An integrated approach to support product supply and end-of-life recovery

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An Integrated Approach to Support Product Supply and End-of-Life Recovery

by

Aysin Rahimifard

A Doctoral Thesis
Submitted in Partial Fulfilment of the Requirements for the Award of Doctor of Philosophy of Loughborough University

Wolfson School of Mechanical and Manufacturing Engineering

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Loughborough University
Avicenna (Abu Ali Sina) or Ibn Sina was a Persian physician and philosopher. He was born near Bukhara, then capital of the Samanid dynasty, one of many royal families who governed the Persian Empire. By the age of 16, he had mastered not only natural sciences and rudimentary metaphysics but also medical theory and practice.

Ibn Sina was one of the main interpreters of Aristotle and was the author of almost 200 books on science, religion, and philosophy. Avicenna's two most important works are: Shifa (The Book of Healing) and Al Qanun fi Tibb (The Canon of Medicine). The first is a philosophical encyclopedia based on Aristotelian tradition and the second is the most famous single book in the history of medicine. His medical system was a long time standard in Europe and the Middle East.

Ibn Sina died in 1037. Later stages of his life, one of his students asked him, "Sir, after all your research and observation what would be the single most valuable knowledge that you consider to pass on?" Then he replied famously;

"Now, I know that my knowledge is so negligible"
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ABSTRACT

This thesis reports on research carried out into development of a systematic approach to support the integration of the product supply and product end-of-life recovery processes. The principal objective of the research is to generate knowledge and generic solutions to facilitate the realisation of end-of-life product recovery as an extension to the product supply chain processes.

The research contribution is divided into three major parts. The first part reviews the most relevant publications and categorises the contemporary approaches to end-of-life product recovery to identify the most relevant research directions. The second part has investigated the novel concepts related to an integrated view of a 'product supply and recovery chain' and the development of systematic approach to the implementation of product recovery procedures. These concepts are then supported by the design and development of an information management system for end-of-life product recovery activities. The third part of the thesis explores the application of the research concepts using a case study of recovery of cutting tools in machining applications. This is illustrated through the design and development of a web based information system to support end-of-life recovery of cutting tools.

The concept of an integrated product supply and recovery chain has provided a powerful perspective for a holistic view of business, technological, information and management requirements for implementation of product recovery activities within different industrial applications. The application of a Product Recovery Implementation Methodology developed by the research has shown significant potential for gaining tactical insights into the decisions involved in adoption of product recovery procedures. The geographical spread of various actors involved in a product supply and recovery chain highlights the requirements for a distributed information system providing a simple, simultaneous, and secure access to information. This has been achieved by the utilisation of a web based information support system.

The case study formulated within the context of systematic recovery of cutting tools has effectively demonstrated the applicability and the significant potential of the research concepts and has demonstrated that the web based distributed information system provides a powerful tool for the integration of processes involved in product supply and recovery.
ABBREVIATIONS

BOM : Bill of Material
DIE : Design for Environment
ECM : Environmentally Conscious Manufacturing.
ELVs : End-of-Life Vehicles
EMS : Environmental Management System
EoL : End-of-Life.
EOQ : Economic Order Quantity
IR : Independent Recoverer
IT : Information Technologies
LCA : Life Cycle Analysis
MP : Maintenance Provider
MRP : Material Requirements Planning
OEM : Original Equipment Manufacturer
PPC : Production Planning and Control
PR : Product Recovery
PRIME : Product Recovery Implementation Methodology
PSRC : Product Supply and Recovery Chain
TRIS : Tool Recovery Information System
TSRC : Tool Supply and Recovery Chain
WEEEE : Waste from Electrical and Electronic Equipment
GLOSSARY

**Command and control:** This is an approach towards being environmentally responsible which comprises of third party enforcement such as government regulations in order to establish environmentally sound practices in industry.

**Core:** A core is a product returned from use for remanufacture.

**Design for Environment (DfE):** Design for environment is a design paradigm, which comprises techniques to improve the design of the product from an environmental perspective.

**End-of-life (EOL) management:** This is a decision process at the end of the product’s life, which involves the choice of different options such as product recovery, recycling and disposal, through cost-benefit analysis and also the safe disposal of remaining waste.

**End-of-pipe solutions:** These are pollution control technologies that are used to treat or dispose of pollutants or harmful by-products by adding some operations or equipment to the end of an existing manufacturing process, leaving the original product and process unaltered.

**Environmental Management System (EMS):** An EMS is a structured management system, which focuses primarily on preventing adverse environmental effects and improving environmental performance by institutionalising various environmental programmes and practices.

**Environmentally Conscious Manufacturing (ECM):** ECM is an approach concerned with developing and utilising equipment, methods and procedures for manufacturing activities from conceptual design to final disposal (including reuse and recycling) such that the environmental standards and requirements are satisfied.
Life cycle analysis (LCA): LCA is a method to examine and quantify the energy and materials used and wasted, to assess the impact of the product on the environment.

Original Equipment Manufacturer (OEM): This is a type of company, which produces complex equipment (such as a computer system), from components usually bought from other manufacturers.

Product stewardship: This is a new after sale concept, which claims that it is a part of producer's responsibility to follow up what happens to the product throughout its usable life until final disposal and to take the necessary action accordingly in order to prevent any harm on the environment.

Recycling: Recycling is retrieving the material content of the used products through various processes leaving the product completely lost its identity at the end.

Remanufacturing: Remanufacturing is bringing the used product back into original condition through a series of operations including disassembly, sorting, replacing or repairing bad components, reconditioning, testing, reassembling, and inspection.

Reverse logistics: This is the whole process in which a manufacturer systematically takes back its used products or parts from the point of consumption for possible recycling, remanufacturing, or disposal.

Self-regulatory: This is an approach towards being environmentally responsible by providing non-prescriptive procedures acting as guidelines to responsible parties, but allowing them to identify and plan their needs and actions.

Sustainable development: Sustainable development is an approach for development to meet the needs of the present without compromising the ability of future generations to meet their own needs.
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Chapter 1

Introduction

Mass industrialisation over the last century has had a negative impact on the natural environment, contributing towards serious problems such as global warming, ozone depletion, acid rain and more importantly serious exhaustion of natural resources. Increased public awareness towards these global environmental problems has enhanced the need for sustainable development, which is defined as “the ability to satisfy the needs of today without jeopardising the needs of tomorrow” (United Nations Department of Economic and Social Affairs 1987). The achievement of sustainable development necessitates significant changes in current patterns of over production and wasteful consumption, and advocates the reduction in the use of natural resources and the prevention of pollution. In the manufacturing industry, this has resulted in significant research in the popular subject of Environmentally Conscious Manufacturing (ECM), which is concerned with developing methods, procedures and equipment for manufacturing applications to satisfy the increasing number of environmental standards and legislation.

One of the major research areas within ECM is End-of-Life Product Recovery (EoL-PR) which is the transformation of used and discarded products into useful condition through re-manufacture, re-use and recycling. In this context, two major directives of European legislation, namely End of Life Vehicles (ELVs) and Waste from Electric and Electronic Equipment (WEEE) directives, make the take-back and recovery of used products obligatory for the Original Equipment Manufacturer (OEM). This has generated concerns and significant interest in EoL-PR procedures not only amongst OEMs, but also among the other parties within the supply chain of these sectors, i.e. ‘extended enterprise’, which include a large number of Small and Medium Enterprises.

EoL-PR provides a powerful means within ECM practices as it aims to achieve both the objectives of effective use of natural resources and prevention of pollution at the same time by extending the life of used resources. Therefore, it is counted as one of the target areas
Chapter I

to be regulated, in view of the application of the principles of sustainable development (Directive-2002/96/EC 2003). Considering the high profitability, growing number of legislative initiatives and growing consumer awareness, EoL-PR needs a special consideration and development of supporting concepts, methods and tools.

Currently, there are a large number of existing recycling and recovery applications within many different industrial sectors, which are often developed on an ‘ad hoc’ basis and mainly due to the hidden economic value within used products. The author argues that in order to make a desired environmental impact, the number of product recovery applications has to be significantly increased and ideally be implemented in every manufacturing application. One of the main obstacles reported by many researchers in achieving such large scale product recovery implementation is the lack of management guidelines, formal procedures and appropriate supporting information systems. To achieve such large scale adoption of EoL-PR within various manufacturing applications, the following assertions are made by the research reported in this thesis:-

i) The scope of the traditional product supply chain must be extended to include the product recovery activities and actors, through development of novel concepts for an integrated ‘Product Supply and Recovery Chain’.

ii) For implementation of product recovery activities, a systematic methodology must be adopted; encompassing the considerations for a wide range of issues including those related to business, technological, logistics and operational planning, and information management requirements.

iii) Bespoke information systems and IT tools must be designed and developed to underpin the implementation and operational planning of PR activities across a product supply and recovery chain.

The overall aim of this research is to provide a clear understanding for the issues involved in EoL-PR and generate an integration framework and supporting methodology together with appropriate tools to facilitate the wider adoption of EoL-PR procedures across the various industrial sectors. Thus, a novel systematic five-stage methodology, referred to as the ‘Product Recovery Implementation MEthodology (PRIME)’ has been developed. This methodology aims to provide a step-wise approach for the identification of business, technological, process, resources and information requirements for the adaptation of EoL-
PR in different applications. Furthermore, the information requirements related to the adoption of PR within manufacturing applications have been investigated. Typically, such information must be efficiently stored, maintained and accessed by a number of PR actors, which may be geographically scattered across many cities, countries or even continents. Thus, this research has explored the use of recent advancements in *Internet technologies* to design and realise a 'A Web-based EoL-PR Information System'.

The structure of the thesis is organised into three parts of background and reviews, theoretical research, and application of research results together with research conclusions, as illustrated in Figure 1.1. Part I, the background and reviews, consists of three chapters, and provides a review of related research publications and background knowledge to the research. Chapter 1 is the main introduction to the research work and outlines the layout of the thesis. Chapter 2 provides a survey of relevant literature in the area of ECM and outlines a framework against which ECM research can be categorised. An overview of research in the area of EoL-PR and the future research directions are presented in chapter 3.

Part II, the theoretical research, comprises of five chapters, which identify the context, objectives and the scope of the research, and describes the adopted procedures to explore the research issues and achieve the research objectives. It commences with chapter 4, which outlines the context of the research by evaluating the competitive published work to position and assess the author's contributions, and defines the domain boundaries of the research within EoL-PR literature. The research objectives together with a description of the scope of research are outlined in chapter 5. The research issues involved in the novel concept of an integrated product supply and recovery chain are discussed and reference configurations for a number of product recovery scenarios are proposed in chapter 6. Chapter 7 describes the various stages of product recovery implementation methodology. The design and development of an information system to underpin EoL-PR activities is described in chapter 8.

Part III of the thesis describes the application of research results and conclusions, and contains four chapters. Chapter 9 is devoted to the introduction of the case study, namely the EoL recovery of cutting tools within metal working industries. Chapter 10 describes the design and implementation of a web based information system to support EoL recovery of cutting tools.
Figure 1.1: Structure of the thesis chapters

The concluding discussion, chapter 11, presents the analysis of the wide range of research issues from the novel integrated product supply and recovery chain to information support requirements for accomplishment of product recovery activities. Finally, chapter 12
summarises the conclusions drawn from the research together with a list of suggested research ideas for the future continuation of this research.

In addition, Appendix 1 and 2 provides related published papers by the author on various aspects of the research.
Chapter 2

Literature Survey on Environmentally Conscious Manufacturing

2.1. Introduction

This chapter represents an overview of the vast amount of literature in the area of Environmentally Conscious Manufacturing (ECM) to position the PR research in relation to ECM. A more detailed review of literature on product recovery research will be presented in Chapter 3.

2.2. Background

All industrial activities require the use of the earth's natural resources such as materials, energy, water, air supply and the land. These resources are limited and as a result of human activities they are depleting rapidly. A number of ecological problems are thought to be due to human (industrial) activities such as global warming caused by green house gases such as CO₂ and NOₓ, acid rain generated by SO₂ emissions, ozone depletion due to use of CFC (chlorofluorocarbon) gases and natural resource scarcity. There have been various responses from a number of different parties to combat these environmental problems at an international level. The concept of sustainable development was introduced by the World Commission on Environment and Development in 1987 (United Nations Department of Economic and Social Affairs 1987). The Montreal Protocol (NWPI 1987) on substances that deplete the ozone layer is a landmark international agreement designed to protect the stratospheric ozone layer. The treaty was originally signed in 1987 and substantially amended in 1990 and 1992. In 1992, an Earth Summit, which had the largest number of world leaders' participation, was held in Rio de Janeiro. The theme of this meeting was to make critical decisions about how the world economies should be run.
Chapter 2

to secure the future of the planet. Consequently, in 1997, the Kyoto Protocol was introduced to commit industrialised countries to achieve quantified targets for reducing their emissions of greenhouse gases. Recently, the international community has reaffirmed their willingness to work together to address common environmental, economical and social challenges at a World Summit on Sustainable Development in Johannesburg in 2002. This summit resulted in a renewed global commitment and increased solidarity from all countries on a number of new targets, which are to be implemented within national strategies on sustainable development.

The concept of sustainable development has its implications in the manufacturing industry, i.e. the reduction of wasteful consumption of natural resources and the prevention of pollution during entire life cycle of production activities. In addition to these international initiatives and legislation to promote sustainability in manufacturing activities, there is an increasing demand by customers, suppliers and the public from manufacturing firms to minimise any negative impact of their products and operations on the natural environment, i.e. being 'environmentally conscious'. Consequently, the research in this area has led to the emergence of a new concept, referred to as Environmentally Conscious Manufacturing (ECM) which is concerned with developing equipment, methods and procedures for manufacturing activities from conceptual design to final disposal (including reuse and recycling) such that the environmental standards and requirements are satisfied. The major objective of ECM is to minimise the environmental load of manufacturing activities by conserving energy and natural resources and protecting the natural environment.

2.3. Environmental Technologies and ECM

Ecological impacts of manufacturing vary depending on material specifications, production efficiencies, energy consumption, pollutant emissions, product delivery systems and recycling (Sarkis 1995). One of the main strategic variables that fundamentally change such environmental impacts is the choice of technology. The development and utilisation of the environmental technologies provide an essential mechanism for achieving improved environmental performance at the operational level.

Shrivastava (1995) defines environmental technologies as production equipment, methods, procedures, product design and product delivery mechanisms that limit or reduce negative
impacts of products or operations on the natural environment. Environmental technologies can be classified into two groups of techniques and management orientation. Shrivastava groups environmental technologies into five themes of design for disassembly, manufacturing for the environment, total quality environmental management, industrial ecosystems and technology assessment.

Another way of classifying environmental technologies, which has gained wide acceptance in the literature due to its simplicity, has been introduced by Klassen and Whybark (1999) consisting of three general categories: pollution prevention, pollution control and management systems. Pollution prevention technologies are defined as fundamental operational changes to a basic product or primary process in order to provide better performance. Such technologies are believed to be very effective, as they are "up-front" rather than "after-thought" activities (Porter and van der Linde 1995). Pollution control technologies are those used to treat or dispose of pollutants or harmful by-products at the end of a manufacturing process. To accomplish this, some operations or equipment must be added to the end of an existing manufacturing process. The management systems category includes infrastructure investments that affect the way manufacturing is managed. These systems function to both control and prevent environmental degradation.

Traditionally, the concept of pollution control has been the main focus of research to improve environmental performance. However, there are many debates and some empirical evidence and survey studies that pollution control technologies have costly implications for production (Klassen and Whybark 1999). As a result, emphasis in research recently has been moved towards prevention technologies. However, Klassen (2000) identifies some barriers, which are commonly encountered in the companies towards adopting pollution prevention technologies. These include technological capabilities and risks associated with pollution prevention, organisational structures and managerial attitudes, work-forces resisting new technological change, public policies which favour command-and-control regulations, and financial constraints in firms.

In the literature, there are a number of review papers, which take ECM approaches from different aspects. Gungor and Gupta (1999) present a comprehensive review about ECM and product recovery, which covers all the areas of ECM. O'Shea et al. (1998) reviews state-of-the-art literature on disassembly planning. Guide et al. (1999) and Bras and
McIntosh (1999) present two overviews of research on remanufacturing planning and control. Mizuki et al. (1996) and Zhang et al. (1997) provide the-state-of-the-art survey in the area of design for the environment. Fleischmann et al. (1997) reviews research related logistics issues arising in the reverse flow of product recovery.

2.4. ECM and Production Research

In simple terms there are two main objectives in environmentally conscious manufacturing:

- Minimise/eliminate pollution
- Minimise/eliminate resource waste.

There have been many different ways of responding to these main environmental concerns by the companies and the research bodies. The author has developed a framework for classifying these approaches based on the three main stages of a product life cycle as shown in Figure 2.1. Based on this classification, the research in ECM can be grouped into four categories of:

i) Research related to the pre-production activities,
ii) Research related to the activities during the production stage,

![Figure 2.1: Framework of ECM research areas based on product life cycle](image)
iii) Research related to the post-production activities including the use stage and EoL management of products,

iv) Supporting research related to planning, designing and establishing environmental practices such as the research activities in the environmental strategy formulation and environmental management systems, which has a resulting effect on all previous three stages.

2.5. ECM Research Related to Pre-Production Activities

The ECM research related to the pre-production stage focuses on designing products with desirable environmental attributes. This is particularly important since the design issues determine the environmental attributes of the product during its entire life cycle. Furthermore, as such ECM pre-production activities involve planning for minimisation of the environmental impact before the actual production starts, any effort is likely to be rewarded by cost-effective and efficient solutions. In the literature, two main subjects are identified relating to environmentally conscious practices at the pre-production stage, namely Life Cycle Analysis (LCA) and Design for Environment (DfE). These research areas are described below.

2.5.1. Life Cycle Analysis

Preliminary studies of Life Cycle Analysis (LCA) dates back to the late 1960s. Life cycle management, which is one of the major subjects in Concurrent Engineering, focuses on all the phases of a product's life with the objectives of reducing the lead-time and consequently costs. From the environmental point of view, LCA examines and quantifies the energy and materials used and wasted, to assess the impact of the product on the environment. Graedel and Allenby (1995) provide a more formal definition of LCA:

"LCA is an objective process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and material uses and releases on the environment, and to evaluate and implement the opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing extracting and processing raw materials, manufacturing.
transportation and distribution, use/re-use/maintenance, recycling and final disposal.”

There are a number of LCA methodologies and their structures vary considerably. However, the basic stages, which are commonly repeated in the literature, are as outlined below (Keoleian and Menerey 1994, Graedel and Allenby 1995, Gungor and Gupta 1999):

Stage 1) Inventory analysis to achieve a balance between material and energy in the system.

Stage 2) System impact analysis on the environment.

Stage 3) Improvement analysis to assess the most promising system improvement to reduce the negative environmental impact.

There are a large number of corresponding publications, which demonstrate LCA in example case studies in order to identify common practices (Alting and Legarth 1995, Probert 1999, Harsch and Schuckert 1996, Kalisvaart and van der Horst 1995).

LCA is a complex analysis; and therefore, there is a requirement for utilising the power of computers for collection, organisation and analysis of the relevant data to cope with this complexity. There have been a number of computer based LCA support tools, developed by Ishii et al. (1994), Rosen et al. (1996), Hooks et al. (1997) and they are classified by Sweatman and Simon (1996). In addition, a number of researchers have focused on the use of knowledge-based techniques for life cycle design (Biswas et al. 1995, Hattori et al. 1995, Watkins et al. 1995, Kleban et al. 1996).

2.5.2. Design for Environment

Design for environment (DfE) is a design paradigm, which comprises of techniques to design products that have minimal negative impact on the environment. The idea is to incorporate the knowledge gained through LCA into the design in order to create environmentally friendly products using environmentally friendly processes. This design philosophy is in contrast to past design approaches that sought planned obsolescence of products, functional redundancy, and over-design for aesthetic and product differentiation (Shrivastava 1995).
According to Fiksel (1996), DfE can be broken down into stages such as manufacturing, consumer use and end-of-life of the product. At each of these stages, different forms of design strategies can be utilised. For example at the manufacturing stage, the design objective could be to design products and processes, which need minimum energy and material consumption for production. Similarly the environmental issues during the usage stage, such as savings on energy consumption, long life, serviceability etc. can be incorporated into the design decisions. Alternatively, there are design objectives, which are related to the end-of-life decisions of the product such as design for disassembly, remanufacture, recycling, etc. Design for disassembly has been particularly emphasised in the literature since disassembly is a common activity for both remanufacture and recycling. Basic rules for design for disassembly are ease of separation, ease of accessibility, common fasteners and minimising their number, elimination of welding process, material selection, low energy use, parts consolidation, etc. (Boothroyd and Alting 1992, Alting and Legarth 1995, Dowie 1994, Harjula et al. 1996, Rhodes 1998, Nagler 1999).

The ultimate goal of DfE is to minimise the overall environmental damage when producing goods and services. Availability of guidelines, checklists and software based DfE tools also aid the designer to achieve this goal (Glantschnig 1995). Among these several systems have been diagnosis and decision-making tools that are derived from qualitative environmental data (Mizuki et al. 1996). The use of quantitative methods such as the Analytical Hierarchy Process, Discounted Cash Flow has been also reported by Veroutis and Fava (1996) and Azzone and Noci (1996).

Rivera-Becerra and Lin (1999) criticised these earlier efforts for relying on personal evaluation in decision-making and developed a methodology to quantify the degree of environmental consciousness of a product with the aim of enhancing decision-making at the design stage through the application of statistical methods and fuzzy set theory. Argument et al. (1998) and Feldmann et al. (1999) examined academic research in the area of environmentally conscious design and attempted to identify the extent to which this research supports industrial practices. Feldmann et al. (1999) developed a Green Design Advisor, which enables online environmental oriented product design assessment and they claim to be the “best practice DfE tool” in the industry as a result of a co-operation between industry and university.
More recent research efforts to support DfE include the developments of tools for the selection of materials (Wegst and Ashby 1998) and selection of appropriate EoL strategies (Rose and Ishii 1999).

2.6. ECM Research Related to Production Activities

The ECM research related to production activities are often referred to as clean production methods and technologies. These span every activity that is associated with transforming raw material into finished product within a factory. Techniques and methods for selecting and planning processes, selecting energy sources, handling the hazardous by-products, and minimising waste have been investigated to improve environmental performance of the production system (Sheng and Oberwalleney 1997, Sheng et al. 1998, Srinivasan and Sheng 1999a-b, Yeo and New 1999, Krishnan and Sheng 2000).

Waste minimisation is another area of investigation for the environmental performance improvement during manufacturing. Opportunities for waste minimisation have been identified and potential financial benefits as well as environmental performance improvement have been demonstrated in the literature (Maunder 1999, Clelland et al. 2000, Goosey 2000). In this context, Goosey (2000) describes environmental best practice opportunities in the printed circuit board industry, and identifies further information sources. Clelland et al. (2000) classifies the waste minimisation practices to guide manufacturers to identify the possible potential improvements in different industries.

2.7. ECM Research Related to Post-Production Activities

The ECM concepts relating to the post-production stage mainly involve waste management and end of life management of products and product recovery. Waste management is related to the safe disposal of the waste produced as a result of the production activities. This is a reactive approach and can be classified as a "pollution control" approach (see Section 2.3). A number of techniques have been developed for collecting and disposing waste (Caruso et al. 1993, Haastrup et al. 1998, Giannikos 1998, Bloemhof-Ruwaard et al. 1996). In addition, Sheng and Hertwich (1998) develop some methods for waste assessment with the aim of identifying the best waste management techniques.
EoL management and product recovery involves recovering of the used products at the end of their lives and bringing them back into use. This approach can be classified as 'pollution prevention' as it aims to convert 'waste' into 'resource'. EoL management and PR constitute the main context of the author's research and the related research is reviewed and discussed in more detail in Chapter 3.

2.8. Supporting Research

In addition to ECM specific research related to the each stage of production life cycle, there are business and organisational issues which have an overall effect on the entire ECM life cycle, addressing the ways of planning, designing and establishing environmental practices. This includes establishment of a 'green' business for every aspect of business management from strategic to personnel management. The research in this area addresses the development of formal management systems, together with a set of policies, procedures, information and decision support systems. These works can be grouped into two main areas of research, namely, Environmental Management Systems and Environmental Strategies, which are briefly reviewed in the following sections.

2.8.1. Environmental Management Systems

An Environmental Management System (EMS) is defined as a structured management system for preventing a company's adverse environmental effects and improving its environmental performance through an institutionalisation of various environmental programmes and practices (Gupta 1995, Sheldon 1997, Steger 2000). An EMS aims to provide guidelines to comply with environmental regulations; and identifies and assesses the environmental effects arising from organisation's existing or proposed activities, products or services, potential emergency situations, the relevant regulatory requirements, environmental objectives and targets (Gupta 1995). It also facilitates planning and control, auditing and reviewing activities to ensure that the environmental policies are followed and are made capable of evolution to suit changing circumstances. This is because environmental management is a continuous process of improving environmental corporate policies and programmes by taking into account the most up-to-date regulatory, technical and scientific developments.
One way of introducing EMS in business is following an established environmental standard offered by independent organisations and validation through certification. Two such standards are the International Standardisation Organisation - ISO 14001 (formerly British Standard: BS 7750) and Europe’s Eco-Management and Audit Scheme (EMAS).

BS 7750 provided the lead in certification and was later subsumed within the ISO 14000 standards. ISO 14000 is developed by one of ISO technical committees referred to as ‘ISO/ TC 207’ responsible for environmental management. ISO 14000 is a family of standards which include standards for environmental auditing, environmental performance evaluation, environmental labelling, life cycle assessment, and environmental aspects in product standards (Cascio et al. 1996, Sheldon 1997). A number of researchers have presented a critical view on the particular cases of ISO 14000 implementation, identified hindering factors and possible benefits as a new management tool through observations and conducted survey studies (Gupta 1995, ISO 1998, Holt 1998, Quazi 1999, Farish 2000, Steger 2000). Similarly, the European Union – EMAS sets certain standards to be observed in various areas of practice within the company and promotes continuous environmental performance improvements within industry. This, however, only applies to sites located in the European Union (Hillary 1994, Charlier 1998).

Typical steps involved in implementation of an environmental management system based on ISO 14001 standard can be summarised as (ISO/TC207 2004) :-

- Initial review to identify environmental aspects of the company activities and their impacts.
- List environmental aspects and impacts
- List relevant legislation
- Prepare environmental policy
- Set feasible objectives and targets
- Produce documented procedures to control all processes and activities with significant environmental impacts
- Conduct environmental audits and reviews to check that the system is operating effectively and take corrective actions if necessary.
As the philosophy behind the environmental management system is strongly related to other dedicated management systems such as quality management systems, health and safety management systems, their integration is commonly emphasised (Aboulnaga 1998, Winkler et al. 1998, Lambert et al. 2000). Winkler et al. (1998) discusses the case of an environmental management system designed on the basis of an existing quality management system. Industrialists have welcomed the ideas on integration of these systems, as it is favourable due to possible cost and complexity reductions.

Clearly, implementation of EMS heavily relies on excessive amounts of information collection, provision and access by the related users. Currently existing information systems to support company’s activities do not include such information. Lambert et al. (2000) describes the essentials and peculiarities of environmental information and proposes an approach to maintain this information in Enterprise Resource Planning (ERP) systems.

2.8.2. Environmental Strategies

Traditionally, the impact of a company’s activities on the environment has not been companies’ priority, thus, environmental issues were dealt on an ad-hoc basis when and if they arose. With the development of serious environmental problems such as global warming, ozone depletion, and acid rain, there is an increasing demand by customers, governments and the public from manufacturing industry to minimise any negative impact of their products and operations on the natural environment. This has resulted in a shift in the way companies are dealing with environmental issues. To cope with these pressures in a cost effective and efficient manner, companies are forced to replace the traditional reactive responses by more proactive, strategic and competitive responses. Many organisations have begun to view environmentally conscious practices from a competitive advantage perspective and have begun to realise the possible profitability in environmentally conscious business practices. This is also reinforced by the introduction of regulatory policies, which go beyond command-and-control mechanisms (Sarkis 1999).

Environmental strategies are a set of guidelines that a company defines to respond to current internal and external pressures and/or to anticipate future evolution of the competitive environment, of regulators and of the customers’ needs (Azzone et al. 1997a & b). The formation process of environmental strategy starts with the decision of strategic
orientation that whether the company will include environmental factors into its overall process. Based on its strategic orientation, the company defines the degree of priority to be attributed to environment-related variables with respect to the other competitive priorities. Finally, the company identifies plans, operating investments and level of commitment for the effective implementation of the selected strategy.

In the literature, there are a large number of models for identification of feasible environmental strategies. In a survey of the environmental management programmes of firms, Hunt and Auster (1990) identify a continuum of five developmental stages of environmental management programmes. These stages are:

i) the beginner who provides no protection from environmental risk
ii) the fire-fighter who provides minimal protection
iii) the concerned citizen who provides moderate protection
iv) the pragmatist who provides comprehensive protection
v) the proactivist who provides maximum protection.

Steger (1993) identifies two dimensions upon which the company’s environmental strategies can be described. These are the ‘potential for market opportunities through environmental protection’ and the ‘level of environmental risk inherent in the company’s activities’. Based on these, four possible types of generic environmental strategies are suggested:

- A defensive strategy (small potential for market opportunities and large environmental risk) implies that the companies may invest in end-of-pipe technologies and incur considerable environmental costs.
- An offensive strategy (large potential for market opportunities and small environmental risk) infers that the company may develop or modify its existing products to show environmental improvements and thereby gain a competitive advantage.
- An innovative strategy (large potential for market opportunities and large environmental risk) implies that a company may tap into the market potentials by major changes in the production processes or the product design.
• An indifferent strategy, infers that the company perceives a small potential for market opportunities and small environmental risk.

Azzone et al. (1997b) examines these existing models to identify the determinant variables to develop a more compact and robust model, which at the same time is more generic. As a result of their analysis, they summarise three strategies, namely a passive strategy, a reactive strategy and an integrated environmental strategy. These strategies are based on company's strategic attitude and degree of priority attributed to the environment. Azzone and Noci, (1998) elaborate on this taxonomy for environmental manufacturing strategies and discussed the implementation issues in the detailed organisational framework of a manufacturing company. They also introduced a performance measurement system based on the environmental strategy of a company to assess the success of the implementation.


Once the environmental strategy has been established, then it is transformed into everyday operational practice. Review studies in this area have highlighted some limitations on existing implementation practices due to the divergence between the environmental strategic targets and the capabilities to achieve them. Although many organisations have begun to consider environmental consciousness from a competitive strategic perspective, there are still some barriers for adopting environmental strategic management, which delay taking initiative actions at this front. Srivastava and Hart (1995) state some of these barriers such as cost of developing solutions, lack of know-how, organisational inertia, and contradictory regulations. James et al. (1999) and Tilley (1999) are among the researchers who report on the gap between environmental strategy and its implementation supported by a range of survey studies. Finally, Ahmed et al. (1998) proposes an empirical method to investigate the impact of environmental strategy on organisational overall performance.
Chapter 3

Review of Research on Product Recovery

3.1. Introduction

This chapter reviews the research work related to product recovery (PR), with the aim of outlining the state-of-the-art methods, technologies and systems. The initial part of the chapter provides an overview of general research and the latter parts present more bespoke solutions encountered in the PR literature. Related research work and its application will be analysed and assessed to position the author’s research contribution to this subject in Chapter 4.

3.2. Background

Manufacturers are facing increasing responsibility for their products at the end of useful life due to legislative, customer and consumer pressures and must provide means for collection, recovery or safe disposal. Although the main motivations for PR are complying with legislation, improving the public image and personal ethical initiatives, in some applications it is also pursued due to the hidden economic value of used products and solid waste.

Currently there are national and international directives making the take-back and reuse, recovery and recycling of used products obligatory for the OEM. For example, the European Union has recently published two major directives, namely the Waste from Electrical and Electronic Equipment (WEEE) (Directive 2002/96/EC 2003) and End-of-Life Vehicles (ELVs) (Directive 2000/53/EC 2000). These directives also provide incentives to design products in such a way that the end-of-life costs could be lowered. This increased popularity of PR activities within many industrial sectors has also given a rise to research interest in this area. In the following sections various research areas related to PR will be identified and relevant research publications will be presented.
3.3. Product Recovery Options

PR is the transformation of the used and discarded products into a useful condition through re-use, re-manufacture and recycling. PR can be achieved in different ways. In the literature, various taxonomies offer alternative perspectives to distinguish among PR options. In general, two forms of recovery for the used product are commonly recognised, namely remanufacturing and recycling. Remanufacturing is recovering the product as a whole through a series of operations, which may include disassembly, replacing or repairing bad components, reconditioning, and reassembling (Fleischmann et al. 1997). Goggin and Browne (2000b) further distinguish component recovery referring to reclamation of parts and modules from the used products.

Remanufacturing differs from repair operations, in the sense that products are disassembled completely and all parts are returned to like-new condition, which may include a number of cosmetic operations. Lund (1998) has developed the following list of criteria for a discarded product to be eligible for remanufacturing:

- The product is a durable good.
- The product fails functionality.
- The product is standardised and the parts are interchangeable.
- The remaining value-added is high.
- The cost to obtain the failed product is low compared to the remaining value-added.
- The product technology is stable.
- The consumer is aware that remanufactured products are available.

On the other hand, recycling is recovering the material content of the product via specialised processes at the end of which the identity of the product is lost. In general, after removing the reusable components, the material separation is performed by various techniques depending on the material characteristics. Then recycling processes are performed on the different types of material (Owen 1993). The relationships between these options are summarised by Thierry et al. (1995) as shown in Figure 3.1.
In order to achieve the desired economic justification and the selection of appropriate recovery options for a particular application, it is necessary to carefully analyse the requirements and the circumstances of the particular industry such as the available market and technology. In general, remanufacturing might become more environmentally friendly as well as profitable since it sustains resource (labour, energy, and overhead) embedded in the product. However, there has to be a market to able to sell the recovered products/parts. Remanufacturing is particularly appealing for the industries that are characterised by long technology cycles and low technological obsolescence such as automobile and tyre manufacturers (Gungor and Gupta 1999, Klausner and Hendrickson 2000) and requires a large amount of time and money investment regarding technology, operational management and logistics. Recycling is more favourable where the recovery of the product or part is not technically feasible or not economically justifiable. Example applications of recycling can be found in metal, paper, textile and plastic industries. In the case of small products, e.g. electronics industry, where disassembly is not cost effective, recycling without separation i.e. bulk recycling, might be more preferable (Knight and Sodhi 2000).
3.4. Operational Issues in Product Recovery Environments

The product recovery environment encompasses manufacturing organisations, which are involved in EoL recovery of the used and discarded products. A product recovery environment may comprise a manufacturing company, which incorporates product take-back and integrates production and recovery lines. Alternatively it may comprise of an independent product recovery company, either anonymously or on a subcontract basis, which collects the used products, re-processes them and sells the recovered products. A summary of the scope of activities within product recovery environments is given in Figure 3.2. Operational characteristics of the activities within product recovery environments are different than the traditional manufacturing activities. In general, a high level of uncertainty regarding the timing, quality and quantity of returned products necessitates high levels of flexibility and agility. Thus new approaches and procedures are needed to match these requirements. The application of conventional manufacturing methods and models to the product recovery environment is only possible with further investigation and modification. In the following subsections, the operational management issues and related tools in product recovery environments will be overviewed and the relevant research literature presented.

![Figure 3.2: Range of activities within product recovery environments](Guide et al. 1999)
3.4.1. Disassembly and EoL Decision

Disassembly is a systematic method for separating a product into its constituent parts, components, subassemblies, or other groupings (Gupta and Taleb 1994). Since it is part of almost all recovery options and widely affects operations planning, issues related to disassembly receive considerable attention by researchers. Disassembly is not simply the reversal of the assembly processes and has different operational characteristics (Gungor and Gupta 1999, Lambert et al. 2000). Although the actual mechanism of disassembly is simpler than that of assembly, the operational scope of disassembly is much more complex (Tani and Guner 1997). Brennan et al. (1994) compares the general operational characteristics of assembly and disassembly systems. Table 3.1 presents the result of this comparison. Although there are similarities between these two systems, they report many differences such as single versus multiple demand sources, single end item versus multiple end item, different planning horizons and by product inventory items. Uncertainty regarding the quantity and quality of the disassembly outcomes is also recognised as a complicating factor for operations planning within disassembly systems.

<table>
<thead>
<tr>
<th>System characteristics</th>
<th>Assembly</th>
<th>Disassembly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand</td>
<td>dependent</td>
<td>dependent</td>
</tr>
<tr>
<td>Demand sources</td>
<td>single</td>
<td>multiple</td>
</tr>
<tr>
<td>Forecasting requirements</td>
<td>single end item</td>
<td>multi-item</td>
</tr>
<tr>
<td>Planning horizon</td>
<td>product life cycle</td>
<td>indefinite</td>
</tr>
<tr>
<td>Design orientation</td>
<td>design for assembly</td>
<td>design for disassembly</td>
</tr>
<tr>
<td>Facilities and capacity planning</td>
<td>straightforward</td>
<td>intricate</td>
</tr>
<tr>
<td>Manufacturing system</td>
<td>dynamic and constrained</td>
<td>dynamic and constrained</td>
</tr>
<tr>
<td>Operations complexity</td>
<td>moderate</td>
<td>high</td>
</tr>
<tr>
<td>Flow process</td>
<td>convergent</td>
<td>divergent</td>
</tr>
<tr>
<td>Direction of material flow</td>
<td>forward</td>
<td>reverse</td>
</tr>
<tr>
<td>Inventory by-products</td>
<td>none</td>
<td>potentially numerous</td>
</tr>
<tr>
<td>Availability of scheduling tools</td>
<td>numerous</td>
<td>none</td>
</tr>
</tbody>
</table>

Table 3.1: Comparison of assembly and disassembly systems

(Brennan et al. 1994)
Gungor and Gupta (1999) divide disassembly research into two main groups: disassembly levelling and disassembly process planning. Disassembly levelling is related to identifying the extent to which disassembly of a product should be performed. Current product recovery technology and the market prices make complete disassembly not profitable. Therefore, the important issue becomes finding a balance between the cost of disassembly and the returned benefit from it. In the literature, this analysis has been carried out usually by cost analysis using various techniques (de Ron and Penev 1995, Lambert 1997, Navin-Chandra 1994).

Disassembly process planning is finding a sequence of disassembly tasks, which minimise the cost of disassembly. The number of alternative disassembly process plans grows exponentially as the number of components increase in a product. Therefore, there is a need for systematic methods to identify the most appropriate sequence. Researchers have used various methods and developed tools to optimise the disassembly sequence including the branch and bound algorithm, graph-based heuristics, goal programming, tree representation, neural networks, cellular automata and Petri nets (Gungor and Gupta 1999, Lambert 1997, Seo et al. 2001, Das et al. 2000). Some other works benefit from CAD integrated visual modelling and knowledge management tools in disassembly process planning (Dini et al. 2001, Hu et al. 2002). A more detailed view on disassembly planning can be found in Gupta and McLean (1996), O'Shea et al. (1998), Wiendahl et al. (1999).

Although a number of methods and techniques have been developed to aid the ease and automation of disassembly processes, in certain cases disassembly of small products still remain economically not viable. Recycling of products with little or no disassembly is referred to as bulk recycling. There are some studies in the literature, which investigate the ways of improving efficiency in bulk recycling (Sodhi et al. 1997, Sodhi and Knight 1998, Knight and Sodhi 2000).

For a given returned item, the selection among the options of product or part recovery, material recovery (recycling) or disposal is commonly referred as the EoL decision, and it is closely related to decisions on disassembly levelling and planning as well as product design and production planning. The EoL decision is recognised as a multi-objective decision and is based on technical and financial constraints. Furthermore, it incorporates
marketing, environmental and social criteria and is affected by the current demand and supply characteristics.

There are number of research studies on developing methods and tools in order to aid the selection of recovery options using linear programming, dynamic programming and data-comparison analysis for various product types (Clegg et al. 1995, Johnson and Wang 1998, Krikke et al. 1998, Low et al. 1998). The main objective in these approaches is to maintain the profitability and not to violate the technical feasibility constraints. However, these were rather isolated technical solutions without integration to other functions of operations planning. Goggin and Browne (2000a) have incorporated demand requirements and supply availabilities to EoL decision-making. In their work, the choice among the predetermined recovery options are dependent on the inventory levels and demand indicators received at the particular time. Erdos et al. (2001) and Xirouchakis et al. (2002) are among the first research works to extend the EoL selection criteria to include social and environmental factors. They developed a multi-criteria decision aid, which ranks the alternative recovery options using a predefined list of indicators. Lee et al. (2001) have investigated the integration of disassembly planning with EoL decision consideration.

3.4.2. Inventory Planning and Control

Inventory planning and control comprises of all activities and procedures used to control and maintain the stock levels to support production at minimum cost. For the traditional manufacturing environments there are an abundance of well-established methods and tools to achieve effective inventory planning and control. However, inclusion of product recovery changes the operational scope of inventory planning and control.

The boundary of a typical inventory management system within product recovery environments is depicted in Figure 3.3. In this context, an inventory control model is required to keep track of returned products, disassembled parts, as well as new parts. Inventory may include returned products, remanufactured parts, components or units, parts that are functional and sold as-is or used as spares, materials that are destined for resale as scrap, new parts manufactured in-house or purchased, work-in-process and finished goods (Guide et al. 1999). In addition to this multiplicity of the inventory items, there are further complications due to a high degree of uncertainty in timing, quantity and quality of
returned products and demand for recovered parts. This makes inventory control within product recovery environment a very complex task.

Fleischmann et al. (1997) investigates the complication factors in the applicability of existing mathematical models for inventory management within product recovery environments and makes the following observations. First, as a result of return flow inventory level between new component replenishments is no longer decreasing it may increase as well. Secondly, in the case of product recovery in integrated manufacturing systems there are two options to fulfil demand, namely reuse or new production order. This means an additional decision-making task requiring co-ordination. Thirdly, having two sources of supply, i.e. recovery or a new order, leads to a two-echelon inventory system.

Therefore, the traditional methods and tools are not directly applicable in the product recovery environments. In the literature, classic inventory control techniques such as reorder point and economic order quantity have been modified accordingly and applied in product recovery environments. These applications can be grouped as deterministic and stochastic inventory models for product recovery systems.

![Figure 3.3: Framework inventory management in product recovery environments (Fleischmann et al. 1997)](image-url)
Deterministic models in which all the demand and return rates are known in advance have been developed by some modifications to the classical Economic Order Quantity (EOQ) formula (Mabini et al. 1992, Richter 1996). However, stochastic models provide better control for the uncertainty inherent in the nature of product recovery systems. These models include periodic review models and continuous review models (Kelle and Silver 1989, Inderfurth 1997, Cohen et al. 1980, Muckstadt and Isaac 1981, Van der Laan et al. 1996a-b). Richter and Sombrutzki (2000) use dynamic programming technique for the inventory control problem in product recovery environments. They modify the well-known Wagner-Whitin algorithm according to the specific requirements of product recovery environments.

3.4.3. Production Planning and Control

Inherited uncertainty and the resulting increased variability makes the use of traditional production planning and control (PPC) methods not adequate in recovery systems. PPC in recovery environments includes the questions of how much and when to disassemble, to remanufacture, and to recycle, how much to produce and/or order for new material and co-ordinate disassembly and reassembly. Figure 3.2 presents an overview of PPC activities within product recovery environments. According to Fleischmann et al. (1997) the complexities arising in these systems regarding PPC also depends on the form of recovery undertaken, i.e. direct reuse, material or product recovery. In the case of direct reuse, which means minor repair and conditioning, there is no additional process that needs significant planning and co-ordination. Material recovery comprises of sets of major processes, but these activities are no different than other production processes from the production management viewpoint. Product and part recovery on the other hand, encompasses the most complex planning and co-ordination requirement among all the recovery options. For product or part recovery, due to the individual repair requirement for every returned product there is no well-determined sequence of production steps. This creates uncertainty scenarios in which planning becomes more difficult. A high level co-ordination is crucial due to interdependency of parts, subassemblies and activities. Guide et al. (1999) summarises 4 major factors that complicate PPC functions in the product recovery environments:
i. Probabilistic material recovery rates of the parts from the inducted cores which implies a high degree of uncertainty in material planning,

ii. Unknown condition of the recovered parts until inspected, thus leading to stochastic routings and lead times,

iii. Part matching problem, as units are often composed of serial number specific parts and components, as well as common or standard ones, and

iv. The need to disassemble the products.

Although there are commonalities amongst product recovery environments in general, classification of these systems is needed in order to assist in development of PPC methods and tools for special needs of particular types. Goggin and Browne (2000b) observe that the degree of customer involvement in manufacturing provides useful insights into the selection of appropriate PPC methods in traditional manufacturing environments as offered by the Customer Order Decoupling Point (CODP) classification. This classification is based on considering the extent of the influence of the timing of a customer order on the production schedule. They propose an analogy with this classification for product recovery environments and refer to it as Customer Order Decoupling for Recovery Environments (R-CODP) (Figure 3.4).

![Diagram](https://via.placeholder.com/150)

**Figure 3.4.** Customer order decoupling point for product recovery environments

(Goggin and Browne 2000b)
This analogy classifies product recovery environments into five groups based on the influence of the timing of the customer order on planning of product recovery operations: *recovery to stock, reassemble to order, disassemble to stock, recovery to order, collection to order*. The suitable PPC methods and tools might be quite different for each one of these environments and in future, this classification could be incorporated in investigation of PPC methods for product recovery environments.

There have been many research works on application of traditional PPC methods in product recovery environments. Some researchers investigate application of *material requirements planning* (MRP) with some modifications in recovery environments. They formulate a reverse or special bill of material (BOM) (Panisset 1988, Gupta and Taleb 1994, Flapper 1994a-b, Thierry 1997). However, the deterministic nature of MRP does not make it appropriate for the product recovery environments, since high uncertainty is one of the major characteristics for such applications (Fleischmann et al. 1997) and there is a lack of standardisation, which is fundamental for MRP implementation (Guide et al. 1997a).

Some other studies explore the use of shop floor control strategies, as the inherited uncertainty makes it very crucial to closely follow the flow of the parts at the shop floor. Guide et al. (1997a) investigates different part release policies and priority rules for controlling queues at the work centres in remanufacturing systems. They conclude that these policies do not make significant differences on the manufacturing performance of the system. Guide (1996) proposes another scheduling approach for product recovery environments using the drum-buffer-rope concept. Kizilkaya and Gupta (1998) propose a flexible KANBAN system for scheduling and shop floor control of a disassembly cell which feeds an assembly line together with new parts in a disassembly integrated manufacturing system. Van der Laan et al. (1999) examine “Push” and “Pull” control strategies in remanufacturing systems and investigate their effect on lead times.

Another critical point in recovery systems is capacity planning. In addition to the impact of uncertain routings on capacity, release of various part types simultaneously as a result of disassembly might create further capacity problems due to the common use of repair facilities. Guide et al. (1997b) propose modifications to traditional rough cut capacity planning techniques to handle the capacity planning complexities in recovery environments.
As previously highlighted, very little control on the return flow of the used products is possible in terms of quantity, quality and timing within product recovery environments. Therefore, it is essential to have appropriate forecasting techniques for activity planning. However, the author’s literature review in this area has highlighted a shortage of research work in adopting forecasting techniques for product recovery environments. One area of the related work that has been encountered is by Marx-Gomez and Rautenstrauch (2002). They adopt knowledge-based approach by using a neuro-fuzzy technique to forecast the return rate of used products.

3.4.4. Reverse Distribution and Logistics

Products or parts destined for remanufacturing, recycling or disposal create a new material flow from user to the reprocessing environments, which is in the opposite direction of the conventional production supply chain. The logistics system that is designed to manage this flow is commonly referred to as reverse logistics (Fleischmann et al. 1997, Dowlatshahi 2000). The main issues in reverse logistics are decisions regarding collection and transportation methods, the number and location of take-back centres, incentives for product returns, and third party service providers (Guide 2000).

Collection and transportation of used products and their packages back into the production environment is called reverse distribution. Unlike the divergent (few to many) structure of conventional forward distribution which comprises the distribution of newly manufactured products to multiple destinations, reverse distribution has a convergent (many to few) structure as seen in Figure 3.5 (Fleischmann et al. 1997). This feature and previously highlighted uncertainty make the designing of reverse distribution networks very complex. In the literature, examples of bespoke reverse distribution networks can be found which are designed using a mixed integer linear programming (MILP) technique both as an independent network and as an integrated network with forward distribution (Caruso et al. 1993, Del Castillo and Cochran 1996, Spengler et al. 1997, Krikke et al. 1999). Listes and Dekker (2001) use stochastic programming in reverse logistics network design to incorporate inherited uncertainty characteristics in reverse distribution. Hirsch et al. (1998) uses simulation technique for modelling reverse distribution. This gives a useful insight at a strategic level.
Quantitative research has provided a detailed view on the issues of reverse logistics, however, they offered point solutions and focused on reverse logistics activities that do not explicitly consider the interface with other functions such as production planning and control, inventory management or EoL decisions. Qualitative research, on the other hand, has adopted holistic approaches to understand reverse logistic issues in the broader context.

Guide et al. (2000) investigate the issues affecting reverse logistics network design and identify the uncertainty factors and their implication on reverse logistics functions. Goggin et al. (2000) define a reverse logistics network as the product recovery chain, which includes main activities such as collection, assessing, routing, recovery, and distribution. They use the commonly adopted CIMOSA methodology to model the product recovery chain, starting with a generic model, followed by a partial model and finally a particular model. Fleischmann et al. (2000) uses the term “product recovery networks” which encompasses several supply chain stages for product recovery activities. They observe that logistics networks are context dependent, and as a result they distinguish three types of recovery logistics networks: bulk recycling networks, assembly product remanufacturing networks, and re-usable item networks.

Guide and Jayaraman (2000) propose a framework to coordinate and monitor reverse logistics activities, and provide an interface between reverse logistics and production
planning and control activities. They propose that a dedicated department must be established to have the responsibility for the accomplishment of reverse logistics activities such as core (used product) acquisition, return forecasting, synchronising return with demand, and product recovery resource planning. Ferguson and Browne (2001) investigate the issues in reverse logistics from an 'Extended Enterprise' viewpoint. They identify information support requirements for EoL recovery of vehicles and present an Internet based information support system.

There are also a number of studies on the collection methods and related financial analysis. Klausner and Hendrickson (2000) developed a model, which aims to aid in designing a take-back system identifying the optimum amount of spending on buy-back and reverse logistics to balance revenue from remanufacturing and recycling. Jung and Bartel (1999) present a pilot take-back project in which they analyse the economics of computer take-back and recycling. In this study the methodology is that the users drop the used product, namely computer equipment to the local retailer, and this provides a cost reduction in collection and distribution and a controlled return of used products.

In addition, there are some case study papers which demonstrate applications of PR concepts and methods within various industries such as electronics (Goggin and Browne 1998, Maslennikova et al. 1998) and automotive (Coppens 2002).
Chapter 4

Research Context

4.1. Introduction

This chapter summarises the author's specific interest in the PR research area and provides an overview of the boundaries of the research reported in this thesis. It identifies the context of the research in relation to other areas of PR research. Furthermore, it presents an evaluation of the related research concepts and corresponding publications for all the themes of this thesis, and aims to position and assess the author's contribution to the research area.

4.2. Research Context

Product Recovery is the transformation of used products back into a useful form through a series of reclamation operations. As this is performed at the end-of-life of the products, the author refers it to as End-of-Life Product Recovery (EoL-PR). It should be noted that in this thesis end-of-life product recovery (EoL-PR) and product recovery (PR) are used interchangeably. Due to the high profitability, a growing number of legislative initiatives and growing consumer awareness, PR is receiving rapidly increasing attention from researchers. The related research encompasses a wide range of issues including the development of business, operational and technological concepts, methods and tools.

The author distinguishes between four forms of EoL-PR, based on the outcome of the recovery processes, namely product recovery, part recovery, material recovery and energy recovery as illustrated in Figure 3.1. Product recovery (remanufacturing) is defined as the recovery of the product as a whole without loss of identity. The recovered product may or may not serve the same purpose or used in the same market as the original product. Part recovery is the recovery of parts and components of the product and is used in cases where it is not possible or feasible to recover the used product as a whole due to various reasons.
Recovered parts could be used in assembly line for production or as spare parts supply for the maintenance and service. In certain industries, parts are bought, recovered and sold as a sole business interest. Material recovery (recycling) is reclamation of the material content of the used product through various processes at the end of which the identity of the used product is completely lost. Finally, energy recovery is the recovery of the energy embedded in the product, parts and material through incineration. Figure 4.1 illustrates the relationship between these product recovery options.

Implementation of EoL-PR is a technical and systematic process, which requires a comprehensive understanding of the business, environmental, engineering and cost issues. It involves a range of decision-making and planning at all management levels. The author recognises that the decision-making in adopting product recovery procedures is two-fold. First, the decision needs to be made on whether or not a company should consider setting up product recovery procedures for its products at the end of their life. This is a strategic level decision. This relates to a company’s position in relation to environmentally conscious practices and its commitment for efficient and effective use of resources. Contemporary environmental strategies are summarised in Chapter 2. Strategic level decisions also consider the level of involvement within realisation of PR procedures as opposed to outsourcing. This identifies a company’s degree of willingness to extend the
scope of its business to include PR procedures as a part of its business and manufacturing activities or subcontract it where it is possible.

Following this strategic decision on adoption of PR, the second decision is about how to realise product recovery adoption. This is a tactical level decision. This involves the process of developing methods for implementing PR procedures. In every application, there would be a number of options to select from for collection and re-distribution channels, recovery options and processes, and recovery partners. The goal is to decide on the most satisfactory combination for a company’s particular requirements. These PR management levels and related issues are illustrated in Figure 4.2.

The research reported in this thesis focuses on the integration of Eol-PR procedures within product supply chain and supporting the tactical planning and decision-making during the process. The research does not consider the decision related to whether or not to adopt PR procedures and comparison between pros and cons of each case. The research hypothesis is based on the assumption that a company has decided at a strategic level to recover its products at the end of life and aims to investigate the development of tools and methods at a generic level to provide the organisations with the ability to efficiently implement PR activities. The major goal of this research is to provide general tactical insights into decisions for adoption of product recovery procedures and to provide the supporting tools and methodologies.

Example decisions

<table>
<thead>
<tr>
<th>Is PR economically viable?</th>
<th>Level of PR involvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>How to implement it?</td>
<td>Ways of achieving it</td>
</tr>
<tr>
<td>What resources?</td>
<td>Realisation and control</td>
</tr>
</tbody>
</table>

Levels of Management

Figure 4.2: Anthony's triangle for organisation (Adapted from Anthony 1965)
4.3. Author’s Research Contributions in Relation to Previous Research Work

There is an established body of research related to the PR of used and discarded products. The research reported in this thesis aims to extend this research work by focusing on integrating EoL-PR procedures within existing manufacturing practices. In order to realise this vision, the author has identified three areas of investigation that are also repeatedly reported by previous research work as major areas for the future research in PR. These are outlined as:

i) Requirements for an integrated product supply and recovery chain,

ii) Requirements for a systematic product recovery implementation methodology, and,

iii) Requirements for efficient information support systems for PR procedures.

In order to effectively position the author’s research, each of these areas of investigation will be explained through the observations and findings of previous relevant research work.

4.3.1. Requirements for an Integrated Product Supply and Recovery Chain

The concept of the product supply chain is now well established within every manufacturing sector, and is defined by Gjerdrum et al. 2001 as:

"...the sequence of processes and activities through which material and information flow in order to manufacture a product and deliver it to the end user. This represents a complete manufacturing and distribution cycle, which includes activities from materials and component procurement, converting them into products, and final distribution until the finished product is in the possession of the final owner."

The establishment of PR procedures within various manufacturing applications has resulted in a novel concept, commonly referred to as the ‘product recovery chain’ which is defined by Goggin et al. (2000) as:

"... the organisation of activities which collectively aim to realise the product recovery by taking the discarded product as an input and outputting it in some useful form; and the related actors who take part in accomplishing these activities. These activities include collection of used products; assessing and
routing; reprocessing them for product, part or material reclamation; redistribution of the recovered products and material; and finally safe disposal of waste..."

Fleischmann et al. (2000) generalised this concept and used the term “product recovery networks” that is defined as :

"...logistics structures constituted of physical locations, facilities and transformation links conveying used products to be used at product, component or material level in some additional applications..."

As the collective output of one consequently becomes input of the other, the activities within the product recovery chain are closely linked with the activities within the product supply chain. There is a high level of interdependence in the form of material and information flows between the various stages of these structures. Thus, all related research work commonly emphasise the need for further research for more co-ordination and closer integration of the activities within the product supply and recovery chains. Goggin et al. (2000) states:

"... It is impossible to totally disassociate resource recovery from the manufacturing (supply) chain, as recovery may be supplied by, or executed by, the elements of the conventional forward (supply) chain... resource recovery is a concept that requires close and collaborative relationships with supply chain elements..."

Fleischmann et al. (2000) observes that :

"... product recovery networks call for co-ordination with (product) supply chain rather than considering each one independently..."

This highlights the requirement of internal and external process integration allowing better co-ordination and collaboration at all levels of planning, execution and control of operations. New business models are required to support such integration by taking a single view of all elements within these product supply and product recovery structures. In the light of this discussion, the development of an integrated view of the ‘product supply and recovery chain’ comprises of one of the major parts of the research reported in this thesis.
4.3.2. Requirements for a Systematic Product Recovery Implementation Methodology

The realisation of PR procedures within manufacturing enterprises requires a major alteration of both the internal and external business and operational structures. This encompasses a number of changes in business and manufacturing practices, organisational structure, information infrastructure and the operating market. To undertake such modifications compels a comprehensive decision-making task which is multi constraint and multi objective; and includes application specific requirements. This requires effective management and control of PR activities to assist in determining the most appropriate solution for a particular application. Previous research as highlighted by Guide et al. (2000) has not supported this requirement:-

"A great deal of the research in remanufacturing systems has much focused on the development of technical solutions rather than the development of managerial techniques."

Furthermore, Guide and Jayaraman (2000) assert that:-

"...While EoL PR is becoming a necessary part of any manufacturing business as a result of the recent trends and requirements, very few guidelines are available for planning, designing, implementing, controlling and managing PR operations..."

The process of PR realisation is intrinsic in nature and necessitates well-understood and agreed procedures. This set of procedures aggregates to a systematic methodology, which is best described as guidelines that are routine, repetitive and programmable for different applications. Given the high profitability and the increasing amount of legislation, there is an immediate need for the development of formal systems to support the lifecycle of the PR realisation process. Guide (2000) states that:-

"...currently, such (PR) systems exist to some extent on a number of scales, however, they lack an integrated body of knowledge of how to plan, design, and implement product recovery operations..."
The discussion above highlights a need for a systematic approach with a reproducible set of procedures, i.e. 'implementation methodology', to support planning, designing, and implementation of PR procedures which constitutes one of the major parts of the author's research. Clearly, such a methodology assists in the generation of cost effective and efficient product recovery procedures.

4.3.3. Requirements for Information Support Systems for PR Procedures

At all levels of planning, designing, implementing and managing PR procedures, a vast amount of information is acquired and processed, underpinning a range of activities such as organising resources, co-ordinating activities and control of processes. Such information is not maintained within the scope of the traditional information systems and their infrastructure does not support this information flow as emphasised by Goggin and Browne (1998):

"... the needs of information systems to support resource recovery are not necessarily met by existing systems to support manufacturing... (hence) definition of the information systems to support the particular activities and business of resource recovery is necessary..."

In a recent survey conducted with 150 companies, which perform product recovery, Rodgers and Tibben-Lembke (1999) observes that the majority of these firms have not achieved an automated information flow to support their processes. Similarly, Goggin and Browne (2000b) assert that:

"... (at present) companies are attempting the issue of resource recovery without the support, in terms of knowledge, expertise and IT infrastructure..."

It is commonly recognised that development of efficient information systems to support product recovery is of significant importance in the medium term priorities for research and development initiatives (NIST 1999, Hitomi et al. 2001). This highlights the requirement for the bespoke information systems to support the various actors and to communicate that information in an appropriate form to sustain the information flow throughout the Product Supply and Recovery Chain.
PR is a collaborative activity, which often takes place across boundaries of organisations. The information exchange might take place between manufacturers and distributors, part manufacturers and finished goods manufacturers, and between consumers, companies and local authorities. Thus, the selection of appropriate media for the implementation of any information support system should be according to the necessity of integrating the distributed entities involved in EoL-PR and providing them with distributed access. The recent advancements in Internet technologies provide a suitable technological solution for the realisation of such a distributed information system. Cheng et al. 2001 states that:

"...Internet has become a new channel of communication among the customers and suppliers in business. It can enable agile manufacturing by extending traditional plant information systems and eliminating barriers to integration. Its platform-independent architecture allows manufacturers to deploy applications across virtual organization, which can include business partners/customers, whose computing environments may be completely different ..."

An Internet based information system allows multiple, simultaneous and distributed access, and provides an appropriate infrastructure to support the collaborative approach which is required for actualisation of PR procedures. This is also recognised by some EoL-PR related research work. Gooley (1998) states that:

"...the Internet is becoming an effective tool for gathering and disseminating information in reverse logistics environments..."

Also Guide (2000) suggests:

"...Information systems using the Internet could be beneficial in bringing buyers and sellers of used items together..."

The development of information systems to support PR procedures constitutes one of the main parts of the research reported in this thesis. The Internet will be utilised as an appropriate technology to implement a distributed information system.
Chapter 5

Research Scope

5.1. Introduction

This chapter outlines the principal aims and the objectives of the author’s research. Furthermore, it identifies the scope in which these aims and objectives are achieved.

5.2. Research Aims and Objectives

The adoption of PR procedures within manufacturing enterprises requires a technical and systematic process, along with a comprehensive understanding of the business, environmental, engineering and cost issues. It implies a major alteration on both the internal and external business and operational structures. Clearly, there should be an in-depth understanding of issues involved and implications of the changes on the existing manufacturing activities for effective development of tools to support the change processes.

The overall aim of this research is to provide a clear understanding for the issues involved in EoL-PR and generate an integration framework and supporting methodology together with appropriate tools to facilitate the wider adoption of EoL-PR procedures across the various industrial sectors. In achieving this principal aim, the major objectives of the research reported in this thesis are defined as follows:

i) To critically study environmentally conscious manufacturing and product recovery.

ii) To develop a framework for integration of processes in a product supply and recovery chain (PSRC).

iii) To develop reference business configurations for PSRC realisation.

iv) To explore the generation of a structured methodology for the analysis of the business, technical, and logistics issues involved in implementation and operations management of EoL product recovery.
v) To specify and model information requirements to support EoL-PR activities.

vi) To design and develop a data repository and communication network to store, maintain and provide access to the EoL information.

vii) To demonstrate the validity of the research concepts through an industrial case study.

5.3. Research Scope

In line with the aims and objectives defined above, the scope of this research is described below.

5.3.1. A Review of Literature in Environmentally Conscious Manufacturing and Product Recovery

A comprehensive literature review in the author's research area has been undertaken in two parts, namely, Environmentally Conscious Manufacturing (ECM) and Product Recovery (PR). The literature review in ECM helps in accumulating background information and links environmental issues within production research. The PR research is identified as one of the major areas in ECM research and a review of the main research work and state-of-art developments in this area has been presented. A particular emphasis is given to position the author's research in its context.

5.3.2. Development of an Integrated Product Supply and Recovery Chain

The establishment of PR procedures within various manufacturing applications has resulted in the emergence of new activities and actors required to accomplish recovery processes at the end of a product's life. In addition to main activities such as supply, production and use within the traditional product supply chain, collection, assessing and routing, reprocessing and redistribution are the major activities within the product recovery chain. The activities within a 'product supply chain' are closely related and significantly influence those within the subsequent 'product recovery chain', and therefore they are required to be considered as one integrated chain (network). Within this research, an integrated view will be developed and the definition of these activities will be enhanced in the light of this integration framework. New actors and their relationship and interactions with the existing functions are to be investigated. The method for this investigation will be logical reasoning
combined with observation of existing practices. Based on this novel view of product supply and recovery chain a number of business scenarios will be specified in a systematic manner to formulate a series of reference business configurations for realisation of the integrated view. The resulting material and information flow is to be identified. These reference business configurations will be used as basis to develop a product recovery implementation methodology.

5.3.3. Development of a Product Recovery Implementation Methodology

EoL-PR relies on a comprehensive understanding of the business, operations and technology issues. It necessitates a number of changes in business and manufacturing practices, organisational structure and information infrastructure. In order to ensure a cost effective and efficient implementation of these changes, a systematic methodology is required. As a part of this research, a systematic and structured methodology will be developed to aid in planning and implementing the necessary alterations within a company’s organisation. This methodology will identify and classify various issues involved in adoption of product recovery in manufacturing organisations. The interrelation and interdependency among various issues will be described. The complicating factors will be addressed and the alternative solutions will be identified. The methods to tackle them will be described at a generic level.

5.3.4. EoL-PR Information Specification and Modelling

The adoption of PR within any manufacturing application results in the generation of a large amount of information related to various activities, which are not included in the existing information infrastructure. Clearly, such information must be efficiently stored, maintained and accessed by a number of different actors involved in various PR activities, in order to support effective planning and control of these activities. In this research, EoL-PR information requirements will be identified and systematically structured for utilisation to support such activities. During planning and control of PR activities different types of decision-making will take place and they will require different types of information. The information specification will be carried out at a generic level to result in a complete and unambiguous PR related information model, which will include both quantitative information for operational planning and tactical level information that may be more
qualitative in nature. Detail information derivation in a specific sector will be exemplified in the case study parts of the thesis.

5.3.5. Design and Development of Product Recovery Information System

Based on the information specification, a computerised data repository system will be designed and developed for storage, provision, and maintenance of this information. The position of the product recovery information system in relation to the existing information support systems will be identified. The PR information system must provide ability for updating and provision of information for many actors, which are most likely to be distributed across different companies. Thus the Internet is seen to be as an appropriate communication media to support the actors and the users of such information that could be physically distributed across cities, countries and even continents. The appropriate technologies will be described to realise the proof-of-the-concept prototype information system. The access of each user will be defined based on technological and operational constraints.

5.3.6. Application of Research Results within an Industrial Case Study

Research concepts will be demonstrated through a case study based on recovery of cutting tools within metal working applications. Due to the lack of formal procedures for tool recycling, this area is seen to provide an enormous opportunity to demonstrate the potential benefits of PR. The case study will consist of the design, specification and implementation of appropriate PR procedures for cutting tools within the machining industry. The research will also investigate a global view of tool recovery for maximising tool usage across a multi-sectorial tool recovery supply chain (e.g. from high precision machining applications in aeronautical industry to more repetitive machining applications in automotive sector). A web based information system will be developed to support the decision-making process involved in recovery of cutting tools.
Chapter 6

An Integrated Product Supply and Recovery Chain

6.1. Introduction

This chapter portrays the author's view of an Integrated Product Supply and Recovery Chain (PSRC). The initial sections of this chapter provide a description of activities and actors within both 'product supply' and 'product recovery' chains. The major part of the chapter outlines the research issues involved in integration of the activities within these chains to develop a novel concept of the 'product supply and recovery chain'. The final part of the chapter identifies two reference business configurations that are defined in this research for the realisation of such integrated product supply and recovery chain. These reference business configurations will be used as the basis for the development of the 'product recovery implementation methodology' and design of the 'product recovery information systems' which are introduced and illustrated in chapters 7 and 8, respectively.

6.2. Traditional Product Supply Chain

Production has been traditionally recognised as the transformation of the raw material into products (Hitomi 1996). This encompasses all the activities from the acquisition of the raw materials from their sources, processing them and distributing the finished products to the customers. To accomplish these activities there is an enormous amount of acquiring, moving and storing goods between sites and across companies, which involves negotiation, planning, coordination and control throughout. This results in a great deal of interdependency in the form of material and information flow between these activities and a complex array of decision-making. Historically, manufacturing companies have dealt with planning and coordination of these activities in a disjoint way, and under a number of different managers. Activities such as acquisition of the raw material, transport from supplier to plant, processes within the plant, transport from plant to customer and all the
related planning, coordination and control was handled in a disintegrated manner by individual business units of participating companies.

Over the last few decades, the market changes such as globalisation of manufacturing business, shortening of product life cycles and demand for high product variety, compelled manufacturing companies to strive for significant improvements in manufacturing management. Such improvements including a greater accuracy in planning, better coordination and greater collaboration within and between all stages of the production life cycle are essential to stay competitive in business. This clearly has necessitated an integrated view to replace the aforementioned fragmented approach among business units and across boundaries of companies, which are involved in the ‘production life cycle’ of a common product. Supported by the developments in the information and communication technologies, the concept of a ‘product supply chain’ has been invented to integrate the operations management of the production life cycle activities across departments, sites and companies to achieve an enhanced coordination and synchronised decision-making.

The product supply chain can be defined as the flow of materials and information between different parties or organisational functions involved in the various stages of production from supplying the raw material until the product is delivered to the customer (Gjerdrum et al. 2001). Virtually, it comprises of multiple companies that function as efficiently and effectively as a single company towards the common target of providing the finished product to the customer. The actors within the product supply chain, typically, include suppliers, manufacturers (including assembly), distributors and customers. There are three dimensions of issues within and among the actors in the product supply chain. Firstly, there is a range of material flow issues such as the raw material supply, their processing, and distribution of the finished product. The second dimension comprises of the information processing and decision making issues that are based on information flows between the actors and their internal functions. Finally, the third dimension relates to financial issues such as handling incoming and outgoing funds. Materials and financial flows take place in the opposite directions, and information flows in both directions between all actors as shown in Figure 6.1.
These issues are organised into various supply chain functions, which despite the variations within every sector basically include:

- **Procurement**: purchasing of raw materials, sub-assemblies and consumables to be used in the processing.
- **Inventory management**: planning and control of parts, components, raw material and finished goods.
- **Manufacturing and assembly**: planning and control, including shop floor scheduling along with the materials handling, storage and movement necessary to reach work-assembly stations.
- **Transportation**: distribution and delivery of incoming and finished goods.

### 6.3 Product Recovery Chain

The establishment of EoL-PR procedures within various manufacturing applications have resulted in the emergence of new activities and actors required to accomplish recovery processes at the end of a product’s life. These activities include collection of used products; assessing and routing; reprocessing the used products for product, part or material reclamation; redistribution of the recovered goods; and finally safe disposal of waste. Correspondingly, the related actors are collectors, recoverers, redistributors and customers. Drawing an analogy to the product supply chain, the *product recovery chain* can be defined as the flow of materials and information between different parties or
organisational functions involved in the various stages of product recovery activities from the acquisition of the discarded product until it is fully transformed back to a useful form and delivered to a (secondary) customer (see Figure 6.2).

A generic material flow diagram for the product recovery chain activities is shown in Figure 6.3. This diagram attempts to encompass all the recovery options and illustrates the relationships between them. Once the product is discarded by the last user then the designated 'collector' re-circulates it to the recovery actor. The decision needs to be made at this point regarding whether or not the product can be recovered. If the product is in an un-recoverable condition such as having major physical damage or it is not cost effective to recover, then it is discarded for possible material recovery or disposal. In some cases, the discarded product undergoes bulk recycling, i.e. recycling without disassembly, if the disassembly is not economically justified. The products that are spared for product or part recovery are channelled through other appropriate routes.

The appropriate channels for a particular used product are determined based on the aforementioned recovery options (see Section 4.2) as a result of their EoL assessment. If its condition satisfies the criteria for the recovery as a whole, then remanufacturing is performed through disassembly, repair and reconditioning and re-assembly. Otherwise it is destined for partial recovery (i.e. part/component recovery) in which the parts and components are restored for reuse. They can be used as replacement parts or sold as spare parts to the customer. In the case of remanufacturing should some of the parts not be suitable for reuse they will be replaced with either new or recovered parts from the part recovery channel.

![Figure 6.2: An illustration of a 'product recovery chain' and related flows](image-url)
Four product recovery chain activities are recognised in this research, namely, collection, sorting and assessing, recovery processes and redistribution. They will be explained in more detail in the following sections.

Figure 6.3: A generic view of the material flows for PR activities
6.3.1. Collection

The product recovery chain activities start with the collection of the used goods from the point of discard for the actualisation of transformation processes. Clearly, the appropriate method for collection of used products varies in different applications. This might include return by the customer to the designated collection points or a bespoke collection organised by a retailer, manufacturer or independent recycling companies. In some applications local authorities such as a city council or a charity organisation might initiate the collection activity for their financial benefits. This might mean installation of purpose-built collecting centres. In the case of return by a customer, collection is often combined with a new purchase. This brings better control over the return rate. The type of the collection method used, and timing and frequency of collection are dependent on the product characteristics such as size, durability etc., market conditions, diversity of the locations of other actors within the product recovery chain, and existence and ease of installation of the collection premises.

6.3.2. Sorting and Assessing

Collected products need to be inspected and their conditions must be assessed for routing to the appropriate product recovery channel. This might be coupled with the preceding collection activities in some applications. After cleaning of the product, it is checked for major faults, which might make it infeasible to perform the recovery processes. In certain cases, disassembly might be required to be included in this assessment stage in order to perform thorough inspection, i.e. distinguishing reusable parts. Purpose-built premises could be allocated where this becomes a major operation with special resources needs. In some cases, e.g. material recycling, sorting might encompass material separation and shredding. At the end of this stage used products are directed to the assigned premises for the actual transformation into a useful form or to the disposal channels.

6.3.3. Recovery Processes

Collected products are sorted according to their assessment and arrive in the reprocessing plants, for appropriate recovery operations. An item reaching this stage has been assigned to product, part / component recovery, or material recovery channels. The recovery actor
might be an OEM or an independent recovery company, which may work autonomously or under a subcontracting arrangement. Product recovery processes typically include disassembly operations, repair/reconditions and reassembly. Test and inspection is needed to ensure the quality requirements of the remanufactured products or the recovered parts and components. In the case of PR by an OEM (OEM recovery), recovery processes can be combined with the manufacturing processes.

### 6.3.4. Redistribution

Redistribution refers to the aggregation of all the activities related to delivering the recovered products to the point of sale or to the original customer. In some cases, the recovered products, part / component or materials are distributed to secondary customers. Secondary customers may be in a different industrial sector as to an OEM. In the case of OEM recovery, it might be feasible to combine distribution channels of the new and recovered products.

### 6.4. An Integrated Product Supply and Recovery Chain

The activities within a ‘product supply chain’ are closely related and significantly influence those within the subsequent ‘product recovery chain’. There are substantial material and information flows between the various stages of these structures as shown in Figure 6.4. During the entire life cycle of the product, the output of one flow becomes input for the other, and vice versa. For example, goods produced at the end of product supply chain after the use stage enters the product recovery chain. Subsequently, the recovered items may be supplied back to the production stage as well as being distributed to secondary users. The information related to the issues such as design criteria, material types and its suppliers, production and assembly processes, marketing strategies, sales and distribution, the provision of a maintenance service and warranties, and user feedback on product utilisation is of paramount importance during EoL decision-making (see Figure 6.4). Furthermore, this information is also needed for identification of the required resources and suitable markets for recovered products, parts and material for economic justification.
Chapter 6

Product supply chain

supply  manufacture  distribution

Collection/assessement  reprocess  re-distribution

Recovery chain

Figure 6.4: Material and information flows between product supply and product recovery chains

In order to generate more holistic solutions regarding planning, designing, implementing and managing PR procedures, the concept of ‘product supply’ and ‘product recovery’ chains are considered conjointly to develop an integrated ‘Product Supply and Recovery Chain’. The author defines PSRC as a collective view of the co-operative relationship between the organisations within the product supply chain and product recovery chain in order to achieve an effective and efficient provision of the entire range of services throughout the product’s lifecycle from product design and manufacture to final disposal including the take-back services, end-of-life management of products, and reverse logistics.

An integrated PSRC provides a complete outlook, in which it is possible to reconcile point solutions developed for individual stages to ensure totality and compatibility amongst them. It is recognised that at present, a significant proportion of recovered resources in particular the recovered materials are likely to be used within different applications and industrial sectors. Therefore, the PSRC defines the bi-directional physical flow not only within a specific chain or network, but also within a “cluster” of related manufacturing applications to realise a complete ‘manufacturing loop’ as shown in Figure 6.5. This novel
holistic PRSC view promotes a change to the traditional definition of manufacturing from “converting raw material to useful products” towards a contemporary sustainable view of limited material bank from which “an amount of a material will be transformed into useful product for a duration and then will be transformed back to some form of material for another use”.

This novel view facilitates the recovery of products, parts, material and energy not only for environmental reasons, but also for realisation of business models which would take advantage of the hidden economical value of used products. Clearly, the realisation of such a PSRC requires a close integration of both material and information flows as depicted in Figure 6.5. The achievement of such integration relies very much on design and development of appropriate information systems which are capable of the supporting planning and decision-making processes involved for both the supply and EoL management of products. Such information system must support distributed access to the required information by a range of actors within PSRC which may be geographically spread across different towns, countries and even continents.

![Figure 6.5: An integrated view of product supply and recovery chain](image-url)
The development of such information system for the integration of the wide range of processes has now become feasible through the emergence and rapid advancements of Internet based technologies. The design of such information system to support an integrated PSRC will be described in Chapter 8 and will be illustrated through a case study in Chapter 10.

The establishment of the PSRC framework highlights the requirements for internal and external process integration between the units of a manufacturing organisation allowing better co-ordination and collaboration at all levels of planning, execution and control of operations. This further stresses the requirement of additional structures for the information and material flows within the entire PSRC. In order to facilitate the definition of these structures and support the implementation of the PSRC and its processes, new business models are required to classify the possible scenarios based on common properties and characteristics in different applications. The information encapsulated within such business models can also be used for day-to-day planning activities within a PSRC. In this research, these business models are identified and named as reference business configurations and are detailed below.

6.5. Reference Business Configurations for Realisation of PSRC

As previously discussed, the PSRC comprises of a number of activities and associated actors, who collectively aim to provide service requirements throughout a product’s lifecycle. There are a number of activities within the PSRC, which includes supply, manufacture, assembly within the product supply chain and collect, assess and recovery within product recovery chain. The current business solutions for EoL-PR is primarily based on two major drivers:

(i) Who is responsible for recovering the product? and
(ii) Who is performing the product recovery?

In this research, the consideration of these two drivers is referred to as ‘responsibility vs. performing’ viewpoint and is used to define the business reference configurations. Based on this viewpoint, the author identifies three primary actors, namely, the original equipment manufacturer (OEM) of the used product, the independent recoverer (IR) whose
sole business is to re-process used products and the user (USER) of the product which directly or by appointing a Maintenance Provider (MP) undertakes repairs and recondition of the product. These actors are referred to as the foundation blocks of the definition of the business scenarios. It should be noted that the actor who performs the recovery functions does not necessarily have the responsibility of its realisation. It is the author’s belief that these two fundamental drivers in responsibility vs. performing viewpoint will predominantly determine the way the PSRC will be realised. Based on this the alternative scenarios have been summarised in Table 6.1.

Through the consideration of these scenarios, the author identifies two overriding business solutions based on the identity of the actor who performs the product recovery processes, namely recovery of EoL products (a) through the addition of recovery capabilities to the OEM or (b) by IR companies whose sole business is to re-process used products. These business solutions coincide with the aggregation of the possible scenarios of each row for each actor shown in the Table 6.1. It should be noted that the third row is corresponding to the USER performing life-extending maintenance and repair operations on the product which does not constitute a business scenario and is recognised to be irrelevant in the context of the author’s research. Thus it is not included in the future discussion.

<table>
<thead>
<tr>
<th>Who is responsible?</th>
<th>OEM</th>
<th>IR</th>
<th>USER</th>
</tr>
</thead>
<tbody>
<tr>
<td>OEM</td>
<td>OEM takes back the discarded product and recovers it in-house (e.g. leasing)</td>
<td>N/A</td>
<td>OEM provides the USER with recovery service, i.e. maintenance</td>
</tr>
<tr>
<td>IR</td>
<td>OEM subcontracts IR</td>
<td>IR acquires the used product and recovers it for its own business interest</td>
<td>IR provides the USER with recovery service</td>
</tr>
<tr>
<td>USER</td>
<td>N/A</td>
<td>N/A</td>
<td>USER performs repair operations</td>
</tr>
</tbody>
</table>

*OEM: Original Equipment Manufacturer
*IR: Independent Recoverer

**Table 6.1**: Summary of product recovery business scenarios
Figure 6.6: Reference configurations for product recovery realisation

These business solutions correspondingly highlight two reference business configurations for the realisation of the PSRC (see Appendix 1), which are illustrated in Figure 6.6 and described below:

6.5.1. Reference Configuration 1 - Recovery by OEM

In this reference configuration the OEM of the product takes the products back at the end of their life and carries out the recovery processes in-house, as illustrated in Figure 6.6a. Although commonly the main motivation for this PR realisation could be the responsibility imposed by legislation and improving the public image, more increasingly financial benefits is also the initiator of this reference configuration.

The OEM takes its own product as input for recovery processes and in the first instance aims to recover the product (i.e. remanufacturing) and re-sells it to the original market. In addition, in the cases where the product recovery is infeasible, modules and parts are recovered and re-used in the manufacturing lines. This realisation requires a significant extension of the scope of the business and manufacturing operations and expansion of facilities to include the required resources to undertake the recovery processes. Therefore, as the operational scope of the OEM increases with these additional activities, this
reference configuration may result in an increased complexity in production planning and control within the OEM. Information sharing is often achieved relatively easy as it is centred on the OEM's operations and violation of confidentiality is not an issue in this reference configuration. The know-how gained in performing product recovery operations could be incorporated in other lifecycle stages of the product (e.g. design consideration for ease of disassembly to improve overall efficiency). As the OEM controls the original market there will be a better control on the return of the used products. This could be enhanced with adoption of some incentives and price reduction strategies associated with customer returns, which in turn offer efficiency and cost reduction for the collection activity.

6.5.2. Reference Configuration 2 – Recovery by IR

In the second reference configuration, an independent recovery company undertakes product recovery either anonymously or on a subcontract basis on behalf of one or more OEMs (see Figure 6.6b). The motivation for IR to take up this business is the financial benefits i.e. hidden value embedded in the EoL products. The recoverer receives the products from the manufacturers or collectors at the end of their life and carries out the required recovery processes. A wide range of EoL products could be processed, as it is not limited to single OEM. This increases the element of uncertainty in timing, quality and quantity of return of the products. The recovery options could be product, module or part recovery the same as in reference configuration 1. In addition, an IR could be specialised in the recovery of material. The recovered products, parts or material are either supplied back to the original manufacturer or sold on to secondary customers.

This reference configuration provides OEMs with the major advantage of outsourcing the recovery processes thus not needing a major alteration in their production facilities. Although, planning and control of recovery processes within the IR still incur the complexities inherent in any product recovery environment, in this case the complexities related to the integration with the traditional manufacturing lines are eliminated. Clearly, in this reference configuration issues related to product confidentiality and EoL information management could be much more complex as an OEM might not be willing to share product information that could be vital for the recovery processes. Similarly, the knowledge gained by the recoverer during the recovery processes is not readily available
for the OEM to incorporate in other stages of the product’s lifecycle for improvement. This shared recovery approach may offer a significant reduction in the cost of recovery processes in the long term as a result of ‘economies of scale’. However due to the current complexity of recovery technologies and unfamiliarity of such re-manufacturing business concepts in many industrial sectors, the IRs may not exist at present or might not provide enough recovery capacity for a complete PR implementation in that sector.

6.5.3. Comparison of PSRC Reference Business Configurations

A comparison of the aforementioned PSRC reference business configurations is presented in Table 6.2 based on a number of critical characteristics. There are a large number of factors influencing the suitability of one of these reference configurations for a particular manufacturing application, including a range of product types, process complexity, reprocessing capacity of OEM, geography of the initial distribution, and relevant legislation. These factors will be analysed in more detail in Chapter 7.

<table>
<thead>
<tr>
<th>Recovery Actor</th>
<th>Reference Configuration 1</th>
<th>Reference Configuration 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motivation</td>
<td>Legislation, customer service, public image, profit-making</td>
<td>Profit-making</td>
</tr>
<tr>
<td>Degree of variety of input EoL products</td>
<td>Low / Medium</td>
<td>Medium / High</td>
</tr>
<tr>
<td>Feasible recovery options</td>
<td>Product and module/part recovery</td>
<td>Product, module/part, material and energy recovery</td>
</tr>
<tr>
<td>EoL-PR market</td>
<td>Same as original</td>
<td>Usually different, but can be original</td>
</tr>
<tr>
<td>Complexity of planning tasks</td>
<td>High</td>
<td>Medium</td>
</tr>
<tr>
<td>EoL-PR information availability to recovery actor</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Life cycle information feedback to OEM</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Degree of uncertainty in return</td>
<td>Medium</td>
<td>High</td>
</tr>
</tbody>
</table>

Table 6.2: Comparison of PSRC reference configurations
Chapter 7

A Methodology for Implementation of Product Recovery Procedures

7.1 Introduction

This chapter describes a methodology developed in this research for implementation of EoL-PR within different industrial sectors based on an integrated framework of the PSRC, which has been introduced in Chapter 6. The first part of the chapter highlights the requirements for such a methodology. The major part of the chapter describes the development and the major stages of the Product Recovery Implementation Methodology (PRIME). Finally, the chapter concludes by outlining the application of PRIME through the various phases of assessment and feasibility analysis, cost-benefit analysis, information system development and implementation.

7.2 Implementation of Product Recovery Procedures

The impact of EoL-PR necessitates significant modifications in the way an organisation operates. This in turn, implies major alterations to a company’s internal and external business and operational structures including a number of changes in business and manufacturing practices, organisational structure, information infrastructure and the operating market. The implementation of these changes requires a comprehensive understanding of the business, environmental, engineering and cost issues.

The facets of PR implementation are illustrated in Figure 7.1. The author identifies the control elements for the PR adoption process as legislation, recovery cost, demand and market conditions, product technical constraints and the availability of appropriate technologies. These drivers need to be carefully analysed, planned, and co-ordinated under a systematic methodology to ensure the generation of cost effective and efficient product recovery procedures. In this research, the author has developed such a systematic methodology to support the implementation of PR procedures within the PSRC framework.
which is labelled as the Product Recovery Implementation Methodology. The various stages of PRIME will be outlined in the following sections of this chapter.

7.3. Product Recovery Implementation Methodology

PRIME is a set of guidelines, which aim to provide a structured approach for identification of business, technological, and information requirements for the adoption of PR in different applications. PR implementation is a complex task in nature as it involves management of change across a number of business and operational functions. The scope for the application of PRIME is summarised as:

- identification of the boundaries of the organisation's activities related to PR procedures;
- matching these activities to the organisation’s operating environment;
- matching these activities to the organisation's resources;
- acquisition, allocation and reallocation of resources;
- providing guidance to the operational decisions;
- identification of the long and short term direction of the organisation.

Figure 7.1: An IDEF0 representation of the product recovery process
The consideration of these issues are organised into five main stages, namely:

i) Evaluation of business implications
ii) Product and technology analysis
iii) Identification of resource requirements
iv) Evaluation of logistics and operation planning requirements
v) PR information specification.

PRIME is designed as an iterative and continuous process as depicted in Figure 7.2. A firm strategic commitment for adoption of PR procedures is the main initiator for PRIME. This is followed by a number of phases (see Section 7.4) where a phase is defined as an application loop through five stages of the methodology. Each phase generates vital information and feedback that will eventually lead to the design specification for tactical and operational plans for implementation of PR procedures as illustrated in Figure 7.3. The goal is to provide general insights into a range of tactical and operational decisions to be made during adoption of PR procedures rather than to optimise the decisions derived.

Figure 7.2: PRIME methodology
Chapter 7

Figure 7.3: A structured view of PRIME
The five stages of PRIME are interrelated and the decisions made in one stage influence the considerations in the other stages. This interaction is more emphasised in the area of information specification as it is solely derived based on the results from the first four stages as illustrated in Figure 7.2. The stages of PRIME will be explained and detailed in the following sections. It should be noted that although the processes are described in generic terms, each industrial application requires a specific derivation as will be further discussed and illustrated within a case study in Chapter 9.

7.3.1. Evaluation of Business Implications

The adoption of PR procedures within manufacturing enterprises results in a requirement for a major alteration in a company’s business structure including the changes in the operating market, business practices, and organisational structures. During the implementation, the issues involved include analysis of market and marketing strategies, pricing of recovered products, and environmental legislation.

The market analysis is performed to reveal the characteristics of the market in which the company is operating. The market characteristics for both the original and recovered products need to be understood. The market segment to which the original product relates would have an impact on the design of PR implementation procedures. One way of classifying the market could be the division between ‘commercial’ and ‘domestic’ sectors. In general, commercial products are the goods that are used by industry whereas domestic products are for household use. These market segments have implications on the geographical distribution of customers and quantity produced which subsequently influence the ease of tracking and collection of the used product.

In order for product recovery to be economically viable there have to be customers available who are willing to buy the recovered products. Marketing implications for the recovered products might change in different sectors. In some cases, the idea of buying recovered products or products with recovered components might be appealing to customers due to green demands (e.g. recycling of carrier bags and food packaging). However, there would be cases where recovered products may not be as attractive due to a lower reliability or cosmetic reasons (reconditioned electric goods and reconditioned cars). Furthermore, this variability in market demand may also vary in different parts of the
world. For example in certain countries the availability of cheap reconditioned goods may be more desirable than green environmental effect of the product recovery and recycling. In some cases, the possibility of marketing recovered parts as spares (e.g. the automotive sector) or use them in the manufacture or re-manufacture lines (e.g. electronics manufacturers) may be a more viable option to investigate. It should also be noted that in certain cases there might be a readily available market for recovered products/parts within a different industry (e.g. use of the recycled material from car tyres as ingredients for road construction). This gives rise to the idea of a cross-sectorial product supply and recovery chain and another alternative for formation of industrial clusters. The availability of the secondary market will significantly affect the choice of recovery options as will be discussed in the ‘Technology Assessment’ section later in the chapter.

Creation of the market for a recovered product requires new marketing tools. Use of new information and communication means such as the Internet could offer a service during the search of secondary markets by bringing buyers and sellers closer. Extension of the customer portfolio in this way clearly increases the chances of matching the demand by attracting customers to these new markets. In addition, ‘Leasing’ could offer an alternative marketing solution by combining the use of new and recovered products to provide the required functionality (service) to the customer while simultaneously offering an advantage of the cost reduction. In such scenarios customer demands may not be affected as much by shortcomings of the recovered products, as they do not have to deal with the repairs and maintenance of the leased products.

Inevitably, the adoption of PR procedures within any application induces an additional operational cost. This cost may be incurred to some extent by all the related actors, i.e. manufacturer, recoverer and the customer. As a cost increase is undesirable by any actor, the relevant legislation often determines the level of cost shared by each actor. One way of incorporating the additional cost is to reflect this in the pricing of the product. Alternatively, the service charges may apply to the individual activities. A separate study is required to be undertaken to investigate the issues related to costing strategies (see Further Work in Chapter 12). It should also be noted that the adoption of PR procedures might result in cost saving benefits, which could include exemption from a hidden cost of disposal activities and the cost of non-compliance with the legislation. Thus, in order to
have more accurate views on regulations, relevant national and international legislation needs to be studied.

The existing business processes change with the inclusion of product recovery. They should include new PR processes and actors. Organisation of these new processes and actors in different business scenarios have been outlined based on two reference configurations in detail in Chapter 6. As the supporting business infrastructure may not always exist, the adaptation of a configuration is determined by the particulars of the market characteristics.

7.3.2. **Product and Technology Analysis**

As previously discussed in Chapter 3, the recovery of used products can take a number of forms. The author identifies four EoL-PR options as outlined below:

- **Product recovery** is the reintroduction of the used product back into the market through a series of processes such as inspection, disassembly, replacing or repairing bad components and re-assembling (often referred to as re-manufacturing).
- **Module & part recovery** where a subset of parts and components of used products can be recovered, repaired or re-conditioned for re-use in production of new products.
- **Material recovery** is retrieving the material content of the whole or a subset of the components of used products through a range of processes at the end of which the identity of the product is completely lost (often referred to as recycling), and finally,
- **Energy recovery** where in limited applications some of the material not recovered through one of the aforementioned processes is used to generate energy (often in the form of heat and electricity).

The feasibility of adoption of various recovery options is constrained by the technical properties of the product and the availability of PR technologies. The product and technology analysis is performed to identify the possible EoL-PR procedures for a specific product, resulting in adoption of a re-manufacturing, re-use or recycling approach. This includes mainly the investigation of the product’s technical properties such as disassembly
possibilities, material properties related to recyclability, possible reuse options for the modules/parts and the supporting process technologies.

It should be noted that the scope of this analysis is to identify the feasible PR options. However, the selection of the most appropriate PR option is a highly complicated task, which is influenced by some other factors highlighted in other stages of PRIME such as availability of the market, ease of operation planning and the economic justification. In most applications due to the economical and environmental implications such as cost, effort, time, and energy associated with re-production, the initial efforts are often directed at the recovery of the whole product, followed by modules and individual parts. The latter two options, namely material and energy recovery are considered in industries that are characterised by short technology cycles and high technological obsolescence. It is also common practice to combine two or more recovery options in order to achieve desired economic justification and satisfy the legislative and environmental requirements of the particular industry.

Therefore, the author recognises that the decision-making related to EoL-PR options are two-fold. The analysis discussed in this section provides insights to the “macro” level decision-making regarding to the identification EoL options for products before implementation takes place. However, at the “micro” level, the question becomes which one of these predetermined PR options determined at the macro level is most appropriate, given a particular supply of product and stated demand for product and parts. This is an operational level decision and performed on a short-term basis at the time of the receipt and assessment of the EoL products.

7.3.3. Identification of Resource Requirements

As previously discussed, realisation of PR procedures requires a number of additional processes such as collection, sorting and assessment, and re-processing, which are not included in the traditional manufacturing activities. These processes consist of new operations, which are to be performed by a new set of resources. Since PR is a newly emerged area, supporting tools and methods are limited. However, PR is becoming a very popular subject and a large amount of research and development efforts are directed at design and generation of such supporting tools and resources. Therefore, the availability of
bespoke hardware, software and human resources together with the supporting know-how regarding PR operations needs to be carefully investigated while being aware of new and emerging technologies.

Hardware requirements comprise of machinery and tools for various operations during the realisation of PR procedures. This may range from purchase of simple tools to installation of a whole work station and recovery line/shop. Software requirements may include decision support systems for operational planning, inventory control and progress monitoring activities. With recent developments in information and communication technology (ICT), resource acquisition in this category may have the most powerful impact on implementation of PR procedures. For example, traditionally heavily human dominated tasks such as disassembly, more recently, with the development in knowledge management systems and robotics (Srinivasan et al. 1999, Hu et al. 2002) has made significant progress towards the automation as discussed in Chapter 3. Consequently, skilled human resources are required for running these new resources, both in hardware and software.

The collection process may require additional transportation vehicles and human resources to be allocated to the task. Assessing and sorting used products may also need special tools for cleaning and inspection together with a specially skilled workforce who has knowledge on a product’s functionality and reprocessing operations. Reprocessing consists of operations such as disassembly, repair/reconditioning and reassembly. Resource requirements may include disassembly, repair and testing equipment. Furthermore, special skills and know-how may be required for certain operations of a particular product type. In the case of material recovery, i.e. recycling, a range of new processes and related machinery will be required. As this might mean a huge undertaking and a diversion from the company's core business, this might necessitate an outsourcing of the recycling processes to a subcontracting company.

The assessment of existing resources and how much of their capacities can serve the recovery purpose will aid in identification of the level of resource acquisition and subcontracting requirements. As a part of this exercise, investigations may involve the search for the companies which provide service for PR operations such as disassembly plants, recycling companies, and companies, which offer broader solutions including more than one aspect of PR operations. Subcontracting of recovery processes to an independent
recoverer can be based on one of the business reference configurations described in Chapter 6. The degree to which the ownership of the recovered items belongs to the subcontractor is affected by various factors such as business considerations and legislation requirements.

7.3.4. Evaluation of Logistics and Operation Planning Requirements

Adoption of PR requires the establishment of an operational infrastructure to support the day-to-day PR operations. The main issues include collection and redistribution mechanisms, planning and control of recovery processes; and inventory control for keeping track of PR related items.

The adoption of PR procedures creates new material flows, which are required to be facilitated through appropriate systems. Discarding the used product by the user is followed by the collection activity. The collection mechanism encompasses a set of facilities, tools and procedures that are used in bringing the discarded item to the point where the actual PR processes take place. This might include establishment of take-back centres, using retail premises for return and coupling the return with a new purchase, or individual collection from the source. The particulars of the operating environment of the company such as the size and other physical properties of the product, geographical distribution of the customer, geographical distribution of the PR facilities would affect the design of an appropriate collection mechanism. In the design of such a mechanism, decisions to be made will include choosing means for collecting, determining the number of sites for collection, the products quantity to be collected, and timing and frequency of collection. Also by offering incentives for return, financial or otherwise, the collection mechanism could be enhanced which might in turn help in eliminating the uncertainty in timing of return.

Similarly, at the completion of the recovery process there is a need for a redistribution mechanism, i.e. facilities, tools and procedures to deliver the recovered product, part or material to the customer. This may include sales activities, warehousing and transportation. Sales activities of the recovered products may be handled separately from the new products through different sales channels. In some cases, these distribution channels for new and recovered products can be combined, in particular when recovered
parts are being offered as spare parts at a reduced price. In a similar way to distribution of the new products, i.e. forward distribution, warehousing and transportation of the recovered products could be performed by the subcontractor companies offering these services. The degree of integration of these service providers to the recoverers might bring the possibility of the combination of the re-distribution with forward distribution. This will reduce the complexity of overall planning and co-ordination within the PSRC.

As previously discussed PR procedures take place in highly uncertain environments regarding the quality, quantity and timing of the returned products. These difficulties with the planning of recovery processes will significantly increase with the product’s BOM complexity, i.e. the number of disassembly levels and the number of items at each level. Therefore, planning and control procedures for PR related operations require special considerations. Issues encountered in the development of such procedures are based on the extent of OEM involvement with PR implementation as defined through reference business configurations in Chapter 6. In the case of OEM recovery, existing planning and control systems are required to be modified and enhanced to incorporate the PR operations with manufacturing processes. Manufacturing lines could be fed with recovered components at the expense of added complexity. The co-ordination between them becomes an intricate task. Thus the resource implications of mix decisions need to be considered.

In the case of IR recovery, the PPC system still has to facilitate the complexity caused by the uncertainty that PR environments encounter. However, the system multiplicity is eliminated in this case. A new set of inventory planning and control functions is required to underpin the follow-up of new inventory items, such as the used products, recovered parts, etc. Inherited uncertainty should also be included in the design of such inventory planning and control procedures. It should be noted that the design of such systems is influenced by the dependency between demand, supply and the PR activities. This indicates the system characteristics being a ‘pull’ or a ‘push’ type system. This is determined by the market conditions for the recovered products/parts and for the discarded products.
7.3.5. Product Recovery Information Specification

The adoption of PR within any manufacturing application results in generation of a large amount of information related to various activities within the PSRC including information on material characteristics, product utilisation history, legislation, market conditions etc. A subset of this additional information is the new attributes of the existing information elements e.g. addition of new attributes to existing product information such as material recycling properties, reusable parts and subassemblies, and disassembly methods and processes. The others include bespoke information elements such as those related to utilisation and EoL condition of the used product, legislation requirements, recovery actors and recovery processes information. This information is gathered throughout the application of the previous four stages of PRIME as illustrated in Figure 7.4.

Figure 7.4: IDEF0 representation of the activities involved in PRIME
Such information must be efficiently stored, maintained and accessed by a number of different actors across the PSRC. The information specification is seen in two views: *where it is generated* and *where it is used*. This highlights the requirements for information systems with the ability to support the introduction of PR procedures in an efficient and effective way by providing access to the required information, for when and where it is needed. As PR procedures are often added to the existing product supply chain implementation of such a system should appreciate the existence of legacy systems and include the required interfaces. Chapter 8 will describe the information specification in more detail and outline the development of PR information systems.

7.4. Application of PRIME

As stated in Section 7.3, due to the interdependency among the decision-making in various stages, the PRIME cannot be applied in a linear fashion and requires an iterative execution plan. Thus the author has identified four phases, that are referred to as PRIME life cycle and they, in aggregation, produce the design specification for tactical and operational plans as illustrated in Figure 7.5. These phases are outlined below corresponding to the *intelligence and design, selection, development and realisation* steps of a typical decision-making processes-:

![Figure 7.5: Life cycle of PRIME: planning, decision-making and realisation](image-url)
Chapter 7

Phase 1. Assessment and feasibility analysis
Phase 2. Cost-benefit analysis
Phase 3. Information system development
Phase 4. Implementation

The first phase involves investigating the requirements and conditions for realisation of PR procedures. This refers to a feasibility study regarding the availability and acquisition of the means and infrastructure to support PR requirements within the five stages of PRIME identified earlier. This involves an exploration of the external environment to the organisation together with an assessment of the organisation itself, in order to identify requirements, availabilities, and opportunities.

This phase should incorporate an analysis of social and technological trends and events, customers and competitors. It focuses on developing alternatives for actions, decisions and resource allocations and the outcome is the list of options and required actions regarding various aspects of PR realisation. The useful contemporary analysis methods and tools could be used as an aid in this phase including marketing auditing and SWOT analysis; segmental ratio and productivity analysis; and competitor and customer analysis.

The second phase is the reviewing and analysis of costs related to a range of alternative courses of action and choosing the most appropriate ones for the particular application of PR implementation. A combination of the risk evaluation, cost-benefit analysis and balance sheet evaluation could be utilised to draw comparisons between alternatives related to EoL-PR options, resource acquisition, and redistribution and reprocessing channels. In this phase, an approach for sales, profit and demand forecasting need to be incorporated to consider the influence of market structure and the implications of product and market evolution on day-to-day EoL-PR activities. The desired outcome of this phase is the most cost effective combination of implementation options which satisfies the legislative requirements and minimises the negative impact on the environment.

The third phase is information system development. This phase involves design and development of information systems to support the introduction of PR procedures and their realisation. Such a system is seen to be developed based on the information specification performed in the preceding PRIME phases. Definition of functionality within an integrated
PSRC framework should incorporate integration with the existence of legacy systems. This will be discussed in detail in Chapter 10. *The fourth phase* is the implementation. Once the activities, skill sets, processes and systems have been defined and developed, they will be implemented within the outlined tactical and operational plans. These plans should be communicated consistently and frequently to all those involved in this process of PR implementation. The progress of the implementation phase should be assessed and controlled based on the objectives defined in the first three phases of the PRIME life cycle.
Chapter 8

Design of an Information System to Support the Product Supply and Recovery Chain

8.1. Introduction

This chapter highlights the requirements and discusses the design of an information system to support the activities within an integrated PSRC. The initial part of the chapter aims to position the concept of a bespoke product recovery information system within the context of existing information systems in manufacturing applications. Subsequent parts describe the PSRC processes from the physical, decision and information viewpoints in order to identify the functional requirements of such an EoL-PR information system. The final sections discuss the design of this information system.

8.2. End-of-life Product Recovery Information System

EoL-PR is a collaborative activity as products are manufactured, sold and then consequently re-processed often in a distributed manner within a global market. Furthermore, the recycled material and the recovered products have a worldwide potential market. Therefore within a PSRC framework, each actor gathers the information they need, evaluates it from the viewpoint of whether it is useful for their own work, and then passes a subset of the information they have generated using their own skills and knowledge to the next actor in the process. It should be noted that such EoL-PR information is not maintained within the scope of the traditional manufacturing information systems, and their infrastructure does not support the information flow related to the recovery of products.

Information systems are tools used for communication which often involve human intervention for producing, collecting, storing and disseminating information. Information technology comprises of a range of tools (e.g. hardware, software, platforms, etc.) that
support this communication. An information system is then a combination of human social activity and supporting information technology, often referred to in the literature as a socio-technical system (Avgerou 2000).

In this research, a bespoke information system has been developed to maintain the additional EoL-PR information and to facilitate and sustain the information flow amongst the wide range of processes involved in a PSCR. Such an information system has two major functions, the first is to support internal activities related to EoL-PR within each actor and the second is to support the communication and information exchange among various actors resulting in effective various processes within the PSRC. The first step in designing such a system is the information specification which is required to identify the information elements and their relationships. In the following sections, these processes of the information derivation and specification together with the design of an EoL-PR information system will be described.

8.3. EoL-PR Information Specification and Modelling

In recent years, significant research effort has been directed at modelling, specification and design of appropriate information systems to support a wide range of functions within various manufacturing applications. In order to effectively specify and model EoL-PR information the processes involved within a PSRC framework need to be clearly identified and understood. To achieve this clear definition of processes within a PSRC, the current concept and methods for enterprise modelling (in particular those related to extended enterprises) has been utilised. An enterprise model is a symbolic representation of individual facts, objects and relationships that occur within the enterprise (Marshall et al. 1992, Burkhart 1992). In general, the reason for conceptualising various aspects of an enterprise in terms of formal models is to provide an explicit method for understanding, controlling and monitoring the enterprise. Thus, enterprise modelling has been identified as an appropriate method for functional and information specification of an EoL-PR information system. In an enterprise modelling exercise three views are often adopted to describe enterprise activities, namely physical view, functional view, and information view. Based on these three viewpoints, EoL-PR information used to support a range of decisions within a PSRC framework is outlined in the following sections.
8.3.1. Physical View

The first step in information specification is to identify the physical elements and their relationships within a system. An initial representation of the EoL-PR physical view has been provided in Section 6.3. This physical view relates to two parts: i) EoL-PR activities, and ii) EoL-PR actors involved in these activities. The activities include collection, sorting and assessment, re-processing and re-distribution as were identified in Chapter 6 and the related material flows were depicted in Figure 6.3. A more detailed view of the relationships between these activities have been modelled using the IDEFO methodology as shown in Figure 8.1. In this figure, each activity is described based on their material and information input and output, the required resources to perform the activity, and the control drivers together with other conditions influencing the achievement of the various tasks within an activity. Each individual PR activity is then modelled in further detail as shown in Figure 8.2.

![Figure 8.1: IDEFO representation of EoL-PR activities](image-url)
Figure 8.2: IDEF0 representation of the detailed tasks within EoL-PR activities
In this research, EoL-PR actors are defined in two groups, namely main (pro-active) actors and the auxiliary (reactive) actors. The main actors are those who are actually responsible for undertaking the recovery processes (e.g. remanufacturing, recycling etc.). Auxiliary actors are those that are used by the main actors to undertake a number of facilitating tasks (e.g. collection, sorting/assessing and redistribution). The author has identified three main actors within the PSRC framework, namely, the Original Equipment Manufacturer (OEM) of the product, the Independent Recoverer (IR) whose sole business is to reprocess the used product and the Maintenance Provider (MP) who during the use stage of the product undertakes repair/reconditioning activities to prolong the product life or provide a further (second) use of the product. An MP may in some cases be the actual user of the product who undertake any repair/reconditioning work.

8.3.2. Functional View

The second view to be considered is the functional and decision view. The author identifies three functional areas:

i. EoL product acquisition
ii. Recovery realisation
iii. Distribution of recovered goods

Each functional area consists of a number of decision-making tasks that require specific information to support them as shown in Figure 8.3. At this point, it should be restated that the focus in this research is on tactical and operational decisions supporting decisions supporting day-to-day activities (see Section 7.3). These functional areas and the related key decisions are examined below.

8.3.2.1. EoL product acquisition

EoL product acquisition is the process of receiving the discarded product from its last user and delivering it to the EoL-PR procedures. This comprises collection of the used products, sorting and assessment of them. The key decision in this function is:
Decisions related to the eligibility of the product for recovery procedures: When the product reaches its EoL, the decision has to be made whether it is eligible for PR or has to be disposed. This decision is based on the product condition regarding its age, functionality and physical state. Previous recovery and utilisation histories together with the reason for discard by the last user also influence this decision.

8.3.2.2. Recovery Realisation

This function relates to the processes that start with receiving the EoL products for recovery until it is ready for customer delivery. This includes a range of decisions and associated operations required for accomplishing the re-processing of the used product. The selection of the appropriate PR option is inevitably the first major step for realisation of PR procedures. Three key decisions are identified for this function:

- Decisions related to the EoL option for the used product: When it is decided that the product is eligible for PR, the next decision relates to which EoL-PR option should be selected, i.e. options among product, part or material recovery.
One of the major factors influencing this decision is the product geometry, i.e. joint structure and degree of ease of disassembly. This decision is also influenced by the information on the product such as its age, use and previous recovery history, remaining functionality and physical condition. Economical viability of the particular PR option is another factor that affects this decision. Economy of the PR procedures is determined based on information such as the price of the new product, recovered product and recycled material, and the cost of PR procedures for each EoL option. The information about demand and inventory status at that particular time are also determinants for this decision.

- **Decisions related to the recovery actor; in-house or subcontracting:** This decision is the selection of recovery actor(s) to perform PR operations. It is constrained by the existence of various recovery actors within the PSRC framework. The information on the recovery (remanufacturing) capacity and the workload of the particular actor also influences this decision. Cost associated with selecting each actor is another determinant that requires information on price and quality of service, location of the facility and ease of transportation of the goods.

- **Decisions related to the timing/phasing of the recovery processes:** These are the planning, scheduling and sequencing decisions related to the wide range of recovery operations to be undertaken. The information within the legacy systems such as inventory levels, production schedules, process times and delivery dates may influence these decisions.

8.3.2.3. Distribution of recovered products

This function comprises of the process and the decisions required for transferring the recovered goods from the point of re-processing facilities to the customer. The customer may or may not be the last user of the product. In some cases, the recovered product/material might be sold in a totally different market. The key decisions in this area are identified to be:
• Decisions related to the re-distribution channel of the recovered product, part or material: This decision is related to the destiny of the recovered item and made by the owner of the discarded item. The recovered item could be returned to its user if there is a service agreement. Alternatively the recoverer may choose to sell the recovered product/material to a secondary customer (i.e. different from the last user of the product). The factors to affect this decision are the recovery order information, quality of the recovered items and demand information for them.

• Decisions related to the pricing of the recovered product, part and material: These decisions are more applicable in cases where recovered products/material are sold to a secondary customer. In cases where the recovered products are to be returned to the last user the cost of recovery processes is incurred through a service charge. The prices for the recovered products/material are determined based on the price of the new product, virgin material, cost of recovery and the level of demand for the recovered products/material.

8.3.3. Information View

The information view is developed based on the information generated through the material flow (i.e. physical view) and is required to support the various aforementioned decisions within the functional view. The information resulted from the physical and functional views must be systematically defined and structured (a task often referred to as information specification) and then represented in the format of information models which are in turn used as a basis for the development of information systems.

Information models contain unambiguous definitions of data, its structure and relationships, and are often generated to support the design of information systems and/or integration of a number of software systems. A large number of methods have been developed for information modelling, which includes both graphical and textual representations (Jorgenson 1992). Currently within modern manufacturing enterprises, these methods and approaches have been utilised to design and implement information models including those for products, processes, resources and in some applications for customer orders. The Product Model identifies and represents the data describing products throughout their lifecycle for a particular application, and is often utilised within the
manufacturing enterprises which have a deterministic established range of company products. In some cases where a company mainly operates on an engineering-to-order basis, Product Models can be replaced by Order Models. In such models order-oriented information related to both the customer requirements and products are stored. In addition to the Product and Order Models, the information related to manufacturing operations and resources together with their physical and logical relationships has been stored in Process and/or Resource Models. A more contemporary approach is to maintain such information related to manufacturing resources, processes and strategies within a Manufacturing Model (Molina and Bell 1998).

In this research the Booch methodology (Booch 1991) has been utilised to specify and demonstrate the range of EoL related information required to support PR. The Booch methodology is based on an object-oriented approach for system design and information specification, which is achieved through the application of class and inheritance diagrams. The typical information related to EoL management of the used products is illustrated in Figure 8.4 and can be broadly categorised as:

- Product technical information
- Product utilisation information
- Recovery process information
- Recovery order information
- Recovery market information

These five categories of EoL management related information are described below.

- **Product technical information**: This is an extension to the existing product models and contains product technical information required to support recovery processes such as product’s geometry, bill of disassembly, list of joints, reusable parts and subassemblies, material recycling properties, material hazard properties, and possible recovery options properties. A subset of such product technical information is available from the OEM and the rest may be generated and added to through recovery experiences.
Figure 8.4: Representation of product recovery information using Booch methodology
• **Product utilisation information:** This represents information on the use history and the condition of the used product (commonly referred to as core) at the end of its life, such as information about the customer, purpose of use, age, reasons for discard, failure history, etc. Typically, such information related to product use is not maintained within the majority of contemporary manufacturing applications, and appropriate product monitoring and tracking tools (e.g. logbooks, built-in electronic chips etc.) are required to capture and store such data. This information can be used for assessing the product’s quality and selecting the appropriate EoL options. A further use of such information can be by OEMs to improve their original product quality. Furthermore in applications where a product can be recovered a number of times, the history of the previous recovery operations should also be maintained.

• **Recovery process information:** Similarly this can be viewed as an extension to the existing process models and comprises of the information related to the type of recovery processes and their properties, and the resources which can perform these processes. Such recovery process information includes disassembly processes, material recycling processes, a list of recovery work centres, the required specialised labour skills, a list of subcontracting companies for disassembly, repair, and reassembly, and their capacities and workloads.

• **Recovery order information:** This can again be viewed as an extension to existing order models and represents customer order information for a product recovery job. This information specifies EoL-PR procedures in terms of description of the required recovery processes, volume of the recovery job, due date for recovery job, its progress status through recovery facilities.

• **Recovery market information:** This category is the information on the recovery market conditions and is often derived from a bespoke analysis to assess the demand for recovered products/materials. This information includes the cost of PR procedures, value of the new product, value of the second hand product, legislative properties about use, recovery and disposal of the product, cost of disposal, and demand information (which may be in the form of forecast values) for the original and the recovered product. This recovery market information is then used to set up
business models for EoL-PR realisation and to determine the PR options, pricing, and operating markets.

Table 8.1 summarises the PR information requirements based on the aforementioned information categories for the various decisions identified earlier as a part of an enterprise functional view.

8.4. EoL-PR Information System Design

In order to achieve integration between various activities within a PSRC, there is requirement to efficiently store, maintain and provide access to the various information categories specified in the previous section. This can be achieved through the design and development of a PR information System. The design of such a PR information system is described in two phases below: (i) the design of a PR data repository and (ii) the design of a PR communication network.

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<td>Decisions related to EOL option</td>
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<td>Decisions related to recovery actor</td>
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<td>Decisions related to timing of recovery procedure</td>
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<td>Decisions related to the redistribution channel for the recovered item</td>
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<td>Decisions related to the pricing of the recovered item</td>
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Table 8.1: Relationships between the functional decisions and the PR information categories
8.4.1. Design of a PR Data Repository

A data repository is the aggregation of data on a particular subject into some accessible place of storage to be used for supporting the related decision-making tasks (Garcia-Molina et al. 2001). When fully populated, a data repository is seen as the backbone of the information system that contains the required information to support the various decision-making processes.

In the case of a PR information system, there are two possible options for the design of a PR data repository system, as illustrated in Figure 8.5. In the first option, the PR related information (i.e. product technical, product utilisation, recovery process, recovery order and recovery market information) can be viewed as an extension to the information maintained within the product and manufacturing models and added to appropriate existing data repository systems within a company. Such an approach is particularly suitable for reference configuration 1 (see Section 6.5) in which an OEM is responsible for both the manufacture and recovery of products.

![Figure 8.5: Pictorial Presentation of PR information System](image-url)
Alternatively, in applications where there are not established or common product and manufacturing models, a more effective approach would be to design and implement a bespoke PR data repository system. For example in the cases where an independent product recoverer is responsible for the recovery of a range of products (i.e. reference configuration 2) often manufactured by a wide range of producers, a bespoke data repository system may be the only cost effective and feasible method of storing and maintaining PR related information.

8.4.2. Design of a PR Communication Network

The second stage of information systems design involves the definition of an information network to facilitate the access to the data repository by the various users. In the case of an integrated PSRC, actors and users of such a PR information system may be physically distributed across cities, countries and even continents.

The recent advancements in web-based information management systems provide a suitable technological solution to the design of a distributed PR information network. A web-based information system allows multiple, simultaneous and distributed access, and also provides an appropriate infrastructure to support the collaborative approach to product recovery by the various actors involved in the PSRC. Furthermore, the platform-independent architecture associated with web-based information systems will eliminate the barriers to integration and allows recovery actors to deploy applications across the entire supply and recovery chain, which can include material suppliers, manufacturers, customers, collectors and re-processors whose computing environments may be completely different. However, this requires long-term partnerships to develop the necessary trust to share sensitive information.

A web-based information network is seen to be the future information management tool for supporting product supply and recovery activities, as illustrated in Figure 8.5. The implementation of one such web-based information network for cutting tools supply and recovery is described in Chapter 10.
Chapter 9

Case Study-Part I:
Cutting Tools Supply and Recovery Chain

9.1. Introduction

The recovery of cutting tools within metal cutting applications has been adopted to demonstrate the novel concepts defined by this research. This chapter presents the first of two case study chapters, describing a cutting tool supply and recovery chain and the application of the PRIME methodology. The second outlines the development of a Web-based Tool Recovery Information System. The initial parts of this chapter provide a general background on cutting tools, tool supply and tool recycling. The latter sections describe the application of the PRIME methodology for EoL recovery of cutting tools.

9.2. Background to Cutting Tools Industry

Cutting tools are used for the metal removal function in machining operations such as milling, drilling, turning, grinding, boring and tapping. There are a wide range of cutting tools based on various types of machining operations which include end mills, slot drills, boring bars, etc. These tools are often stored as an assembly within machining centres and typically consist of 4-5 components such as tool holders, shanks, collets, and tool studs.

Numerous innovations in cutting tools and their designs have appeared to improve productivity and quality, with the use of new cutting materials and more complex geometries. Cutting tools can also be divided into two groups of solid cutting tools and tools made up of multiple inserts, i.e. indexable cutting tools. The examples of these tools and tools assemblies are illustrated in Figure 9.1.
Figure 9.1: Example of solid and indexable cutting tools available in the market

The period that a cutting tool can be used for its machining operation before a tool becomes worn is referred to as its tool life, which is often defined as either in terms of a 'number of minutes or hours of cutting time' or 'the number of parts manufactured'. Tools gradually lose their accuracy and cutting capabilities over their tool life, in which case they are referred to as worn or spent. It should be noted that though tools could be considered as a 'product' from the point of view of Tool Manufacturers and Suppliers, they are considered as a 'perishable resource' by tool users. In this context and from a sustainable manufacturing viewpoint, the cutting tools as perishable resources with a limited life are ideal candidates to be considered for EoL recovery and reuse. This would result in an improvement in material usage and a reduction in energy required for their manufacturing, both of which are among the most important environmental considerations in EoL management of products.

At present, a small subset of solid cutting tools are reground and reused in machining applications. This recovery of cutting tools is completely on an 'ad hoc' basis and has been adopted in a small percentage of applications where such recycling and reuse of tools are feasible. As part of this case study, a number of tool manufacturers, tool retailers and cutting tool users have been visited and interviewed. This has identified three major reasons for the restriction in a wider adoption of tool recovery and reuse:
i. Due to the limited availability of regrinding resources and formal supporting procedures, the regrinding of tools cannot be economically justified.

ii. At present, there is a relatively small number of companies whose sole business is the regrinding of cutting tools. These companies are subcontracted either by tool users or tool manufacturers/retailers. One of the major obstacles in operation of such independent tool recovery companies is related to unavailability of appropriate information systems and the lack of information sharing amongst tool manufacturers, retailers and users. Thus a need has been identified for a formal information system to support the tool recovery.

iii. In a number of applications (e.g. aeronautical) due to requirements for high precision machining, the recovery and reuse of cutting tools is not feasible or not permitted due to the safety implications. However, tools used in these applications can be recovered for use in other manufacturing sectors (e.g. automotive) in which a high volume of repeated parts/components are machined. Such a concept of sharing of tools within different manufacturing sectors cannot at present be economically justified, due to a lack of formal procedures and appropriate management and information systems.

The major assertion made in this research is that the adoption of systematic recovery and recycling procedures for cutting tools will promise to provide significant financial benefits as well as environmental benefits within the majority of machining applications. However, as highlighted through the author’s communications with cutting tool manufacturers and users, tool recovery processes are not supported by formal management and information systems, resulting in significant restrictions against the adoption of the tool recovery procedures. This research proposes a systematic methodology for the adoption of EoL-PR procedures for cutting tools supported by a specially designed web-based distributed information system, as outlined in the remaining sections of this chapter and Chapter 10.

9.3. Tool Supply and Recovery Chain and Related Actors

The ‘Tool Supply Chain’ often comprises of activities that are commonly found within other typical manufacturing applications such as acquisition of raw material, the wide range of processes involved in manufacturing of cutting tools and distribution of the cutting tools to the customers (which in this case are some other manufacturing
companies). The EoL recovery of cutting tools involves the collection of worn-out tools, and a series of recovery operations (such as regrinding and recoating), and re-distribution to the user. The author refers to the organisation of these related activities as the ‘Tool Recovery Chain’. Thus, the Tool Supply and Recovery Chain (TSRC) can be defined as an aggregated view of the tool supply and tool recovery chains to encompass all the related activities from material supply and tool manufacture, to a number of tool use (reuse) and the final disposal of cutting tools (for material reclamation). The major actors within a TSRC are illustrated in Figure 9.2 and identified as:

- Tool Manufacturers,
- Tool Suppliers,
- Tool Users across a range of industrial sectors,
- Tool Recyclers (consisting of independent tool regrinding and/or re-coating companies),
- Material Recyclers (who take back un-refurbishable tools as scrap for material reclamation).

![Diagram of Tool Supply And Recovery Chain](image)

**Figure 9.2:** Major actors within Tool Supply And Recovery Chain
9.4. Reference Configurations for the Realisation of TSRC

The range and complexity of cutting tool recovery processes may vary significantly in different applications. Consequently dependent on the range and complexity of the required processes, the tool recovery can be performed internally within a user company or externally by returning the tool to the original tool supplier or to a third party independent recovery/recycling company as shown in Figure 9.3. Based on the reference business configurations generated by this research (see chapter 6), two business configurations for recovery of cutting tools have been identified, namely :-

(a) Tool recovery business configuration 1: in which Tool Manufacturers/Suppliers (as an OEM) include recovery capabilities as part of their businesses. This provides the Tool Manufacturer/Supplier with the ability of offering the maintenance service for extending a tool life based upon a Tool User’s request, and results in economic benefits for both the Tool Manufacturer and Tool User. This configuration requires the Tool Manufacturers/Suppliers to invest in extension of the scope of their business and manufacturing operations which clearly needs to be carefully considered and economically justified.

Figure 9.3: A framework for recovery/recycling of cutting tools
(b) Tool recovery business configuration 2: in which the tool recovery is carried out by a Tool Recycler whose sole business is to regrind and/or re-coat worn tools, and are subcontracted directly by Tool Users or indirectly through Tool Manufacturers/Suppliers. The reground tools are either supplied back directly to the Tool Users or to the Manufacturers/Suppliers. In some cases the Tool Recycler may choose to extend the scope of their business in addition to a subcontracting role and to purchase worn tools and after recovery, to sell the recovered tools (second hand tools) to other customers from a different industrial sector.

The realisation of one or more of these business configurations is influenced by a number of factors such as the range of tool types, annual volume of tools used, tool material properties, work-piece materials, geographical distribution of tool suppliers and recyclers. As stated in cases where the recovery of tools involves simple regrinding processes, Tool Users may prefer to recondition their worn cutting tools through the addition of tool rework processes and resources (e.g. CNC tool regrinders) as part of the tooling activities within the tool room/store. This clearly does not constitute a business configuration and at present is a rare occurrence in the majority of machining applications. Finally, it should also be noted that tools may be deemed not recoverable after a number of reuses or due to a tool breakage during the machining operations. Such tools are scrapped and sold (often for a small fraction of the original price) to Material Recyclers who are capable of reclaiming material from such non-refurbishable tools.

9.5. Application of PRIME Methodology within Cutting Tools Industry

Implementation of any PR procedures involves both internal and external changes to the way a company operates, with the cutting tool industry being no exception. This necessitates the identification of an organisation's activities related to PR procedures, matching these activities to an organisation's resources, which often may involve acquisition of new resources, planning for the PR operational decisions and provision of supporting hardware and software tools.

Based on the Product Recovery Implementation Methodology (outlined in Chapter 7) the five major subject areas will be investigated for the specific case of implementation of cutting tool recovery procedures.
9.5.1. Evaluation of Business Implications for Cutting Tool Recovery

The adoption of a systematic cutting tool recovery procedure within machining applications requires a major alteration in business structures and operational planning of both the Tool Users and the Tool Manufacturers/Suppliers. From the Tool Users point of view the recovery and reuse of worn tools can be justified due to the following observations from the survey carried out as part of this case study:

- the number of worn tools produced by a small CNC machining shop is typically over 500 per year valued typically at around £10,000.
- less than 50% of the useable tool life is often being utilised at a CNC machining station.
- a typical metalworking SME holds more than 1000 tools at an average cost of £75 per year.
- the cost of cutting tools is often as much as 15-20% of overall production costs.
- less than 15% of refurbishable tools are being recycled.
- Worn tools regain 90-100% of the cutting capability and service life of a new tool by being reground and recoated while the cost of these recovery operations is estimated at only 10-35% of the cost of a new tools.

The introduction of lean manufacturing concepts due to the pressures of the global market has given rise to a constant demand to lower the production costs. This places special significance on the regrinding of worn cutting tools which could provide considerable financial benefits. The author recognises the critical decision factors in the adoption of a tool recycling solution by the Tool Users will be based on a cost benefit analysis related to the cost of:

i) new tool verses reground and/or re-coated tool;
ii) internal tool rework against external recovery and recycling;
iii) material recycling and disposal.
From the Tool Manufacturers/Suppliers viewpoint, the market analysis revealed that the cutting tool industry mainly operates in 'commercial' sector (see section 7.3.1) i.e. their customers are other manufacturing companies. In addition, there is usually a long-term well-established business relationship based on frequent purchases (often in large volumes) between Tool Manufacturers/Suppliers and Tool Users. These are important factors that favourably influence the set up of the tool recovery business configurations, since the processes such as after-sales tracking and collection of products are easier to manage as the number of customer sites is enumerable. Furthermore, as stated previously Tool Manufacturers and Suppliers have identified significant potential in recovery and re-supply of cutting tools into other manufacturing sectors. For example in certain applications such as the aerospace industry where part accountability is critical only new tools are used in machining a part. In such cases these tools are often made of solid carbide material and are of high quality but very costly. These tools can be reground and recovered to enable them to be re-used in the original user company for different operations or recovered for use in another company within a different industrial sector.

In addition, this research has explored the introduction of the 'leasing' concept used in other Eol-PR applications for replacement of product ownership with service provision within the cutting tool industry. This initiative has been positively received by both the Tool Users and Tool Manufacturers/Suppliers. Such 'tool leasing' initiative requires a major deviation from traditional business processes and must be supported by appropriate operational management and information systems. The use of the Internet-based technology could bring considerable benefits for such collaborative working relationships within a TSRC. The design and functionality of such a web-based information system will be outlined in Chapter 10. A tool leasing approach would provide major financial benefits for the Tool User by reducing the 'cost of tools per parts', and also through simplification of tool planning activities and elimination of tool disposal costs. At the same time, it provides Tool Manufacturers/Suppliers with an opportunity to significantly increase the material usage intensity and to extend the business scope to undertake a subset of tool planning activities required by their Tool Users. This also would lead to a closer relationship between Tool Users and Tool Manufacturers which can be exploited in other ways such as tool design and prototyping, and more effective tool stock control together with the improvements in tool logistic planning.
9.5.2. Product and Technology Analysis for Cutting Tool Recovery

The product and technology analysis is performed to identify the possible EoL-PR procedures for a specific product, resulting in adoption of a re-manufacturing, re-use or a recycling approach. As previously discussed, cutting tools can be categorised into two groups, i.e. solid cutting tools and indexable cutting tools. Although the examples of PR procedures for cutting inserts are found in practice (Hogarth 2000), the focus of this case study is the application of PR procedures on solid cutting tools, i.e. solid carbide drills and end-mills.

Tool recovery in this research is defined (based on the definition provided in Section 4.2) as the ability to regrind or rework a worn tool either (a) as a remanufactured tool or (b) for material reclamation (material recycling). Remanufacturing of a cutting tool is realised through a series of operations such as cleaning, regrinding and recoating. The need for disassembly operation is eliminated since the cutting tool is often disassembled from the tool assembly after its use by the Tool Users. Typically, the regrinding process starts with cleaning once the worn tools are received after which a visual inspection is performed to check, for major cracks, damage, or corrosion, which may make it impossible to regrind/recover the tool. Then the worn edge is cut and removed. This is followed by the main regrinding operation and where necessary, recoating operations. Tool regrinding could be divided into two groups:

i) regrinding a tool, keeping the original physical specifications, referred to as ‘Tool Recondition’, and

ii) regrinding a tool to a different physical specification (e.g. length, diameter) referred to as ‘Tool Reincarnation’.

Tool Recondition is the capability to regrind the worn-out tools to the same functional specification as the original tool. In other words, the reconditioned tool can be used for the same operation. On the other hand, Tool Reincarnation is the ability to remanufacture the worn tool with a different specification for the purpose of using it for another operation. In this case, the remanufactured tool may or may not be returned to the same user.

Material Recycling is the ability of the reclamation of material from worn tools, which are deemed to be non-refurbishable. Such scrapped tools are returned to the Material...
Recyclers with re-processing of the material content of the cutting tools re-supplied to the metal working industries.

As previously discussed in Chapter 7, the author recognises the decision-making related to EoL-PR options as two-fold, namely macro and micro decision-making. The analysis discussed in this section relates to "macro" level decision-making, i.e. identification of every feasible EoL option for cutting tools. However, at the "micro" level, the question becomes which one of these predetermined PR options identified at the macro level is most appropriate, given a particular state of a worn tool and the available tool recovery options within a specific scenario. This is an operational level decision and performed at a time of the collection, cleaning and assessment of a worn tool. The factors which affect the choice of a PR option for a particular cutting tool, are identified as -:

i) the material used to manufacture the cutting tool,
ii) geometry and size of the cutting tool, and
iii) the machining operations and materials being cut by the tool.

Cutting tools are usually made of one of three materials namely high speed steel (HSS), tungsten carbide and ceramic. Although HSS and ceramic tools are regrindable with some special considerations, it is more common and economical to regrind carbide tools. The choice of a regrinding option depends on the particular geometry of the cutting tool. For example, regrinding of an end mill can be achieved in two ways: either by regrinding the worn end but maintaining the original specifications, i.e. tool recondition, or regrinding the diameter and generating a tool with new specifications i.e. tool reincarnation.

In machining operations the selection and use of appropriate tool geometry is as important as the use of the right machine with correct set-up and fixture. This could mean using specially designed tools, which are not classified as a standard tool and often are not presented in a supplier's catalogue. The non-standard tools are referred to as special tools and their physical specifications may significantly vary (Figure 9.4). Regrinding of these tools requires special consideration and may prove difficult or even impossible due intricate details. However, there have been some innovations in tool recycling related to special tools in particular, new regrinding software tools to support complex regrinding operations as will be explained in the next section.
The machining operation that a cutting tool is used for can also influence the regrinding process as it indicates the place and the shape of the wear and provides some insights into the required regrinding processes. A further issue to consider is that in some cases where a specialised material is being cut (e.g. titanium) the tools will become impregnated with the hazardous material and are unrecoverable. This requires specific disposal procedures at the end of the tool life.

9.5.3. Identification of Resource Requirements for Cutting Tool Recovery

The issue of resource requirement for tool recovery/recycling has attracted significant attention in recent years, resulting in the advancement of the regrinding technology and the reduction of the cost of regrinding centres. However, there are other resources (in addition to hardware) required for EoL-PR of cutting tools which include the software support tools and skilled human resource. Therefore the resource requirement for cutting tools recovery can be investigated in three main areas: hardware, software, and skilled human resource requirements.

Hardware requirements for tool recovery include those for re-grinding, re-coating and material recycling processes. Regrinding machinery varies from the manual tool regrinder to CNC regrinding machines. As CNC technology continues to advance regrinding operations, it provides low cost and high precision regrinding operations. This is particularly important for regrinding of special tools, which is often more complicated and demanding. As the grinding technology moves on, companies such as Walter and Schneeberger (Anon 2001, Schneeberger 2000) have started to offer regrinding machines
capable of achieving these intricate details. For example, a 5-axis CNC machine is used to provide accessibility to the surfaces and remove the obstacle of geometry for the regrinding operation. 5-axis grinding permits the rational and accurate generation of practically all tool geometries. Having now been equipped with the CNC technology, these machines provide robust mechanical systems with a high precision in regrinding operations. Another example is advanced regrinding technology of Soag Machinery (Soag 2003). This machinery has been developed to decrease operation times when regrinding the chisel point of a standard jobbing drills with more accurate dimensions. Although this is not a new process in itself, it was cost limiting because of the time it took to locate the original drill point for regrinding.

With the advancement in the CNC regrinding technology, in-house tool regrinding has been revived especially in high volume production environments such as the automotive sector. If regrinding cutting tools in-house is not considered viable, there are specialist regrinding companies available to outsource regrinding processes. Furthermore, there is an ever-increasing willingness amongst Tool Manufacturers/Suppliers for taking back their products at the end of their life. The other two recovery processes namely recoating and, in the case of scrap tools, material recycling are specialised processes requiring bespoke equipment. Thus these processes are usually outsourced to specialised companies.

Tool recovery software support systems include those for the design specification of regrinding processes to minimise the operation time of regrinding. With the aid of appropriate regrinding software a complex regrinding operation can be performed in minutes rather than in hours. The software guides the operator in ensuring that certain characteristics of the regrinding operation are met to make the tool practically feasible. In this aspect, regrinding of special tools could mostly benefit from a specialist regrinding software. Most standard CAD/CAM packages are too limited to undertake the regrinding verification process although quite complex tool design can be achieved (Anca 2002). One example of a regrinding software is the Quinto regrinding software developed by Schneeberger (Schneeberger 2002a) that is a windows-based, touch screen programming software providing the appropriate mathematical intelligence, to support rational regrinding (see Figure 9.5). This software provides a data driven approach to complex regrinding operations which will only require the regrinding parameters such as feed, grinding wheel assignment and tolerances have to be individually defined.
Regrinding applications can be unique and demanding. For example, in the nuclear fuel industry, cutting tools are reground un-manned due to the use of dangerous materials within the restricted areas. Since the operator views the work via a CCTV screen every movement of the cutting tool becomes a critical factor. Therefore, off-line simulation tools for regrounding provide useful service for trial regrounding on-screen (see Figure 9.6). 'Cyber Grinding' and CIMulator 3D (Anon 2001) are such 3-D regrounding simulation tools which allow significant details of the tool to be defined before it is reground. Every detail such as thickness, flute depth, relief, can be modelled and examined. Each separate grinding operation can be shown in a different colour, to clearly highlight any possible collisions. With these tools, any regrounding process can be easily modified at any time before the actual operation. The resulting 3-D representation of the finished tool, with appropriate data, can be transferred directly to the compatible cutting tool regrounders. It is reported that the use of such 3-D regrounding simulation software can significantly increase the utilisation of the regrounding machines (Anon 2001).

Clearly, the use of such 5 axis CNC regrounding machines, regrounding support software and 3-D regrounding simulators require specially skilled human resources which may not be readily available in every Tool User or even in a Tool Manufacturer/Supplier. The development of such skilled human resources constitutes one of the major steps towards a wider adoption of tool recovery in metal cutting applications.
9.5.4. Evaluation of Logistics and Operational Planning Requirements for Tool Recovery

Establishment of EoL-PR requires the operational infrastructure to support the day-to-day activities such as collection and redistribution mechanisms, planning and control of recovery processes; and inventory control for keeping track of recovered items.

The collection mechanism compasses a set of facilities and procedures that are used in bringing the discarded item to the point where actual PR processes take place. In the case of cutting tool recovery, the worn tool is required to be collected from the Tool Users, and transported to the recovery actors, i.e. Tool Manufacturer, Tool Supplier or Tool Recycler. Similarly, the re-distribution mechanism is required to return the reground tool to the User. As mentioned previously, within a TSRC, there is often a long-term established relationship between the Tool Manufacturer, Supplier and Tool User. This facilitates the combination of forward distribution with a reverse distribution within a TSRC environment.

For the collection and re-distribution mechanism in a TSRC environment there are number of methods offered by major Tool Suppliers in the UK. Kennametal Hertel Ltd (Kennametal-Hertel 2003) is one of the largest manufacturers of cutting tools in the world. They are also an integrated supply provider (ISP) - they supply companies with all their tooling requirements from every source. They have created a special service called the BlueBox service for tracking of worn tools for regrinding operations.

Figure 9.6: Quinto simulation program: e-grinding, trial grinding on screen
(Schneeberger 2002b)
They supply “BlueBoxes”, which are rectangular plastic containers (blue in colour) along with foam packaging to protect the contents and a regrinding order form. The BlueBoxes are used to enable tools to securely travel between the tool user and the tool regrinding actor. The worn tools are placed in the box and the related regrinding order is filled in based on the specific requirements of the Tool User. The boxes are collected by the authorised parcel companies. Different sizes of the BlueBox are available with different tool holding capabilities. An example of such a BlueBox and the related regrinding order form is depicted in Figure 9.7.

One other possibility for collection and tracking of worn tools is based around the recent development of the ‘tool dispensing machines’ supplied and manufactured by Supply Point Systems (SPS) (SPS 2003). The SPS Tool Dispensing Machine is an effective mechanism for allowing production operators to access cutting tools as well as providing a good tracking system for regrinding of worn tools.

The SPS Tool Dispenser consists of a base unit, drawer trays which hold between one and four drawers of different heights, a PC-based controller, light-pen, optional bar-code or swipe-card readers and an electronic system which controls the drawer locks and allows them to be opened by the required amount in order to withdraw an exact number of tools from any drawer, as shown in Figure 9.8.

<table>
<thead>
<tr>
<th>Shank Dia</th>
<th>Total no of end mills</th>
<th>Type of regrind</th>
<th>Z=2/3</th>
<th>Z=4</th>
<th>Z=6/8</th>
<th>Z=2</th>
<th>Z=4</th>
</tr>
</thead>
<tbody>
<tr>
<td>From 8 up to 10</td>
<td>7</td>
<td>Face</td>
<td>Uncost</td>
<td>Coated</td>
<td>Uncost</td>
<td>Coated</td>
<td>Uncost</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>From 10 up to 16</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From 16 up to 22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From 22 up to 28</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From 28 up to 34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From 34 up to 40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From 40 up to 46</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>From 46 up to 52</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 9.7: Example of Regrinding Order for solid-carbide end mills
(Kennametal-Hertel 2003)
Figure 9.8: SPS Tool Dispenser and its tracking capability for regrinding worn tools (SPS 2003)

Cutting tools are defined as New, Used, Rework and Scrap, and assigned to individual drawers of the Dispenser. Once the cutting tool becomes worn, the operator returns it to the specified drawer and these worn tools are collected or sent back to the regrinding company for recovery operations at the designated periods. All products within the dispenser are constantly monitored and all transactions are recorded by the PC controller of the unit. These mechanisms provide ease of collection and redistribution, and help in eliminating the uncertainty in timing of return. The tools quantity to be collected, and timing and frequency of collection are the decision variables, which need to be determined based on the particular parameters such as volume of tool use and the size of the tools. Aforementioned mechanisms are used for the cases when the reground tools are returned to the original user. However, in some applications, worn tools are recovered and available for tool recycling across different industries. This may include sales activities, warehousing and transportation. Sale activities of the reground tools may be completely separated from the new products with different sale channels.

Planning and control procedures for PR activities require special considerations due to previously discussed inherited uncertainty. Within the TSRC, uncertainty in relation to quantity and timings of cutting tool returns are minimised as a result of operating in a commercial sector. This is due to the long-term relationship between suppliers and
consequently allowing the application of the controlled collection mechanisms. However the uncertainty regarding quality of the worn tools still remains an issue, but as cutting tool recovery comprises of a few uncomplicated operations and routings are standardised and straightforward, planning and control of such processes should not provide a significant challenge.

9.5.5. Information Specification for Cutting Tool Recovery

EoL-PR for cutting tools within a TSRC results in the generation of a large amount of information related to activities during entire ‘tool life cycle’. This additional information is not commonly stored within ‘Computerised Tool Management Systems’ and includes the data relating to the tool material properties, processing data related to regrinding and re-coating, tool tracking data, number of parts and material machined by the tool, remaining tool life, possible recovery options for the tool, original Tool Supplier, etc. This tool recovery information is accumulated throughout the application of the previous four stages of PRIME as depicted in Figure 9.9.

Figure 9.9: IDEF0 representing the information flow through the application of PRIME stages
It should be noted that users of such information are the various actors in TSRC and therefore a distributed information system has been designed and implemented using web-based technology. Implementation of such a system should consider the existence of legacy systems and the required interfaces. Chapter 10 will describe the development of this information system for TSRC in more detail.
Chapter 10

Case Study-Part II:
A Web Based Information System to Support Tool Supply and Recovery Chain

10.1. Introduction

This chapter describes the second part of the case study in the recovery and recycling of cutting tools, namely the implementation of the Tool Recovery Information System (TRIS) developed to support the integration of tool supply and tool recovery chains. The initial part of the chapter outlines the functional requirements of TRIS through the three enterprise viewpoints identified in Chapter 8, i.e. physical, functional and information viewpoints. The design specification of a data repository and a communication network for TRIS is explained. The latter parts of the chapter provide a computational viewpoint of TRIS and illustrate the key operational characteristics. Please note that due to confidentiality reasons none of the data provided by the collaborative companies has been directly used in the computational viewpoint of TRIS. All the data appearing in Figures 10.9-10.27 are modified versions to ensure confidentiality. Therefore, the author declares that if there is any similarity with real data it is purely coincidental.

10.2. Tool Recovery Information System

The Tool Recovery Information System is a proof-of-the-concept prototype system (see Appendix 2) to support EoL-PR activities for cutting tools within the Tool Supply and Recovery Chain proposed in Chapter 9. The users of TRIS typically consist of cutting tool manufacturers, cutting tool suppliers, cutting tool users, tool regrinding companies and material recyclers, which are often geographically spread, highlighting the requirements for a distributed information system. With the advent of Internet technologies, a web based distributed information system provides a suitable technology for implementation of
TRIS. Therefore, TRIS has been designed and implemented as a web-based information system to support the integration requirements within a TSRC. Figure 10.1 depicts the distributed nature and the utilisation of TRIS by various actors within a Tool Supply and Recovery Chain.

10.3. Functionality Requirements of TRIS

In order to effectively identify the functionality required from TRIS, a systematic approach to enterprise modelling outlined in Chapter 8 has been utilised. The following sections will describe the physical, functional and information views for the activities within TSRC.

10.3.1. Physical View: TSRC Actors and Activities

The key actors within the TSRC are identified in Chapter 9 as the tool manufacturer, tool supplier, tool user, tool recycler and material recycler. These actors perform a range of activities including supply of raw material, manufacture of cutting tools, utilisation of cutting tools within machining applications, and return of worn tools for the appropriate recovery processes and redistribution of reground tools to either the original or another user. The appropriate recovery channel for the worn tool could be the original manufacturer, the supplier and an independent tool regrinding company, or it could be a material recycling company if the tool is non-refurbishable and must be scrapped. Figure 10.2 illustrates a flowchart of activities and material flow within a TSRC.

Figure 10.1: The utilisation of TRIS within a Tool Supply and Recovery Chain
Chapter 10

Supply material for tool manufacture

- Manufacture cutting tools
- Distribute cutting tools to tool user
- Use cutting tools in machining operations
- Tool has reached EOL
  - no
  - yes
    - Max no of regrinding exceeded?
      - yes
      - no
        - Collect the used tools
        - Send the collected tools to regrinding channel
        - Decide on EOL option
          - tool recovery
            - Regrind it to selected size
            - Quality control
          - material recycling
            - Send it to recycling channel

Figure 10.2: Flow chart for key activities in TSRC
Chapter 10

10.3.2. Functional View: TSRC functions and decisions

Three functional areas that were identified as part of enterprise modelling in Chapter 8 are:-

i. EoL cutting tool acquisition,

ii. Cutting tool recovery realisation, and

iii. Re-distribution of reground tools.

Each of these areas and the related decisions will be discussed for the case study of recovery of cutting tools below.

10.3.2.1. EoL cutting tool acquisition

The major objective of this function is to collect and return the worn tools from the tool user to the tool recovery actor, which could be the tool manufacturer, supplier or independent tool recycler. The responsibility for the collection and return of tool in the majority of cases is with tool users. However, in some cases, based on a pre-defined agreement the tool recovery actor may actually collect and transport the worn tools to the regrinding premises. The main decision in this function is:

- **Decisions related to the eligibility of the cutting tool for regrinding procedures**: This decision is often made by the tool user. Every cutting tool has a *tool life* determined based on the tool characteristics indicated by its manufacturer, identifying the operations specifications for which the tool will be used. Once the tool reaches its end of life, the tool user assesses its condition to decide if it is eligible for regrinding procedures. If major faults such as cracks, distortions, and corrosion appear then the tool will be destined for material recycling. As there is a limit on the number of regrinds performed on a cutting tool which is also determined by the tool manufacturer, one other factor affecting this decision is the *number of regrinding operations* performed on the cutting tool.

10.3.2.2. Cutting Tool Recovery Realisation

This process consists of receiving the worn tool, cleaning and preparation, a regrinding operation (and possibly a recoating operation), and finally making the tool ready for redistribution to the customer. The key decisions in this process are:
• Decisions related to the regrinding option for the worn cutting tool: The regrinding of the cutting tool can be performed in more than one way depending on the geometry of the tool. For example, an end-mill can be reground on its face or side. The reground tool can be used for the same operation or for a different one. When the customer sends the worn tool for the regrinding process, they request a certain regrinding specification. The regrinding actor takes this specification into account and unless there is a reason for not being able to proceed based on this, it performs the requested regrinding option. Otherwise, it regrinds the tool based on a different regrinding specification, which is feasible with the tool's particular condition and its geometry. It will clearly inform the tool user of this change of regrinding specification.

• Decisions related to the choice of regrinding actor: Regrinding can be performed by the tool manufacturer, tool supplier or an independent tool recycler. If the requested regrinding option requires a special operation, e.g. a special finish or recoating, then the tool manufacturer/supplier could employ a specialised company to perform it. The factors influencing the choice of regrinding actors include the regrinding specification required by the tool user, the regrinding capability of regrinding actors and their capacity.

• Decisions related to the timing of the regrinding operations: This is the decision often made by the tool user when to send the worn tools to the selected recovery actor. It is determined by the quantity of worn tools, response time (lead time) by the recovery actor and due date for the recovery job requested by the tool user.

10.3.2.3. Re-distribution of reground tools

This function governs the activities related to delivering reground tools to the customer, namely storage, sales and transportation. If the worn tool is to be scrapped, it is passed to a Material Recycler. In cases where regrinding operations are performed based on a pre-arranged procedures between the Tool User and Tool Manufacturer/Supplier, this function involves transporting the reground tools to the tool user's site, that can be combined with the forward distribution. However, if the regrinding actors resells the recovered tools to
secondary customers then the storage, sales and transportation activities needs to be further considered. This also requires price setting for the reground tools. The key decisions are:

- **Decisions related to the re-distribution channel of the reground/worn tools:** This decision is related to the destiny of the worn or reground tool and is made by the owner of the tool, i.e. the Tool User or the Tool Manufacturer. If the reground tool is not to be returned to the tool user then the tool manufacturer/supplier sells it on to the second hand market. If the tool has been decided to be scrapped, then it is sent for material recycling. The factors, which affect this decision, are the *quality and quantity of the reground tools* and the *demand* for them.

- **Decisions related to the price of the reground/worn tool:** When reground or worn tools are sold to a secondary tool user, the price needs to be determined. The affecting factors on this decision are the *price of the new tool*, *price of the material*, *cost of regrinding* and the *demand for the reground tool*.

### 10.3.3. Information View: TSRC Information Specification and Modelling

The information required to support the aforementioned decisions within a TSRC are grouped into five categories (identified in Chapter 8), namely cutting tool technical information, cutting tool utilisation information, recovery process information, recovery order information, and cutting tool market information.

*The cutting tool technical information* consists of typical tooling information such as tool identification, technical specification, tool assembly description, tool supplier/manufacturer, tool presetting data and tool life, and also includes information related to the possible tool recovery (regrinding) options, operations times, and more detailed data on material types and characteristics for recycling purposes. *The cutting tool utilisation information* contains the utilisation history for a particular cutting tool which includes the material cut, speed and face(s) of the operation for the tool was used on, and the history of previous recovery activities and the related actors on this tool. *The recovery process information* refers to mainly information related to various types of recovery processes (i.e. regrinding, re-coating, material recycling) and tool recovery actors which may be the tool user (through internal tool reworking activities), the tool manufacturer/supplier, and a tool
recycler or material recycler. The recovery order information contains the operational information on a specific recovery job including customer identification, regrinding description, due date, volume of the regrinding job, order status and other special request for a particular regrinding order. Finally, the cutting tool market information includes information on cost of regrinding, value of the new and reground tools, demand information for the new and reground tools and related legislation regarding recycling and disposal of cutting tools.

The Booch representation of cutting tool recovery information specified above is depicted in Figure 10.3. This model identifies information entities, their relationships and associated rules and contains four information classes representing solid cutting tools, used tools, recovery actors, and recovery orders. These classes and associated attributes are used to derive the data fields and database file structures (see Section 10.4) for information storage. The data fields will be populated with the particular details of case study information as outlined in the remaining sections of this chapter.

10.4. Design of Tool Recovery and Information System

The design issues related to TRIS implementation will be described below in two parts as discussed in Section 8.4, namely design of TRIS data repository and design of TRIS communication network.

10.4.1. Design of TRIS Data Repository

A data repository is the aggregation of data on a particular subject into some accessible place of storage to be used for supporting the related decision-making tasks. The process of designing a data repository begins with an analysis of information required and the relationships among the elements of that information. Then the structure of the database that is often referred to as database schema is specified, which is given a physical existence by using specialised software called database management system.
Figure 10.3: Booch representation of cutting tool recovery information for TSRC
A data repository for TRIS has been developed based on the cutting tool recovery information model specified in the previous section. The TRIS data repository represents the backbone of the information system. The TRIS database schema is created using objects defined in Booch information model, which are then converted into information tables used as a part of relational database implementation. Sample data for the object of solid cutting tool and its related relational database table are shown in Figure 10.4.

![Figure 10.4: Modelling the attributes of solid cutting tool](image_url)
The TRIS data repository has been implemented using the Microsoft Access database management system. The database comprises of a range of tables, including main tables for Solid Cutting Tool, Regrinding Kit, Regrinding Processes, Regrinding Job, Recovery Actors, and Tools for Sale and auxiliary tables for temporary data storage during transactions. These tables are linked via primary data fields as illustrated in Figure 10.5. Here the primary data fields are indicated as shaded and the arrows indicate the relationships. The data integrity between the tables has been achieved based on the 2nd normalisation, i.e. no functional dependencies between primary data fields.

10.4.2. Design of TRIS Communication Network

As stated previously, TRIS is a web based distributed information system and the communication network is developed using an Internet based technology. It is designed and implemented using the commonly adopted three-tier architecture (Huang and Mak 2001), as shown in Figure 10.6.
In this approach, the first tier includes application clients, i.e. web pages viewed via a web browser, which is linked to the system by the connecting web server (in this case a Jakarta Tomcat web server). This tier allows the user to interact (view, edit or add data) with the system. The second tier is the application tier, which comprises of a software module developed using the Java Server Pages (JSP) for accomplishing the computational activities in response to user requests, according to a predefined set of business (operational) logic rules. The third tier is the persistent data storage level, which stores and maintains data for the application, in this research a database developed in Microsoft Access.

During the operation of TRIS, the user accesses the system via a web browser, e.g. Netscape or Internet Explorer, for obtaining, storing or updating information such as new cutting tools, recovery actors, materials and tool recovery history etc. The web server performs the necessary actions to update the database, and generate the web pages to present the requested information to the user as depicted in Figure 10.7.
Clearly developing such a web-based application requires significant time, effort and skills which might not be readily available in the manufacturing companies. One commonly adopted solution in such cases is the Application Service Provider (ASP) Model (Schofield 2000), which brings a new way of supplying software solutions to users. In this approach, a third party software company (i.e. ASP) develops the web based application and offer services in the form of hosting and maintaining the system on behalf of the customers. Customers don’t purchase the software licence but lease the software on a rental agreement.

This approach is particularly suitable in cases where the IT skills required to develop such web based applications are not available within a company and also in cases where multiple companies are involved in development and use of the system. In such cases the ownership and maintenance of the web-based application might prove to be very complicated. Furthermore with this approach new comers to the TSRC can easily and quickly join and utilise TRIS over the Internet without major interruption to their existing IT infrastructure. Therefore, such an ASP model is seen to be an appropriate software deliverance approach for TRIS.

Figure 10.7: Communication network in TRIS.
10.5. TRIS Modules and Functional Capabilities: Computational Viewpoint

A web based proof-of-the-concept prototype system, namely TRIS is designed for a wide range of users which include cutting tool manufacturer and/or a cutting tool supplier, a number of cutting tool users, tool regrinding companies and material recyclers to store, access and update data related to recovery and reuse of cutting tools. There is a range of functionalities and the access to these functionalities where necessary is password protected. This provides data security and ensures the accuracy and quality of data stored in the information system. The main functionalities provided by TRIS modules are:

- Database maintenance
- EoL decision support
- Recovery order support
- Sales support

There is also a provision for the design of a User Management module to regulate authorisation and password issues. The security of web-based systems is the subject of many current research projects with particular importance in applications such as banking, government organisations and etc. However, design issues related to the development of a secure User Management module is outside the scope of this case study.

These modules work interactively to support the key decisions for TSRC activities. The relationship between the modules and the aforementioned TSRC key decisions are depicted in Figure 10.8. The TRIS user interface pages are designed in two parts, namely; a navigation frame and transaction frame as shown in Figure 10.9. The left hand side frame (i.e. navigation frame) presents the list of all the functionalities. The right hand side frame updates itself upon user interaction. The TRIS modules and their functionalities will be described in the following sub sections.
Figure 10.8: The TSRC key decisions supported by TRIS software modules

Figure 10.9: TRIS opening page
10.5.1. Database Maintenance Module

This module provides the user with access to main database tables such as cutting tools and recovery actors. The authorised user can add, view, and edit data using this module. Figure 10.10 shows the database maintenance menu for the cutting tools. For the cutting tools, the maintenance menu is divided into two sub sections, namely standard cutting tools, which are typically found in the manufacturer's catalogue and special cutting tools, which are specially designed and manufactured based on customer requirements. This is required due to variations in data fields in these two cutting tool types. Figures 10.11, 10.12 and 10.13 shows the user interface pages for the cutting tools database maintenance functions.

Similarly, the recovery actors database maintenance menu is shown in Figure 10.14. This menu provides the user with data entry, update and view functionalities on the recovery actor database. Figures 10.15, 10.16 and 10.17 shows the user interfaces for these functionalities.

![Figure 10.10: Cutting tools database maintenance menu](image)

Figure 10.10: Cutting tools database maintenance menu
List of cutting tools in the database

<table>
<thead>
<tr>
<th>Tool Type ID</th>
<th>Catalog No.</th>
<th>Description</th>
<th>Manufacturer</th>
<th>Supplier</th>
<th>New Value</th>
<th>More Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDI-051</td>
<td>CDI-051-1250</td>
<td>Carbide Jobber Drill 1.4</td>
<td>Chisso Wood Inc.</td>
<td>Faraday</td>
<td>15.5</td>
<td>More</td>
</tr>
<tr>
<td>CDI-051</td>
<td>CDI-051-1270</td>
<td>Carbide Jobber Drill 1.4</td>
<td>Chisso Wood Inc.</td>
<td>Faraday</td>
<td>16.6</td>
<td>More</td>
</tr>
<tr>
<td>CDI-051</td>
<td>CDI-051-1280</td>
<td>Carbide Jobber Drill 2.3</td>
<td>Chisso Wood Inc.</td>
<td>Faraday</td>
<td>17.5</td>
<td>More</td>
</tr>
<tr>
<td>CDI-051</td>
<td>CDI-051-1290</td>
<td>Carbide Jobber Drill 2.10</td>
<td>Chisso Wood Inc.</td>
<td>Faraday</td>
<td>18.0</td>
<td>More</td>
</tr>
<tr>
<td>CDI-158</td>
<td>CDI-158-4300K</td>
<td>Jobber Length 3 Flute Carbide Drill - 10.2</td>
<td>Tationally and Saw</td>
<td>Faraday</td>
<td>27.83</td>
<td>More</td>
</tr>
<tr>
<td>CDI-158</td>
<td>CDI-158-4300K</td>
<td>Jobber Length 3 Flute Carbide Drill - 12.0</td>
<td>Tationally and Saw</td>
<td>Faraday</td>
<td>33.99</td>
<td>More</td>
</tr>
<tr>
<td>CDI-158</td>
<td>CDI-158-4300K</td>
<td>Jobber Length 3 Flute Carbide Drill - 13.0</td>
<td>Tationally and Saw</td>
<td>Faraday</td>
<td>51.67</td>
<td>More</td>
</tr>
<tr>
<td>CDI-158</td>
<td>CDI-158-4300K</td>
<td>Jobber Length 3 Flute Carbide Drill - 14.0</td>
<td>Tationally and Saw</td>
<td>Faraday</td>
<td>63.12</td>
<td>More</td>
</tr>
<tr>
<td>CDI-158</td>
<td>CDI-158-4300K</td>
<td>Jobber Length 3 Flute Carbide Drill - 15.0</td>
<td>Tationally and Saw</td>
<td>Faraday</td>
<td>63.12</td>
<td>More</td>
</tr>
<tr>
<td>CDI-158</td>
<td>CDI-158-4300K</td>
<td>Solid Carbide Drill for Iron - 1.5</td>
<td>Series Inc.</td>
<td>Faraday</td>
<td>78.88</td>
<td>More</td>
</tr>
<tr>
<td>CDI-158</td>
<td>CDI-158-4300K</td>
<td>Solid Carbide Drill for Iron - 3.0</td>
<td>Series Inc.</td>
<td>Faraday</td>
<td>78.88</td>
<td>More</td>
</tr>
</tbody>
</table>

Figure 10.11: Data view function for cutting tools in TRIS

Add a standard cutting tool

Please enter tool information

- tool type ID: (DIJ-158-4300K)
- order catalogue no: (DIJ-158-4300K)
- description: Jobber Length 3 flute carbide drill - 10.2
- dia (mm): 10.2, flute length (mm): 23, overall length (mm): 33
- reginding length (mm): 10
- machining material: Steel Ferrous
- Speed/Feed: recommended tool life: 150, max no reginding: 10
- manufacturer: Dojoen and Son, supplier: Kennametal
- new value (£/unit): 195, scrap value (£/unit): 5

Figure 10.12: Data entry function for cutting tools in TRIS
Edit cutting tool details

Please type cutting tool ID: 

tool type ID: HIT-126-0020L order catalogue no: HIT-126-0020L

description: Solid Carbide Drill for Irons - 8.5 View Technical Drawings
dia(mm) 8.5 flute length(mm) 110 overall length(mm) 150

regrinding
length(mm) flutes machining material iron, cast

recommended tool life 150 max no regrinding

manufacturer Hitachi Inc. supplier Kennametal

new value (£/unit): 78 scrap value (£/unit): 0

Figure 10.13: Data update function for cutting tools in TRIS

Actors Database Maintenance

Please select one of the following options:

- View actors database
- Register a new actor
- Edit an existing actor information

Figure 10.14: Recovery actors database maintenance menu of TRIS
List of actors in the database

<table>
<thead>
<tr>
<th>Company ID</th>
<th>Name</th>
<th>Description</th>
<th>Address</th>
<th>City</th>
<th>Postcode</th>
<th>Regrinding</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>101</td>
<td>Serenelid</td>
<td>Tool Mender</td>
<td>Brown Road 12, City</td>
<td>City</td>
<td>postcode</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>102</td>
<td>First Inc</td>
<td>Tool Mender</td>
<td>12, Queen Park</td>
<td>City</td>
<td>postcode</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>103</td>
<td>Mini Ltd</td>
<td>Tool Mender</td>
<td>5, Lemon Road</td>
<td>City</td>
<td>postcode</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>104</td>
<td>Bright Inc</td>
<td>Tool Mender</td>
<td>14, Brown Gate</td>
<td>City</td>
<td>postcode</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>105</td>
<td>Shop Inc</td>
<td>Tool Mender</td>
<td>16, Lemon Road</td>
<td>City</td>
<td>postcode</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>106</td>
<td>Company Ltd</td>
<td>Tool Mender</td>
<td>16, Lemon Road</td>
<td>City</td>
<td>postcode</td>
<td>Yes</td>
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<tr>
<td>107</td>
<td>Company Ltd</td>
<td>Tool Mender</td>
<td>16, Lemon Road</td>
<td>City</td>
<td>postcode</td>
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<td>Yes</td>
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<tr>
<td>108</td>
<td>Company Ltd</td>
<td>Tool Mender</td>
<td>16, Lemon Road</td>
<td>City</td>
<td>postcode</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>109</td>
<td>Company Ltd</td>
<td>Tool Mender</td>
<td>16, Lemon Road</td>
<td>City</td>
<td>postcode</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>110</td>
<td>Company Ltd</td>
<td>Tool Mender</td>
<td>16, Lemon Road</td>
<td>City</td>
<td>postcode</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Figure 10.15: Data view function for recovery actors in TRIS

Register a new TSRC actor

Please enter company information

- Company ID: 222
- Company Name: Shine Ltd.
- Description: Tool Supplier
- Address: 19 Nipton Road
- Postcode: NG2 3ME, City: Nottingham

Available Tool Recovery Functions
- Receiving
  - Collection Information
    - Collection Day: Friday
    - Exceptions Allowed
  - Delivery Information
    - Delivery Day: Monday
    - Transport Provided

Submit Reset

Figure 10.16: Data entry function for recovery actors in TRIS
10.5.2 End-of-life Decision Support Module

This module provides functionalities to support EoL decisions for worn cutting tools for various regrinding options together with the options of scrapping the tool for material recycling when any of the regrinding options are deemed infeasible. The user of the worn cutting tool requests a regrinding option however the recovery actor has to evaluate the condition of the worn tool regarding to whether the requested regrinding option is feasible or not. TRIS provides the following functionalities to support this decision:

- Provision of regrinding history: This option allows the user to track the tool regrinding history. Worn cutting tools are tracked in the system as a group, namely a recovery kit, which will be explained in detail in the next sub section. The user can view the related regrinding history by searching on the recovery kit identification number. The information about the previous regrinding operations will appear on the screen as shown in Figure 10.18.


Figure 10.18: View regrinding history for cutting tools in TRIS

- Assessing the tool condition: This option supports the user by evaluating the condition of the worn cutting tool on an individual basis. It would provide a checklist against which the user can identify if the tool is suitable for regrinding operations or has to be scrapped (see Figure 10.19).

- Assessing the regrinding processes: This option allows the user to interface with a commercial tool regrinding software to identify the technical specification of the regrinding operation. A link with Schneeberger regrinding software (Schneeberger-UK 2003) to support regrinding processes has been demonstrated in Figure 10.20.

10.5.3. Recovery Order Support Module

This module provides the functionalities for the processing of a regrinding order. Since it is not practical and cost effective to track the tools on an individual basis within a TSRC, the worn tools are followed in groups. For this purpose, an entity called ‘recovery kit’ is defined to aggregate the worn tools that are a subset of a cutting tool type. The related functionalities are:
Assess condition of used cutting tool

Please type cutting tool ID:

tool ID [DIJ-158-4300K]

condition assessor:
- coating required:
- preferred recovery option:
- crack
- bent
- corrosion
- design flaw
- vertical wear
- horizontal wear

Submit | Reset

Machine Cell Information

Figure 10.19: Assess the condition of a given cutting tool in TRIS

Retrieve regrinding information

Please type cutting tool ID: [DIJ-158-4300K]

Submit | Reset

Diameter
Diameter reduction
Corner radius
Length of cutting edge
Chucking length
Position CC edge

Total intended

Postal intended

Machine length

Figure 10.20: Interface with a 'regrinding software' in TRIS
• Place an order for a recovery kit: This function is for the user, who wishes to send the worn tools to the recovery actor. Figure 10.21 shows the recovery kit order menu in which there are two options for the user. First the user creates a ‘recovery kit’ which is the collection of the used tools with the same cutting tool identification number. The interface page for this function is shown in Figure 10.22. Once the recovery kit is created, the user can send a regrinding order to the recovery actor as shown in Figure 10.23. The user specifies its requirements on the order such as the preferred actor, type of regrinding operation and coating.

• Return a recovery kit: Once regrinding is complete, the recovery actor sends feedback to the system on the specification of the regrinding operation performed on the ‘recovery kit’. This information is used by the owner of the order to follow the progress of recovery kit that was sent. It can be also viewed by the recovery actor as a regrinding history for future regrinding operations. The user interface for this function is shown in Figure 10.24.

![Recovery kit order menu in TRIS](image)

**Figure 10.21:** ‘recovery kit’ order menu in TRIS
Figure 10.22: Creation of a 'recovery kit' in TRIS

Make a new recovery kit

Please enter recovery kit information

- Make a new kit
- Return to Recovery Kit Order Menu

Figure 10.23: Sending a regrinding order on a 'recovery kit' in TRIS
Figure 10.24: Returning a regrinding order on a ‘recovery kit’ in TRIS

- Track the progress of the recovery job: The user who wishes to view the progress of the recovery jobs can view the list of recovery jobs through this menu item as shown in Figure 10.25. In this list the recovery jobs are tracked based on a ‘recovery kit’ identification number.

10.5.4. Re-Sales Support Module

This module supports the activities involved in the sales of reground tools. The information on reground tools is posted on the site and whoever is interested in purchasing these tools will do so using an on-line purchase facility. The functions provided in this module are:

- View items for re-sale: This option opens with a menu showing the list of cutting tools types available at the time as shown in Figure 10.26. The user can view each of these cutting tool types on a screen shown in Figure 10.27 and can proceed with the purchase of any of the available items.
List of recovery jobs

<table>
<thead>
<tr>
<th>Job No</th>
<th>KPN</th>
<th>Tool ID</th>
<th>Description</th>
<th>Unit</th>
<th>Due Date</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1001-09</td>
<td>01-003</td>
<td>T02.00A- 0003</td>
<td>Solid Carbide Microgrind End Mill 8 11.35°</td>
<td>002</td>
<td>02/12/2003</td>
<td>Begin</td>
</tr>
<tr>
<td>1001-09</td>
<td>01-003</td>
<td>T02.00A- 0003</td>
<td>Solid Carbide Drill for hole - 11.35°</td>
<td>004</td>
<td>06/12/2003</td>
<td>Begin</td>
</tr>
<tr>
<td>1001-09</td>
<td>01-003</td>
<td>T02.00A- 0003</td>
<td>Solid Carbide Microgrind End Mill 8 11.35°</td>
<td>002</td>
<td>13/12/2003</td>
<td>Begin</td>
</tr>
</tbody>
</table>

Exit to Recovery Order Menu

Figure 10.25: Tracking a recovery job in TRIS

Used Cutting Tool Sales

This is a TRIS subsystem to support used tool sales

Please select one of the following options:

- View drills for sale
- View ceramic inserts for sale

Figure 10.26: Menu for provision of cutting tools for sales in TRIS

130
Figure 10.27: List of reground tools for sale in TRIS

- Add an item for sale: The user who wishes to sell the worn/reground tools using the system, sends the related information using the interface shown in Figure 10.28. The worn tools can be reground, scrapped for regrinding or scrapped for material recycling. The price of the worn/reground tools is determined based on the type of the tool and calculated as a percentage of the original price depending on the condition of the tool (e.g. scrap, reground etc.).

10.6. Provision of Access to TRIS

As stated previously, the provision of secure access to any web-based application is vital for accuracy and quality of the data maintained in the system. Table 10.1 summarises the various functionalities supported by TRIS and the author's view on the provision of access by the various users of TRIS.
Add a cutting tool for sale

Please enter cutting tool information

catalog no CHR-025-12385 1 description carbide jobber drill dia 1.8
manufacturer Chamwood Inc sold by Sharp Inc

quantity 22 type reground Price $15 available after 9/2/04

Figure 10.28: Adding a reground tool for sale in TRIS

<table>
<thead>
<tr>
<th>Software Module</th>
<th>Functionality</th>
<th>User*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Maintenance</td>
<td>Add database information</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>Edit database information</td>
<td>All</td>
</tr>
<tr>
<td></td>
<td>View database information</td>
<td>All</td>
</tr>
<tr>
<td>EoL Decision Support</td>
<td>View regrinding history</td>
<td>TM, TS, TU, TR</td>
</tr>
<tr>
<td></td>
<td>Assess worn tool condition</td>
<td>TM, TS, TR</td>
</tr>
<tr>
<td></td>
<td>View regrinding process information</td>
<td>TM, TS, TR</td>
</tr>
<tr>
<td>Recovery Order Support</td>
<td>Send regrinding order</td>
<td>TU</td>
</tr>
<tr>
<td></td>
<td>Return regrinding order</td>
<td>TM, TS, TR</td>
</tr>
<tr>
<td></td>
<td>Track regrinding order</td>
<td>TU, TM, TS, TR</td>
</tr>
<tr>
<td>Sales Support</td>
<td>Add tools for sale</td>
<td>TM, TS</td>
</tr>
<tr>
<td></td>
<td>View tools for sale</td>
<td>TU, TR, MR</td>
</tr>
</tbody>
</table>

* Tool Manufacturer-TM, Tool Supplier-TS, Tool User-TU, Tool Recycler-TR, Material Recycler-MR

Table 10.1: The use of TRIS by TSRC actors
Chapter 11

Concluding Discussion

11.1. Introduction

The purpose of this chapter is to bring together and discuss the major research issues to formulate research conclusions. This discussion will be based on the broad headings identified as the research scope in Chapter 5, to highlight the key findings and knowledge gained from the research.

11.2. Literature Survey of ECM and PR

The comprehensive literature review carried out as a part of this research has highlighted the ever-growing popularity of ECM and EoL-PR research due to the increasing amount of national and international environmental legislation together with consumer pressures on the reduction of the negative impact of manufacturing activities on the natural environment. The ECM framework based on the product life cycle and pollution prevention and control proposed by this research to classify such large volume of research work enables a clear context for further research requirements in this area to be established. This framework has enabled the author to clearly define the major areas of this research as:

i) Requirements for an integrated product supply and recovery chain
ii) Requirements for a systematic product recovery implementation methodology
iii) Requirements for efficient information support systems for PR procedures.

The work by Goggin et al. (2000) and Fleischmann et al. (2000) was of particular relevance to the first research issue, whereas for the second issue Guide et al. (2000) and Guide and Jayaraman (2000) are found to be supportive to the author’s assertions. For the third issue, similar assertions are made by Hitomi et al. (2001) and NIST (1999). The
author’s view, on using the Internet as the implementation medium within the context of EoL-PR, has also been advocated by Gooley (1998), Guide (2000) and Ferguson and Browne (2001). The specific quotations from these researchers in Section 4.3 highlights the timely contributions of author’s research to this subject.

11.3. Development of an Integrated Product Supply and Recovery Chain

One of the major aims of this research has been to provide a clear understanding of the processes and issues involved in EoL-PR to facilitate the wider adoption of such procedures within various industrial sectors. The initial investigation on the organisational issues involving EoL-PR has highlighted the substantial requirements for linking the material and information flows between product supply and product recovery chains. Under the light of this view, the definitions of product supply and product recovery chains have been reconsidered to generate a new perspective for an integrated ‘Product Supply and Recovery Chain’ (PSRC). This perspective has provided the basis for a novel approach to identify the issues involved in EoL-PR implementation, model the EoL-PR activities and to specify the requirements for information support. It was recognised that this perspective will impose changes to the business and operational structures of manufacturing companies within a PSRC. This necessitates the definition of a closer business relationship between various actors in a PSRC. Therefore, this research has proposed two reference business configurations to establish such business relationships, based on the scenarios for recovery by the OEM through extension of their business activities or by an independent recovery company used as a shared resource by a number of manufacturers to established EoL-PR procedures.

11.4. Development of a Product Recovery Implementation Methodology

The most frequently reported obstacle in the wider implementation of EoL-PR by both the industrialists and academics is the lack of formal methods and systematic guidelines for manufacturing companies which often have limited time, knowledge and skill to support the establishment of such EoL-PR procedures for their products. Furthermore, there is a severe shortage of experts in this area who can provide customised support to the large number of manufacturing enterprises who are considering to adopt such procedures to gain a market advantage or are forced to consider PR due to environmental legislation. These have indicated the need for a step by step, easy to follow methodology to consider the wide
range of business, technological, and operational issues involved in adoption of Eol-PR procedures. The research reported in this thesis has proposed one such methodology referred to as the 'Product Recovery Implementation Methodology' (PRIME). This methodology has been developed to gain a tactical insight and support the operational issues involved in implementation of Eol-PR procedures. The five steps of PRIME provides managerial guidance to a range of issues related to changes in business processes, technological and resource requirements, operational and logistic planning, and perhaps most importantly the information support required for implementation of EoL-PR procedures. Furthermore, the research has exemplified these key issues through some practical solutions. The application of PRIME was seen to be a continuous iterative process based on the feedback and knowledge gained from the subsequent steps. Four execution phases based on feasibility, selection, development and realisation have been proposed to facilitate the application of PRIME which has been effectively demonstrated for the systematic recovery of cutting tools within machining applications.

11.5. EoL-PR Information Specification and Modelling

The initial exploration of Eol-PR activities within different applications has highlighted that the implementation product recovery processes will result in generation of a large amount of information, which currently has not been stored and maintained within existing IT tools and information systems utilised by manufacturing companies. Furthermore, it is recognised that EoL-PR necessitates significant modifications in the way an organisation operates and such PR related information is vital to support this change process. Therefore one of the major objectives in this research has been to specify, design and develop bespoke information systems to support Eol-PR activities. In achieving this objective, a commonly adopted enterprise modelling approach based on physical, functional and information viewpoints has been utilised to identify the information required to support a wide range of PR related decision making tasks involved in each of these enterprise viewpoints. The formalised description of this information has been achieved using a commonly adopted information modelling method, namely Booch class diagrams.

It was also identified that to support the integration within a PSRC, the distributed access to such information must be provided to a number of actors involved in the product recovery processes. The investigation of a web-based information system has highlighted
the suitability of such a technology solution for development of PR information systems. The implementation of such a web-based information system has been considered in two stages, namely design of a data repository and the design of communication network. These processes were validated through implementation of a Web-based cutting Tool Recovery Information System, as outlined in chapter 10.

The author argues that the generation of such information systems is the most influential step in facilitating the wider adoption of product recovery procedures by various manufacturing companies in different industrial sectors and a fundamental tool to support and enable the closer integration of various processes within a PSRC.

11.6. A Case Study on Recovery of Cutting Tools in Machining Applications

For the purpose of validation and demonstration of the research concepts, a case study on the recovery of cutting tools within machining applications has been undertaken. The motivation for this study was the isolated examples of recovery or recycling procedures for worn cutting tools highlighted by previous research at Loughborough. To identify requirements and establish boundaries for the case study, a number of industrial visits and interviews were undertaken. During the author’s survey of tool manufacturer/suppliers, tool users and regrinders, and grinding software vendors, it became apparent that there was a significant scope and financial benefits for a systematic recovery of cutting tools. However, due to a lack of formal management procedures and supporting information systems such tool recovery procedures have not been commonly established in tool industry. Therefore, the undertaking of this case study was warmly encouraged by every company visited.

A clear objective of this case study was to follow step by step the research concepts proposed by this work, and to show their feasibility and applicability. Therefore, the first step in this case study was to develop an integrated view of Tool Supply and Recovery Chain (TSRC). Both the material and information flows among various actors in the TSRC were identified and modelled. This was followed by application of the five steps of PRIME in the case of cutting tool recovery, which provided a comprehensive view of information required to support such recovery processes. Subsequently, A proof of concept prototype system referred to as a Tool Recovery Information System (TRIS), was developed based on common commercially available software tools. The development of
TRIS has demonstrated that the web based information system provides a powerful tool for the integration of structures within TSRC. Furthermore, the case study has proved the applicability of the research by demonstrating the concepts and illustrating the significant potential of an integrated approach to Product Supply and EoL-PR within manufacturing applications.
Chapter 12

Conclusions and Further Work

12.1. Introduction

This chapter identifies the major conclusions drawn from the author’s research. The latter sections of the chapter outline the further avenues of work to extend the novel concepts proposed by this research.

12.2. Conclusions from the Research

The conclusions formulated from the research are as follows:

i) The ever-growing amount of national and international environmental legislation related to “producer responsibilities” is forcing an increasing number of manufacturing companies across various industrial sectors to consider the end-of-life management of their products. This legislative pressure together with modern consumer demands for the reduction of the negative impact on the environment inevitability necessitates the inclusion of product recovery procedures within the majority of manufacturing applications in the imminent future.

ii) The initial investigation into requirements for implementation of product recovery has indicated that the scope of the traditional product supply chain must be extended to include the product recovery activities and actors. The novel concept of an integrated ‘Product Supply and Recovery Chain’ proposed by this research has provided a powerful perspective for a holistic view of business, technological, information and management requirements for implementation of EoL-PR within different industrial applications. The high volume of information exchange among the actors of a PSRC has further
substantiated the author’s view on the requirements for a closer integration of product supply and product recovery processes.

iii) The survey of the research work and the state-of-art approaches in implementation of PR procedures has highlighted that the mass adoption of these activities is hindered due to the lack of systematic guidelines and formal supporting systems. This research has developed one such systematic approach named the Product Recovery Implementation Methodology that encompasses the considerations for a wide range of issues involved in EoL-PR including those related to business, technology, resources, operational planning and information management requirements. The application of PRIME has shown significant potential for gaining tactical insights into the decisions involved in adoption of EoL-PR procedures.

iv) The adoption of EoL-PR procedures results in major alterations on a company’s internal and external business together with their operational structures, and must be supported by appropriate business models. The perspective proposed by this research based on two major drivers of ‘who is responsible for recovery of a product’ and ‘who is performing the recovery process’ provides a systematic approach to defining such business models. This ‘responsibility vs performing’ viewpoint has been utilised to develop two reference business configurations which can be used in different industrial applications to develop bespoke business models.

v) Consideration of various issues involved in adoption of EoL-PR procedures has indicated the requirements for a formal information management system to support the various processes involved in both the implementation and operational stages of PR activities within any applications. Furthermore, the geographical spread of the various actors involved in a product supply and recovery chain emphasises the requirements for a distributed information system providing a simple, simultaneous, and secure access to information. The web-based information system design proposed by this research provides an efficient method of achieving such information support for EoL-PR activities.
vi) The design of any information system must be based on a clear understanding of the business operations and organisational structures. The approach adopted by this research for modelling an enterprise based on physical, functional and informational viewpoints has been demonstrated to be an effective method of providing such a clear understanding of business operations and organisational structure for design of EoL-PR information system.

vii) The author’s survey of EoL applications has shown that there may be positive or negative marketing implications related to the adoption of EoL-PR. This may be very positive in applications such as recycling of plastic bottles and carrier bags, whereas the use of recycled or reconditioned parts in some other industries (e.g. automotive or computer industry) may not necessarily encourage an increase in sales due to cosmetic or reliability concerns. Therefore, such implications for the secondary market must be carefully considered and taken into account while selecting the most appropriate PR options for a particular product.

viii) The case study formulated within the context of EoL-PR of cutting tools within machining applications has effectively demonstrated the applicability and the significant potential of the research concepts. The integrated view of a 'Tool Supply and Recovery Chain' and the application of the five steps of PRIME have resulted in specification, design and implementation of a web-based Tool Recovery Information System (TRIS). This proof-of-concept system has demonstrated that the web based information system provides a powerful tool for the integration of processes involved in the TSRC.

ix) The overall conclusion of this research is that though the significant body of research on technological solutions for product recovery is generating innovative and highly sophisticated results, in the short term it is the shortcomings in business, information and management solutions which provide the biggest obstacle in mass adoption of EoL-PR for the majority of industrial applications. This research has provided a holistic view of issues, with simple and repeatable guidelines supported by appropriate reference configurations to develop such business, information and management
solutions. It is claimed that the utilisation of the novel concepts proposed by this research provides a simple, economical and systematic approach to facilitate the change in current views on product recovery processes from being 'cost burdens' to providing 'profit making opportunities'.

12.3. Further Work

The author recognises the following areas of further work as the most valuable extensions to the research.

12.3.1. Further Development of PRIME Methodology

PRIME has provided an effective stepwise approach to consider all the relevant issues surrounding EoL management of products. The major aim of this research has been the closer integration of product supply and product recovery processes and consequently a particular emphasis has been given to the issues and required software support for the fifth stage of the PRIME methodology, i.e. PR information specification and design. There is a requirement to explore the issues related in each of the other four stages and to provide software support specially designed based on the requirements of each stage. In fact the original intention of the author was to provide a CASE tool to support all five stages of PRIME. However, further consideration highlighted the range of issues to be investigated, hence making it infeasible to be thoroughly studied as a part of one PhD programme. Therefore, the author identifies a need for further development of the PRIME methodology by concentrated efforts into each individual stage to develop bespoke solutions for cost benefit analysis, establishment of the most appropriate marketing strategy, knowledge based system to support technological requirements, product recovery inventory systems, planning heuristics and algorithms to support recovery planning, and combinations of forward and reverse logistics, etc.

12.3.2. Application of PRIME in Different Industrial Sectors

The considerations of issues within various stages of PRIME have been developed on a very generic level. However, it is recognised that application of this methodology in different sectors requires some customisation. Furthermore, the consideration of these issues within different industrial applications could provide a means of improving the set
of guidelines included in PRIME to develop a comprehensive EoL-PR specifications. Thus, further work is encouraged to be carried out on a number of case studies within manufacturing companies and their PSRC partners in different industry sectors.

12.3.3. Enhanced Integration Solutions for Product Supply and Recovery Chain

It has been recognised that there is a requirement for IT tools to support the integration of product supply and product recovery chains due to the close link through the high volume of information and material flows. Information models generated by this research have fulfilled the initial requirement for generating IT support tools to achieve such integration across the PSRC. The author suggests that the generation of IT solutions needs to be further investigated based on integration standards such as 'Standard for the Transfer and Exchange of Product Model Data' (STEP) which is currently being utilised to support integration of various processes in manufacturing applications (Rahimifard and Newman 1996).

The class diagram of the Booch methodology has been used as a pseudo-information modelling tool for realising the conceptual information schema. As part of the STEP standard, there is a neutral database specification language, namely EXPRESS, providing a powerful tool to develop information models in a coded format that can be translated and used in other software systems. Therefore, the author proposes a further work in developing EXPRESS schemas for the PR information models generated in this research for further software development and to integrate legacy systems within a PSRC.

In addition in the cases of recovery by OEM (i.e. reference business configuration 1), one further possibility to be explored is the extension of existing commercial ERP systems (e.g. SAP, BAAN) to include software modules to support environmental policies in particular EoL management of products. Such ERP systems are adopted to provide a closer integration of manufacturing activities and hence they can be used to support integration of PSRC.

12.3.4. Development of Concepts Related to Ownership

This research has been based on the traditional view of the manufacturing businesses, i.e. the product ownership by customers. However, due to increasing amount of PR legislation related to producer's responsibility, there may be requirements for a change in the
traditional business culture and the ownership concepts. The author recognises that one approach for reinvention of such concepts is ‘product leasing’ i.e. ‘service provision’ as opposed to the traditional view of ‘product ownership’. In such an approach, manufacturing businesses instead of selling the product to the customer will sell the service associated with the use of the product so that EoL-PR processes can be more easily incorporated to the other stages of the product life cycle.

In the case of the cutting tool industry to the best knowledge of the author, the concept of tool leasing has not been formally implemented within any industrial applications. However, a number of industrial partners visited in this research programme including a tool supplier, tool management software vendor, and two of the tool users have shown interest in a further study to explore costing and information requirements for such a tool leasing approach. In such an approach, the tool builders/suppliers provide the users with the complete tool assembly and are paid for the tooling service based on a number of criteria such as the ‘number of parts produced with the tool’, rather than the traditional method of purchasing of the tool hardware. The ownership of tools always remains with the tool recyclers (i.e. Supplier, Distributor or Refurbisher) who are responsible for the take back and recovery of the tools. Therefore the author recognises a requirement for further research work to investigate the application of ‘tool leasing’ and development of methods and supporting management procedures.

12.3.5. Extending the Functionality of Tool Recovery Information System

TRIS provides computerised support for EoL-PR processes including, EoL decision-making, recovery order realisation, sales and database management functions within a T SRC. However, further investigation should be carried out to improve TRIS through additional functionalities. Financial functionalities may include costing of PR processes, financial reporting, and loss-profit assessment. In addition, since legislation is a major part of EoL-PR procedures a software module is required to incorporate the legislation compliance within such an information system. One of the key difficulties in supporting the EoL-PR processes is the dealings with the uncertainty in relation to quality and quantity of the used product returns. Therefore balancing supply with demand of the recovered products through the incorporation of forecasting and networked inventories across the PSRC should be considered.
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Appendix 1

Reference Configurations to Support the Implementation of the Product Recovery Supply Chain

A1.1. Introduction

This paper was presented in the 5th IFIP International Conference on Information Technology for Balanced Automation Systems in Manufacturing and Service held in Cancun-Mexico in 2002.
Increased public awareness towards the global environmental problems together with government regulations has forced current manufacturing companies to be more conscious of the effect of their activities on the natural environment. One of the many efforts to combat these environmental problems is to recover products at the end of their life in order to conserve natural resources, minimise energy consumption and reduce waste disposal problems. Recently an increasing number of manufacturing enterprises aim or are forced by legislation to adapt product recovery into their existing business practices. This has highlighted a need for a systematic approach for enhancement of information, business and production management systems to deal with additional activities and processes related to the recovery of products. The research reported in this paper aims to provide a clear understanding of such product recovery activities by extending the traditional manufacturing supply chain through the definition of a product recovery implementation methodology and its application via two reference Configurations.

1. INTRODUCTION

The mass industrialisation over the last century has had a negative impact on the natural environment, contributing towards serious problems such as global warming, ozone depletion, acid rains and natural resource depletion. As a result, there is an increasing demand by customers, suppliers and the public from manufacturing industry in general to minimise any negative impact of their products and operations on the natural environment, i.e. being environmentally conscious. As a result, the recent research in this area has led to the development of Environmentally Conscious Manufacturing (ECM) concepts, which are concerned with developing equipment, methods and procedures for manufacturing activities from conceptual design to final disposal (including re-use and recycling) such that the environmental standards and requirements are satisfied. Two of the major research areas in ECM is the End-Of-Life (EOL) management and Product Recovery (PR) which is the transformation of the used and discarded products into useful condition through re-manufacture, re-use and recycling. The main motivations for PR are economic gains, complying with legislation, improving the public image and personal ethical
initiatives. However, complying with legislation related to PR will become more
important in the near future because national and international directives will make
take-back and recovery of used products obligatory for the Original Equipment
Manufacturer (OEM) instead of being an option. In Europe, Waste from Electric and
Electronic Equipment (WEEE) directive is in the preparation stage and expected to
be in law by the end of year 2002. This directive will require one hundred percent
take-back and a high percentage of PR of used products from electric and electronic
goods producers. As a result, this puts extra pressure on such companies to establish
take-back and PR as a part of their business activities.

In this paper the issues related to product recovery activities within an extended
manufacturing supply chain are discussed and a number of reference configurations
for such supply chain are defined. The initial part of this paper provides a review of
relevant literature, and the major sections discuss the new concept of the product
recovery chain and analyses the implication of extension of the existing
manufacturing supply chain through product recovery adaptation. Furthermore, a PR
implementation methodology together with a number of reference configurations has
been presented to support the realisation of various product recovery supply chain
scenarios within different manufacturing applications.

2. REVIEW OF RELEVANT RESEARCH

The increasing significance of product recovery within manufacturing activities has
brought a corresponding influence in the research covering the production life cycle
stages from product design to final disposal. In the design stage, new concepts have
emerged such as design for disassembly, re-manufacturing, re-use, and recycling,
which incorporate end-of-life decision considerations as design objectives (Alting
and Legarth 1995, Harjula et al. 1996). Within the production stage, operational
management issues related to product recovery include disassembly and re-
manufacturing planning and control (Gupta and Taleb 1994, Gungor and Gupta
1999, Lambert et al. 2000). The important issue is to find a balance between the cost
of disassembly and re-manufacturing and the returned benefits, as explored by
Lambert (1997) and Navin-Chandra (1994). There are also a number of studies
exploring the use and suitability of a Material Requirement Planning (MRP) based
approach with some modifications for scheduling in recovery environments (Gupta
and Taleb 1994, Guide et al. 1997). Other researchers propose and investigate the
use of alternative approaches for scheduling and control at the shop floor such as the
drum-buffer-rope concept (Guide 1996); flexible KANBAN (Kizilkaya and Gupta
1998), “Push” and “Pull” control strategies (Van der Laan et al. 1999). Other issues
investigated in this area relate to inventory control requirements within recovery
systems which differ from traditional manufacturing systems due to a high degree of
uncertainty in timing, quantity and quality of returned products and the demand for
recovered parts (Fleischmann et al. 1997, Guide et al. 1999, Richter and Sombrutzki
2000).

One of the critical decision making tasks relates to end-of-life (EOL)
management, namely the selection of options among the recovery of the used
product as a whole, component or part recovery, material recovery (recycling) or
disposal. The objective is to maintain the profitability and not to violate the technical feasibility constraints (Johnson and Wang 1998, Krikke et al. 1998, Low et al. 1998, Jung and Bartel 1999, Goggin and Browne 2000). Finally, a significant body of research has explored the new material flows within PR applications from the user to the producer, which includes the collection and transportation processes and is referred to as reverse distribution (Spengler et al. 1997, Jung and Bartel 1999, Klausner and Hendrickson 2000).

3. PRODUCT RECOVERY SUPPLY CHAIN

In product recovery applications, the traditional view of the manufacturing supply chain has been extended to include the activities, actors and the structures required to accomplish recovery at the end of products’ life. This has resulted in the emergence of the new supply chain concept, referred to as ‘product recovery supply chain’. The original manufacturing supply chain concepts supports a one-way economy, which transforms raw material into useful products. However the recovery of products, parts, material and energy within the product recovery supply chain is ultimately resulting in a bi-directional physical flow within what the authors defined as a complete ‘manufacturing loop’ (see Figure 1).

![Manufacturing chain vs. manufacturing loop.](image)

The additional activities in the product recovery supply chain as opposed to the traditional manufacturing supply chain are the collection, assessing, sorting, and re-processing redistribution and disposal of waste. There are new actors associated with each of these activities and the new bi-directional workflow structures to represent not only the traditional flow of products from the manufacturer to customer, but also the flow of used products back from the customer to be recovered. This recovery of used products can be classified into a number of levels as illustrated in Figure 2 and outlined below:-

- **Product recovery** is the reintroduction of used product back into the market through a series of processes such as inspection, disassembly, replacing or repairing bad components and re-assembling (often referred to as re-manufacturing).
• **Module & part recovery** where a subset of parts and components of used products can be recovered, repaired or re-conditioned for re-use in production of new products.

• **Material recovery** is retrieving the material content of the whole or a subset of the components of used products through a range of processes at the end of which the identity of the product is completely lost (often referred to as recycling), and finally,

• **Energy recovery** where in limited applications some of the material not recovered through one of aforementioned process is used to generate energy (often in the form of heat and electricity).

It should be noted that in most applications due to the economical and environmental implications such as cost, effort, time, and energy associated with re-production, the most preferred approach to recovery in the first place should be directed at the recovery of the product, followed by modules and parts. The latter two options, namely material and energy recovery should be considered in industries that are characterised by short technology cycles and high technological obsolescence.

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**Figure 2 - Product recovery operations and their relationships.**

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**4. REFERENCE CONFIGURATIONS FOR PRODUCT RECOVERY**

The adoption of PR procedures within manufacturing enterprises requires a major alteration on both the internal and external business and operational structures. Clearly, there should be an in-depth understanding of such implications on the existing manufacturing activities before considering any major modification of business and operational processes. It is crucial to assess and evaluate alternative approaches in product take-back and recovery before final decisions are made. In order to develop reference configurations for product recovery, the research reported in this paper has generated a novel systematic five-stage methodology, referred to as the ‘Product Recovery Implementation MEthodology’ (PRIME). The various stages of PRIME are illustrated in Figure 3 and outlined below:-

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i) **Technological Assessment**: the evaluation of available technologies in various applications to identify the most appropriate PR procedures for a specific product, resulting in adoption of a re-manufacturing, re-use or recycling approach.

ii) **Business and Economical Evaluation**: this includes a cost-benefit analysis, investigation of relevant national and international legislation, identification of marketing implications for both the original and recovered products, and business process planning to include new processes and actors.

iii) **Resource Assessment**: the evaluation of various required resources including the internal and external hardware, software and human resources.

iv) **Logistic and Operation Planning**: Product take-back logistics, planning and control of recovery processes, inventory control of new and recovered product.

v) **Information Specification**: identification of product and manufacturing information related to additional activities included in a product recovery supply chain.

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**Figure 3 – Product Recovery Implementation Methodology**

There are basically two possible business solutions for the realisation of product recovery within manufacturing applications, namely (a) through addition of recovery capabilities to Original Equipment Manufacturer (OEM) activities or (b) by third party independent recovery companies whose sole business is to re-process used products. This correspondingly highlights two possible reference configurations for the realisation of PR procedures within a manufacturing enterprise, namely

- **Reference Configuration 1 - Recovery by Manufacturer**: in this reference configuration the original manufacturer of the product takes the products back at the end of its life and carries out the recovery processes in-house, as illustrated in Figure 4a. This is often achieved by the expansion of the business
and manufacturing facilities to include the required resources to undertake the recovery processes. This reference configuration provides more control over the secondary market for the OEM, and the information required for disassembly and remanufacturing is readily available within the company which makes the implementation of product recovery procedures easier.

- **Reference Configuration 2 — Recovery by Independent Recoverer**: in the second reference configuration, an independent recovery company undertakes PR on behalf of one or more OEMs (see Figure 4b). The recoverer receives the product(s) from the collectors at the end of their life and carries out the required recovery processes, and supplies them back to the original manufacturer or sells them on to a secondary customer. Clearly, in this reference configuration a particular OEM has less control over the secondary market, and issues related to product confidentiality and EOL information management is much more complex. The independent recoverer often has access to a vast amount of information supplied by a number of OEMs, and has the additional advantage of supplying the recovered products to a much larger market.

![Diagram](image)

Figure 4 - Product recovery realisations.

There are a large number of factors influencing the suitability of one of these reference configurations for a particular manufacturing company, including product size and type, process complexity, production capacity, geography of the initial distribution, and relevant legislation. These factors should be carefully analysed and assessed before establishing the suitability of one of these recovery reference configurations. For example, within a company where manufacturing activities are mainly consists of assembly of large and specially designed products in small batches, the first reference configuration is considered to be more attractive than within a high volume components manufacturing company. One of the other key decision issues is the geographical distribution of customers and effort involved in the collection of used products which may make the first reference configuration
infeasible. Furthermore, the PR processes such as disassembly, repair and reassembly will require additional planning, control and co-ordination which could result in undesirable complexity and higher product costs.

The second reference configuration provides OEMs with the advantage of outsourcing the recovery processes thus not needing a major alteration in their production facilities. Such a shared recovery approach may significantly reduce the cost of recovery processes. However, due to complexity of recovery technologies and unfamiliarity of such re-manufacturing business concepts, in many industrial sectors these independent recoverers may not exist at present.

5. CONCLUDING DISCUSSION

The frequent emergence of a large number of national and international legislations are necessitating the adoption of PR procedures in an increasing number of industrial sectors and placing the responsibility of recovery and final disposal of used products firmly on the original manufacturer. Furthermore, the significant attention paid to the environmental impact of manufacturing activities in recent years, highlights the paramount importance and inevitability of the inclusion of product recovery procedures within an increasing number of manufacturing applications in the near future. This has also resulted in emergence of new customer and manufacturer relationships such as the ever increasing popularity of ‘product leasing’ in electronic and automotive industries.

At present the recovery of products may not be economically viable in many industrial sectors. In addition the adoption of PR may or may not have a positive marketing impact. For example, the use of a recycled product with a complex disposal requirement (e.g. plastic bottles) provides a positive image and marketing implications, whereas the use of recycled or reconditioned parts within the automotive industry may not encourage an increase in sales. This has resulted in a lack of significant and a consistent desire by the manufacturing companies and in particular the small to medium enterprises (SMEs) to adopt the PR procedures. SMEs represent the largest proportion of the manufacturing sector, generating more than half of the total production output in every industrial country, and therefore the required and desired levels of reduction in negative impacts of manufacturing activities on environment can only be achieved through development of simple, economical and systematic approach for the adoption of PR within SMEs.

The review of literature has shown that the previous PR research work has concentrated on isolated topics rather than developing a holistic view linking and integrating all aspects of product recovery procedures. The research reported in this paper has defined reference configurations based on a systematical methodology for the implementation of PR procedures. These reference configurations encapsulate the results from the assessment and definition generated by each stage of the methodology and provide a clear view of a possible approach to realisation of PR procedures. Future research will aim to generate a CASE software tool to support the various stages of the PRIME methodology for each reference configuration. This CASE tool includes a knowledge based advisory system for PR legislations and technologies, a business model, a planning model, supported by the product and
resource information models which are enhanced to include the PR related information.

6. REFERENCES

Appendix 2

A Web-based Information System to Support End-of-life Product Recovery

A2.1. Introduction

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A Web-based Information System to Support End-of-life Product Recovery

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ABSTRACT
Increased public awareness towards global environmental problems has forced manufacturing companies to consider the negative impacts of their activities on the environment. In this context, the effective management of products at the end of their useful life has become of paramount importance due to the ever increasing national and international legislation and directives aimed at making take-back and recovery of used products obligatory for the Original Equipment Manufacturer. This highlights a need for a systematic approach for enhancement of information, business and production management systems to deal with additional activities and processes related to the recovery of products. The research reported in this paper has developed a five-stage methodology to support product end-of-life management within manufacturing companies. The modelling and design of appropriate product recovery information systems, which constitute the main core of this methodology, is also described. The paper concludes with the description of an application of this methodology and information system design for the recovery of cutting tools at the end of their useful life in metalworking applications.

Keywords: Product take-back, end-of-life management, environmentally conscious manufacturing, recycling of cutting tools.

1. Introduction

Mass industrialisation over the last century has had a negative impact on the natural environment, contributing towards serious problems such as global warming, ozone depletion, acid rain and more importantly serious depletion of natural resources. As a result, there is an increasing demand by customers, governments and the public from manufacturing industry to minimise any negative impact of their products and operations on the natural environment. This has resulted in significant research in the popular subject of Environmentally Conscious Manufacturing (ECM), which is concerned with developing methods, procedures and equipment for manufacturing applications to satisfy the increasing number of environmental standard and legislation.

One of the major research areas within ECM is Product Recovery (PR) which is the transformation of used and discarded products into useful condition through re-manufacture,
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re-use and recycling. In this context, two major directives of European legislation, namely the End of Life Vehicle (ELV) and Waste from Electric and Electronic Equipment (WEEE) directives, will make take-back and recovery of used products obligatory for the Original Equipment Manufacturer (OEM). This has generated concerns and significant interest in PR procedures not only among the OEMs, but also among the extended enterprises within the supply chain of these sectors, which include a large number of Small and Medium Enterprises (SMEs).

Currently there is a large number of recycling and recovery applications within many different industrial sectors, which are often developed on an ad hoc basis and mainly due to the hidden economic value within used products. The authors argue that in order to make a desired environmental impact, the number of product recovery applications has to be significantly increased and ideally be implemented in every manufacturing application. One of the main obstacles reported in the literature in achieving such large scale product recovery implementation is the lack of formal methods and appropriate supporting information systems [1].

The research reported in this paper has generated a novel systematic five-stage methodology to support the product end-of-life (EoL) management in manufacturing applications, entitled “Product Recovery Implementation Methodology (PRIME). At the core of PRIME is the specification and design of appropriate information systems to underpin the various stages of this methodology. The initial part of the paper provides a review of relevant literature, together with a brief description of the various stages involved in the PRIME methodology. The latter sections describe the modelling and design of a Web-based product recovery information system, and discuss the application of the PRIME methodology to the recovery of cutting tools within machining applications.

2. Review of Relevant Research

The increasing significance of product recovery within manufacturing activities has brought a corresponding influence in research covering the various stages of the production life cycle [2]. New design concepts have emerged such as design for disassembly, re-manufacturing, re-use, and recycling which incorporate EoL decision considerations as design objectives [3,4,5]. Determining the EoL option for discarded products is closely related to disassembly planning, and therefore there are a number of studies, which have explored the most appropriate level of disassembly and disassembly planning and sequencing [6, 7, 8, 9].
In addition, a number of researchers have investigated a range of factors such as the economical, technical, environmental and social criteria, which influence the EoL options [10, 11, 12, 13, 14]. There are also a number of studies exploring the use of existing and novel production planning and control approaches for coordination of product recovery operations on the shop floor [15, 16, 17, 18]. Inventory control within recovery systems, has been recognised as different from traditional manufacturing systems due to a high degree of uncertainty in timing, quantity and quality of the returned products [19, 20].

A significant body of research has explored the new material flow within PR applications from the user to the producer, which is often referred to as reverse distribution and includes the collection and transportation processes [21, 22]. The establishment of PR procedures within various manufacturing applications have also resulted in the emergence of new activities and actors required to accomplish recovery processes at the end of a product’s life. These activities include collection of used products; assessing and routing; reprocessing them for product, part or material reclamation; redistribution of the recovered products and material; and finally safe disposal of waste. These activities have been investigated under the broader perspectives such as the product supply chain and the extended enterprise [23, 24], and also being linked with the various functions of production planning and control [25]. The requirements for PR information models and systems have also been considered with a number of bespoke solutions being identified [26, 27, 28].

The existing research in this area has provided an initial basis to support a sustainable approach to EoL and PR activities. However, due to the extreme requirements for rapid growth of these activities across the globe, there is a need for a more holistic systematic approach to support all aspects of EoL and PR. The focus of the research in this paper is on the first steps towards such a holistic vision through a ‘Product Recovery Implementation Methodology’.

3. Product Recovery Implementation Methodology

EoL product recovery relies on a technological solution along with a comprehensive understanding of the business, environmental, engineering and cost issues. The adoption of PR procedures within manufacturing enterprises requires a major alteration on both the internal and external business and operational structures. This necessitates a number of changes in business and manufacturing practices, organisational structure, supporting
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information infrastructure and the operating market. Clearly, there should be an in-depth understanding of implications of these changes on the existing manufacturing activities to ensure the generation of a cost effective and efficient product recovery procedure. As a result, a novel systematic five-stage methodology, referred to as the ‘Product Recovery Implementation MEthodology (PRIME)’ has been developed. This methodology aims to provide a step-wise approach for identification of business, technological, process, resources and information requirements for the adoption of PR in different applications. The goal is to provide general tactical insights into decisions to be made during adoption of PR procedures rather than optimise the decisions derived. The various stages of PRIME are described in detail in Rahimifard et al. [29], and outlined below:

   i) Evaluation of business implications and economical justification
   ii) Assessment of available recovery technologies
   iii) Identification of resource requirements
   iv) Evaluation of logistics and operation planning requirements
   v) Development of a PR information system

At the core of the methodology is the realisation of appropriate information systems to support the information flow between various stages of PR implementation, as depicted in figure 1. The remaining sections of this paper describe the modelling, design and implementation of such PR information systems.


4.1. Information Modelling for Product Recovery

The adoption of PR within any manufacturing application results in generation of a large amount of information related to collection, assessment, remanufacturing processes, including information on material characteristics, disassembly maps, sales and distribution, warranties and maintenance, product utilisation and EoL condition of the used product. Clearly, such information must be efficiently stored, maintained and accessed by a number of different actors involved in various PR activities.

In recent years, significant research effort has been directed at modelling, design and development of appropriate information systems to support a wide range of functions within various manufacturing applications [30]. Information models contain unambiguous definitions of data, its structure and relationships, and are often generated to support the
design of information systems and/or integration of a number of software systems. A large number of approaches, methods and tools have been developed for information modelling, which include both graphical and textual representations. Currently within modern manufacturing enterprises, these methods and approaches have been utilised to design and implement information systems based on a number of information models, including those for products, processes, resources and in some applications for customer orders.

In this research the Booch methodology [31] has been utilised to specify and demonstrate the range of EoL related information required to support PR. The Booch methodology utilises an object-oriented approach for system design and information specification, which is achieved through the application of class and inheritance diagrams. The typical information related to EoL management of the used products is illustrated in figure 2, and can be broadly categorised as:

![IDEFO representation of the activities involved in PRIME methodology](image)

Figure 1: IDEF0 representation of the activities involved in PRIME methodology
- **Product recovery information**: This contains product information such as material used, product design, bill of disassembly, possible recovery options, material recycling properties, legislative properties about use, recovery and disposal of the product, etc.

- **Remanufacturing information**: This comprises of information relating to the type of recovery processes and their properties and the resources which can perform these processes which could include both external resources such as subcontracting companies as well as internal resources such as additional work centres and skilled labour specialised in disassembly, repair and reassembly.

- **Product utilisation information**: This provides a history of product use and the condition of the product at the end of its life (commonly referred to as core), which includes information about the customer, purpose of use, age, reasons for discard, failure history, etc. Furthermore in applications where a product can be recovered a number of times, the history of the previous recovery operations is also maintained.

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**Figure 2**: Representation of product recovery information using Booch methodology
4.2. Information System Design for Product Recovery

Typically, there are two stages involved in design of an information system, namely the design of a data repository and an information network. In the case of product recovery information system, there are two possible options for the design of a data repository system, as illustrated in figure 3. In the first option, the PR related information (i.e. product recovery, remanufacturing, and product utilisation information) can be viewed as extension to the information maintained within the existing product and manufacturing models. Such an approach is particularly suitable for an OEM which is responsible for both the manufacture and recovery of products. Alternatively, in applications where there is not an established or common product and manufacturing models, a more effective approach would be to generate a bespoke PR information model. For example in the cases where an independent recoverer is responsible for the recovery of a range of products, often manufactured by a wide range of producers, a bespoke data repository systems may be the only cost effective and feasible method of storing and maintaining PR related information.

The second stage of information systems design involves the definition of an information network to facilitate the access to the data repository. Due to inherited distributed nature of PR procedures, related actors and users of such information system may be physically located across cities, countries and even continents. The recent advancements in Web-based information management systems provide a suitable technological solution to the design of a distributed PR information network. A Web-based information system allows multiple, simultaneous and distributed access, and also provides an appropriate infrastructure to support the collaborative approach to product recovery by various actors involved in PR procedures. Furthermore, the platform-independent architecture associated with Web-based information systems [32] eliminates barriers to integration and allows recovery actors to deploy applications across the entire product supply and recovery chain, which can include material suppliers, manufacturers, customers, collectors and reprocessors whose computing environments may be completely different. As a result, such a Web-based approach to information network design is proposed by the authors to be the future information management tool for supporting product recovery activities, as illustrated in figure 3. The implementation of one such Web-based information network for the recovery of cutting tools is described in the next section of this paper.
5. Application Study: Information Support for Recovery of Cutting Tools

5.1. Recovery of Cutting Tools

The recovery of cutting tools within metal working applications has been adopted to demonstrate the novel concepts defined by the research. A cutting tool often consists of an assembly of 4 or more components, including a number of durable parts (namely tool shank, collets and studs) that are used for holding the tool assembly in the machine, together with the consumable parts (i.e. solid tools or inserts) which are the material removal parts of tools. The cutting tools are categorised based on various types of machining processes such as milling, drilling, turning, grinding, boring, and tapping. These tools gradually lose their accuracy and cutting capabilities over a period (tool life), in which case they are referred to as worn or spent.

The assertion made in this case study is that the adoption of a recovery or recycling procedure for cutting tools promises to provide significant financial benefits within the majority of machining applications. This is apparent from consideration of the following:

- a typical metalworking SME holds more than a 1000 tools at an average cost of £75 per year.
- the cost of cutting tools is often as much as 15-20% of overall production costs.
- the number of worn tools produced by a small CNC machining shop is typically over 500 per year.
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- less than 50% of the useable tool life is often being utilised at a CNC machining station.
- less than 15% of refurbishable tools are being recycled.

The focus of this study is on the recovery of the consumable components of cutting tools, which are usually made of one of three materials namely high speed steel, tungsten carbide or ceramic. These consumable items can be classified as refurbishable (i.e. they can be recovered for a limited number of times before they are scrapped) or throwaway (which are scrapped when they are worn). The recovery of tools is often based on three major processes of re-grinding, re-coating and material recycling. One further issue to consider is that in some cases where a specialised material is being cut (e.g. titanium) the tools will become impregnated with the hazardous material and are unrecoverable. This requires specific disposal procedures at the end of the tool life.

The major actors for cutting tools EoL recovery are shown in figure 4 and consist of tool manufacturers, tool suppliers and retailers, tool users across a range of industrial sectors, tool recyclers (consisting of tool regrinding and/or re-coating companies), and material recyclers (who take back un-refurbishable tools as scrap for material reclamation). In this study the following terminology for realisation of cutting tools recovery has been defined:

![Figure 4: A framework for recovery/recycling of cutting tools](image-url)
- Tool Rework: is the capability to regrind limited tools internally within the manufacturing enterprise.
- Tool Recycling: is the ability to take back the used worn tools by external companies (i.e. the original tool supplier or a third party tool refurbishing company) for the purpose of regrinding, re-coating and re-supplying.
- Material Recycling: is the return of worn /used tools for reclamation of material.

5.2. Information Modelling and Design

At present, the recovery of cutting tools is not supported by a formal information system, resulting in significant restrictions for adoption of the tool recovery procedures. This research proposes the development of one such system, referred to as a Tool Recovery Information System (TRIS), which has been realised in three stages, namely:

i) Specification of tool recovery information using the Booch methodology,
ii) Implementation of a data repository using the Microsoft Access database management system, and
iii) Implementation of an information network, using a three-tier Web-based architecture.

Figure 5 illustrates the typical information related to recovery of cutting tools using a Booch representation, based on the PR information categories identified in Section 4.1. The tool recovery information has been grouped into three classes representing refurbishable solid cutting tools, recovery processes, and used tools. The solid cutting tool class in addition to common information such as tool identification, technical specification, tool assembly description, tool supplier/manufacturer, tool presetting data and tool life also includes information related to the possible tool recovery (regrinding) options, times, costs and more detailed data on material types and characteristics for recycling purposes. The tool recovery process class contains mainly information related to various types of recovery processes (i.e. regrinding, re-coating, material recycling) and recovery actors which may be the tool user (through internal tool reworking activities), the original tool manufacturer, and an independent tool recoverer or material recycler. The used tool class contains the utilisation history for a particular cutting tool which includes the material cut, speed and location for tool usage, and the history of previous recovery activities and actors on this tool.

The data structures defined through the Booch representation have been utilised to design and implement a data repository system for TRIS, using the Microsoft Access database.
management system. This database comprises a range of tables, including those for Material, Recovery Processes, Recovery Actors, Solid Cutting Tool and Used Tool. The typical data stored and maintained within these tables, together with the data relationships are depicted in figure 6. The web-based information network for TRIS has been developed using the commonly adopted three-tier architecture as shown in figure 7. The first tier includes application clients, i.e. web browser which is linked to the system by the connecting web server (in this case a Jakarta Tomcat web server). This tier allows the user to interact (insert and collect data) with the system. The second tier is the application tier, which comprises of a software module developed using the Java Server Pages (JSP) for accomplishing the computational activities in response to user requests, according to a predefined set of business logic rules. The third tier is the persistent data storage level which stores and maintains data for the application, i.e. the Microsoft Access database. Figure 8 depicts the utilisation of these screens by the major actors involved in the cutting tool recovery. This provides an effective view of a distributed information system to support a wide range of requirements by actors within a tool supply and recovery chain.

Figure 5: Booch representation of product recovery information for TRIS.
Figure 6: Sample Tables within the Tool Recovery Data Repository System

Figure 7: Web application architecture
5.3. Functional View Point

The typical users of TRIS include cutting tool manufacturer and/or supplier, a number of cutting tool users, tool regrinding companies and material recyclers. This web based information system provides remote access for these users over the Internet to store, share, and maintain their data relating to recovery of cutting tools. Four major functional modules have been developed in TRIS based on the consultation with industrial partners of the research, namely:

- **Databases Maintenance Module** which provides access for the (authorised) user to view, add, and edit data in the related databases. Figure 9a-9c shows a subset of the user interface screens for this module.

- **EoL Decision Support Module** which provides support in identifying the most suitable recovery process for a given cutting tool based on its use and regrinding history (see figure 9d), EoL tool condition and feasible regrinding processes.

- **Recovery Order Module** which is used by tool users, tool manufacture and tool regrinder to place a recovery order for a specific collection of tools (referred to as tool recovery kit), to coordinate and monitor its progress, and to provide feedback on order completion (see figure 9e).
Appendix 2

**welcome to TRIS**

Tool Recovery Information System

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**a)** Home Page for TRIS

**b)** Cutting Tool Database

**c)** Add/Edit Cutting Tool Screen

**d)** Recovery History Screen

**e)** Monitoring the Progress of Recovery Kit

**f)** List of Used/Reground Tools for Sale

**Figure 9**: Example Screens from TRIS
Sales Support Module is used to share information related to used tools, reground tools, and scrapped tools for resale to various actors within tool supply and recovery chain and to provide on-line sales and purchase facility, referred to as e-tool (see figure 9f).

6. Concluding Discussion

The ever-growing amount of national and international environmental legislation is necessitating the adoption of PR procedures in an increasing number of industrial sectors. Furthermore, modern consumer pressures for the reduction of the negative impact on the environment is another indicator to the inevitability of the inclusion of product recovery procedures within the majority of manufacturing applications in the near future. At present, the wider adoption of PR activities are hindered due to a number factors, such as:

- The recovery of products is not economically viable in many industrial sectors;
- There is a lack of independent recoverers in many applications, or where they exist the required recovery capacity is inadequate;
- The general resistance by manufacturing companies to share information on their materials, product design, and product utilisation due to modern pursers in highly competitive global market;
- The varying marketing implications for adoption of product recovery which may be very positive in applications such as recycling of plastic bottles and carrier bags, whereas the use of recycled or reconditioned parts within the automotive industry may not necessarily encourage an increase in sales; and
- In general the PR activities are not supported with appropriate IT software tools.

It is recognised that, as a result of these issues, adoption of PR procedures are not encouraged to a wider scale within manufacturing companies, in particular, SMEs. The authors argue that desired levels of reduction in negative impacts on environment can only be achieved through development of simple, economical and systematic approach for the adoption of PR within SMEs. In this context to achieve such a large scale adoption of PR, the following assertions are made by the research reported in this paper:

i) The scope of the traditional product supply chain must be extended to include the product recovery activities and actors, through development of novel concepts for an integrated “Product Supply and Recovery Chain”.

ii) A systematic methodology encompassing the considerations for a wide range of issues including those related to business, technological, operational planning and information
management requirements for implementation of product recovery activities must be adopted.

iii) Bespoke information systems and IT software tools must be designed and developed to underpin the implementation of PR activities.

The PRIME methodology presented in this paper provides one such systematic approach to support the mass inclusion of PR within various manufacturing applications, based on an integrated view for product supply and recovery chain. Furthermore, the Web-based information systems presented provide an efficient tool to support the information requirements and enable the close integration of various PR activities. The future of this research is based on the use of such distributed information systems as facilitator for the increase in ‘product service provision’ as opposed to the traditional view of ‘product ownership’.

7. References


31 Booch, G. *Object-Oriented Design with Applications* (Benjamin/ Cummings Inc.), 1991.