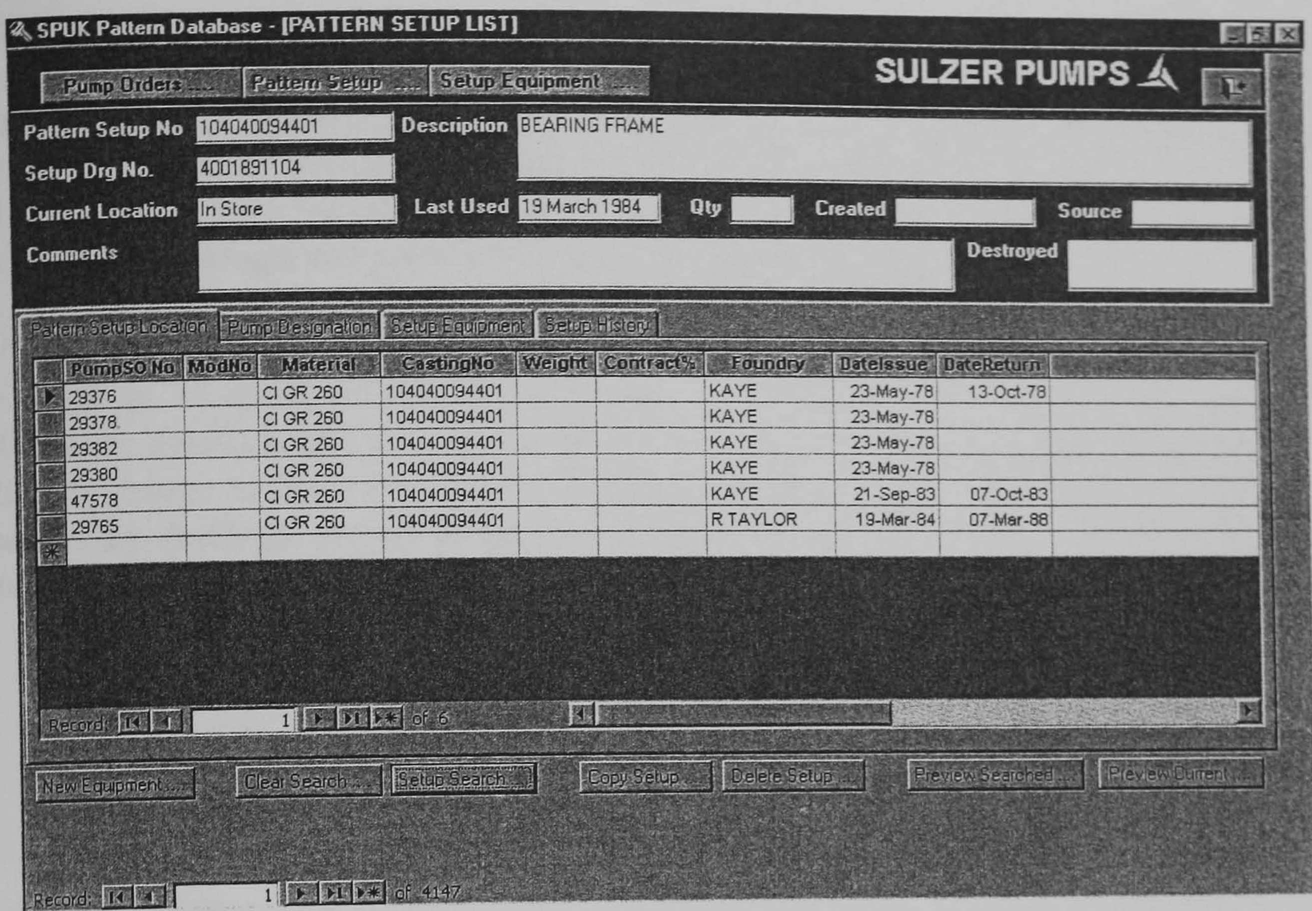


Figure 4 **Pattern Set-up Screen**

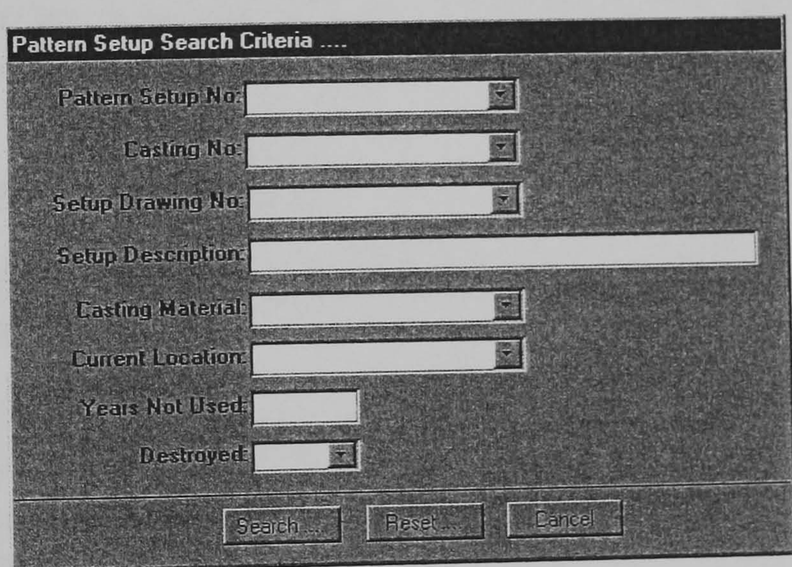


Figure 5 **Pattern Set-up Screen Search Criteria**

If it is necessary to remove a particular pump order from the pattern set-up or to add an existing pump order to the pattern set-up, this should be done through the Pattern Set-up Location folder. Refer to Section 2.0, note 4 for how to delete a record, and note 5 for how to add in a new record.

When adding a new record of an existing pump order, move the mouse cursor to the Pump SO Number column, under the folder Pattern Set-up Location, and click on the scroll down icon for a list of pump order available. Find and select the required pump order. The details of the pump will be automatically filled in. Remember to assign the necessary casting information, foundry to send, and date order is issued.

If a new pump order is using the set-up, it is recommended that the new pump order be added first in to the database using the ***Pump Order Screen*** and the set-up be assigned from the ***Pump Order Screen***.

When maintaining records, if a new set-up equipment, one that does not exist, is required for a pattern set-up, then the button "New Equipment", at the function button area, should be activated. **Note:** It is important NEVER to add in a new equipment that does not exist to a pattern set-up using the add-in a new record method as explained in Section 2.0, note 5. Doing so will result in an error message prompting no match could be found. To overcome this, click OK on the error message and press the ESC button on the keyboard.

When "New Equipment" is activated, the user will be taken to the ***Set-up Equipment Screen***, see Figure 6 for an example of this screen snapshot. Note that the equipment number, in the controlled item details section, is automatically assigned as "New Equipment". **Note:** It is very important to change to the correct new equipment number - NEVER forget to change this or an error caused by duplicate set-up equipment number will occur. If an error message concerning duplicate values appear after activated the "New Equipment" button, do the following:

- Click OK on all the error messages displayed
- Go to the ***Set-up Equipment Screen***
- Search for Set-up Equipment with Equipment number = "New Equipment"
- If it is a wrongly entered record, then delete the record using the delete button provided at the function button area; if it is a valid record but the equipment number has not been correctly assigned, then change the equipment number to its correct equipment number.

When viewing records, the "New Equipment" button does not exist, instead the "P/Set-up Summary" is shown. When activated, the user will be taken to ***Pattern Set-up Summary Screen***. Refer to Section 7.0 for more details.

6.0 SET-UP EQUIPMENT SCREEN

Figure 6 shows a snapshot of the ***Set-up Equipment Screen*** while Figure 7 shows the search criterion for set-up equipment.

Similar like the ***Pattern Set-up Screen***, all fields, in the set-up equipment details section, are manual inputs except for Current Location and Last Used, which are automatically updated every time the particular set-up is sent to produce a specific casting for a particular pump order. Although these two are updated automatically, it is possible to change their values manually.

Three folders are provided under the data associated with the set-up equipment:

- Pattern Set-up - to show what/which pattern set-up the particular equipment is used in. When maintaining records, this is editable, therefore new record can be added in, obsolete records can be deleted, and changes can be made to every data in each row. However, when viewing records, this is non-editable.
- Equipment History – to show the history of changes the specific set-up equipment. Similar as Pattern Set-up folder, this folder is editable when maintaining records and non-editable when viewing records.
- Where Use / Location - to show where the equipment is used for, i.e. for which pattern set-up in which pump order, and the location where the casting is produced. This folder is ALWAYS non-editable for all users.

If it is necessary to remove a particular pattern set-up from the equipment or to add an existing pattern set-up where the equipment is used, this should be done through the Pattern Set-up folder. Refer to Section 2.0, note 4 for how to delete a record, and note 5 for how to add in a new record.

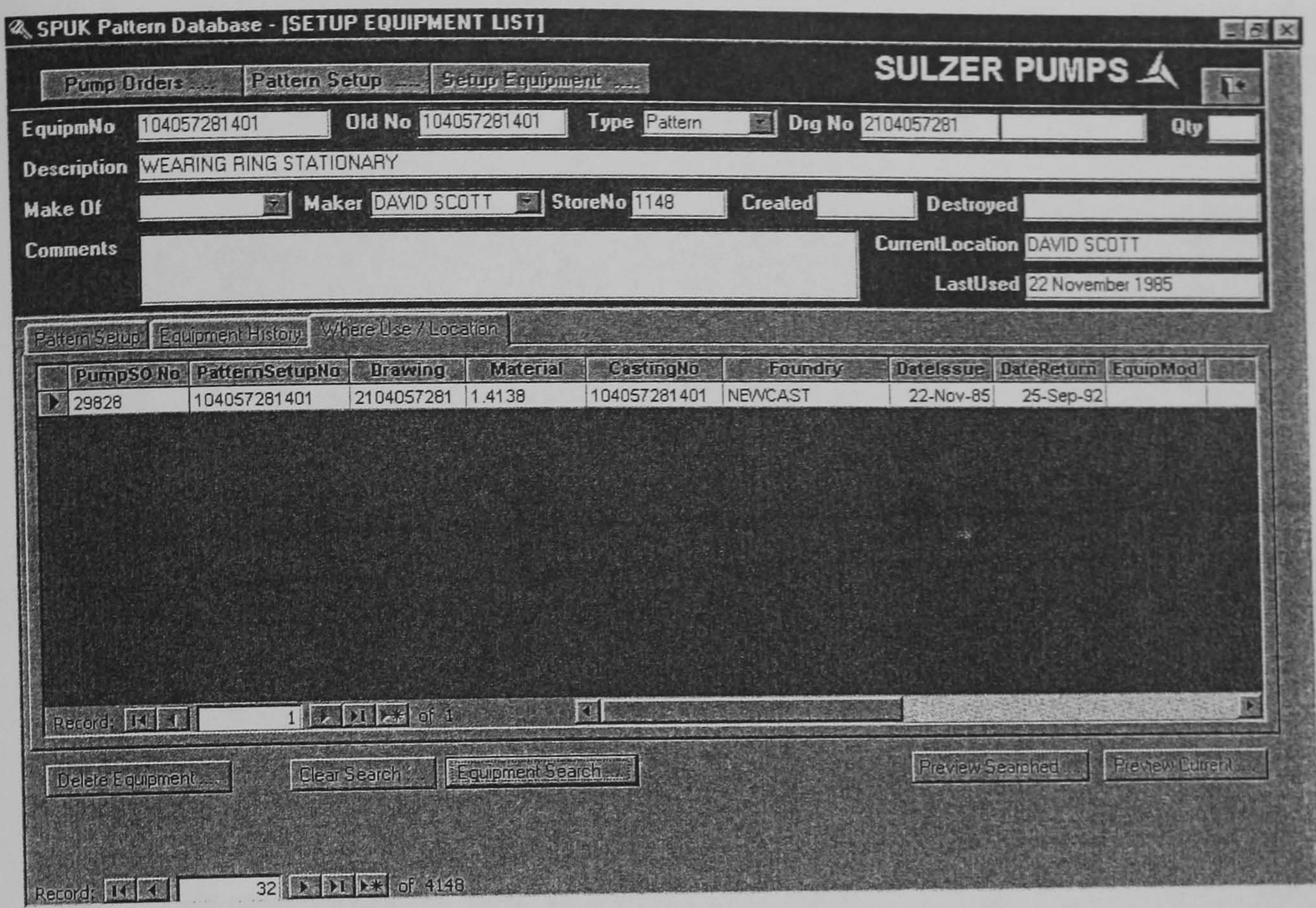


Figure 6 Set-up Equipment Screen

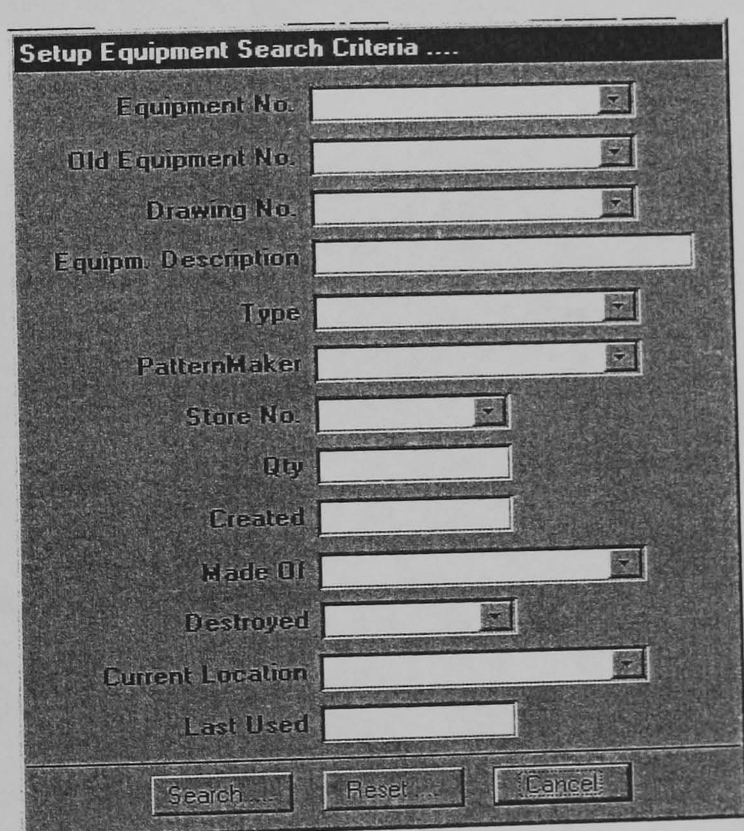


Figure 7 Set-up Equipment Screen Search Criteria

When viewing records, the "Delete Equipment" button does not exist, instead the "Equipment Summary" is shown. When activated, the user will be taken to Set-*up Equipment Summary Screen*. Refer to Section 7.0 for more details.

7.0 SUMMARY SCREEN

Upon selecting the option View Records - WWW in the Pattern Database Start Up Form, the ***WhatWhereWhen (WWW) Screen*** will be displayed, as shown in Figure 8. ***WWW Screen*** is a summarised view of where pattern set-up is used in what pump order and when and where it is sent to produce the required casting. The search criterion for this summarised ***WWW Screen*** is shown in Figure 9.

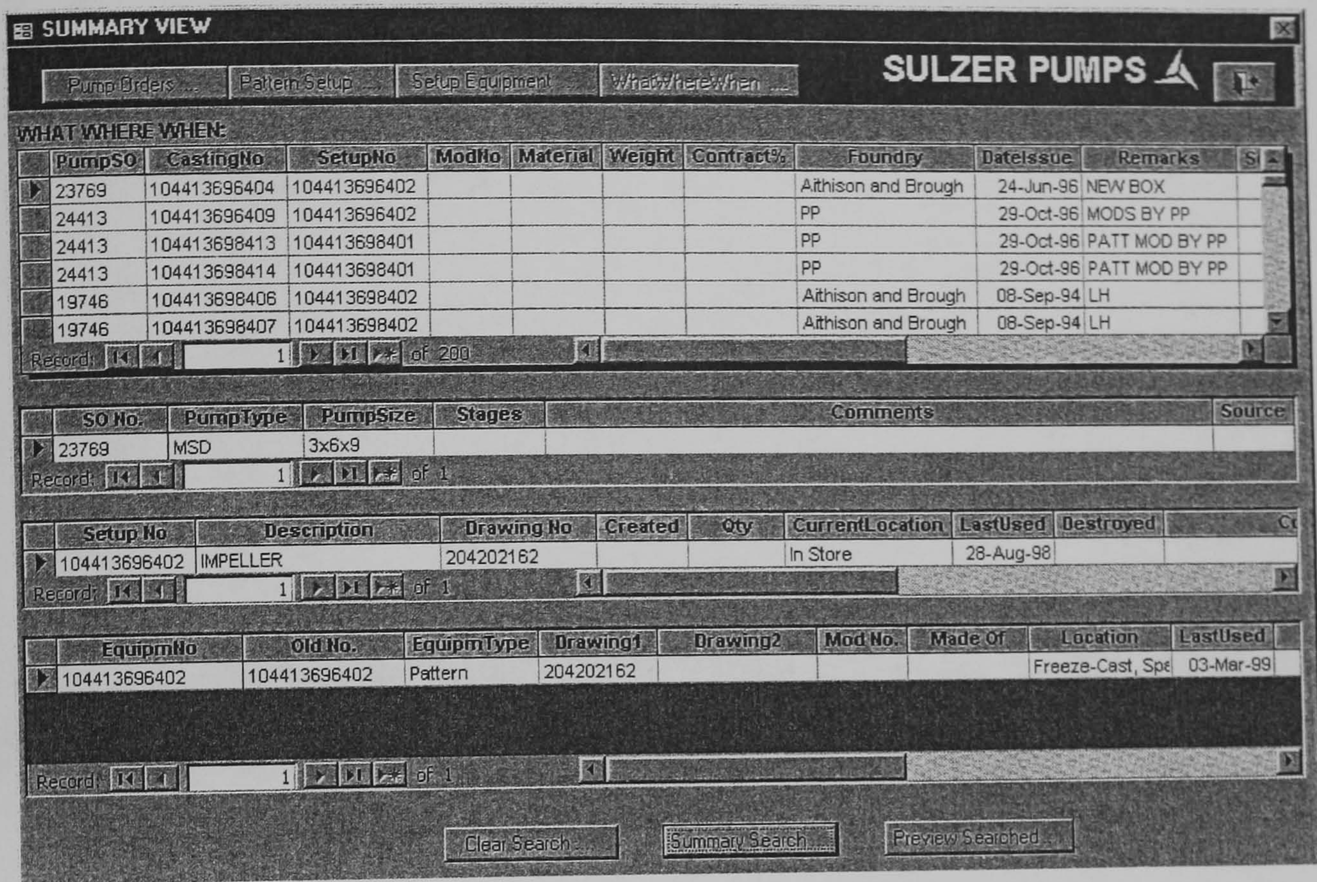


Figure 8 WWW Screen

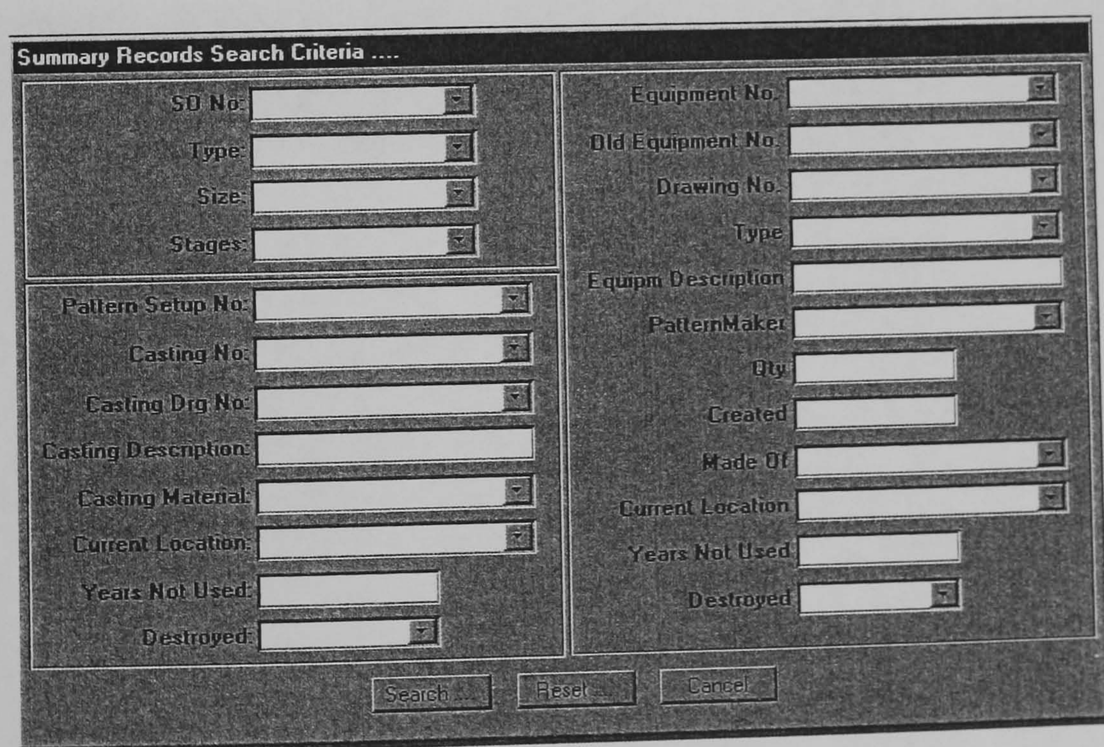
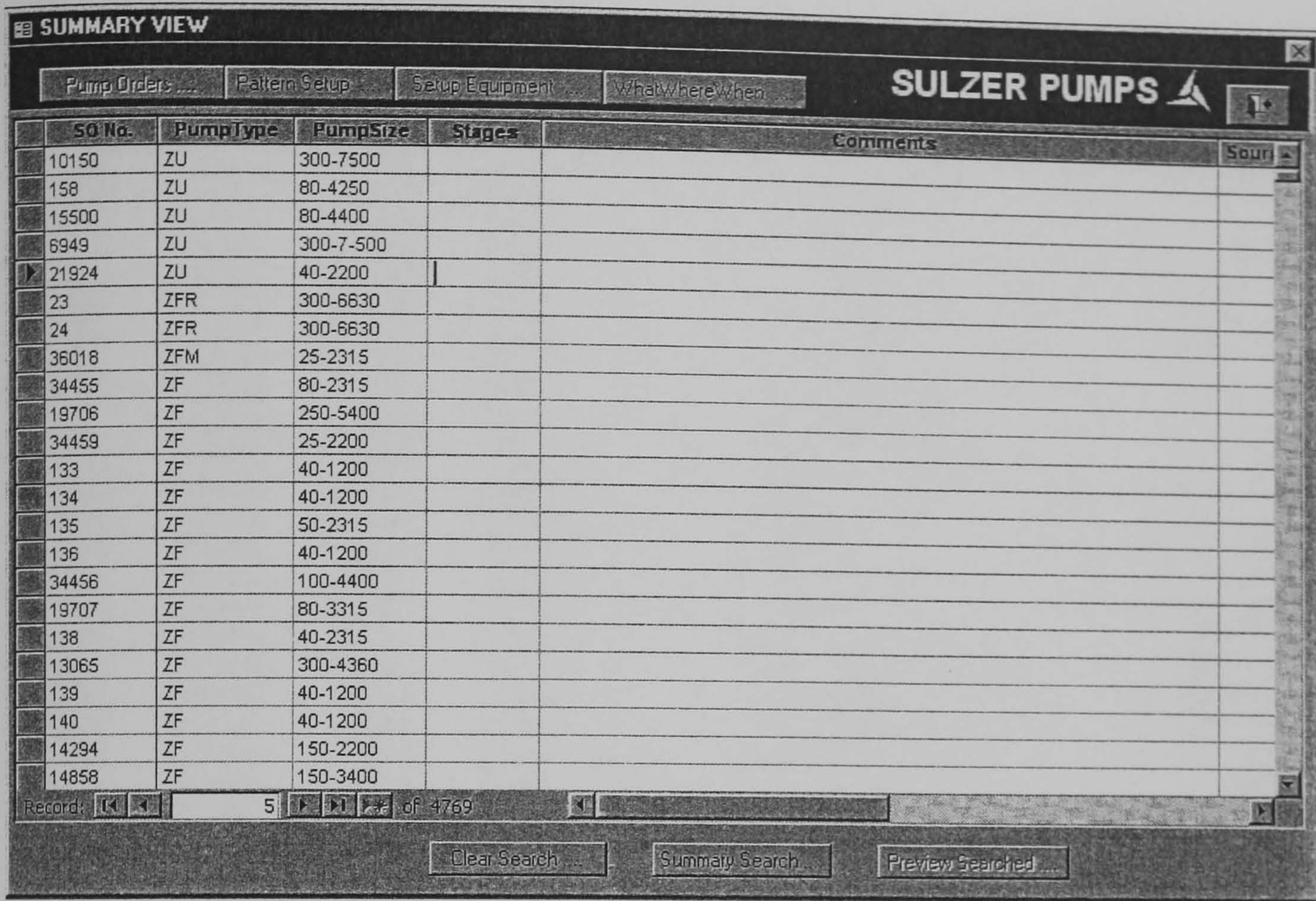


Figure 9 WWW Screen Search Criteria

The ***Summary Screen*** also consists of another three summarised screen for the three controlled items: ***Pump Summary*** (see Figure 10), ***Pattern Set-up Summary*** (see Figure 11) and ***Set-up Equipment Summary*** (see Figure 12).

As mentioned in Section 2.0, this ***Summary Screen*** is non-editable for ALL users. This also means that all the above screens, which are within the ***Summary Screen***, are non-editable.



SUMMARY VIEW

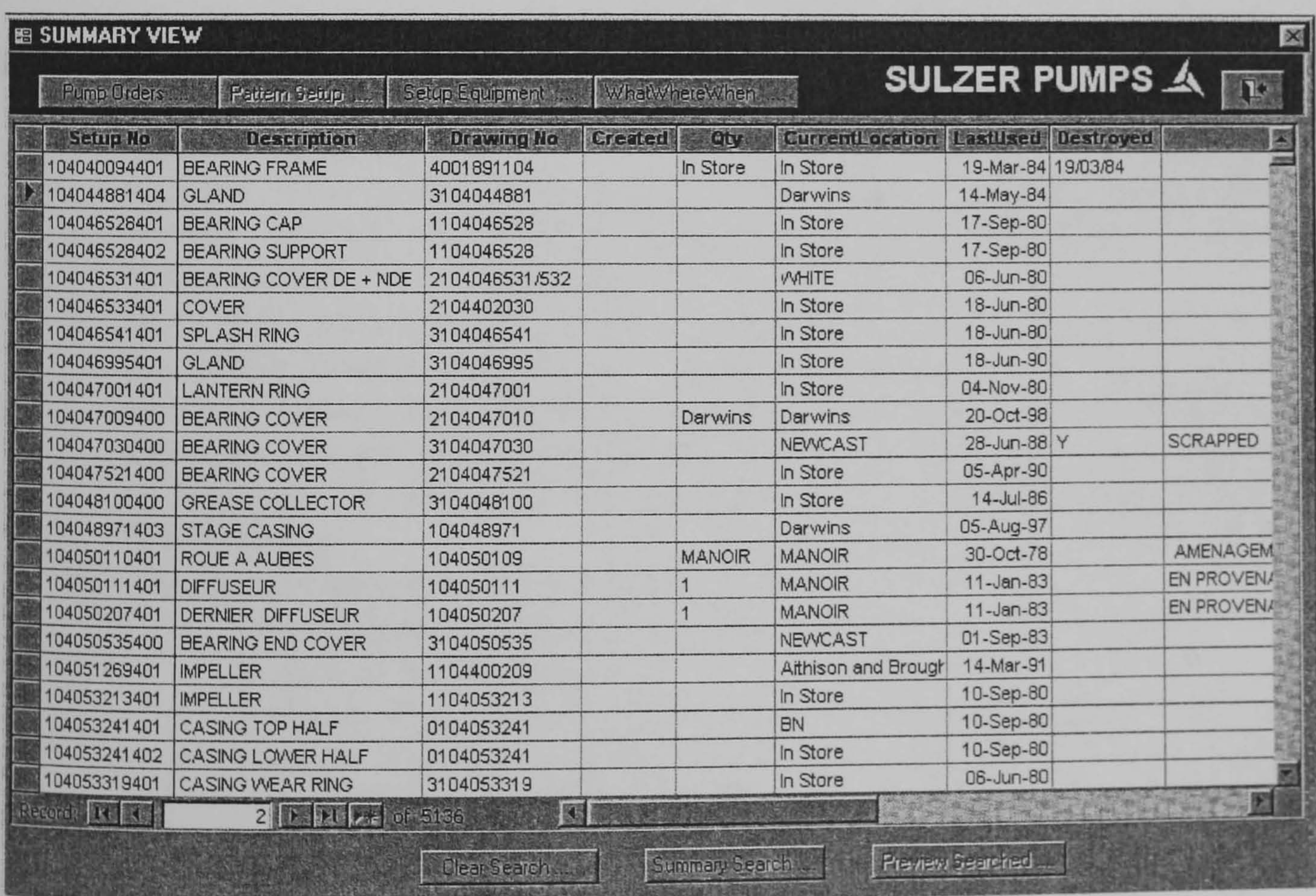
Pump Orders ... | Pattern Setup ... | Setup Equipment ... | WhatWhereWhen ... | SULZER PUMPS

SO No.	PumpType	PumpSize	Stages	Comments	Sour
10150	ZU	300-7500			
158	ZU	80-4250			
15500	ZU	80-4400			
6949	ZU	300-7-500			
21924	ZU	40-2200			
23	ZFR	300-6630			
24	ZFR	300-6630			
36018	ZFM	25-2315			
34455	ZF	80-2315			
19706	ZF	250-5400			
34459	ZF	25-2200			
133	ZF	40-1200			
134	ZF	40-1200			
135	ZF	50-2315			
136	ZF	40-1200			
34456	ZF	100-4400			
19707	ZF	80-3315			
138	ZF	40-2315			
13065	ZF	300-4360			
139	ZF	40-1200			
140	ZF	40-1200			
14294	ZF	150-2200			
14858	ZF	150-3400			

Record: 5 of 4769

Clear Search ... | Summary Search ... | Preview Searched ...

Figure 10 Pump Order Summary Screen



SUMMARY VIEW

Pump Orders ... | Pattern Setup ... | Setup Equipment ... | WhatWhereWhen ... | SULZER PUMPS

Setup No	Description	Drawing No	Created	Qty	CurrentLocation	LastUsed	Destroyed	
104040094401	BEARING FRAME	4001891104		In Store	In Store	19-Mar-84	19/03/84	
104044881404	GLAND	3104044881			Darwins	14-May-84		
104046528401	BEARING CAP	1104046528			In Store	17-Sep-80		
104046528402	BEARING SUPPORT	1104046528			In Store	17-Sep-80		
104046531401	BEARING COVER DE + NDE	2104046531/532			WHITE	06-Jun-80		
104046533401	COVER	2104402030			In Store	18-Jun-80		
104046541401	SPLASH RING	3104046541			In Store	18-Jun-80		
104046995401	GLAND	3104046995			In Store	18-Jun-90		
104047001401	LANTERN RING	2104047001			In Store	04-Nov-80		
104047009400	BEARING COVER	2104047010		Darwins	Darwins	20-Oct-98		
104047030400	BEARING COVER	3104047030			NEWCAST	28-Jun-88	Y	SCRAPPED
104047521400	BEARING COVER	2104047521			In Store	05-Apr-90		
104048100400	GREASE COLLECTOR	3104048100			In Store	14-Jul-86		
104048971403	STAGE CASING	104048971			Darwins	05-Aug-97		
104050110401	ROUE A AUBES	104050109		MANOIR	MANOIR	30-Oct-78		AMENAGEM
104050111401	DIFFUSEUR	104050111		1	MANOIR	11-Jan-83		EN PROVEN/
104050207401	DERNIER DIFFUSEUR	104050207		1	MANOIR	11-Jan-83		EN PROVEN/
104050535400	BEARING END COVER	3104050535			NEWCAST	01-Sep-83		
104051269401	IMPELLER	1104400209			Aithison and Brough	14-Mar-91		
104053213401	IMPELLER	1104053213			In Store	10-Sep-80		
104053241401	CASING TOP HALF	0104053241			BN	10-Sep-80		
104053241402	CASING LOWER HALF	0104053241			In Store	10-Sep-80		
104053319401	CASING WEAR RING	3104053319			In Store	06-Jun-80		

Record: 2 of 5136

Clear Search ... | Summary Search ... | Preview Searched ...

Figure 11 Pattern Set-up Summary Screen

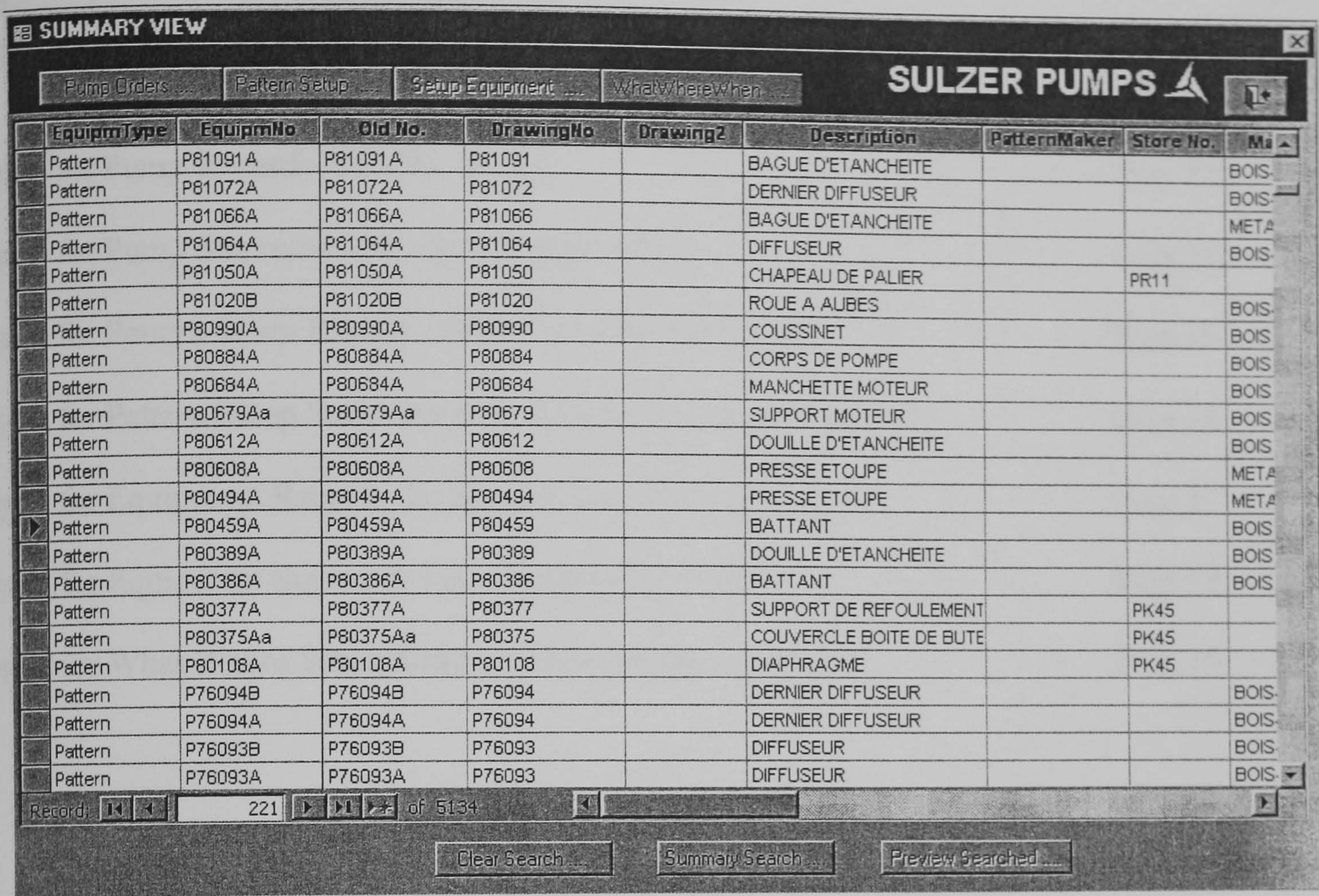


Figure 12 Set-up Equipment Summary Screen

The summarised screens design can be divided into three sections:

- The Header has 4 buttons: ***Pump Order***, ***Pattern Set-up***, ***Set-up Equipment***, and ***WhatWhereWhen***. Note that when in one specific screen, the associated button is disabled. For example, ***Pump Order*** button is disabled in the ***Pump Order Summary Screen***. An exit button is also provided on the right hand side of this area. The header is shaded with a blue background.
- The Details section which shows the summarised records of the four. The design of the WWW Summarised Screen is slightly different from the other three summary screens. Whilst the other three summary screen provide the details of the respective controlled items separately, the WWW Summarised screen shows, in one screen full, all the details of each pump order, pattern set-up, and the set-up equipment for each WWW record.
- The function button section which has three buttons:
  - Clear search - to re-set the search and display all records available for the respective controlled item.
  - Summary Search - to activate the summarised search criteria
  - Preview Searched - to preview print all the found records based on the summarised search criteria. **Note:** this button is always disabled, or greyed, before performing a summarised search or when the Clear Search button is activated.

8.0 SAMPLE REPORTS

PUMP RECORD 18133

SULZER PUMPS

SO No. 18133 **PumpType** MSD **PumpSize** 4x6x10.5 **PumpStages**

Comments

SetupNo	Description	DrgNo	Material	Location	LastUsed	Destroyed	EquipmNo	EquipmDrgNo	ModNo	Issued	Foundry	Eq/Destroyed
104413231403	STAGE PIECE	3104415711		DARWINS	28-Jul-98		104413231403	3104415711		06-Dec-93	PP	
	STAGE PIECE	3104415711		DARWINS	28-Jul-98		104413231403	3104415711		17-Nov-93	PP	
104415708401	BEARING HOUSING	0104415708	BS3100 GR A2 C ST	Darwins	10-Mar-00		104415708401	0104415708		11-Nov-93	NORTON	
104415709401	IMPELLER RH	2104415709		Freeze-Cast, Spain	23-May-00		104415709401	2104415709		13-Nov-93	FYSA	
104415710401	IMPELLER LH	2104415710		Freeze-Cast, Spain	23-May-00		104415710401	2104415710		13-Nov-93	FYSA	
104415714401	VOLUTE CASING UPPER	1104415714		Bonds Foundry	21-Feb-00		104415714401	1104415714		19-Nov-93	HiTec Foundry	

Date Printed: 20 January 2002

PUMP SUMMARY LIST

SULZER PUMPS

SO No.	PumpType	PumpSize	Stages	Comments
18133	MSD	4x6x10.5		
19746	MSD	3x6x9		
19752	MSD	6x8x12		
21380	MSD	6x8x12		
23544	MSD	6x8x12.5		
23769	MSD	3x6x9		
23811	MSD	4x6x10.5		
24018	MSD	6x8x13.5		
24196	MSD	3x4x11.5		
24347	MSD	4x6x10.5		
24413	MSD	3x6x9		
30830	MSD	12x12x15B		
31391	MSD	6x8x11		
31392	MSD	6x8x11		
31393	MSD	6x8x11		
31394	MSD	6x8x11		
31395	MSD	6x8x11		
31396	MSD	6x8x11		
31514	MSD	3x6x9c		
31983	MSD	6x8x11		
32764	MSD	12x12x15		
33351	MSD	4x6x10.5		
33629	MSD	6x8x11		
33630	MSD	6x8x11		
34487	MSD	3x6x9		
34755	MSD	3x6x9		
35189	MSD	6x10x12.5		
35198	MSD	3x6x9		
35351	MSD	6X8X12.5		
35736	MSD	4x6x10.5		
35831	MSD			
35946	MSD	3X6X11.75		
36015	MSD	6x8x11		
36016	MSD	6x8x11		
36159	MSD	6x8x13.5		

ate Printed: 20 January 2002

Report for Pump Summary List - Pump Type: MSD

PATTERN SETUP RECORD 104040094401

SULZER PUMPS

Setup No 104040094401 **Drawing No** 4001891104 **Description** BEARING FRAME

LastUsed 01-Jan-00 **CurrentLocation** NORTON **Destroyed**

Comments

EquipmNo	Type	Description	EquipmDrawing	Mod No.	Made Of	PatternMaker	Destroyed
104040094401	Pattern	BEARING FRAME	1			DAVID SCOTT	

Pump SO	Pump Type	Pump Size	Stages	Material	CastingNo	Foundry	Issue	Return	Remarks
29765				CI GR 260	104040094401	NORTON	01-Jan-00		
47578				CI GR 260	104040094401	KAYE	21-Sep-83	07-Oct-83	
29380				CI GR 260	104040094401	KAYE	23-May-78		
29382				CI GR 260	104040094401	KAYE	23-May-78		
29378				CI GR 260	104040094401	KAYE	23-May-78		
29376				CI GR 260	104040094401	KAYE	23-May-78	13-Oct-78	

Date Printed: 20 January 2002

PATTERN SETUP SUMMARY LIST

SULZER PUMPS

Pattern Setup No / Drawing No	Description	Current Location / Last Used	Created / Destroyed	Source	Comments
104136322401 104136322	ROUE A AUBES	A. BROUGH 08-Nov-91		SPF	
P56448A P56448	DIFFUSEUR	A. BROUGH 23-Jul-98		SPF	FRAIS LE GUILLOU 11925 FRF EN 1991
P56542A P56542	ROUE A AUBES	A. BROUGH 23-Jul-98		SPF	FRAIS LE GUILLOU 9275 FRF EN 1991 - A MANTES 1 BOYAU RESINE + 1 MOULE D'AILETTES CASIER 268 25/7/88
P56565A P56565	ROUE A AUBES	A. BROUGH 20-Jun-95		SPF	FRAIS LE GUILLOU 6625 FRF EN 1991 - A MANTES 1 NOYAU RESINE + 1 MOULE D'AILLETTES CAISER 268 25/7/88
P56637Aa P56637	DERNIER DIFFUSEUR	A. BROUGH 10-Jul-92		SPF	FRAIS LE GUILLOU 15900 FRF EN 1991
P72986A P72986	PIECE CONDUCTRICE	A. BROUGH 03-Apr-91		SPF	
P73025Aa P73025	FLASQUE D'ASPIRATION	A. BROUGH 03-Apr-91		SPF	
P73347A P73347	PIECE DE REFOULEMENT	A. BROUGH 03-Apr-91		SPF	FRAIS LE GUILLOU 1325 FRF EN 1991

Date Printed: 20 January 2002

Report for Pattern Setup Summary List- Current Location: A.Brough

EQUIPMENT RECORD 104051269401

SULZER PUMPS

EquipmType Pattern **EquipmNo** 104051269401 **Old No.** 104051269401 **DrawingNo** 1104400209 **Pattern Maker** DAVID SCOTT

Description IMPELLER

Created **Made Of** **Qty** **Store No.** 41 **Destroyed**

Comments

Setup No.	Drg No	Description	Eq/Mod	Material	CastingNo	PumpSO	P_Type	P_Size	Stgs	Foundry	Issue	Return	L/Used	Cur/Location
104051269401	1104400209	IMPELLER		13/4 GR NI CAST ST	104051269402	10975				Aithison and Brough	14-Mar-91		14-Mar-91	Aithison and Brough
104051269401	1104400209	IMPELLER		13/4 GR NI CAST ST	104051269402	47578				APV	29-Feb-84		14-Mar-91	Aithison and Brough
104051269401	1104400209	IMPELLER		13/4 GR NI CAST ST	104051269402	29765				APV	29-Feb-84		14-Mar-91	Aithison and Brough
104051269401	1104400209	IMPELLER		13/4 GR NI CAST ST	104051269402	42107				SHEEPBRIDGE	04-Apr-80		14-Mar-91	Aithison and Brough
104051269401	1104400209	IMPELLER		13/4 GR NI CAST ST	104051269402	29382				SHEEPBRIDGE	14-Mar-78		14-Mar-91	Aithison and Brough
104051269401	1104400209	IMPELLER		13/4 GR NI CAST ST	104051269402	29380				SHEEPBRIDGE	14-Mar-78		14-Mar-91	Aithison and Brough
104051269401	1104400209	IMPELLER		13/4 GR NI CAST ST	104051269402	29378				SHEEPBRIDGE	14-Mar-78		14-Mar-91	Aithison and Brough
104051269401	1104400209	IMPELLER		13/4 GR NI CAST ST	104051269402	29376				SHEEPBRIDGE	14-Mar-78		14-Mar-91	Aithison and Brough

EQUIPMENT SUMMARY LIST

SULZER PUMPS

Equipment Type / Equipment No / Old No	Equipment Drawing No / Qty	Description	Pattern Maker / Store No / Made Of	Current Location / Last Used / Destroyed	Comments
Pattern	1104400209	IMPELLER	DAVID SCOTT	Aithison and Brough	
104051269401			41	3/14/1991	
104051269401					
Pattern	1104053213	IMPELLER	DAVID SCOTT	DAVID SCOTT	
104053213401			120	9/10/1980	
104053213401					
Pattern	104061220	IMPELLER	DAVID SCOTT		
104061220001				7/21/1982	
104061220001					
Pattern	0104068577	IMPELLER	DAVID SCOTT	NEWCAST	
104068577402			C	1/17/1983	
104068577402					
Pattern	2104411485	IMPELLER	DAVID SCOTT	W & M	
104083725401				2/21/1989	
104083725401					
Pattern	2104083736	IMPELLER	DAVID SCOTT	DAVID SCOTT	
104083736000			1087	9/8/1988	
104083736000					
Pattern	2104083772	IMPELLER	DAVID SCOTT	WESTCROFT	
104083772000			1087	9/12/1988	
104083772000					
Pattern	2104083858	IMPELLER	DAVID SCOTT	DAVID SCOTT	
104083858000			1087	9/8/1988	
104083858000					
Pattern	2104417856	IMPELLER	DAVID SCOTT	Westley [Cardley Heath	456=PATT ONLY ENDS 405
104117856401			1320 = V CBX, S	11/13/2000	
104117856401					
Pattern	3104413696	IMPELLER	DAVID SCOTT	Freeze-Cast, Spain	
104413696401			1016	10/29/1999	
104413696401					
Pattern	204202162	IMPELLER	DAVID SCOTT	Freeze-Cast, Spain	
104413696402			1016	3/3/1999	
104413696402					

WHAT WHERE WHEN SUMMARY LIST

SULZER PUMPS

PUMP				PATTERN SETUP			CASTING		EQUIPMENT			
SO No.	Stages	SetupNo		Description	CurrentLocation		CastingNo	DateIssue	EquipmNo	Type	ModNo	Description
Type	Source	DrawingNo			LastUsed	Source	Material	DateR'turn	OldNo	MadeOf	Qty	
Size		SetupMod	Qty		Destroyed		Foundry	Source	DrawingNo		Source	Destroyed
18133		104413231403		STAGE PIECE	DARWINS		104413231404	12/6/1993	104413231403	Pattern		STAGE PIECE
MSD		3104415711			7/28/1998				104413231403			
4x6x10.5							PP		3104415711			
18133		104413231403		STAGE PIECE	DARWINS		104413231404	11/17/1993	104413231403	Pattern		STAGE PIECE
MSD		3104415711			7/28/1998				104413231403			
4x6x10.5							PP		3104415711			
18133		104415708401		BEARING HOUSING	Darwins		104415708401	11/11/1993	104415708401	Pattern		BEARING HOUSING
MSD		0104415708			3/10/2000		BS3100 GR A2 C ST		104415708401			
4x6x10.5							NORTON		0104415708			
18133		104415709401		IMPELLER RH	Freeze-Cast, Spain		104415709402	11/13/1993	104415709401	Pattern		IMPELLER RH
MSD		2104415709			5/23/2000				104415709401			
4x6x10.5							FYSA		2104415709			
18133		104415710401		IMPELLER LH	Freeze-Cast, Spain		104415710402	11/13/1993	104415710401	Pattern		IMPELLER LH
MSD		2104415710			5/23/2000				104415710401			
4x6x10.5							FYSA		2104415710			
18133		104415714401		VOLUTE CASING UPPER	Bonds Foundry		104415714411	11/19/1993	104415714401	Pattern		VOLUTE CASING UPPER
MSD		1104415714			2/21/2000				104415714401			
4x6x10.5							HiTec Foundry		1104415714			
19746		104413698402		IMPELLER	Aithison and Brough		104413698406	9/8/1994	104413698402	Pattern		IMPELLER
MSD		1204202161			8/28/1999				104413698402			
3x6x9							Aithison and Brough		1204202161			
19746		104413698402		IMPELLER	Aithison and Brough		104413698407	9/8/1994	104413698402	Pattern		IMPELLER
MSD		1204202161			8/28/1999				104413698402			
3x6x9							Aithison and Brough		1204202161			
19746		104413698402		IMPELLER	Aithison and Brough		104413698406	9/8/1994	104413698402	Pattern		IMPELLER
MSD		1204202161			8/28/1999				104413698402			
3x6x9							Aithison and Brough		1204202161			
19746		104413698402		IMPELLER	Aithison and Brough		104413698407	9/8/1994	104413698402	Pattern		IMPELLER
MSD		1204202161			8/28/1999				104413698402			
3x6x9							Aithison and Brough		1204202161			

APPENDIX E - Late Product Configuration Tool

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LATE PRODUCT CONFIGURATION TOOL

Chapter Four discussed the three important issues identified from the three industrial case studies carried out: firstly, effective product data management for NPD; secondly, using existing designs to promote standardisation; and finally, effective one-time order capture. The three case studies had identified that dispersed non-interconnected systems used throughout NPD, coupled with the traditional "over the wall" approach, have had caused tremendous losses to manufacturers in terms of re-work, scrap, and materials and labour wastage.

The three case studies also showed that highly customised product manufacturers, for example those in the make-to-order type industries, require an accurate first time product definition from the order bidding stage, and the sharing and maintaining of this accurate product data throughout the entire NPD process. Outcomes from the three case studies suggested using a late product configuration tool as a solution to aid product development process that emphasises on mass customisation.

A late product configuration tool can assist sales at the initial order bidding stage drawing on its vast knowledge of assembly and component relationships. In this way, it acts as an alternative to an actual product expert. It also provides the visibility of all processes related to a product and its documentation, especially the production status and parts availability. Hence, any product re-configurations, where and when required can be initiated to provide a quick response to changing customer requirements. This is important particularly with existing systems currently in use in most SMEs, it is almost impossible for manufacturers of complex assembled products to re-configure an order once it is moving through the factory floor

The author also envisaged that such tool can be developed to assist the organisation of customers, sales, design, and manufacturing information such that marketing, design engineering, and manufacturing are all involved in the product definition phase. It incorporates the product expert's knowledge and can be made accessible to all relevant parties throughout the entire NPD.

The objective of this chapter is to present the concepts underlying the development of a generic late product configuration tool, LPCon. It discusses the design concepts that involve the use of basic PDM systems functionality in providing the availability and visibility of relevant and accurate product data, and the use of object oriented technology to implement the configuration process. Two objectives are set for the proposed LPCon:

- To enable effective one time order-capture by providing computerised product expertise at the initial stage of the order capture process.
- To provide the visibility of product status to permit any late product re-configurations upon request by customers before delivery.

Also discussed are the potential benefits of using LPCon. As the proposed tool is targeted on SMEs, this chapter also presents a prototype development of LPCon, emphasising the platform for system development and the proposed computer architecture.

This chapter concludes by addressing how the above mentioned objectives of LPCon are met.

1 Design Concepts Development

The envisaged manufacturing environment for using of LPCon is of the type configure-to-order process, shown in Figure E.1, as proposed by the author. Refer to Section 3.1 for the detailed discussion of the configure-to-order process.

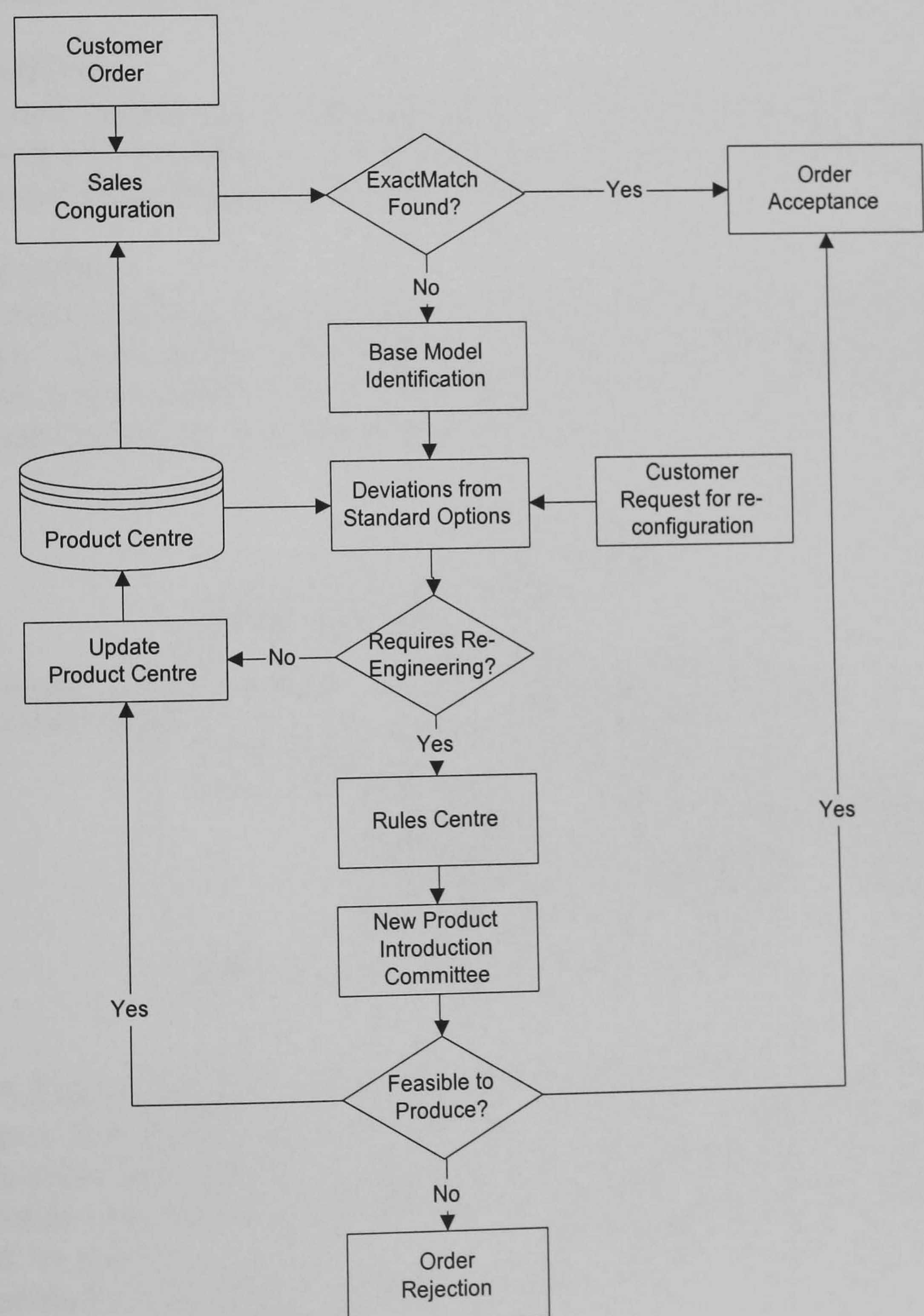

Figure E.1 Configure-to-Order Process

The product configuration process can be activated from two different stages during the product development process. The first is at the initial stage of capturing customer order where LPCon will act as a computerised product expertise to aid Sales. The second is when a customer order has progressed in to the product development process and can be at any stage of the product development process. To make this late configuration possible, it is necessary to have a closed loop relationship between the physical product, processes that produce the physical product, and the documentation that supports the physical product. This will provide the visibility of the product availability, all processes related to a product and its documentation.

Specifically, the main ideas behind the LPCon can be viewed from two perspectives:

- Front Office.
  The main objective is to track and analyse order generation and manage sales contacts and opportunities. Two key modules available for the Front Office are Customer Order Processing, and Sales Configuration.

- Back Office.
  The main objective is to provide the "behind the scenes" support to the Front Office. Four modules are available in the Back Office: Sales Configuration (which is also available in the Front Office), Document Control, Manufacturing Process Control, and Purchasing Order Processing.

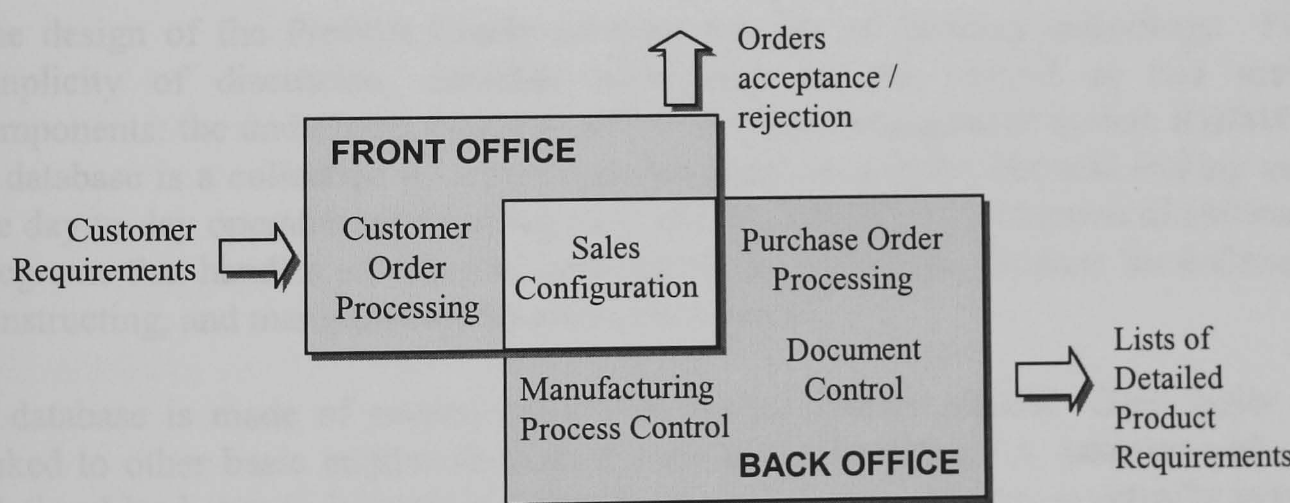

Figure E.2 Proposed Modules in LPCon

Figure E.2 shows the grouping of the modules, the input and the respective outputs. The inputs that trigger off the LPCon is the customer requirements. The main function of the Sales Configuration module is to prompt the user to enter the general specification of the product required and the operating conditions in which it will be required to function. It then converts customer requirements into a technical specification for processing by the Back Office.

The technical product specification generated is then fed through the other three modules in the Back Office into detailed requirements of all components within the finished product's bill of materials. The detailed requirements of an individual component will be represented by a set of characteristic values that describe the product uniquely.

The outputs from the LPCon vary according to the two offices. For the Front Office, the output can be either acceptance or rejection of order. For the Back Office, product documentation is produced, such as bills of materials for manufacturing, detailed drawings from design, and purchase orders to suppliers.

To allow all the five mentioned modules to function properly, the proposed design concept is divided into two parts: the Product Centre and the Rules Centre. The Product Centre is intended to provide the basic functionality offered by many commercial PDM systems, mainly the data vault, data security and accuracy; documents management; part classification, product structure management, and engineering change management. The Rules Centre provides the engine to drive the configuration process. It contains all the necessary relevant configuration algorithms for the purpose of product configurations.

2 Product Centre Design

The objective of the Product Centre is to create a PDM environment that will provide the closed loop relationship between the physical product, the processes that produce the physical product, and the required supporting documentation. This will provide the visibility of the product availability, all processes related to a product and its documentation.

The design of the Product Centre involves the use of database technology. For simplicity of discussion, database technology can be viewed as two main components: the underlying database and the database management system (DBMS). A database is a collection of related data necessary to support decision making and the day-to-day operation of an enterprise, whilst a DBMS is a collection of software programs that handles all requests to access to the underlying database for defining, constructing, and manipulating databases on demand.

A database is made of several entities or distinguishable objects. Each entity is linked to other basic entities through the use of relationships. A database without relationships between its entities will only consist of data, i.e. what is actually stored in the database, whilst a database with appropriate relationships linking the entities together provides information, the meaning of the data stored. For example, given a supplier (data), it is then possible to find information about the parts supplied by that supplier if there is a relationship between the two entities "Suppliers" and "Parts".

An entity has a set of properties or attributes that provides more meaningful information about the entity. For example, entity "Parts" has attributes such as part name, description, unit of measure, date of obsolete, etc. Each attribute is represented by a data type, which is a set of values that can be either a number, a string of characters, a date, etc. An attribute can be either a manual input value or a derived value by the system.

Specifically, the Product Centre uses relational database technology whereby an entity is represented by a table that consists of rows and columns. A column represents an attribute of an entity and a row consists of data or values of the respective property for a specific record. An important constraint on an entity is the key or uniqueness constraint on the attributes. An entity usually has at least one attribute whose values are distinct for each individual record in the table. Such an attribute is called the key attribute or primary key and its values can be used to identify each record in the entity uniquely. For example, the attribute Part ID is unique to the entity "Parts" and hence is the primary key of that entity. It is also possible for an entity to have no key attribute.

Another important constraint on an entity is the referential integrity constraint, used to maintain the consistency among records of two tables. A foreign key is used to define this referential integrity. A foreign key is an attribute of a table that refers to a key attribute of another table. For example, in a relationship formed between entities "Suppliers" and "Parts", two important attributes in this relationship will be the SupplierID and the PartID, which are foreign keys as they refer to key attributes in entities "Suppliers" and "Parts" respectively.

The main advantage of designing the Product Centre using the database approach is that it provides an enterprise with a centralised control of the valuable product data. The envisaged benefits are that all product data can be shared; data redundancy can be reduced if not eliminated; and data security, consistency, accuracy and integrity can be ensured.

The Product Centre consists of five integrated and shared relational databases which are the proposed five modules and its main function is to manage the product data efficiently and effectively. The conceptual design or schema for the Product Centre is DBMS independent, therefore it can be developed on virtually any relational database programs. The design of each database is now discussed in detail.

2.1 Sales Configuration

The objective of this module is to provide the identification and product data management of all physical parts that are procured, designed, manufactured, or maintained in a company. It is made of eleven entities: Part Details, Part BOM, Structure Type, Part History, Part Characteristics, Part Category, Part Family, Part Group, Part Style, Part Forecasting, and Part Inventory. Figure 5.3 shows the relationship between these seven entities in Sales Configuration.

Part Details describes the physical part itself and has twelve attributes, as shown in Figure E.3. In order to allow flexibility in defining the number of hierarchy allowed in the bill of materials (BOM), without imposing any constraints, a part is identified with a specific BOM level:

- ❖ Level 0 - end product [e.g. truck]
- ❖ Level 1 - assembly [e.g. drive system]
- ❖ Level 2 - sub assembly [e.g. lubrication system]
- ❖ Level 3 - single component [e.g. fuel tank].

The last four attributes in Part Details allow identification of each physical part and hence provides the part classification functionality, as found in many PDM systems.

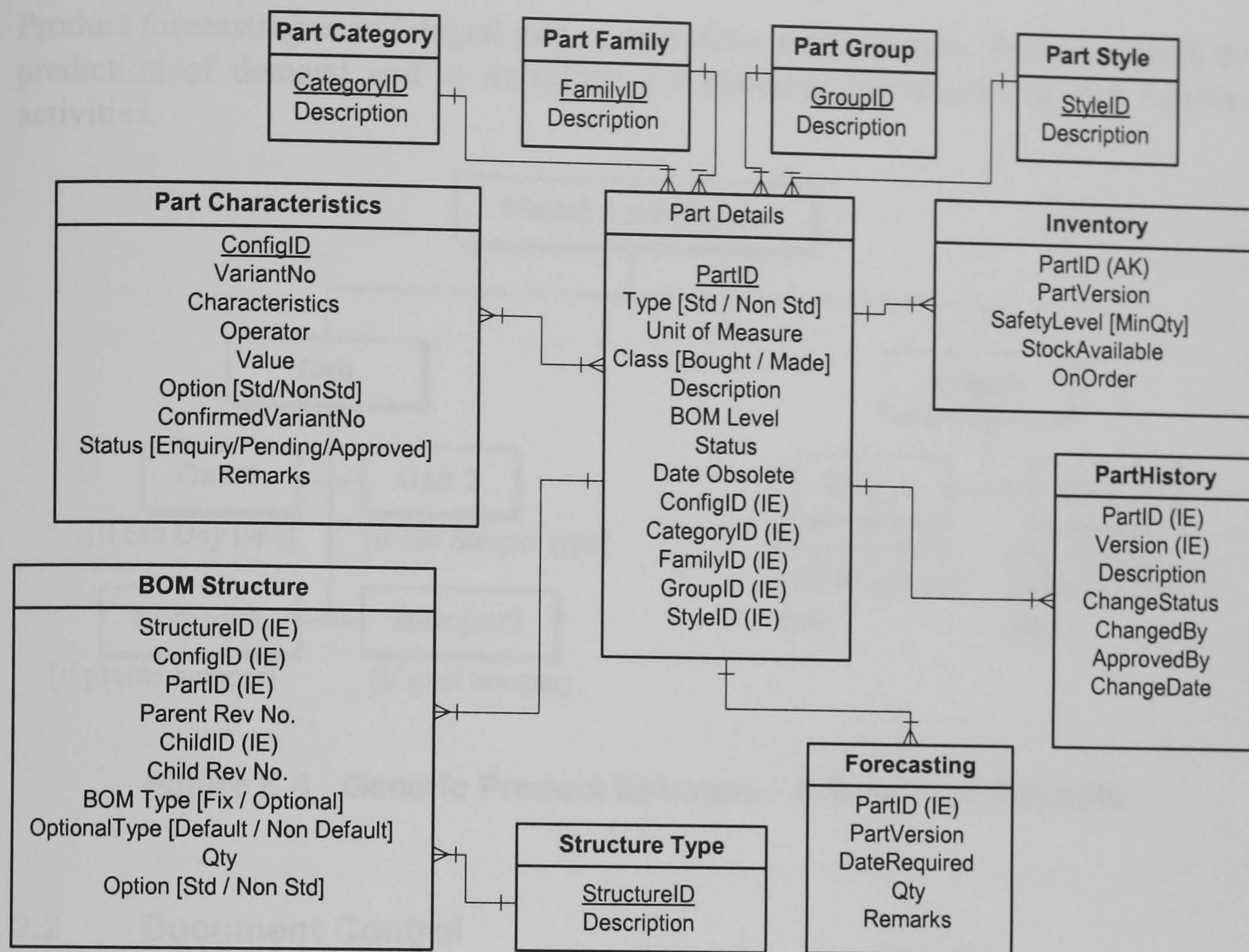

Figure E.3 Sales Configuration - Entities Relationships

The default product structure is a generic BOM, which includes all of the possible physical parts that make up a physical arrangement either as single components, sub-assemblies, assemblies, or end products. A simple generic product structure for a typical commercial truck is shown in Figure E.4. A product structure mainly consists of at least one child part within one parent part. Also, a part can exist as child part to many parent parts defined as it is a general practise that a part can be used in more than one assembly of the same end product, or even in a completely different product. It is therefore necessary to represent a "where used" facility to allow the identification of all parent parts, besides the product structure of a specific part.

Whilst the default product structure is the product assembly structure that inherently creates and maintains the BOM, it is also possible to have further user-defined structures to view products from different views. Structure Type provides the capability to handle multiple views of a product, such as maintenance or manufacturing perspective, in order to support multiple views of a product throughout the NPD.

In order to facilitate proper engineering change management on each part, it is necessary to introduce the Part History, which shows the changes each part undergoes and is made of eight attributes. To store the rules for configuration purposes, Part Characteristics provides the design characteristics of each unique family of product. To configure a product, it is necessary to know the product structure as well as the parts availability. Hence Part Inventory is provided.

Product forecasting is an integral part of operations management. Part Forecast is the prediction of demand and is important for planning manufacturing and logistics activities.

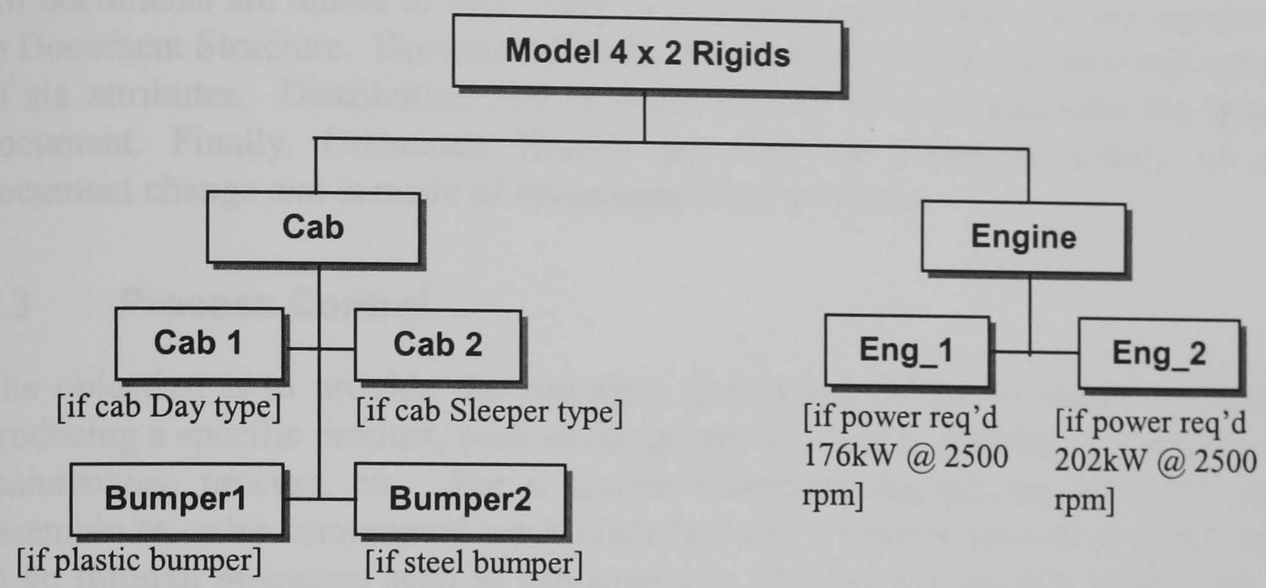

Figure E.4 Generic Product Structure - A Simplified Example

2.2 Document Control

The objective of Document Control is to provide the necessary document management functionality, found widely in all PDM systems, to control the relationship, history, and maintenance of all documents used within the NPD. It has five entities: Document Type, Document Details, Document Structure, Document History, and Document Distribution List. Figure E.5 shows the relationship between these five entities in Document Control.

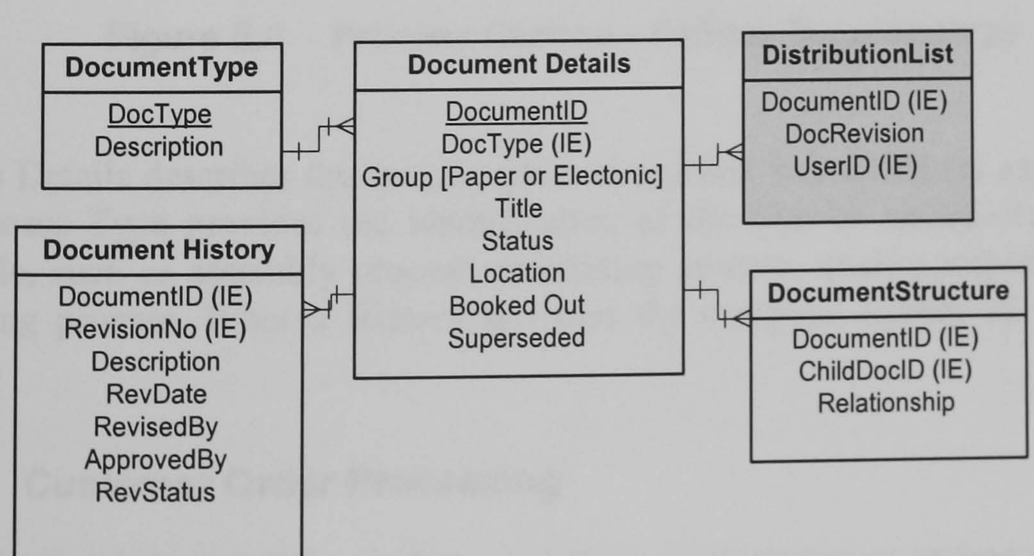

Figure E.5 Document Control - Entities Relationships

It is important to able to classify each document used or available to its type to facilitate easy and quick search. A document can be a 2D CAD drawing, 3D model, sales order, purchase order, CNC programs, test specification, etc. Document Type provides such capability to identify the type of document.

All documents are linked to each other in a hierarchical manner and are represented in Document Structure. Document Details describes the document itself and consists of six attributes. Distribution List provides the list of users requiring the specific document. Finally, Document History provides the complete history of each document change and is made of seven associated attributes.

2.3 Process Control

The objective is to provide the complete description of the processes required in producing a specific product, such as design process, manufacturing process, test and maintenance process, etc. For a simple manufacturing process example, in an assemble to order commercial truck manufacturer, a vehicle (an end product) needs to go through processes such as cab assembly, framing the chassis, joining the cab and chassis, painting, and testing. It is made of three entities: Process Type, Process Details, and Process History.

Figure E.6 shows the relationship between these four components in Process Control.

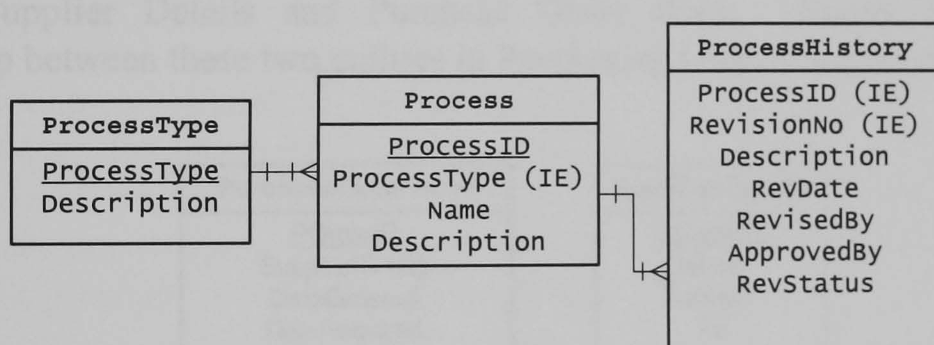

Figure E.6 Process Control - Entities Relationships

Process Details describes the specific process and has four attributes associated with it. Process Type provides the identification of the type of manufacturing process available, such as assembly process, machining process, quality inspection process, or testing process. Process History provides the complete history of each process change.

2.4 Customer Order Processing

The objective is to generate, analyse, and track all customer or prospect requests for initial order definition from the time of the first enquiry until an order is placed. This will generate and track all orders from the point the orders are entered till shipment, and assist in the management of customer contacts and requirements. It has two entities: Customer Details and Customer Order Book. Figure E.7 shows the relationship between these two components in Customer Order Processing.

The Customer Order Book, which manages all orders generated, or quotation requested, by customers. It has seven attributes. Customer Details provides all relevant information about a customer. Thirteen attributes are associated with each customer.

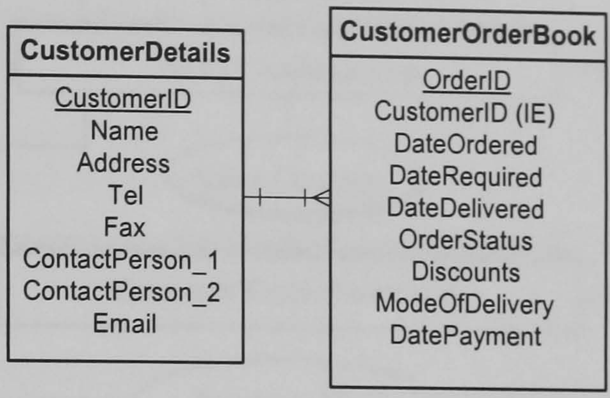

Figure E.7 Customer Order Processing - Entities Relationships

2.5 Purchase Order Processing

The objective is to generate, manage, analyse, and track purchase orders to provide efficient materials management. These orders also include the internal orders (manufacturing orders) to control the work in progress. It is also made of two entities: Supplier Details and Purchase Order Book. Figure E.8 shows the relationship between these two entities in Purchasing Order Processing.

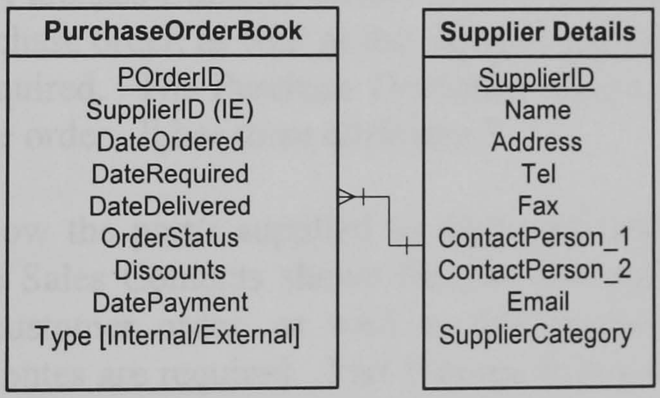

Figure E.8 Purchasing Order Processing - Entities Relationships

Supplier Details provides all relevant information about each supplier. Fourteen attributes are associated with each supplier. The Purchase Order Book, which has seven attributes, manages all orders generated for vendors.

2.6 Product Centre - Database Schema

An entity-relationship (ER) diagram is used to model the conceptual design of a database application. The proposed simplified ER diagram for the Product Centre is shown in Figure E.9. Here, the standard conventions used for ER diagrams are not taken into consideration. The relationships linking the five integrated databases are discussed in detailed.

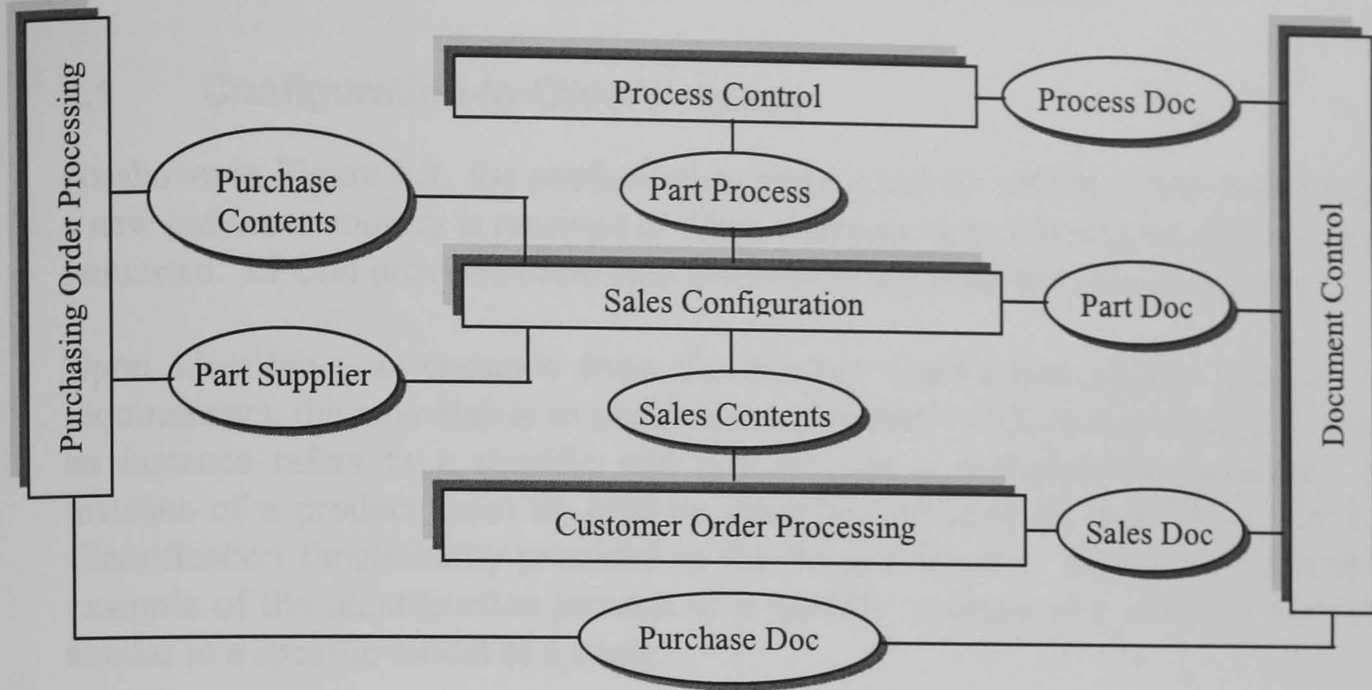

Figure E.9 Simplified Product Centre ER Diagram

As many documents are produced to describe a part, it is important to associate the relationships between the part and the document in a meaningful way. Part Document provides this relationship and it is made of five attributes. Similarly, it is also important to associate all documents with a specific process. Process Document provides such relationship and is made of four attributes.

The Sales Document shows all the documentation for a specific sales order. It has three attributes. The Purchase Contents shows the part and the quantity ordered and received for each purchase order, as well as the required and received dates, therefore four attributes are required. The Purchase Document shows all the documentation for a specific purchase order. It has three attributes.

The Part Supplier show the part/s supplied by each individual supplier and it has eight attributes. The Sales Contents shows the part and the quantity ordered and delivered for each customer order, as well as the required and delivery dates. Therefore, seven attributes are required. Part Process shows the processes that each part has to undergo, which has five attributes.

3 Rules Centre Design

With all relevant product data accurately defined and their relationships established in the Product Centre, the Rules Centre provides the engine to drive the configuration process. The objective is to manage and validate all order definitions from initial enquiry until order delivery where it is technically, commercially, and legally feasible to produce.

The Rules Centre provides a temporary storage for the product definition process before a configuration is approved. The design of the Rules Centre involves two entities in the Sales Configuration module of the Product Centre: Part Characteristics and Product Structure. Here, the configure-to-order process is discussed in more details and the setting of the configuration algorithms is described.

3.1 Configuration-to-Order Process

As shown in Figure E.1, the configuration process can be activated from either when a new customer enquiry is received or when a change to an existing customer order is requested. LPCon provides these two means to every customer enquiry received.

Upon identifying an instance from the Product Centre that closely matches the requirements, the next step is to perform the necessary configuration required. Here, an instance refers to a specific end product that a manufacturer produces. An instance of a product from its product classification is made possible by the Part Classification functionality provided in the Product Centre. Figure E.10 shows an example of the identification process of a specific instance of a truck, or here it is similar to a specific model of a truck.

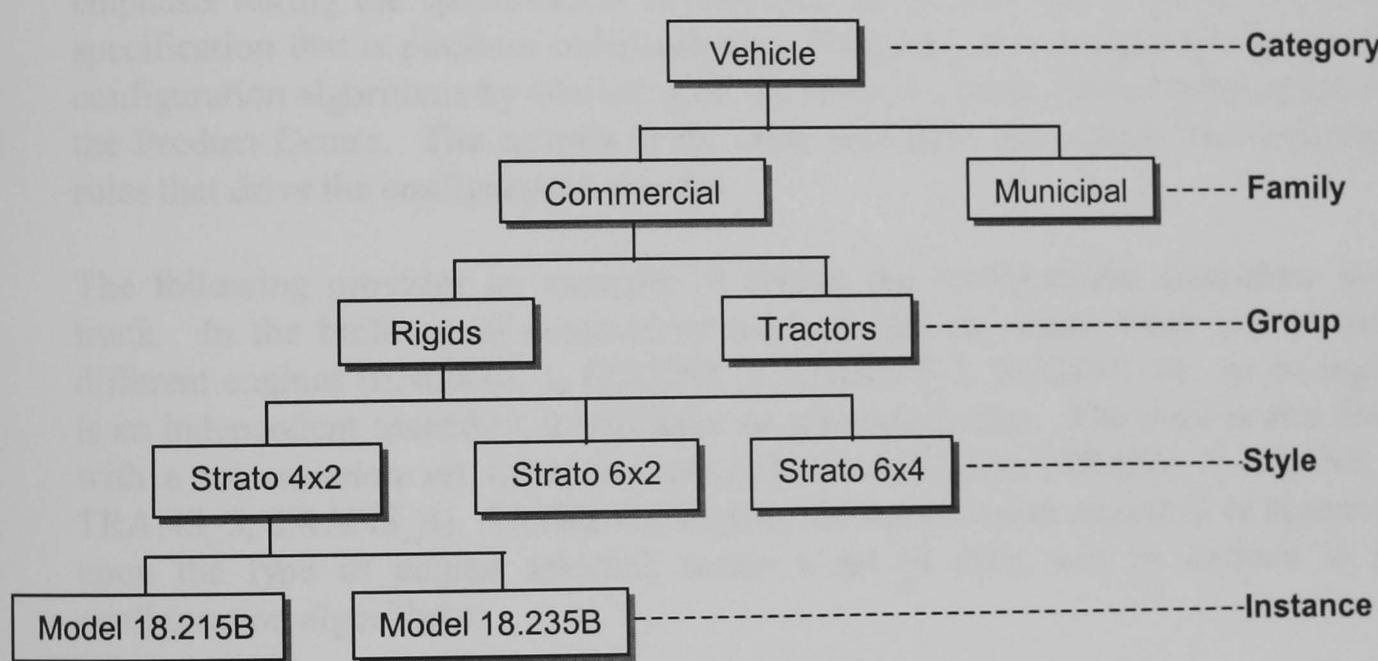

Figure E.10 Product Classification

The configuration or re-configuration process will only be subjected to the new product introduction (NPI) route if a non-standard or non-existence variant is required. Here, a variant, or an option, is a combination of features used to build up an instance. For example, adhering to the example of a truck, an instance, for example Model 18.215B, can have two variances: one is fitted with a 200 litres fuel tank and the other is with a larger fuel tank, 300 litres. For a non existing variant, where more changes are still required from an identified variant, the change characteristics process (or more appropriate, the configuration process) will be carried out based on the rules in the Rules Centre. Any requirements not included in the Rules Centre, LPCon will assign a temporary configuration number and assign the configuration status as "Enquiry".

Upon notifying the NPI committee on the special customer order, LPCon will change the configuration status to "Pending", which differentiates it from customer orders with "enquiry" configuration. If the configuration is feasible to be produced, the NPI committee will update the configuration status to "Approved", or reject if it is not with a message with reasons for rejection. Figure E.11 shows the detailed envisaged configure-to-order process using the LPCon.

3.2 Configuration Algorithms

Tiihonen identified two apparent ways to understand product modularity [Tiihonen et al 1996]. The first starts from customer needs and modularises the product into functional modules, and the second looks at the modularity from the product structure and manufacturability. LPCon looks at both ways as the first helps the configuration process at the sales stage, where it maps customer requirements to a technical specification, and the second helps at the delivery process by identifying the possibility of producing the required changes.

Knowledge based engineering tools can be employed to provide the rules which govern the "why" and "how" of a design rather than just the "what". However, the emphasis during the specification development of LPCon was to produce a model specification that is platform independence. Therefore, it is decided to structure the configuration algorithms by tabulating all the rules in a table: Table Characteristics in the Product Centre. The records in the table will form the basis of the underlying rules that drive the configuration process.

The following provides an example of setting the configuration algorithms for a truck. In the build-up of commercial truck, it has an engine from four possible different engines (ENGINE_1, ENGINE_2, ENGINE_3, ENGINE_4). As an engine is an independent assembly, it will have no associated rules. The truck is also fitted with a transmission set from four possible transmissions (TRANS_1, TRANS_2, TRANS_3, TRANS_4). Unlike the engine, the transmission assembly is dependent upon the type of engine selected, hence a set of rules will be defined in the configuration algorithms:

TRANS_1 [ENGINE]	-	ALL ENGINE TYPES
TRANS_2 [ENGINE]	-	ENGINE_1 or ENGINE_2
TRANS_3 [ENGINE]	-	ENGINE_3
TRANS_4 [ENGINE]	-	NOT ENGINE_4

There are three possible air-conditioning units that can be fitted to a truck (AC_1, AC_2, AC_3). The selection of the type of air-conditioning depends on the combination of the selected engine and transmission set:

AC_1 [ENGINE, TRANS]	-	(ENGINE_2 and TRANS_2) or (ENGINE_2 and TRANS_1)
AC_2 [ENGINE, TRANS]	-	ENGINE_3 and TRANS_3
AC_3 [ENGINE, TRANS]	-	TRANS_4

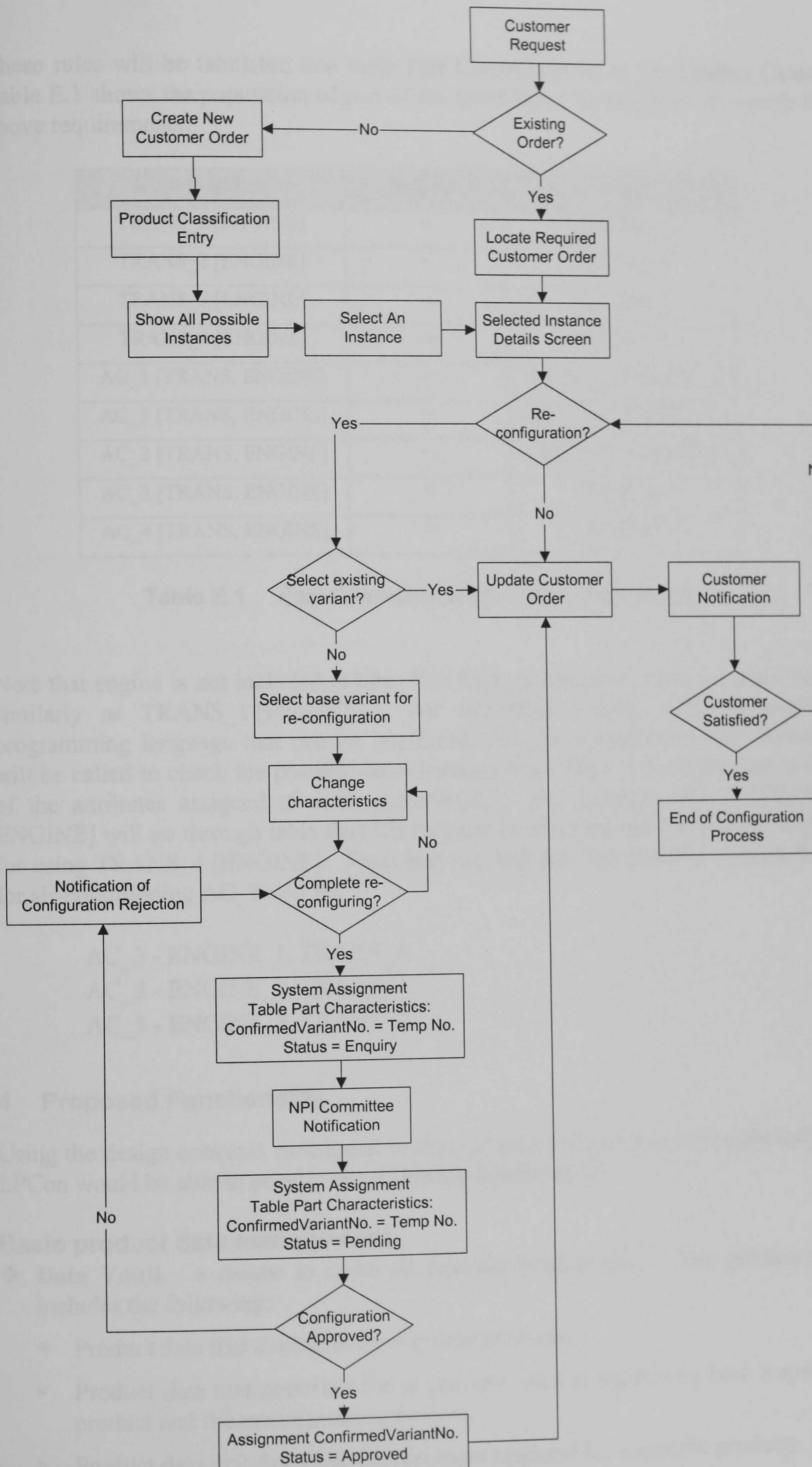

Figure E.11 Detailed Configure-to-Order Process using LPCon

These rules will be tabulated into table Part Characteristics in the Product Centre. Table E.1 shows the population of part of the table Part Characteristics to satisfy the above requirements:

Characteristics	Operator	Value
TRANS_2 [ENGINE]	=	ENGINE_1
TRANS_2 [ENGINE]	=	ENGINE_2
TRANS_3 [ENGINE]	=	ENGINE_3
TRANS_4 [ENGINE]	<>	ENGINE_4
AC_1 [TRANS, ENGINE]	=	TRANS_2, ENGINE_2
AC_1 [TRANS, ENGINE]	=	TRANS_1, ENGINE_2
AC_2 [TRANS, ENGINE]	=	TRANS_3, ENGINE_3
AC_3 [TRANS, ENGINE]	=	TRANS_4, *
AC_4 [TRANS, ENGINE]	=	*, ENGINE_3

Table E.1 Part Characteristics - Table Population

Note that engine is not included in table Part Characteristics as it has no constraints, similarly as TRANS_1 [ENGINE]. An additional coding, using appropriate programming language that can be interfaced with the chosen relational database, will be called to check the possible combinations when there is no restriction to one of the attributes assigned to each characteristic. For example, AC_3 [TRANS, ENGINE] will go through table Part Characteristics to determine the possible engine for using TRANS_4 [ENGINE]. From this construction, the possible combinations for air-conditioning AC_3 will be:

AC_3 - ENGINE_1, TRANS_4
AC_3 - ENGINE_2, TRANS_4
AC_3 - ENGINE_3, TRANS_4

4 Proposed Functionality

Using the design concepts mentioned in the previous section, it is envisaged that the LPCon would be able to provide the following functionality:

Basic product data management:

- **Data Vault** - a means to store all relevant product data. The product data includes the following:
  - Product data that describes the physical products;
  - Product data that describes the documents used in supporting both a specific product and the manufacturing process;
  - Product data that describes the processes required for a specific product;
  - Product data that describes the customers and the sales documentation for each a specific product;

- Product data that describes the suppliers and the purchase documentation for each a specific product.

- **Product Data Structure** - the bill of materials that describes the build of a specific product
- **Part Classification** - classification of parts into categories, families, groups and styles to allow fast retrieval of a required part
- **Engineering Change** which facilitates controlled engineering change process for all products, documents, and manufacturing processes:
  - Automatic notification of changes to all involved members of a project
  - The visibility of status of all changes made - approved, pending, rejected, etc.
- **Document Distribution** - issuance of documents to the list of pre-defined users

Product configuration:

- Design Characteristics - the design characteristics that define a part / product
- Build Up Characteristics - BOM characteristics that define a specific instance of a product in its family.

Materials requirements planning:

- Procurement Plan - tracking of work in progress and handling and tracking purchase activities such as materials procurement
- Part Inventory - the list of part available in stock, on order.
- MRP - calculating order release based on order requirements.
- Supplier Performance - analysis of vendor in terms of types of item provided, items price or cost attractiveness, speed of delivery, delivery performance, and quality of items provided.

Shop Floor Control

- Production Progress - tracking of the status of each work order on the shop floor.
- Production Performance - comparisons of actual production time against standard production time for each process.
- Production Scheduling - monitoring the loading capacity of work orders on the shop floor.

5 Potential Benefits of LPCon

As LPCon provides the closed loop relationship between a physical part, its processes and supporting documentation, it is possible for a user to see all the related data that he/she needs from the perspective that he/she wants. For example, purchasing would see a screen with information such as the supplier, cost, stock level, a list of different format models/drawings that he can distribute to suppliers, and engineering change orders - all centred around the one item.

LPCon provides an innovative business environment where all parties, both internal and external to the organisation, are involved and are able to contribute to the entire NPD in a concurrent manner. Internal parties are all functional groups within the organisation, whereas customers and suppliers are the external members. Suppliers refer to those providing goods as well as services to the manufacturers.

LPCon allows the sharing of product data from a central data vault and hence the product data is always up-to-date and accurate. This inadvertently reduces errors in quotation and ordering processes and enables more accurate quotations for price and due date. Ultimately, optimisation of sales and purchasing networks will improve customer satisfaction and good working relationship with suppliers respectively. Also, LPCon reduces repetitive clerical work within the NPD and allows more time spent on decisions making to improve the performance of the organisation.

6 LPCon Prototype Development

To validate that proposed design concepts, the author developed a prototype LPCon based on the mentioned design concepts. It is intended to implement the prototype system within a company, however, due to time constraint and other unforeseen difficulties, the author only managed to demonstrate the prototype to one of the collaborating companies.

Here, the computer architecture of the prototype and the main interfaces for inputs are discussed.

6.1 Computer Architecture Proposal

Using the analogy of "client/server" concept, the prototype is divided into 2 distinguishable units, namely DataSource for the storage of all the source data, and Interface for human-machine interaction. Figure E.12 shows the simplified proposed computer architecture for the prototype.

The aim of having two separate units is to increase the flexibility of developing the prototype. The design of DataSource and Interface are independent of each other - the DataSource can be developed on any relational databases, whilst the Interface can be developed using virtually any development tools.

As the targeted end users for this proposed tool are SMEs, it is decided to use MS Access as the development platform. Two case studies from Chapter 4 have shown that MS Access, a widely available and affordable database application can be used to develop a moderately sophisticated application. This would benefit many SMEs as most of them already have MS Access. This is important because the focus of the literature on PDM is upon large, relatively expensive PDM packages that are beyond the means of the majority of SMEs. Furthermore, as mentioned in Chapter 5, MS Access provides a relatively easy to use database management capabilities. Additional functionality not available in MS Access can be written using MS Visual

Basic, an object oriented programming language, which is already embedded in MS Access.

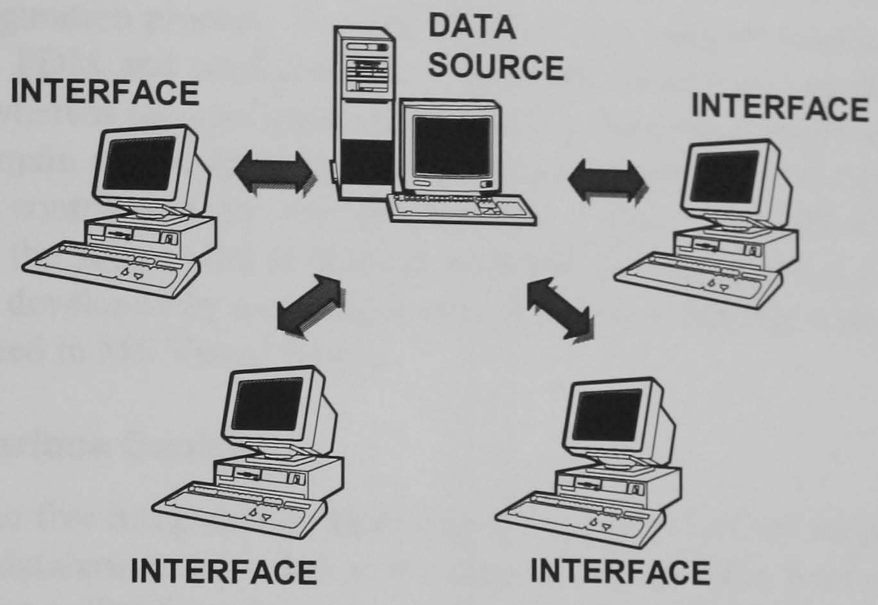

Figure E.12 LPCon Computer Architecture

There will be only one computer or location in the network that contains the DataSource - this will ensure the integrity of the product data stored. The location for storing the DataSource needs to be carefully studied to support multiple simultaneous access to information by many users in the company. Although the prototype DataSource is developed using MS Access, it is possible to transfer it to any relational database such as Oracle or MS SQLServer, when the need arises.

The Interface can be installed in any Windows compatible machines of potential users but must be linked to the DataSource to allow the access and retrieval of the required information. Again, although the prototype Interface is developed using MS Access, it is possible to create the Interface using other applications, for example a web enabled application if internet access is one of the company's requirements.

- <u>Software Operating Environment:</u>
  - ❖ MS Windows for Workgroup Version 3.11 or above, Windows NT, Windows 95 (or higher)
  - ❖ MS Access 97 minimum (for the prototype)

- <u>Minimum Hardware Configuration</u>
  - ❖ Networked client machine
  - ❖ Minimum PII-266 motherboard or better is recommended
  - ❖ Minimum 64Mb RAM is recommended
  - ❖ Minimum available disk space required for running Interface is 10Mb for the Interface.
  - ❖ Recommended screen resolution for display is at least 1024 x 768 pixels

6.2 The Inputs / Outputs Interface Designs

LPCon is intended to provide the basic PDM functionality as well as performing the product configuration process. For this purpose, two separate interface designs have been created: PDM and configuration. The PDM interface is developed solely on MS Access, whereas the configuration interface is developed solely using MS Visual Basics. The main reason for using two different development platforms for the two interfaces is contributed by the convenience factor. The PDM interface was developed by the author who is familiar with MS Access, whereas the configuration interface was developed by a colleague who is not very familiar with MS Access but very well versed in MS Visual Basics.

- **PDM Interface Design**

For each of the five integrated databases used to support LPCon, an option to view or modify each database is provided at the start-up screen. The product configuration interface is also called from this start-up screen. Figure E.13 shows the snap shot of the start-up screen.

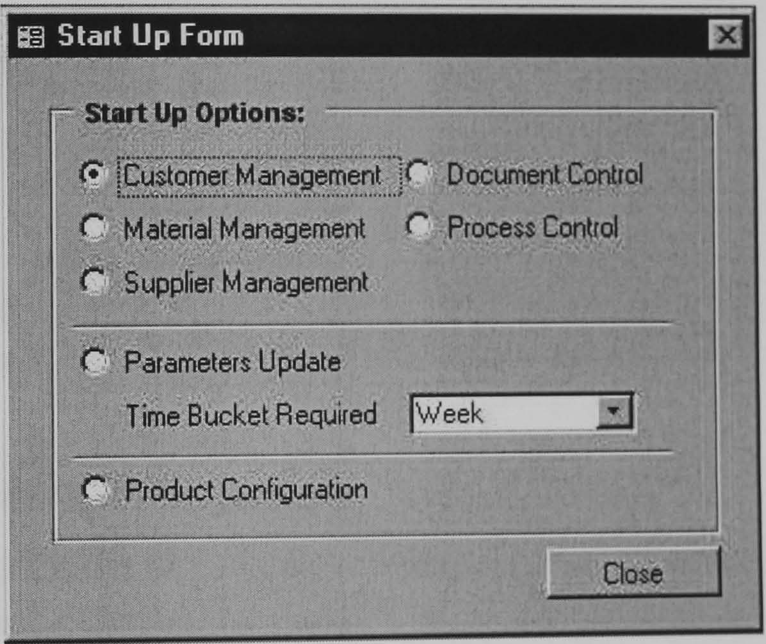

Figure E.13 LPCon – Start-Up Screen

There are three main screens under the PDM interface design: Part, Document, Process, Customer, and Supplier. Here, only the Part screen design will be discussed as the design concepts and considerations used for all three screens are the same.

The main goal of all the three screens design is to display all available and relevant information about the particular part without over congesting the screen with too much information. For the Part Screen, it was decided to permanently display the basic details of a physical part and to provide an option to list all other relevant information that is available. Once relevant information is chosen for viewing, it will be displayed below the part basic details. Figure E.14 shows the Part screen with its relevant BOM details.

The adopted layout design of the screen allows only the required information to be displayed when requested. The availability of all relevant information of a particular part can be seen from one screen. For example, from Figure E.14, it can be summarised that the part with PartID = %BUTTON PRONG BACK has only three additional information: its suppliers, customer (or sales) orders, and its material requirements, MRP. From Figure 5.14, it is clearly shown that this part is an approved to use (Status = Approved) component (BOM Level = 3) that the company buys (Class = Procured) and is currently still in use (Date Obsolete = blank).

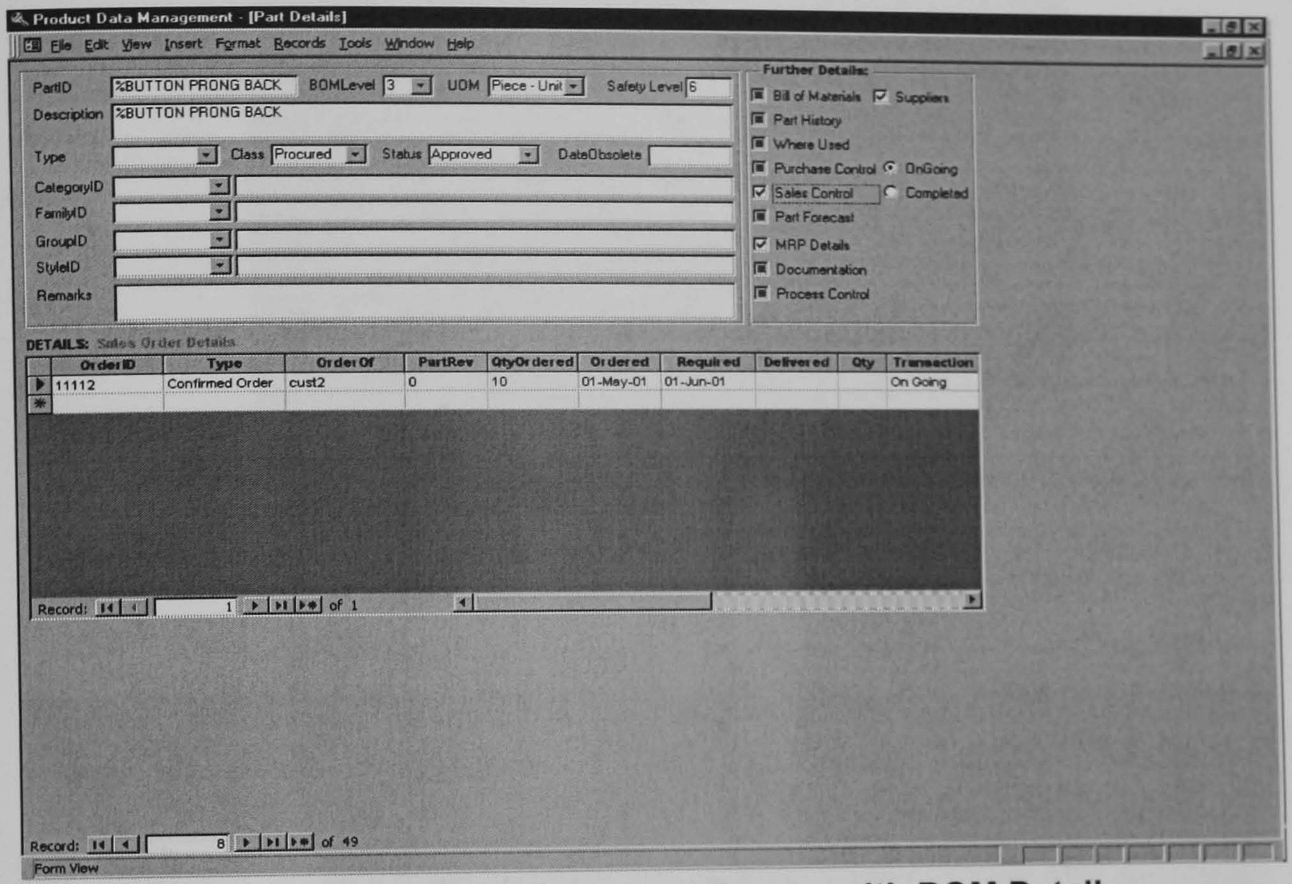

Figure E.14 LPCon - Part Screen with BOM Details

- ## Configuration Interface Design

Selecting the option Product Configuration from the start up screen, see Figure E.13, a blank configuration screen will be displayed. Two options are made available for the purpose of configuration: new order or existing order. This is aligned with the configuration process mentioned in section 3.1. If an existing order is selected, then a list of currently available orders will be displayed and the user can select the required one. If, however, a new order is chosen, then a criteria input window will be displayed. The configuration criteria screen is customised according to the company requirements and the type of product to be configured. Figure E.15 shows an example of a configuration criteria screen that is customised to a company that produces commercial trucks.

A product tree that matches the chosen configuration will be displayed once all the relevant criteria have been entered. Using the same concept of not over congesting the screen with too much information, the two aspect of configurations and the order details are located under separate tabs. Figure E.16 shows the general information of the selected vehicle, which in this case is a commercial rigid truck with 4x2-axle configuration. Figure E.17 shows the build-up features of the selected vehicle, whereas Figure E.18 shows the technical design specification.

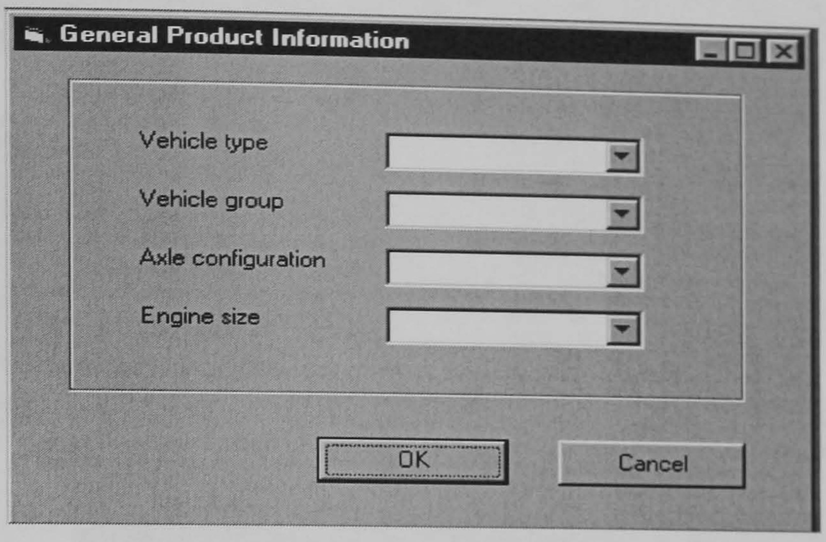

Figure E.15 LPCon - Configuration Criteria Input Screen

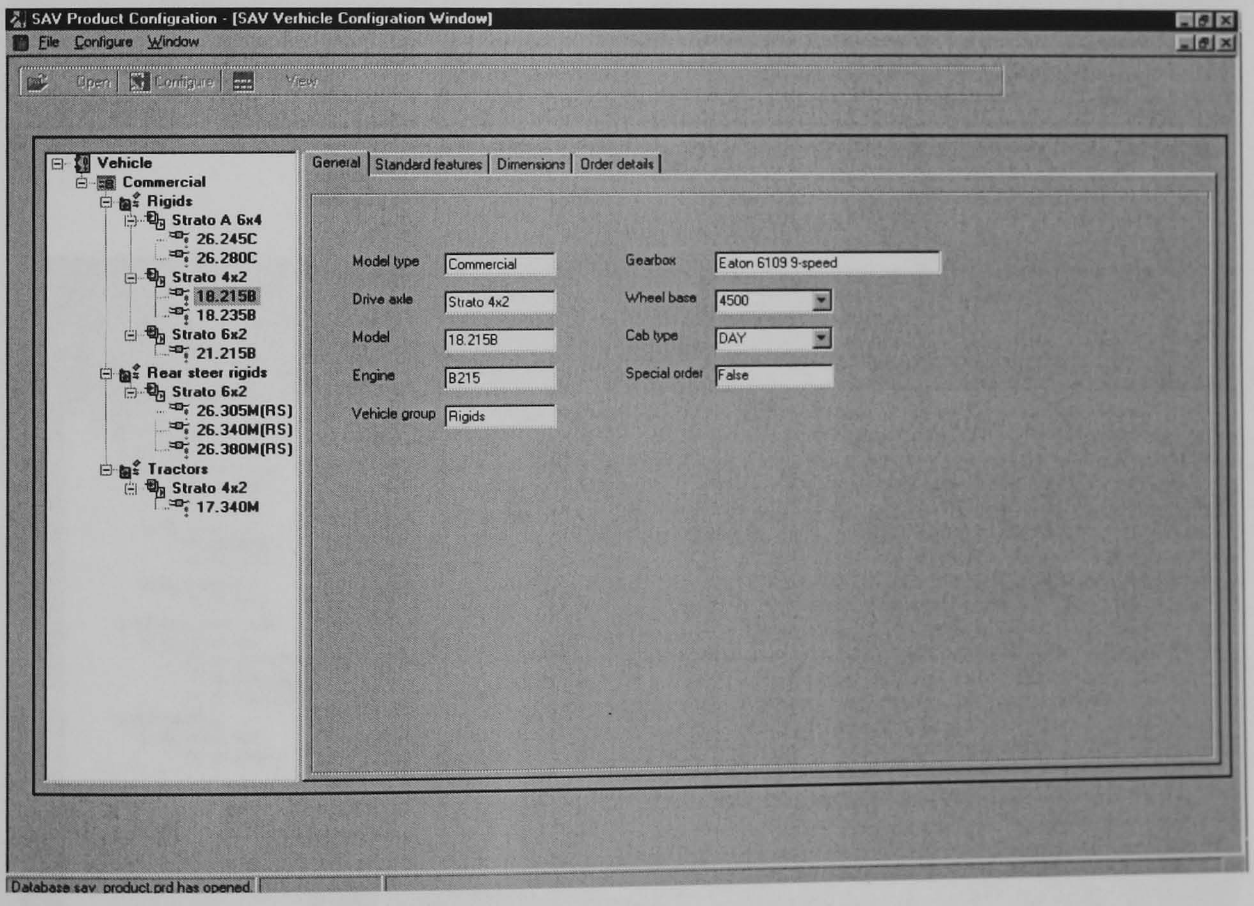

Figure E.16 LPCon - General Product Details Screen

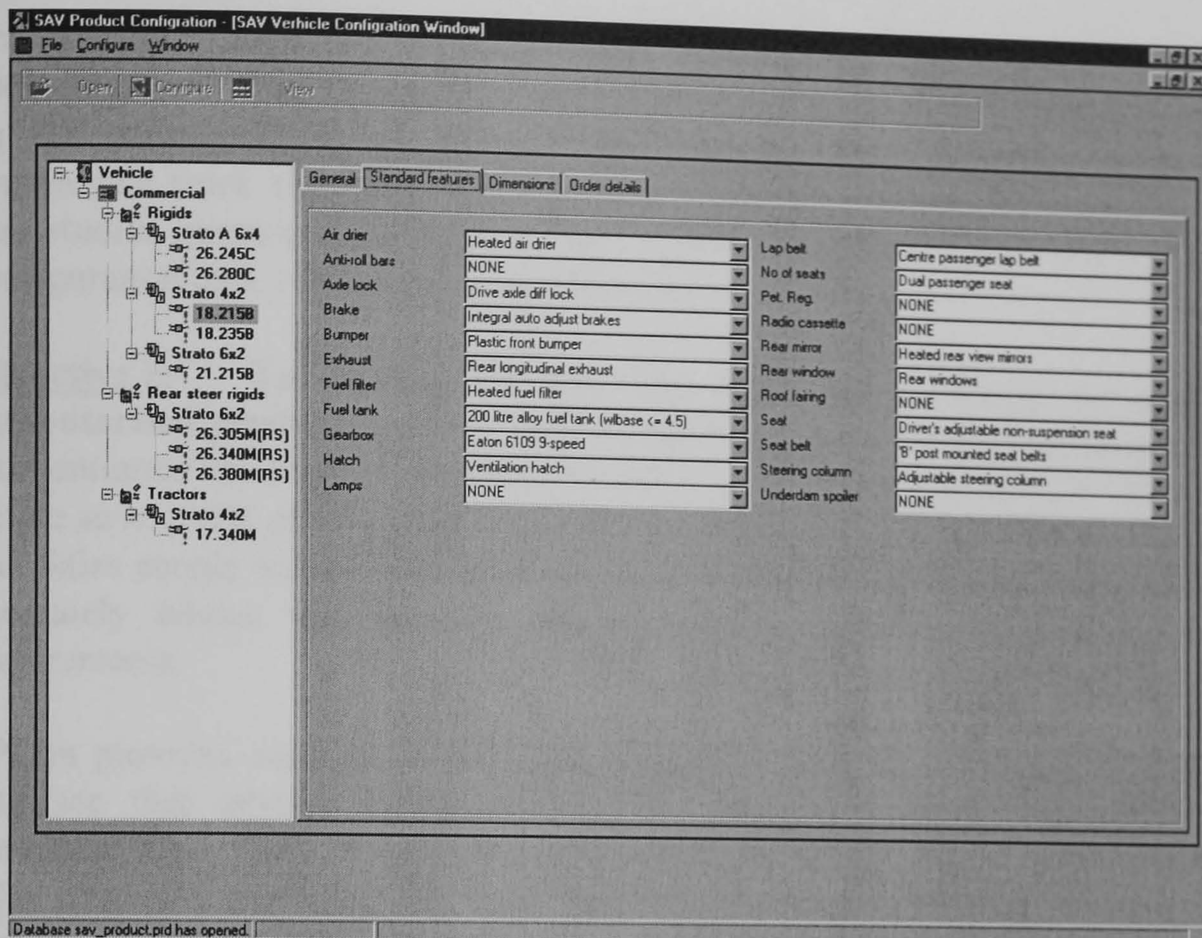

Figure E.17 LPCon - Product Build-up Features Screen

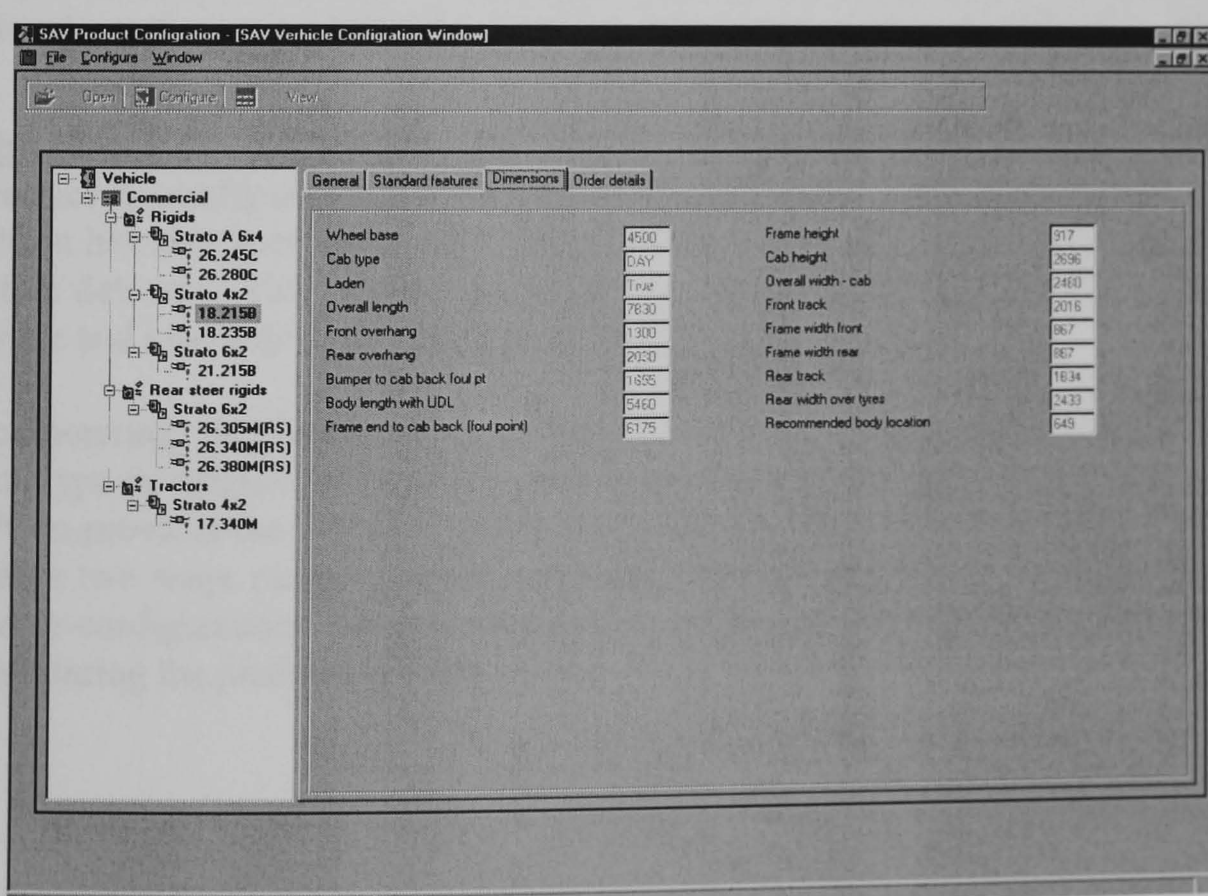

Figure E.18 LPCon - Product Dimensions Screen

7 Conclusions

The concepts underlying the development of a late product configuration tool has been discussed. The envisaged benefits have also been presented. A prototype based on the mentioned design concept has been produced and demonstrated to a commercial truck company, which is a collaborating company in one of the three case studies mentioned in Chapter Four. The two objectives set for the late product configuration tool, LPCon, have also been met:

<u>Objective 1</u>: **To enable effective one time order-capture by providing computerised product expertise at the initial stage of the order-capture process.** As mentioned in Chapter Five, effective one time order-capture refers to the ability to define an accurate product specification at the initial order bidding stage. This means that Sales people will have to be equipped with the company's product knowledge to accurately advise the delivery and cost of a product based on customer's requirements.

LPCon provides supports to the Sales people through an interactive man-machine interface that advises the availability and possibility of the required product configurations. This is made possible by the Product Centre, which contains the rules governing the "why" and "how" of the design of a product, and the Rules Centre that drives the configuration process. The design specification for LPCon has involved the gathering of product information from all relevant members in the product development process, i.e. from the early order entry stage through to the production process, to form this pool of product knowledge in the Product Centre. All the information is made widely available and accessible to all relevant members throughout the entire product life cycle by incorporating basic PDM functionality.

<u>Objective 2</u>: **To provide the visibility of product status to permit any late product re-configurations upon request by customers before delivery.**
LPCon has also been designed to support the need for any product re-configurations before delivery. This requires the production status for each work order to be made visible and available to all relevant members.

Incorporating the functionality of the production tracking and shortage control prototype developed for one of the case study companies mentioned in Chapter Five, LPCon provides the visibility of all work orders' status on the shop floor. This is to enable two ways communication between Sales and production people should any late re-configurations are requested by customers or when unforeseen difficulties arise during the production stage.

APPENDIX F - Commercial PDM Systems Survey Instrument

SURVEY OF PRODUCT DATA MANAGEMENT (PDM) SYSTEMS

Introduction:

PDM systems have been around for about 20 years, however there is no classification of the commercially available PDM systems in terms of the functionality offered. There is a need to classify these commercially available systems to aid manufacturing enterprises in finding PDM systems that are suitable for their requirements, especially the small and medium sized manufacturing enterprises (SMEs) with their limited resources in terms of both financial and IT skills.

Objectives:

We intend to achieve the following three objectives with this questionnaire:

- To categorise commercially available PDM systems according to the functionality offered
- To categorise commercially available PDM systems according to the targeted client base
- To categorise commercially available PDM systems according to their cost

Benefits:

A summarised list of commonly available PDM systems, their functionality, cost of implementation, and their degree of ease of use and maintenance could provide potential users with a faster means to select the correct system. Such a list is also very useful for PDM system vendors themselves to view, at a glance, where they positioned along with others. This provides a means for improving and upgrading both product and service.

Unless otherwise indicated by you, we will send all respondents a copy of the completed survey report as a token of appreciation for your time and effort in completing the questionnaire. We believe such report will be of enormous use to you and your company.

General Notes:

This questionnaire is divided into five sections within four pages. A short note is provided at the beginning of each section to explain the purpose of the respective section. It is estimated that the questionnaire takes about 20 - 30 minutes to complete.

Please provide appropriate answers for all questions. If the question is not relevant, please feel free to comment on why it is not relevant.

Please feel free to add any comments you might have. Use additional paper if necessary.

If you have any brochures covering the PDM products that your company provides, we would be most grateful to receive them. This will help us to better understand your products.

If your company provides more than one PDM systems, please use one questionnaire for each PDM system.

Kindly return the completed questionnaire in the self addressed envelope provided.

If you need explanations or are not sure about the meaning of any terms mentioned in the questionnaire, please do not hesitate to contact me:

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Tel: +44 (0) 1484 47 3396 Fax: +44 (0) 1484 47 2340
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Confidentiality Guarantee

Individual responses to this questionnaire will be treated as strictly confidential and will be used to meet the mentioned three research objectives.

Information will not be made available to any third parties and will not be used without your consent.

Any published data will be grouped in ranges for the purpose of analysis and results publication.

RESPONDENT INFORMATION

Your Details:

Name ____________________

Job Position ____________________

Responsibility ____________________

____

Years of employment ____________________

Tel. ____________________

Fax ____________________

Email ____________________

COMPANY PROFILE

Company Name ____________________

Address ____________________

____

Email ____________________

WWW URL ____________________

Background

Year Established ____________________

Turnover / Sales ____________________

Parent Company ____________________

Software Supply Status:

☐ PDM Developer ☐ ERP Developer
☐ CAD Developer ☐ System Integrator
☐ Database Developer ☐ Others. Please specify:

____

____

PDM qualified staff experience

Longest (years) ____________________

Shortest (years) ____________________

1.0 PRODUCT INFORMATION

The purpose of this section is to provide details of the PDM system surveyed. It would be appreciated if you can provide any information you deem useful but not included in this section. Please use one questionnaire per PDM system.

1.1 PDM Product Name: ______________

1.2 Product first released date:
Year: ______ Quarter: ______

1.3 Latest product information:
Version. ______________
Released: Year ______ Quarter ______

1.4 Improvement made to the latest version:
____
____
____
____

1.5 Envisaged new version release date:
Year: ______ Quarter: ______

1.6 Product information website, if any:
____

1.7 Degree of customisation:
- ☐ Off the shelf
- ☐ Minimum - no programming skill required
- ☐ Medium - so so programming skills required
- ☐ High - Excellent programming skills required
- ☐ Others. Please specify: ______________

____

1.8 Approximate product pricing:
[Please note that none of this information will be made explicitly during the analysis, but will be grouped under defined ranges, such as: less than £10,000; £10,000 - £30,000; etc., to ensure our confidential assurance of all information provided. It is very useful and important for us to have this information in order to meet the third objective set for this questionnaire - see page 1]

Software only *(per license)* ______
Typical No. of Users ______
Implementation cost ______
Training *(typical cost per person)* ______
Annual Maintenance / support ______
Others. Please specify. ______
____
____
____

1.9 Additional cost for added modules / functionality.
(*Please use another sheet of paper if there are more than 5 modules available.*)

<u>Module Name</u>	<u>Cost per module</u>
[1] ______	[ ]
[2] ______	[ ]
[3] ______	[ ]
[4] ______	[ ]
[5] ______	[ ]

1.10 Completion of system implementation:
Longest (months) ______
Shortest (months) ______

2.0 CLIENT BASE

The purpose of this section is to identify the targeted client base.

2.1 World wide client base (approximate):
____

2.2 Major client base:
Country ______ % ______

2.3 Number of installation(s)

	UK	*World Wide*
Full production	______	______
Partial production	______	______
Pilot run	______	______

2.4 User Profile (an approximate):

	UK	*World Wide*
Min annual turnover	GBP ______	USD ______
Max annual turnover	GBP ______	USD ______
Min people employed	______	______
Max people employed	______	______
Min user seats	______	______
Max user seats	______	______

2.5 Five major clients in the UK: [*It would be most useful if you are able to list 5 current users of this product. We will not approach them without contacting you first.*]
[1] ______________
[2] ______________
[3] ______________
[4] ______________
[5] ______________

2.6 Estimated % of current UK client base:

Small and Medium Enterprises: less than 250 employees and annual sales less than £30 million. ______

Large Enterprises: 250 or more employees, and annual sales of more than £30 million. ______

2.7 Industry sectors covered and targeted:

Covered	*Targeted*
☐ Aerospace	☐ Aerospace
☐ Automotive	☐ Automotive
☐ Electronics	☐ Electronics
☐ Engineering/Mech	☐ Engineering/Mech
☐ Food and Drinks	☐ Food and Drinks
☐ Ship Building	☐ Ship Building
☐ AEC	☐ AEC
☐ Pharmaceutical	☐ Pharmaceutical

☐ Others, please specify:

Covered:	*Targeted:*
______	______
______	______
______	______
______	______

3.0 COMPUTING ARCHITECTURE

The purpose of this section is to understand the computing platform required to implementing this product.

3.1 Database system supported:

- ☐ Sybase
- ☐ Informix
- ☐ Oracle
- ☐ MS-SQL
- ☐ INGRESS
- ☐ MS Access
- ☐ Others, please specify:

______

______

3.2 Computing platform supported:

- ☐ UNIX
- ☐ IBM / PC
- ☐ Macintosh
- ☐ Others, please specify:

______

______

3.3 Operating system supported:

- ☐ Windows NT
- ☐ Windows 95/98/2000
- ☐ Sun
- ☐ Silicon Graphics
- ☐ IBM AIX
- ☐ UNIX - HP
- ☐ Others, please specify:

______

______

______

3.4 Recommended hardware configurations:

	Server	*Clients*
Processor speed	[ ]	[ ]
Operating Memory	[ ]	[ ]
Hard-drive capacity	[ ]	[ ]
Others, please specify:		
______	[ ]	[ ]
______	[ ]	[ ]

3.5 Network software supported:

- ☐ Novell Netware
- ☐ TCP/IP
- ☐ DECNET
- ☐ NT
- ☐ Others, please specify:

______

______

3.6 System design:

- ☐ Object oriented
- ☐ Client / server
- ☐ Web enabled / based
- ☐ Multiple Windows enabled
- ☐ GUI
- ☐ Textual user interface
- ☐ Others, please specify:

______

______

______

3.7 Data exchange standard supported:

- ☐ IGES
- ☐ DXF
- ☐ STEP
- ☐ PDES
- ☐ XML
- ☐ WfMC
- ☐ AIIM
- ☐ Microsoft DCOM
- ☐ OMG (COBRA)
- ☐ VRML
- ☐ Others, please specify:

______

______

______

3.8 ISO9000 Compliant?

☐ Yes ☐ No

If "No", will it be ISO9000 compliant in future?

☐ Yes ☐ No

If "Yes", estimated time planned?

- ☐ Less than 6 months
- ☐ 6 - 18 months
- ☐ More than 18 months

4.0 SYSTEM FUNCTIONALITY

The purpose of this section is to satisfy one of the objectives of this survey: to categorise commercially PDM systems according to their offered functionality. Hence, this is an important section and it would be most appreciated if you can provide as much information as possible about this product.

Please check the appropriate boxes or alternatively, you can provide your product brochure that contains functionality offered by this product. The latter option is preferable because the information would be more extensive.

Please include any information that you deem important / critical which is not included in this section. Please use another sheet of paper if necessary.

4.1 System functionality:

- ☐ Electronic Vault
- ☐ Document Management
  - ☐ Document Revision Control
  - ☐ File Access Control
  - ☐ Check In / Check Out
  - ☐ Document Hierarchy
  - ☐ Red-line Markup
  - ☐ Raster Viewing
  - ☐ Raster Editing
  - ☐ Image Processing
  - ☐ Indexing
  - ☐ Others, please specify:
- ☐ Workflow:
  - ☐ Engineering Change Control
  - ☐ Engineering Release
  - ☐ Document Distribution
  - ☐ Project Management
  - ☐ Automatic Notification
  - ☐ Others, please specify:
- ☐ Configuration Management:
  - ☐ Life Cycle Management
  - ☐ Product Structure
  - ☐ Parts Classification
  - ☐ Part Serial No. Tracebility
  - ☐ Alternative Views
  - ☐ Others, please specify:
- ☐ Others, please specify:

5.0 SYSTEM INTEGRATION

The purpose of this section is to investigate the scope of this product accessible to other manufacturing information systems of different capability.

Please tick the appropriate boxes and list the software applications that are integrated / interfaced with this PDM system. Also, please indicate the technique of integration, such as file transfer, API, COBRA, etc.

If possible, please provide an extensive list to enable us to analysis the extent of accessibility of this PDM system. If necessary, please add on to another sheet of paper.

5.1 Manufacturing information systems of different capability

- ☐ ERP / MRPII
- ☐ Advanced Planning and Scheduling (APS)
- ☐ Manufacturing Execution system (MES)
- ☐ Computer Aided Tools
  [Please specify if it is CAD for Mechanical, Electronic, Piping, etc., or CAE, CAM, etc.]
- ☐ Viewing Tools:
- ☐ Office Administration Tools:
- ☐ Project Management Tools:
- ☐ Others. Please specify.