REFERENCE CONFIGURATIONS TO SUPPORT THE IMPLEMENTATION OF THE PRODUCT RECOVERY SUPPLY CHAIN

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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

crucial 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).

Figure 1 - Manufacturing Chain vs. Manufacturing Loop

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.

Figure 2 - Product Recovery Operations and Their Relationships.

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 :-

- 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.
- 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.

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.

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

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