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A survey based framework for Recovery and Remanufacturing issues of Orphan Products

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Abstract

The impact of business on environment is a growing concern for public and government. New regulations require companies to take responsibility for products at the end of their useful life. Historical waste from products sold before take-back laws came into force pose a different challenge, especially when producers of such waste no longer exist. To prevent occurrence of such orphan products, recent regulations mandate that producers provide financial guarantee for the end-of-life environmental costs. Although a better alternative to disposal is remanufacturing of orphan products, there is very little in the literature that addresses this issue.

Based on a survey of over 140 published papers during the last decade, we analyze product recovery and remanufacturing issues pertaining to orphan products. We also develop a framework that distills the factors governing strategic behavior of players involved in product recovery. Using the framework we identify research areas on recovery of orphan products.

A survey based framework for
Recovery and Remanufacturing issues of Orphan Products

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1. Introduction

Over the recent past there has been growing concern on the impact of business on environment. These arise on account of depletion of natural resources, waste generated from production systems and at the end-of-life of products. Increasingly, firms are under pressure to take responsibility of restoring, sustaining and expanding the planet's ecosystem instead of merely exploiting them. Amory et al. (1999) coined the term *Natural Capitalism* and argued that firms must shift to biologically inspired business models, such as closed loop production systems, and also invest in natural capital. This will not only protect the environmental resources but also will improve profits and competitiveness. Hart et al. (1999) insisted that firms should reduce the total environmental burden by moving beyond 'greening' and take ownership of the environmental impacts associated with the total life cycle of the product. This essentially calls for fundamental changes in the underlying product and process design, taking into account all possible effects a product might have through out its life on the environment both within the firm and beyond its boundaries and the use of clean technologies.

With increase in economic and social costs of disposal, increasing protests from environmental protection groups against dumping wastes in third world countries (Taylor 2002) and reducing spaces for landfill (Renkow 1994), legislations have also evolved from the earlier forms of pollution-level control to the recent forms like ‘compulsory take back of products at the end-of-life’. These legislations are based on ‘extended producer responsibility’– a policy tool to minimize environmental waste generated from businesses. Clearly, the central issue is ensuring long term environmental protection while the economic activities across nations and societies increase. Mark et al. (1997) illustrated how life cycle oriented environmental management practices by firms have evolved through coercive pressure (legislations), normative pressure (firm’s internal value system) and mimetic pressures (peer pressure from firms within an industry).

In the last ten years we see a multifaceted approach to tackle the problem of environmental protection and sustenance. Policy makers have brought in new legislations that put regulatory pressures on businesses as a means to tackle the problem. Notable among them are the EU directives on compulsory product take-back at the end-of-life, The Netherlands National Environmental Plan and the package recycling and product take-back laws in Germany (Sharfman et al. 1997). While policy makers enforced regulations, distinctive and new industry practices addressed the problem from the other side (see Fleischman, 2000 for examples of product recovery activities by firms). Researchers have also addressed several issues in this area and provided important guidelines for practice (see for example Krikke et al. 2004, Blackburn et al. 2004, Guide et al. 2000). The literature that deals with these issues is broadly referred to as reverse logistics and remanufacturing.

A majority of the work in reverse logistics and remanufacturing literature has focused on operational issues pertaining to product recovery. These include, for instance, optimal design of the reverse logistics network, assessing economics of remanufacturing operations, forecasting of returns, inventory management, production planning and control, shop floor scheduling and competition issues in remanufacturing. However, reverse logistics also involves multiple players, such as OEMs, customers, regulatory bodies, and other business entities, who take part in various product recovery activities and environmentally safe disposal. The role of these players, the division of work and responsibilities, planning and execution of the work, profit imperatives and incentives, economic and social impact of regulations are some of the important issues that need to be addressed in a reverse logistics problem. This provides the strategic perspective to the reverse logistics problem. To the best of our understanding, this is an under-researched area.

In this paper, we take a strategic perspective and address these issues of reverse logistics. We begin with a discussion on the role played by regulation in the recent past in ensuring environmental protection and sustenance and also raise the concern that if the producer of a product does not exist at the end of product life (orphanage), there could be potential environmental threats. We define orphan products and highlight the specific challenges involved in product recovery of orphan products. Based on a survey of the research in the last ten years in reverse logistics, we identify areas that require more research pertaining to recovery of orphan products in order to address those challenges.

The rest of the paper is organized as follows. In §2 we discuss the recent legislations that address the issue of minimizing environmental waste from businesses. We also raise the challenges in managing future historical waste that are inadequately addressed in these legislations. In §3 we introduce a variation of the typically used reverse logistics framework for a better understanding of these challenges. We then define orphan products and superimpose the case of orphanage on this framework to highlight the specific challenges involved in product recovery of orphan products. In §4 we explain our survey methodology and present review of research in the last ten years in reverse logistics. Based on our understanding of research we present a framework to identify the factors that govern the strategic behavior of players involved. Finally we identify the specific research issues related to reverse logistics of orphan products in §5.

2. Regulatory issues pertaining to historical waste

The role of regulatory agencies is significant in ensuring environmental protection and sustenance as evidenced from the increasing number of recycling and product take back laws in the recent past. In the United States, The Labeling of Products Using Ozone-Depleting Substances (1993) required manufacturers using ozone-depleting chemicals (ODCs) in their own products or third-party products whose manufacture includes the use of ODCs, to label any resulting end product as such (Sharfman et al. 1997). Tofffel (2003) report the legislations calling for electronics recycling that were introduced in the states of California (SB 1523 and 1619 in 2002), Massachusetts (Bill 4716 in November 2001, Bill 1533 in January 2003), and Minnesota (HF 882 and SF 838 in 2003). In Germany, the Commercial and Industrial Waste Avoidance and Management Act

(KrW/AbfG) holds producers responsible for end-of-life disposition, recovery and reuse of their products (Guide et al. 2001).

Similarly, in response to the rapid growth of waste from electrical and electronic equipment, the European Commission has adopted two proposals for directives in June 2000; Waste Electrical and Electronic Equipment (WEEE) and Restriction of the use of certain Hazardous Substances in Electrical and Electronic Equipment (ROHS). These proposals emphasize on the principle of 'Extended Producer Responsibility', wherein producers are held responsible, individually or collectively (through a consortium of firms), for the environmental impact of their products through out the entire product life cycle, as well as when the products become waste. Manufacturers are required to pay for the end-of-life recovery costs (financial responsibility) and also take responsibility of collection, treatment, recovery and finally, environmentally safe disposal of the end-of-life products (physical responsibility). Thus the WEEE directive has made an attempt to address the recovery of end-of-life products whose producers exist.

Interestingly, the directive has also raised the issue of 'historical waste', i.e. waste from products sold in the market before the take-back legislations came into force. Historical waste may be of two types: those whose producers exist and those whose producers no longer exist due to business failure. The latter is referred to as O*rphan Products* (Toffel 2003). Two models were proposed to handle historical wastes. In the collective responsibility model, the cost of managing historical waste has to be shared by producers in proportion to their current market shares. A transitional phase of five years was allowed to producers to create funds for managing historical waste. On the other hand, in an individual responsibility model, firms need to build reserves and provide financial guarantee to cover costs of managing future orphan waste.

However, the most significant challenge comes from orphan products whose producers do not exist due to business failure. According to Hambrick et al. (1998), annual failure rate per 10,000 large firms rose from consistently bellow 100 between 1967 and 1982, to consistently over 300 since 1985. Clearly, in the context of reverse logistics, these firms potentially leave significant amount of orphan products, which can increase environmental pollution. An interesting fallout of these regulatory requirements is the core issue of recovery and safe environmental disposal of such products. In order to understand the challenges pertaining to reverse logistics of orphan products, we first identify various aspects of reverse logistics using a framework.

3. Reverse Logistics: A framework

Reverse logistics begins at the customer end and typically involves several entities, options and decision points. Figure 1 (p. 36) represents a simplified framework for reverse logistics, which is a modified version of Thierry et al. (1995). We use a three-dimensional classification to describe various aspects of reverse logistics: networks, decision options and entities. Earlier frameworks including that of Thierry et al. (1995) have not explicitly discussed the third dimension, viz., entities involved in reverse logistics in an integrated fashion as we have attempted here.

Networks in reverse logistics

As shown in figure 1, the entire reverse supply chain can be segmented broadly in two parts. The *Product Take-back Network* (PTN) pertains to collecting the product from the customer at the end of her use. Product acquisition, transportation and distribution of used products from consumers to one or more of the product recovery facilities are the major activities of this part of the network. In the *Product Recovery Network* (PRN), several players perform one or more of the several recovery activities such as reuse, repair, refurbishing, recycling, remanufacturing and disposal (landfill).

Decision options in reverse logistics

Critical decisions interface the two networks and provide overall directions as to how the product collected using the take back network is eventually recovered and/or disposed in an environmentally safe manner. These decisions, for instance, include which product recovery option to be used, who are the entities involved in each of these options, the competitive behavior of these entities and how the economic benefits are shared among the various players. Thierry et al. (1995) provides a detailed description of how these various product recovery options vary in degree of disassembly.

The network and decision options dimensions of the reverse logistics framework suggests that the activities in PRN are merely an operational deployment of the choices exercised under decision options and follows the activities of PTN.

Entities in reverse logistics

A majority of research in reverse logistics has focused on the network and decision options. However, it may be useful to bring another perspective to the problem by understanding the entities involved. Clearly, multiple entities are involved in a reverse logistics network and have multiple goals and motivation to participate. The customer and the regulatory agencies are important entities in reverse logistics. While the customer actions trigger other activities in the entire network, the regulatory agencies provide overall policy directives through legislation, monitor and control of several activities and entities involved in reverse logistics.

Recent regulatory postures clearly indicate that eventually the OEMs have the ultimate responsibility for product take-back and adhering to recycling targets. For example, the End-of-Life Vehicle Recycling Initiative (1996) of Japan and the EU Directive on End-of-Life Vehicles (2000) mandate that 95% of vehicle must be recycled by 2015 (Toffel, 2003). However, the product take-back activities may be organized in multiple ways. OEMs may either have their own setup to collect the used products, or use their trading partners such as retailers to perform the task, or engage third party agencies. Third party logistics providers are often involved in shipping the returns to recovery facilities.

In the PRN, players have different roles to play. The OEMs may take part in all of the product recovery activities such as repair, refurbish, remanufacture, and recycle. Alternatively, they may contract these activities to other players. If there are enough economic incentives, third-party agencies may collect and recover used products and sell them to secondary markets. However, this may have important marketing and economic implications in the long run (Fleischmann 2000)

The addition of the third dimension to the reverse logistics framework raises several interesting questions. Since there are multiple players and multiple arrangements among these players possible, an important question that arises is how are the product recovery activities ultimately organized among various entities in order to satisfy environmental goals and expectations of the regulators and the society? What are the implications of third parties performing certain task in reverse logistics vis-à-vis the OEMs? Analyzing the reverse logistics problem from a perspective of entities requires that the following issues are addressed: the ownership structure (who are the players involved and in which product recovery activities), factors governing the behavior of the players (the incentives of players to participate in product recovery activities), impact of regulation and strategic and economic advantages of making these choices.

The foregoing discussions show that in cases where OEMs of product continue to exist, there is scope to investigate the roles of various entities and alternative arrangements for reverse logistics. However, the nature of issues is likely to be different in the case of orphan products.

Orphan products: Implications for reverse logistics

Orphan products may be defined as products, at any stage of their life cycle, whose manufacturers do not exist currently or even if they exist, are not involved in the production or providing any kind of service associated with the product. The following situations often cause orphanage:

1. Products whose manufacturers no longer exist in business due to business failure
2. Products, whose manufacturers exist, but have stopped production and/or services associated with the products due to change in business strategy and product portfolio, or due to government regulation, which impose ban on certain products
3. Products whose manufacturers have stopped production and/or services associated with the products due to take-over by other firms and subsequently have changed product portfolio

It appears that orphan products may pose several challenges in all stages of the reverse logistics network that we discussed in the previous section and pose environmental threats in terms of increased landfill, which is a great concern for policy makers and the society at large. We identify some of them in this section. We observe that in cases (2) and (3), appropriate legislations can be brought in to ensure that firms take up responsibility of the end-of-life products that are not currently in their portfolio. Thus the environmental impact of such wastes may be reduced. However, the situation mentioned in (1) may lead to increased landfill and pollution as no firms might be willing to claim ownership of end-of-life orphan products. Clearly, the absence of the OEM poses the most significant challenge and could result in lack of accountability for the end-of-life recovery activities. The mandate of the existing legislations – compulsory physical responsibility, in terms of product acquisition and adherence to recycling targets at the end of product life, is severely threatened.

Second, non-availability or difficulty in obtaining certain key information could de-motivate other players to take up recovery activities of orphan products. Thierry et al. (1995) argued that third party agencies would select product recovery options based on information on products, such as materials used, their value and potential hazardous nature. Furthermore, other information such as know-how of product recovery and waste management operation, magnitude and uncertainty of return flows and market opportunity of remanufactured products are critical factors that create incentives for other players to engage in product recovery activities. In the case of orphan products such information may not be available, which could introduce further complexities to the problem.

Finally, the timing and type of product return (commercial return, warranty return, repair, end-of-use return or end-of-life return) determine the residual value that can be recovered from used products. The more is the time taken to retrieve returned products, the less is the chance of economic and viable reuse. Products with high obsolescence, such as consumer electronics are less likely to be recovered if there are delays in the reverse supply chain. Delays in retrieval potentially occur in the case of orphan products due to two reasons: third party agencies may not be aware of the customer base of orphan products or customers may not be aware where to return the used products.

These challenges indicate that the PTN may become the potential bottleneck stage in reverse logistics of orphan products. It is well known that remanufacturing is a better alternative to disposal because it reduces the total environmental burden. Policy makers would like to reduce the amount of landfill by increasing net remanufacturing activity. However, they cannot control exit of firms (business failures), which is governed by several other factors. In case of orphanage who will the regulator pin the responsibility on? What are the options available to pursue targeted environmental goals? What factors will drive various entities to participate in this process? Legislators may like to contract with third parties for the collection, recycling and environment friendly disposal of end-of-life orphan products and use the reserves to cover the associated costs. However, it is not clear what factors will motivate the third party to engage in product recovery and remanufacturing activities of such products.

4. Product take back Network: A survey of research

Literature in reverse logistics has addressed several functional issues, such as, design of reverse logistics network, economics of remanufacturing operations, forecasting of returns, inventory management, production planning, shop floor scheduling and competition issues in remanufacturing. To the best of our understanding, these issues pertaining to orphan products have received a scanty attention in both research and practice. However, to ascertain our conjecture that the PTN is the bottleneck step in reverse logistics of orphan products, we have surveyed the literature during the last ten years.

The goal of our survey is two fold:

a) To understand the nature of issues addressed in the reverse logistics literature in general and those pertaining to PTN in particular to deduce the salient aspects pertaining to entities and their roles in PTN
b) To relate the existing research to the issue of orphan products and identify useful areas for future research

Research Methodology

We review extant literature on reverse logistics that have been published in 27 peer-reviewed journals during the period 1996 – 2006. We focus on this period for two reasons. First, during this period various legislations on extended producer responsibility and end-of-life product recovery have come up. Second, there has been an increased level of research and publication pertaining to these issues during this period. Our choice of journals are mainly from two regions; the EU region, where the regulatory initiatives have resulted in active research and practice of reverse logistics leading to a rich collection of literature on the topic and those published from USA, which often tend to address contemporary issues in management and practice.

Table 1(a) (p.33) shows the list of journals that we have considered for the survey and the number of papers that have appeared during the chosen time of our study. In all, we have covered 144 articles. More than half of these papers appeared in journals published from Europe, reflecting the high levels of interest in the region. Table 1(b) (p.33) provides the areas of work in reverse logistics covered in these papers. It is clear from the table that a number of studies have addressed issues pertaining to PRN, which include economics of remanufacturing operations, forecasting of returns, inventory management, production planning and control, shop floor scheduling (see table 2, p.34). A significant amount of work (31 papers in our list) addressed general issues highlighting the importance of green supply chains, strategic issues and frameworks in reverse logistics. However, we found limited work (refer table 3, p. 35) on PTN.

Research pertaining to Product Take back Network

We review literature that address issues in the PTN and categorize them into three dominant areas of work, viz. product acquisition, logistics design, players and competition.

Product acquisition

Product acquisition is the first step in the PTN, where used products are collected from customers. Guide et al. (2001) insist that firms should manage product returns, by using market-driven system instead of passively accepting the waste stream system. Controlling quantity, quality and timing of returns determines profitability of operational issues, such as production planning and control policies, inventory policies etc. in the PRN. The authors also propose a decision framework, based on the EVA concept, to assess potential economic benefits of product recovery activities.

On the issue of product acquisition, literature has addressed design of return policies for maximizing profit of product recovery activities. Guide et al. (2003) develop a profit maximization problem for a remanufacturer and determine the optimal acquisition prices and optimal selling prices for remanufactured products. Ray et al. (2005) study the optimal pricing/trade-in strategies for a profit-maximizing firm selling durable and remanufacturable products to replacement customers. The authors consider three pricing schemes and identify the most favorable pricing strategy for the firm when faced with a particular market condition. Mukhopadhyay et al. (2004) consider a retailer who sells directly through the Internet and develop a profit-maximization model to obtain optimal policies for price and the return policy in terms of certain market reaction parameters. The authors show a number of managerial guidelines for using marketing and operational strategy variables to influence the reaction parameters so as to obtain the maximum benefit from the market.

Another body of literature within product acquisition discusses different collection schemes by OEMs and the involvement of third parties. Savaskan et al. (2006) considered two collection choices of an OEM, viz. the direct collection system and the indirect collection system (through retailers) to collect post consumer goods and examined how the allocation of product collection to retailers impact their strategic behavior. In an earlier work, Savaskan et al. (2004) considered subcontracting to a third party along with these two collection options and a decentralized decision making system, with the OEM being the Stackelberg leader. The authors find that the agent who is closer to the customer (retailer) is the most effective undertaker of product collection activity for the OEM. Jahre (1995) surveys collection schemes for household wastes and finds that postponing separation and sorting in reverse distribution channels increases customer service and reduces unit costs because of volume efficiencies. Mukhopadhyay et al. (2006)

propose the use of a fourth party logistics (4PL) as a return service provider, and develop profit-maximization model to jointly obtain optimal policies for the OEM and the 4PL. Among the managerial implications cited in this paper, it is important to note that the profits of OEM and 4PL increases with increasing customer's sensitivity of demand with respect to the generous return policies.

Players and Competition

Literature on competition in remanufacturing is broadly confined to analyzing the factors that define the role of independent remanufacturers vis-à-vis OEMs for remanufacturing of returned products. None of the studies have addresses a situation of absence of OEMs.

Heese et al. (2005) showed that a firm could gain a competitive edge by introducing product take-back. The first firm to offer take-back sometimes can deter its competitor from following this profitable strategy, especially if the product has high price sensitivity and a high degree of substitutability and if the firm has some additional advantages in terms of production cost or market share. They find that though product take-back is always beneficial to the customers and hence should be supported by lawmakers, it depends on the degree of competition. However, Ferguson et al. (2004) observed that sometimes OEMs choose not to remanufacture as the remanufactured product cannibalizes sales of the higher-margin new product. They find that this strategy may backfire for OEMs when the end-of-life products are attractive to independent remanufacturers and hence analyze two entry-deterrent strategies: remanufacturing and preemptive collection.

Given the existence of secondary markets and the cost benefits accruing to a player through remanufacturing, literature has also addressed a combination of players (OEMs, third party) who compete for returned products and take part in remanufacturing. Majumder et al. (2001a) considered a two-period model where both the OEM and an independent remanufacturer compete and set prices. The OEM may choose to remanufacture or not in the second period based on the "shell allocation mechanism" observed in the respective market. They showed the existence of unique pure-strategy Nash equilibrium solution for the problem.

Ferrer et al. (2006) studied the duopoly environment, where an independent remanufacturer intercepts a fraction of the used products made by the OEM, in two-period and multi-period scenarios. They obtain closed-form solutions for prices and quantities in the Nash equilibrium and characterize the optimal solution region. They find that if remanufacturing is very profitable, the OEM may forgo some of the first-period margin by lowering the price and selling additional units to increase the number of returned products available for remanufacturing in future periods. Moreover, the market share of the independent remanufacturer increases with the remanufacturing savings. If the remanufacturing savings is very high, threat of competition increases, and the OEM is more likely to completely utilize all available returns, offering the remanufactured products at a lower price.

Webster et al. (2007) consider that the OEM does not engage in remanufacturing but a remanufactured product cannibalizes the new products. Assuming a two-period model where the manufacturer launches new generation of a product in the first period, a remanufacturer acquires returns at the end of the first period, and the manufacturer and remanufacturer compete for sales in the second period, the authors show that industry is better off with take-back laws than without.

Andreas et al. (2005) study the integrated remanufacturing and procurement decision of a reseller, who is not the OEM but has remanufacturing capability. They model a heterogeneous supply of used or end-of-life mobile phones and a heterogeneous demand for these phones in the secondary markets and determine the optimal number of used products that should be procured, the cut-off quality level of a product to decide whether it should be remanufactured or disposed and the optimal number of products that should be remanufactured

Logistics

Another stream of research has focused on logistics design issues. Fleischmann et al. (2001) present a generic facility location model and discuss differences with traditional logistics settings. They analyze the impact of product return flows on logistics networks and argue that the influence of product recovery is very much context dependent. While product recovery may efficiently be integrated in existing logistics structures in many cases, the authors cite other examples require a more comprehensive approach redesigning logistics network in an integral way. Other work in this area focus on quantitative models and applications of various tools such as math programming, simulation etc. to design the logistics network, determine facility locations and optimal vehicle routings.

However, these work do not explicitly discuss the players involved and their motivation in participating in logistics activities. On the other hand, they focus on specific solution methodologies that one could adopt to solve the logistics problem on hand. Therefore we do not dwell further into this topic.

The interesting fall out of these studies are several. First, multiple players could potentially take part in reverse logistics and the studies portray the existence of competition for returned products. One can broadly classify them as OEMs and third parties. For profitable product recovery, OEMs should acquire right quality and quantity of returned products and hence should formulate optimal return policies. Furthermore, in order to operationalize product acquisition, OEMs may co-opt third party economic agents. The role of these players influences the design of return policies of the OEMs.

Second aspect is the issue of competition in remanufacturing. Competition is due to economic benefits realized from product recovery. In such a scenario the critical decision is how the OEMs can control the overall product recovery network. The studies indicate that due to significant economic benefits to the players an appropriate policy framework would guide the manner in which the entire activity is organized. Furthermore, OEMs can devise strategies and incentives to control the magnitude and timing of returned product flows into the hands of independent remanufacturers in the context of the economic attractiveness of returned products.

Some studies indicated that the role of the players, the economic benefits and the nature of the competition that can emerge are significantly impacted by the returned product characteristics. Used product characteristics determine the recoverable value, which in turn drives the economic feasibility of handling returns and extraction of value. For e.g., capital goods, such as photocopiers, machine tools, power generators, ships and aircrafts are often exclusive in design and manufacturing, requires high cost of collection, handling and transportation and also involves huge capital investments to remanufacture. This may serve as a barrier for independent remanufacturers to take up product recovery activities even if the recoverable value is high. However, there are products like cell phones, tires, computers and automotive parts which do not involve huge investments in remanufacturing and hence are often attractive to independent remanufacturers. Such products may be readily acquired at the end-of-life. Therefore, the stage of life cycle of the product, the existence of secondary markets and cannibalization of another product by the remanufactured product are some aspects of the returned product profile that determine its attractiveness.

Returned product characteristics also impact the nature of environmental threats. Regulatory agencies respond to these threats through specific regulations such as WEEE, ROHS and End-of-life Vehicles as we have already discussed. Clearly, regulatory issues are integral to any analysis of reverse logistics and influence the behavior of various players in the network. However there are hardly any work dealing with a policy framework to assess the impact of regulatory requirements such as product take-back laws.

Based on literature review, we develop a framework as shown in Fig 2, to identify the following factors that govern the strategic behavior of players in the product take-back network

- Returned product characteristics: the recoverable value in the returned product depends on the nature of the product (durables, semiconductors, hazardous substances etc.) and the stage of the product life cycle.
- Economic issues: Cost benefits of product recovery, which depends on the product characteristics, product reusability and substitutability and know-how of optimal remanufacturing operation.
- Policy and regulatory issues: Based on the potential impact of the used products on environment, legislations like compulsory take-back laws at end-of-life and legislations imposing recycling targets are framed.
- Role of players and competition issues: Given market for remanufactured products exist and players have economic advantage in acquiring and remanufacturing used products, OEMs and independent remanufacturers compete for used products.

5. Research Issues for Orphan Products

The framework indicates potential areas that need to be focused in the case of orphan products. The first major aspect that requires careful analysis is the role of players when OEMs no longer exist. In figure 2, we show that certain links no longer exist in the case of orphan products (shown using dotted lines). Past studies have invariably assumed OEMs to be present and to play a leadership role in product recovery. In all studies involving multiple players, the analysis proceeds along the lines of OEMs sharing the economic gains in a particular fashion. These aspects make the analysis restrictive in the case of orphan products. In the absence of OEMs, the responsibility to ensure targeted levels of product recovery shifts entirely into the hands of the regulation. Research in orphan products must address this issue in detail. Several question emerge for possible analysis:

(a) What factors will drive the independent economic agents to voluntarily engage in product recovery activities in the case of orphan products?

(b) What kind of incentive mechanisms that the regulatory agencies must design to attract the independent economic agents to engage in product take back and recovery activities?

(c) Currently, very little work has progressed on alternative regulatory formulation for future orphanage. There are uncertainties associated with predicting future orphanages and operational challenges in implementing regulatory requirements (see Toffel, 2003 for details). More work is needed to identity effective regulatory policies for optimal control and enforcement of future orphanage.

The other issue pertains to the competitive dynamics of other competing products to that of an orphan product. Since an orphan product has lost the locus of control, competitors can devise strategies to take back and recover an orphan product. It is interesting to explore any operational and/or strategic advantages of recovering and remanufacturing an orphan product. Modeling the behavior of other players and their approach towards orphan products may provide more insights to the regulatory agencies to devise effective policies and incentive mechanisms to prevent future orphanage.

6. Conclusion

Product recovery activities are gaining increased importance with the growing pressure of regulation on businesses to reduce the adverse environmental impact of their products. In this paper we highlight the regulations that hold OEMs responsible for compulsory take back and recovery of their products at the end-of-life. However, when the OEM ceases to exist, the challenge lies in acquisition and recovery of her orphan products and hence could lead to potential environmental threats. We present a reverse logistics framework that involves various product take back and product recovery activities. We emphasize that multiple players are involved in reverse logistics. We review literature on product take back and product recovery activities to identify the various roles played by the OEM and third parties. Based on literature review we develop a framework and show the various factors that govern strategic behavior of players. Whether other players would take up orphan products for recovery and reuse depends on the product characteristics, economic benefits and the role of regulations in providing adequate incentives. Therefore, more research is required on framing incentive mechanisms for third parties to take up recovery of orphan products.

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Table 1 (a): Journals covered for articles in Reverse Logistics: 1996-2006

Journal Name	# of articles
International Journal of Production Economics	24
European Journal of Operational Research	24
International Journal of Production Research	14
Omega	14
International Journal of Physical Distribution & Logistics Management	8
California Management Review	9
Management Science	8
Production & Operations Management	7
Interfaces	6
Supply Chain Management: An International Journal	3
International Journal of Operations and Production Management	4
Journal of Operations Management	4
Manufacturing & Services Operations Management	2
Harvard Business Review	3
Journal of the Operational Research Society	2
European Management Journal	1
Decision Sciences	1
Logistics Information Management	1
Production Planning & Control	1
The Journal of Business & Industrial Marketing	1
Management Research News	1
Transportation Research Part E	1
Industrial Management & Data Systems	1
MIT Sloan Management Review	1
Proceedings of The Institution of Mechanical Engineers	1
IIMB Management Review	1
Journal of Business Logistics	1
Total	**144**

Table 1 (b): Number of articles across various areas of work in Reverse Logistics

Area of work	# of articles
Product Recovery Network (PRN)	71
Product Take-back Network (PTN)	42
Framework of Reverse Logistics	15
Survey and general issues in Reverse Logistics	16
Total	144

Table 2: Literature on Product Recovery Network (PRN)

Inventory Management	Scheduling	Economics of Remanufacturing
Mahadevan et al. 2003	Ketzenberg et al. 2003	Gonzalez aet al. 2005
Choi et al. 2006	Guide 1996	Willems et al. 2006
van der Laan et al. 2005	Guide et al. 2005	Lebreton et al. 2004
van der Laan et al. 1997	Guide et al. 1997b	Souza et al. 2002b
van der Laan et al. 1999		Erdos et al. 2001
van der Laan et al. 1996a	**Forecasting**	Ferrer 2001
van der Laan et al. 1996b	Maples et al. 2005	Matthews 2004
van der Laan et al. 2003	Kelle et al. 1989	Dobosa et al. 2006
van der Laan et al. 1999a		Nakasimha et al. 2004
Kiesmulle 2003a	**Line Balancing**	Nakasimha et al. 2002
Kiesmulle 2003b	Seamus et al. 2005	Richter et al. 2003
Gregory et al. 2005	Kekre et al. 2003	Seitz et al. 2004
Kiesmuller et al. 2003c		Tang et al. 2004
Kiesmuller et al. 2001	**Production Planning**	Ayres et al. 1997
Konstantaras et al. 2007	Franke et al. 2006	Geyer et al. 2004
Dobos 2003	Ferrer et al. 2001	Teunter et al. 2002b
Mostard et al. 2006	Souza et al. 2002a	Teunter 2006
Inderfurth et al. 2001a	Guide et al. 1997a	Gerner et al. 2005
Inderfurth et al. 2001b	Guide et al. 1998	Mitra 2005
Inderfurth 2004	Guide et al. 2003	
Richter et al. 2001	Guide 2000	
Richter et al. 2000	Lia et al. 2007	
Toktay et al. 2000		
Zhoua et al. 2006		
de Brito et al. 2003		
Fleischmann et al. 2003		
Tang et al. 2005		
Teunter et al. 2004		
Teunter et al. 2002a		
Teunter et al. 2000		
Minner 2001		
Mitra 2006		
Bayındır et al. 2003		
Bayındır et al. 2006		
Wanga et al. 2006		
Bayındır et al. 2005		

Table 3: Literature on Product Take-back Network (PTN)

Players & Competition	Logistics design	Product Acquisition
Breen 2006	Krikke et al. 2004	Jahre 1995
Meade et al. 2002	Blackburn et al. 2004	Mukhopadhyay et al. 2004
Krumwiedea et al. 2002	Listese et al. 2005	Mukhopadhyay et al. 2006
Kokkinaki et al. 2002	Schultmann et al. 2006	Savaskan et al. 2004
Heese et al.2005	Salema et al. 2006	Savaskan et al. 2006
Andreas et al. 2005	Fleischmann et al. 1997	Guide et al. 2001
Majumder et al. 2001a	Jayaraman et al. 2003	Guide et al. 2003
Majumder et al. 2001b	Kroon et al. 1995	Ray et al. 2005
Ferguson et al. 2004	Autry et al. 2001	
Webster et al. 2007	Aminia et al. 2005	
Ferer et al. 2006	Kara et al. (Article in press)	
Debo et al. 2005	Krikke et al. 2003	
	Guide et al. 2000	
	Guide et al. 2005	
	Jayaraman et al. 1999	
	Guide et al. 2006	
	Fleischmann et al. 2000	
	Mina et al. 2006	
	Pati et al. 2006	
	Min 1989	
	Fleischmanna et al. 2001	
	Beamon et al. 2004	

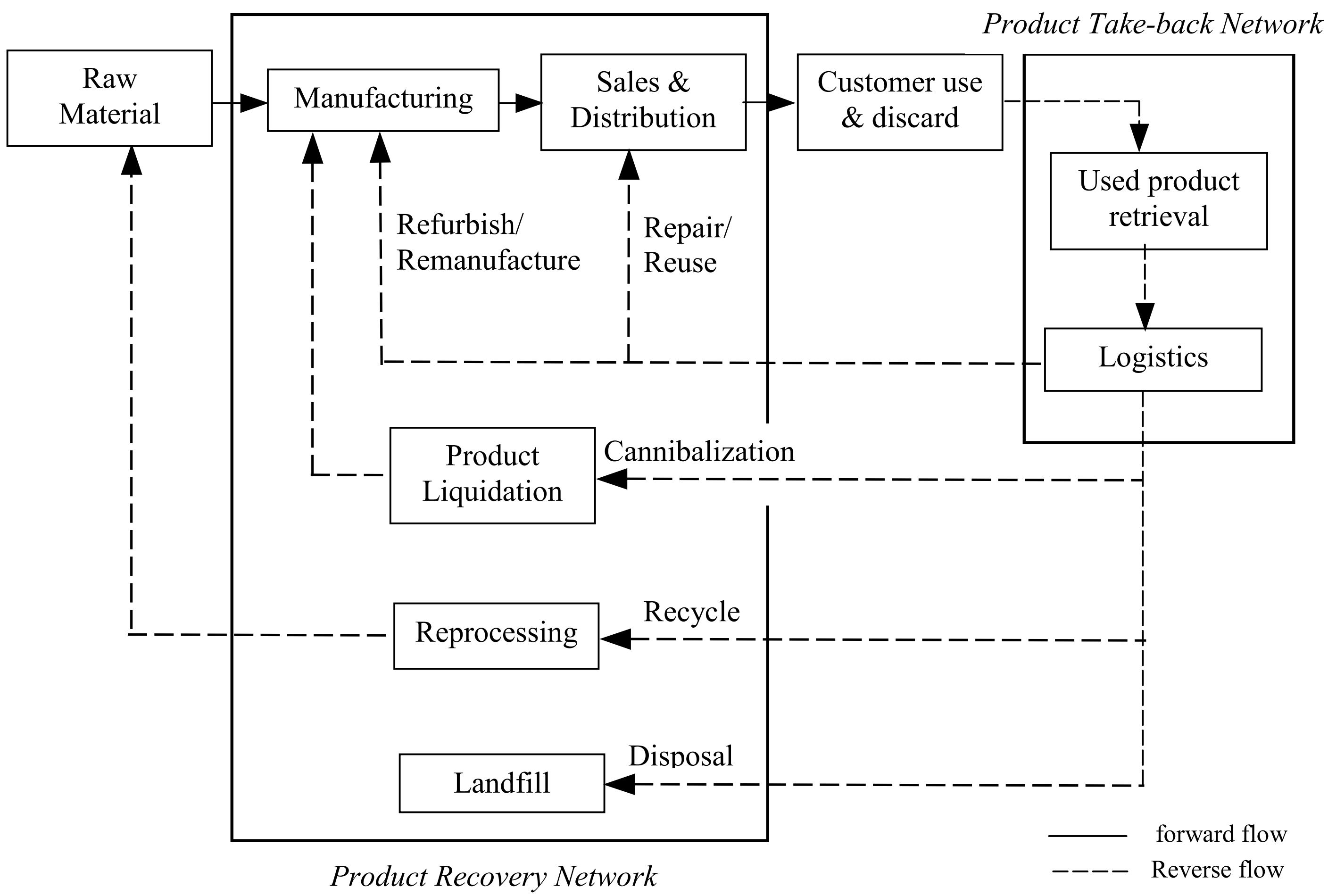

Fig 1: A generic reverse supply chain framework

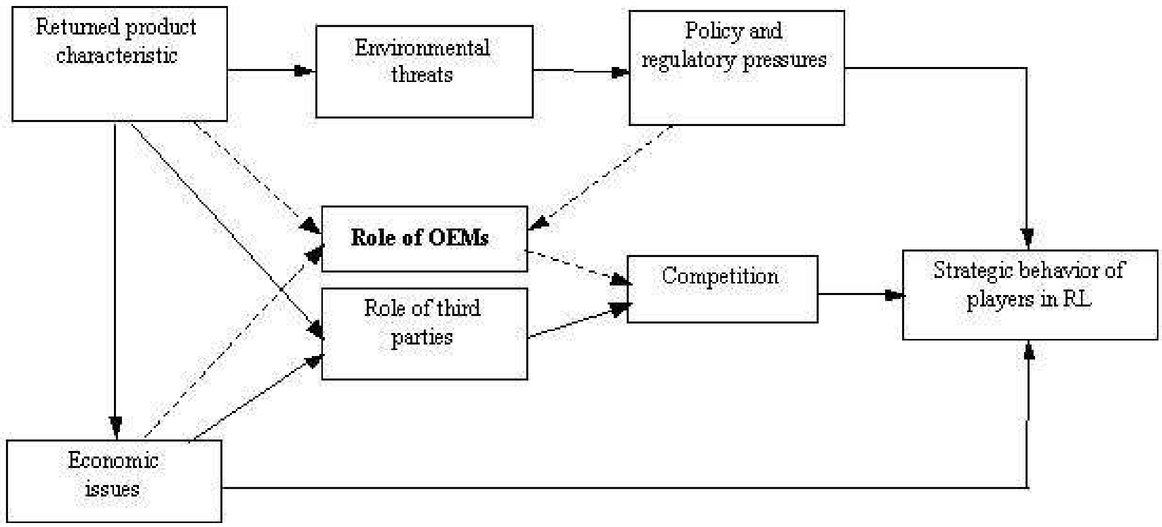

Fig 2: Drivers of Product Take-back Network