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Role of information technology and collaboration in reverse logistics supply chains

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Closed-loop supply-chain channels are distribution systems that include activities supporting both the forward flow of goods from the manufacturer to the consumer as well as the reverse flow from the consumer to the manufacturer. In this paper, we identify the reverse logistics supply-chain channels, identify problems that companies face when they handle product returns along these channels and present the critical role that information technology and collaboration can play to mitigate many of the problems and deficiencies. A key element in reducing uncertainties in the different stages of the reverse channel of a supply chain is access to accurate and timely information on the status, location, and condition of products moving about in the supply chain. It is imperative that firms operating in the reverse supply-chain channels collaborate to integrate and share information in a timely fashion. We present a case study based on our interaction with two major consumer electronics companies and demonstrate how the use of radio frequency identification device technology in a warehousing operation can reduce the overall distribution costs for the organisation.

Keywords: supply-chain management; reverse logistics; RFID; collaboration; information technology

1. Introduction

Closed-loop supply-chain (CLSC) channels are distribution systems encompassing both the forward flow of goods from the manufacturer to the consumer, as well as the reverse flow from the consumer to the manufacturer. The forward channel is relatively straightforward and well understood. Reverse logistics involve managing the receipt, handling and disposition of returned merchandise. The reverse logistics functions are comprised of a set of unique, complicated and time-sensitive tasks. Hence, optimal performance of these tasks which include inspection of returned products, crediting customer accounts and resale of the returned merchandise etc. require specialised operations and information technologies (ITs). Achieving efficiencies in the reverse channel is more difficult due to the nature of these operations involved. The focus of this article is on how collaboration amongst reverse channel partners and use of IT can improve the efficiencies of operations in this channel. In recent years, there has been a surge in the traffic volume

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in the reverse channel due to a variety of factors. For example, warranties, return policies and competitive pressures have forced companies to accept returns more so today than in the past. Additionally, environmental and legislative pressures have forced companies to accept products at the end of their useful lives (*e.g.* toner cartridges and disposable cameras).

With the explosion of online and mail order retailing, and the high rates of product returns associated with these channels, manufacturers are finally paying close attention to the importance of having an effective reverse logistics system. In terms of traffic volume, it is predicted by Forrester Research Group that the value of returned goods, through internet channels alone, will be over $11 billion by 2010, with the cost of processing those returns about $9 billion (http://www.internetretailer.com/internet/marketing-conference/35906-dealing-returns.html, Connaughton 2006). Given that online commerce still constitutes a small percent of total commerce, assuming a 10% volume due to online commerce, the overall traffic of returned goods would be of the order of $110 billion with costs of handling those returns about $90 billion. Given these trends, there is a need for businesses to adopt new technologies and collaboration amongst channel members to mitigate some of the costs involved in the reverse channel.

A successful remanufacturing and recovery operation has to be good at wringing productivity out of materials and resources. Table 1 (Guide *et al.* 2000) shows the key differences between reverse logistics and forward supply chains across different factors such as environmental, design, logistics and forecasting.

A critical issue in recoverable manufacturing that includes refurbishing and remanufacturing is easy access to used products. Remanufacturing requires that used products be obtained from the end-user at the end of their current life cycle so that the value added may be recovered and the products returned to functional use again (Guide *et al.* 2000). Products to be remanufactured need to be collected and completely disassembled. Each part is cleaned, inspected, then refurbished or replaced while parts that are damaged may require some amount of repair. Parts are then reassembled and tested to ensure that they perform to original specifications. The performance of

Table 1. Key differences between reverse logistics and forward value chains.

Factors	Reverse logistics recoverable value chains	Traditional (forward) value chains
Environmental Focus	Focus is to prevent post-production waste from occurring	Focus in on pre-production and pollution prevention/ remediation
Design	Remanufactured products have to be designed for easy disassembly. While this may add some cost up-front, the pay-off will occur during the product's second, third or fourth life cycles	Focus in on environmentally conscious design, fabrication and assembly
Low Fashion	Remanufacturing is mostly used in heavy industrial applications where customers care more about performance rather than looks.	Novelty is a key marketing issue. While performance is most definitely an order winner, it pays to be fashionable in most industries
Logistics	Forward and reverse flows Uncertainty in timing and quantity of returns Supply driven flows	Focus on open forward flow No need to handle returns Demand driven flows
Forecasting	Need to forecast both the availability of core and demand for end products	No need for parts forecasting Focus on forecasting end products only

remanufactured products must be as good as new, in order to compete with new products. Some of the industries and name-brand companies that support recoverable manufacturing include: diesel engines (Caterpillar), disposal cameras (Kodak), copiers (Xerox and Canon), furniture (Miller SQA) and cell phones (Motorola). In the literature dealing with reverse logistics value chains, one can find several case studies and work focused on quantitative modeling. For an overview of case studies on this topic, the reader is referred to De Brito *et al.* (2003). For an overview on quantitative modeling, the reader is referred to Fleischmaan *et al.* (1997). In addition, for more overviews on reverse logistics value chains, the reader is referred to the following body of literature: Stock 1992, Rogers and Tibben-Lembke 1999, Guide *et al.* 2000, Linton and Jayaraman 2005, Jayaraman and Luo 2007, Linton *et al.* 2007.

Extending the value chain to include recovery operations, such as recycling, reuse, and remanufacturing adds an additional level of complexity to value chain design and a new set of strategic and operational issues. These issues arise from two fundamental problems: uncertainty associated with the recovery and replacement process with regards to quantity, timing and quality of returns; and the process associated with collection and transportation of used products and packaging. From an industry perspective, various companies such as Canon, Philip Morris, IBM, Estee Lauder, HP and Nortel Networks have all allocated a number of resources toward the practice of reverse logistics (Meijer 1998, Andriesse 1999, Meyer 1999, Toktay *et al.* 2000, Linton and Johnson 2000). The operational aspects of such recovery operations have received the most attention, with a number of publications dealing with inventory control (Van der Laan *et al.* 1996, 1999, Toktay *et al.* 2000), production planning and control (Souza *et al.* 2002, Ferrer and Ketzenberg 2004) and disassembly planning and scheduling (Johnson *et al.* 1995 Sodhi and Knight 1998, Guide *et al.* 1999). Strategically, this problem is often viewed as a narrowly focused issue without any visibility at the corporate level.

In this paper, we identify the costly bottlenecks in the reverse channel and offer some technology solutions to alleviate those costs. Through an analytical model, we study the sensitivity of certain cost-saving factors on reverse-channel value. A large-scale simulation case study based on two large electronic manufacturers demonstrates the reduction in cost through the use of radio frequency identification device (RFID) technologies.

2. Reverse channel activities

The reverse channel activities (Jayaraman *et al.* 1999, Guide *et al.* 2000) include:

(1) Product acquisition – activities required to collect returned goods from the end-users or consumers.

(2) Testing, sorting and disposition – activities that evaluate the condition of the returned goods and determine the most appropriate mode of disposition, *i.e.* reuse, recycle or remanufacture. In the reuse option, the product can be resold without any further processing. This would be the case if a product was returned because the consumer changed their mind about their purchase and the product was in good condition. In the remanufacture disposition option, the product enters the reverse channel at the fabrication stage where it is disassembled, remanufactured, and reassembled to flow back through the forward flow channel as a remanufactured product. This option is exercised if goods with defects are returned or if goods which have run their useful lives can be remanufactured. In recycling, the last disposition option, the product enters the reverse value channel in the raw-material procurement stage where it is used with other raw materials to produce new products. In recycling, the identity and functionality of products and components is lost.

(3) Reverse logistics – activities required to physically move the goods from the point of collection to the disposition destination.

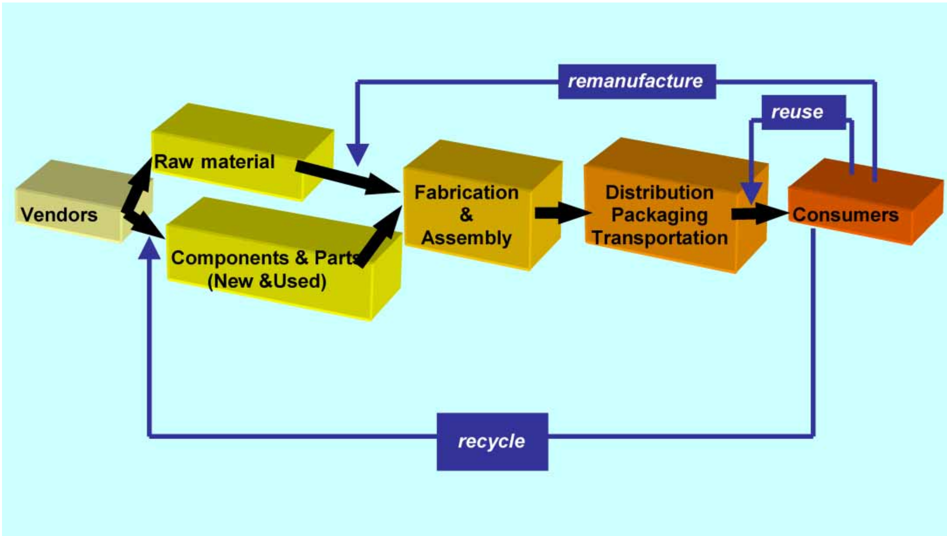

Figure 1. Various disposition policies for product return.

(4) Remanufacture, recycle and reuse – activities required to proceed with the most economically and technically feasible disposition option. The activities in this stage are very product specific.
(5) Marketing – activities required to create and exploit the markets for refurbished or recycled goods (Figure 1).

Based on these activities, we develop a mathematical model for analysing the reverse-channel value and the value added due to technology.

2.1. *Analytical model for reverse channel value*

To develop an analytical model to estimate the value in the reverse channel, we first define some cost and revenue terms as follows: these costs and revenue terms apply to an organisation involved in reverse logistics. We assume that the organisation makes an initial capital investment in setting up systems to handle the various reverse logistics activities and then incurs recurring annual costs to handle the various activities and to maintain the infrastructure. We assume that the initial investment serves the company for a number of years.

2.1.1. *Initial investment without IT investment*

Let IntInvInf: Initial Investment in Infrastructure to handle reverse logistics, not including IT investment, IntInvIT: Initial Investment in IT to handle reverse logistics.

Recurring annual values: N the useful service life in years for the initial capital investment; $C_{\mathrm{Aq},i}$ cost of operations for the acquisition of returned goods in year i; $C_{\mathrm{tsd},i}$ cost of testing, sorting and disposition in year i; $C_{\mathrm{tr},i}$ cost of transportation for appropriate treatment in year i; $C_{\mathrm{RRR},i}$ cost of refurbishing, recycling or reusing in year i; $C_{\mathrm{m},i}$ cost of marketing, in year i.

We assume that these costs include the costs of maintaining the facilities that support these activities. We next assume that implementing technological solutions will improve the efficiencies of some of these activities and result in cost reductions. However, implementing a technology also comes at a cost and therefore a reduction in overall cost implies that the reduction in costs (without technology) exceeds the extra cost of using the technology.

Let β represent the cost reduction factor due to these efficiencies. If there is a net reduction in the cost, then β lies between 0 and 1. A β of 0.8 would imply that costs are reduced to 80%. A β of 1 implies no net cost reduction. If there is no net reduction in costs, *i.e.* the cost reduction is less than the cost of the technology, β can exceed 1. In the absence of technology, β defaults to 1. So without loss of generality, we can assume β to be between 0 and 1.

β_{Aq} : cost reduction factor due to technology for the acquisition activities.
β_{tsd} : cost reduction factor due to technology for the testing, sorting and disposition activities.
β_{tr} : cost reduction factor due to technology for the transportation activities.
β_{rrr} : cost reduction factor due to technology for the refurbishing, recycling, reusing activities.
β_{m} : cost reduction factor due to technology for marketing activities.
$\mathrm{REV}_{\mathrm{RRR},i}$: revenue from refurbished, recycled or reused goods in year i.
$\mathrm{VAL}_{\mathrm{RC}}$: value of reverse channel.

In the absence of technology,

$$\mathrm{VAL}_{\mathrm{RC}} = \left(\sum_{i=1}^{N} \mathrm{PV}\big(\mathrm{REV}_{\mathrm{RRR},i} - (C_{\mathrm{Aq},i} + C_{\mathrm{tsd},i} + C_{\mathrm{tr},i} + C_{\mathrm{RRR},i} + C_{\mathrm{m},i})\big)\right) - \mathrm{IntInvInf} \quad (1)$$

Where PV represents the present value of the future cash flows.

In the presence of technology,

$$(\mathrm{VAL}_{\mathrm{RC}})^{\mathrm{tech}} = \left[\sum_{i=1}^{N} \mathrm{PV}\big(\mathrm{REV}_{\mathrm{RRR},i} - (\beta_{\mathrm{Aq}}.C_{\mathrm{Aq},i} + \beta_{\mathrm{tsd}}.C_{\mathrm{tsd},i} + \beta_{\mathrm{tr}}.C_{\mathrm{tr},i} + \beta_{\mathrm{RRR}}.C_{\mathrm{RRR},i} + \beta_{\mathrm{m}}.C_{\mathrm{m},i})\big)\right] - (\mathrm{IntInvInf} + \mathrm{IntInvIT}) \quad (2)$$

Value added due to technology:

$$\left[\sum_{i=1}^{N} \mathrm{PV}\big[(1-\beta_{\mathrm{Aq}}).C_{\mathrm{Aq},i} + (1-\beta_{\mathrm{tsd}}).C_{\mathrm{tsd},i} + (1-\beta_{\mathrm{tr}}).C_{\mathrm{tr},i} + (1-\beta_{\mathrm{RRR}}).C_{\mathrm{RRR},i} + (1-\beta_{\mathrm{m}}).C_{\mathrm{m},i}\big]\right] - \mathrm{IntInvIT} \quad (3)$$

Although use of various technologies can favorably impact all five β values in Expression (3) above, we will focus on technologies that can reduce β_{Aq}, β_{tsd} and β_{tr}. To get a sense of how sensitive even small reductions in β_{Aq}, β_{tsd} and β_{tr} are, we must consider the magnitudes of C_{Aq}, C_{tsd} and C_{tr}. Given that in 2010, the sum of the five costs is estimated to be of the order of 90 billion. Suppose the three cost factors C_{Aq}, C_{tsd} and C_{tr} combined amount to 40% of the total costs or roughly 36 billion, a β_{Aq}, β_{tsd} and β_{tr} average value of even 0.8 will amount to savings of 7.2 billion (20% of 36 billion). In a case study which we describe later in the paper, we find that use of RFID tagging, instead of bar-codes can reduce β_{Aq} and β_{tsd} to as much as 0.67. A β value of 0.67 for all cost components could potentially provide savings of 30 billion (33% of 90 billion). In the next section, we will look at the reverse channel activities more closely and identify areas where technology can provide cost savings.

Of course, the savings come at the expense of some costs of implementing and operating the technological solutions which in expression (3) appear as (i) IntInvIT or the initial investment in technology and (ii) operating costs embedded in β. If the cost of operating the technology equals to the reduction in operating costs in the absence of technology, then β equals to 1. The present value of the savings over the useful life must of course be greater than the initial investment to make the investment economically feasible.

2.2. *Discussion of costs for adopting IT solutions*

There are two types of costs involved with any IT-based solution – an initial capital cost and an operating cost. For example, if an RFID-based solution for tracking inventory is implemented, the initial costs would include the cost of setting up the infrastructure for reading the RFID tags. These costs can include RFID readers, the cost of software that handles the interface between RFID readers and the existing inventory system and the cost of training the workers on the use of new system. The operating costs would include (i) the cost of the RFID tag itself (ii) the cost of tagging each inventory item and (iii) the cost of maintaining the RFID readers, and the software upgrades.

To set up a web-based system for returns, for example, the initial capital costs will include the cost of building, testing and implementing the web application and integrating it with the existing IT infrastructure of the organisation and the cost of any additional servers to run the applications. The operating costs would include the costs of maintaining the servers, the cost of software upgrades and the cost of recovering from breakdowns and/or failures. To implement any collaborative effort between two parties using technology, again there will be two types of costs – capital cost of developing, testing and implementing the collaborative system, and integrating it with the existing IT systems of each of the parties involved. These costs can include hardware, software and personnel and training costs. The operating costs will include the costs of maintaining the servers, the cost of software upgrades and the cost of recovering from breakdowns and/or failures.

2.3. *Problems with reverse channel*

We identify here some problems that firms engaged in reverse supply-chain channels would face in the near future:

2.3.1. *Lack of information and technological systems*

Dearth of good information systems is a serious problem faced by firms engaged in the implementation of reverse logistics. Efficient information systems are needed for individually tracking and tracing product returns and linking them to initial sale. In a survey conducted by Rogers and Tibben-Lembke (1999), manufacturers lag behind retailers in almost every technology category (Tables 2 and 3).

The survey also indicated that retailers are also more likely to use barcodes, computerised return tracking, electronic document interchange and radio frequency to enhance their reverse logistics management. This problem keeps β_{Aq} and β_{tsd} of expression (3) at a high level.

2.3.2. *Inadequacies of IT infrastructure*

Many organisations focus their supply-chain related IT investments on forward channel functions such as order management and fulfillment. Hence, they are often faced with inefficient and undisciplined returns management processes. Further, most supply-chain management and enterprise resource planning (ERP) systems provide only limited returns management capability

Table 2. Online return costs.

Direct costs	Indirect costs
Retailer costs	
Lost consumer revenue	Lost bargaining power with suppliers
Original costs of bringing the product to the market	Negative impact on brand
Customer service costs	Weakened competitive advantage due to customer dissatisfaction
Processing costs for returns	Impact on customer lifetime value and switching costs
Increased inventory cycle time	
Manufacturer costs	
Lost revenue from retailers	Retailers frustrated with product returns processing
Processing costs for returns	Impact on customer lifetime value due to customer dissatisfaction
Increased inventory cycle time	Added burdens and distractions for logistics operations

Table 3. Comparison of technologies utilised to assist reverse logistics processes by retail and manufacturing.

Technology	Retailers, %	Manufacturers, %
Automated material handling equipment	31.1	16.1
Bar codes	63.3	48.7
Computerised return tracking	60	40.2
Computerised returns entry at most downstream point in supply chain	32.2	19.1
Electronic data interchange	31.1	29.2
Radio frequency	36.7	24.6

such as credit orders and return material authorisation (RMA). These systems do not provide robust decision support for returns authorisation and disposition policies. Another problem lies with limited and poor data visibility. Customer satisfaction levels may drop due to a frustrating returns process. Organisations also do not expend enough effort to stay in touch with the location, status and condition of returned items. This problem also increases the level of β_{Aq} and β_{tsd} in Expression (3).

2.3.3. *Cost of returns and recovery*

Goods that are returned before the end of their useful life directly reduce a firm's revenue. Goods that are recovered at the end of their useful life for the purpose of recycling or remanufacturing incur significant collection costs. Customers and retailers send returned products back to suppliers and distributors for credit. Storage, handling and shrinkage costs increase at every step of the way as the product becomes outdated. This increases the administrative costs in managing the complex return policies among several retailers, distributors and manufacturers. Problems in recovering used products (stage one of reverse channel) stem from the existence of a large number of potential collection points. For example, virtually every room in every office building uses a printer cartridge that needs to be collected. Coupled with the large number of collection points is the high degree of uncertainty about the quantities collected from each location and the timing of collection (Guide *et al.* 2000, Van Hillegersberg *et al.* 2001). These uncertainties make the collection process difficult and costly.

Once the goods are collected, they need to be evaluated (stage two of reverse channel), for their condition, as it dictates whether the product and its parts will be reused, remanufactured or recycled. Lack of appropriate identification mechanisms can make product identification extremely difficult. Determining the condition of a product often requires a high degree of expertise which can be costly. Further, due to the high variance in quality, the evaluation process is prone to errors, further adding to costs.

There are a number of fixed costs as well. Returned goods do not result in a corresponding decrease in inventory carrying costs or other fixed costs. If the returns are due to incorrect fulfillment of order, or defects, there are also indirect costs of loss of reputation or brand. All these costs, direct or indirect, adversely impact the firm's bottom line. Again, use of technologies can potentially reduce β_{Aq} and β_{tsd} in Expression (3).

3. Solutions

A key element in reducing uncertainties in the first two stages of the reverse channel of a supply chain is access to accurate and timely information on the status, location and condition of products moving about in the supply chain. Keen and Mackintosh (2001) argue that the unique value in e-commerce should come from the ability of its supporting technologies in offering supply-chain visibility to as many of the operational steps, people, documents and communications events as needed within a business process design. We propose two broad solutions–collaboration and use of IT based systems in a CLSC environment.

3.1. *Collaboration amongst supply-chain partners*

Supply-chain collaboration is any kind of joint, coordinated effort between two or more entities in a supply chain to achieve a common goal. There are three key characteristics of collaboration: sharing of real-time information, alignment of interest of individuals and organisations and standardisation of processes. All players in the reverse supply chain stand to gain through collaborations. For example, there are dozens of companies manufacturing printer cartridges. They can all collaborate and pool the collection process, share and thus reduce the cost to each player. Retailers and manufacturers can collaborate to streamline the collection and sorting process as well. We posit that collaboration, through use of appropriate technologies can reduce β_{Aq}, β_{tsd} and β_{tr} that appear in expression (3). Collaboration, in turn, is a function of articulating expectations, making mutual commitments and delivering and tracking such commitments (Kumar 2001). We now provide several opportunities for collaboration in the reverse channel:

3.1.1. *Gate keeping*

This is the first step towards collaboration that occurs at the customer-retailer interface when the product is returned. Gatekeeping is the screening of defective and unwanted products at the customer-retailer interface which is essentially the entry point in the reverse-logistics process. Any product that has a lapsed warranty should not be allowed into the channel. Such products consume a lot of time and effort. A potential area of conflict, at this stage, is in the decision of the right disposition mode. Verification of products at the store level may be done using invoices or product serial number but requires sound information systems to accomplish the task. For example, Nintendo has developed an innovative gatekeeping system for tracking the electronic game products they manufacture. They provide a rebate of \$0.50 if retailers register the game product sold to the consumer at the point of sale. Nintendo and the retailer can then determine if the product is under warranty. The company has developed a special packaging with a window that allows the product serial number to be scanned at the retailer's point-of-sale scanner. This information updates a database that a retailer can then access when the customer returns the video game.

3.1.2. *Centralised return centre*

The next opportunity for collaboration comes at the retailer-manufacturer interface. Once a product is returned to the retailer, it should be sent to a centralised return centre (CRC) where they are sorted, processed and then shipped to their next destination. Such a system can generate economies of scale and help reduce costs. An RMA is a request sent to the suppliers from the retailers' CRC, for an approval to return products. In order to reduce the delay in processing an RMA, the suppliers could collaborate with the retailers to allow raising RMAs at regular intervals depending on the product in question rather than at fixed time intervals. For example, in industries like agriculture and pharmaceuticals, which involve perishable goods or goods subject to expiration, quick processing of RMA is critical in maximising reverse flow value.

3.1.3. *Return price rationalisation*

The price on a product varies frequently over the life cycle of a product. Consumer product returns can occur at any time during the product life cycle and are hence increasingly important to manufacturers. This continuous change in price poses a challenge in financial reconciliation when products are returned. Price visibility is extremely important due to the financial impact it has on the different supply-chain partners. Suppliers and retailers should work on a return policy that does not force either of them to take losses due to price changes.

3.2. ***Technologies supporting CLSC***

A number of specialised software companies have developed packages to deal with returns. Online return capabilities and electronic processing of returns drastically increase the speed of handling returns, increase customer satisfaction and reduce costs. According to the Gartner Group, electronic handling of returns costs \$4.05 per unit versus \$25.00 per unit, if handled through a call center, a significant reduction in β_{Aq}. Right from local screening of products and packages to their final disposition, IT can and should be used at every step of the CLSC. For example, during the first stage when customers and retailers want to return a product, they can visit a manufacturer's website, search by order number of stock keeping units (SKU) to identify the product to be returned and check the procedures and policies for its return. The website and its associated software can also be used to capture the reason for return so that the manufacturer can determine the disposition mode up-front thereby minimising the costs of transportation and processing time, a reduction in β_{tsd} and β_{tr}.

From a planning perspective, product collection at either the manufacturer's site or at a central collection centre can also be simplified if the personnel at these sites have a better understanding, in advance, of the quantity of products to be returned and their location so that freight can be combined. An example of such sophisticated solution is Return Valet™ by catalog retailer, Spiegel, Inc. In collaboration with Newgistics and local postal facilities, Spiegel has developed a capability where customers can return their mail-ordered products to a local post office. The clerk validates and confirms the return procedure online, prints a receipt with the credit amount and sends the product back to Spiegel's distribution center, which automatically issues a credit when the product arrives. Collecting the correct type of information from retailers and customers at the point of return will ease the process of issuing credit for the returned products. In the CRC, IT can help the employees in the complex decision making process of final disposition of the returned product. DecisionOne^{TM}, a computer maintenance company, uses software which includes its customers such as Dell and Sun's own decision rules for deciding whether to repair, disassemble, reuse or scrap returned products.

A good reverse logistics system includes proper data collection and effective reporting. To help understand a consumer's reason for returning a product, a company must collect consistent and structured data concerning the reason for product return and its current condition (Kokkinaki *et al.* 2000). With this information, trends should be analysed to determine the root causes. One technology, that is, rapidly gaining importance is RFID. Advances in RFID technology is making it possible to tag almost everything, spurring a revolution in how physical objects interact with information services (Angeles 2005, Borriello 2005). This technology is beginning to deliver significant cost reductions in retailers, automotive, pharmaceutical, and personal computer supply-chain processes.

The RFID technology could also be used to effectively protect against the return of counterfeit items – a critical issue in the pharmaceutical and agricultural industries where manufacturers must safeguard the chain of custody and monitor batches and lots, as well as expiration dates on products. For example, one of the biggest problems retailers face with returned products is the high degree of uncertainty in determining whether a returned item was sold by the store. Fraudulent returns presented at one store may have been stolen at various points along the supply chain or purchased below full retail value at an outlet store, and then returned to retail stores for a full refund (O'Connor 2004). The serial number on the electronic product code (EPC) of a tag is reserved to clearly identify the unique product item. RFID technology uses this EPC-compliant tag to uniquely identify nearly 69 billion items for a single SKU. Software companies are now developing RFID-based applications that use a reader to 'lock' the tag at the checkout counter for every item when it is sold. If the item is eventually returned, then the tag can be used to determine the product's validity. The use of RFID to validate the item thus removes the proof-of-purchase from the customer's hands and places it on the item.

3.3. *Web-based collaboration*

Web-enabled systems make it easier for all players to collaborate and exchange information. Internet trading hubs and warranty aggregator hubs such as Bid Vantage and ServiceBench.com bring buyers and sellers of parts together online. This minimises the need for a firm to hold large inventories of spare parts. Vendors of e-service solutions, such as Viryanet and iMedeon, have developed systems that incorporate wireless communications with Internet applications to create a portal. These portals provide a virtual-service environment where all the players in field service, depot repair and remanufacturing support services can communicate and interact on an online, real-time basis regarding the status of a single, specific transaction regardless of who owns the request, who is providing the solution, or where in time the transaction is occurring.

Web-based collaborative return authorisation (WCRA) seems to be a commercially deployable solution that has been proposed to handle various reverse logistics activities (www.clearorbit.com). WCRA consolidates visibility to suppliers, manufacturers, third-party logistics providers, repair depots and customers while controlling the flow of material from one point to another point along the reverse supply chain. This is now possible through secure portals that allow third parties to login and upload relevant information to the host ERP. To properly reconcile inventory and accommodate various disposition activities, the host ERP must receive notification that a returned product has been received by a third party and a new product has been sent out. The host ERP must also track the disposition of the returned items and coordinate various activities. Consumers can now enter data manually and the ERP then recognises that inventory and sends back authorisation and item-specific labels that move the product appropriately from point-to-point in the reverse logistics recovery system. Since the host ERP is deployed securely over the web, it is available to anyone, anywhere and hence reduces costly investment in databases.

In the next section, we present a case study based on RFID as an emerging technology that has generated a lot of interest in the CLSC area.

4. Case study

Our case study is based on two major consumer electronics companies and demonstrates how use of RFID technology can reduce costs (β_{Aq}, β_{tsd} and β_{ts}). The basic objective of this case study is to explore the impact of adopting RFID technology on some of the costs in the reverse channel. In particular, we focus on issues that pertain to the flow of product returns through the warehouse. As mentioned before, product acquisition in CLSC is characterised by a high level of uncertainty with regard to both quality and quantity of returns. This uncertainty is largely on account of lack of information associated with these products. Networked RFID systems help connect products tagged with an RFID chip to an information network, providing complete information about the product's life cycle to all networked partners. RFID is now receiving considerable attention in business and government settings as an enabling technology that can improve asset tracking and inventory control to improve supply-chain operations. The implications for product handling in the warehouse are of growing interest to managers, as warehouse operations assume more return product responsibility for customers and integrate those processes into their forward-flow distribution processes. For example, products being returned are often aggregated from the retailer and palletised for reverse transport to the warehouse. These pallets can be uniform, homogenous pallets containing a single SKU, or mixed pallets with several different SKU to be processed upon receipt at the warehouse.

Based on our interactions with warehousing managers during site visits at two major consumer electronics and consumer process goods companies, CRCs seem to be a popular reverse-logistics strategy where all products returned are sorted, processed and then shipped to their next destination. There are several benefits that companies can accrue by using this strategy. They include: *consistency*: By collecting returns at a central depot, the company can make more consistent decisions about product disposition. This would lead to more standardised processes and efficient sorting processes for products; *improved customer service*: The centralised return depots can speed the reconciliation process, improve material authorisation and issuance of credit and also serve as a good marketing strategy to gain customer loyalty; *compacting of disposition time*: CRCs tend to expedite flow of materials in the reverse logistics pipeline. The disposition of returned products to a CRCs makes it easier to determine whether a returned product may be reused as is, remanufactured, disassembled for components and parts or recycled. Of course, using a centralised return strategy has problems such as an increase in shipping and transportation time and the corresponding increase in transportation costs and the difficulty in consolidating all return shipment to the centralised facility. In any case, it is important to clarify that for these warehousing managers, the benefits clearly outweighed the costs and hence the choice to use a centralised returns strategy to process returns.

With RFID technology, important measures such as inventory can be tracked in real time. In a typical warehouse, three activities must occur. The first activity that occurs at the receiving dock when shipments arrive from the factory or from customer returns is the need for personnel at the warehouse to check the number of cases in the shipment against what appears in the documentation. This is now typically done by scanning the barcode labels on the cases. After the implementation of RFID, tags will be affixed to cases at the factory. Checking at the receiving dock will then be done by readers installed around the entrance that can automatically scan the RFID tags. The second activity is taking control of inventory of both new and returned products. Managers need to keep track of shipments and receipts that flow into and out of their facility. In order to minimise any error in this process, remote readers can be installed at fixed points in the warehouse to keep track of inventory. The third activity that will be affected by RFID is picking cases of products to fulfill orders. Warehouse management software now keeps track of the type of goods that are stored on each shelf as well as provides information to forklift operators' terminals on the exact location of the products. To minimise any misplacement of cases, RFID readers can also now be mounted on the forklift vehicle to help workers to rapidly locate goods down aisles and in bay locations with less effort.

4.1. *Quantifying benefits of RFID technology*

Benefits from RFID implementation were identified based on our experience from fieldwork and knowledge of the high-tech consumer electronics and consumer product goods industries. Key personnel were interviewed across a wide range of functional departments at these two companies. It is clear that the benefits of RFID implementation stemmed from the ability to automatically keep track of the number of cases passing through certain key areas in the warehouse. Accurately tracking the location and quantity of such new and returned goods at key areas of the warehouse is of immense value to the warehouse managers.

This motivated us to develop an exploratory simulation experiment that involves a performance comparison of the warehousing centre, that is, using barcode technology with a configuration of a proposed warehouse that has fully deployed auto-ID in its mixing operations. Driven by the anecdotal debate and the absence of any field testing, it focuses on a set of key experimental conditions. The experiment discussed below assumes that there is a warehouse co-located with a company-owned manufacturing facility. There are several potential product arrival modes. First, product arrives from the manufacturing facility at a known rate via sophisticated conveyor systems to palletiser where they are aggregated into unitised loads. Second, product also arrives as inter-facility transfers from other manufacturing facilities via trailer load. Finally, product also arrives by railcar into the warehouse.

A hypothetical warehouse can be configured to consist of several standard processes. In this study, a warehouse comprised of standard receiving, putaway (storage), picking, staging and loading and returned goods processing areas are considered. Raw data for the simulation was collected from the companies. Documents such as productivity logs for work shifts, facility layout diagrams and monthly operational reports were reviewed, which helped to calibrate the model under typical daily operations. Using these reports, processing characteristics were assigned to all operating tasks and the simulation was populated with data reflecting a typical 24-h period.

4.2. *Setting for simulation and results*

Using an agent-based commercial software package, IBM WBI Workbench © (2006), the warehouse configuration depicted in Figure 2 was formulated in an Intel-based computing environment. The model consisted of key processing areas such as returns inspection, distribution centre storage, picking, packing and loading. Within the model, the detailed product flow for each processing area is based on the task-level processing logic and operating times that was captured from the site visits. As experimental factors for analysing the returned goods area of the operation, this study is concerned with product arrival proportions among the three modes listed (EXPV1) the type of product picking required (EXPV2) and the proportion of daily inbound receipt volume that is returned goods for processing and re-distribution (EXPV3).

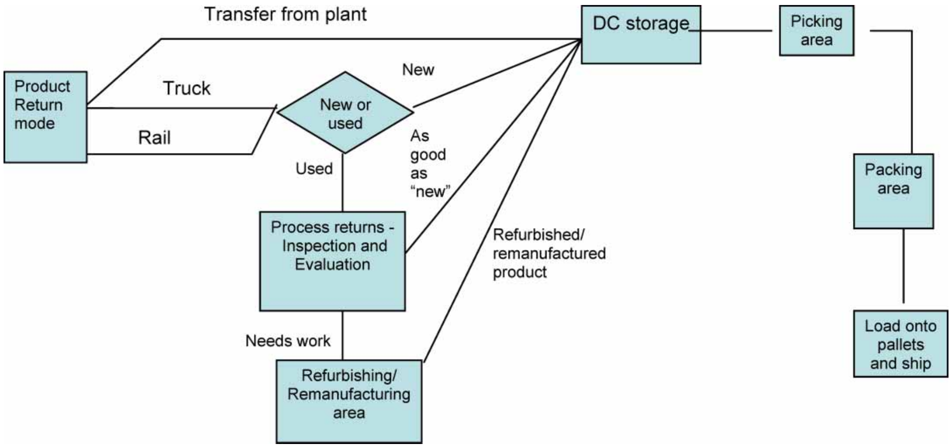

Figure 2. Overview of activity decision flow diagram.

Below, we discuss how the intensity of these parameters was varied over a series of simulation runs from the case study environment. For these focal parameters, the experimental settings are as follows:

(1) **EXPV1** (arrival modes by rail, trailer and conveyor, respectively): Three settings include (20, 60, 20%), (30, 60, 10%), and (10, 70, 20%)
(2) **EXPV2** (homogenous pallets, mixed pallets, partial pallets, respectively): Three settings include (60, 0, 40%), (33, 34, 33%), and (70, 0, 30%).
(3) **EXPV3** (proportion of returned goods arriving): three settings: 5, 10, 15.

We chose conservative settings for the three factors in order to mimic our actual observations as closely as possible, but not necessarily identically. For example, the settings for EXPV1 reflect the fact that most inbound warehouse receipts and all returned goods receipts occur via trailers, but yet there are environments where receipts from attached manufacturing plants or by railcar also occur. Thus, EXPV1 represents increasingly complex inbound receiving by rail, truck and conveyor modes. Settings for EXPV2 (pallet homogeneity) reflect the practice that unit loads are not always homogenous pallets of a single SKU. Rather, they are increasingly mixed pallets or partial pallets of mixed SKUS that must be processed differently. Therefore, EXPV2 represents shipping pallet configuration complexity in terms of SKU variety. Finally, EXPV3 represents some experimental allocations to returned goods processing in the warehouse, also in increasingly complex returns proportions. Product returns typically arrive by truck to the warehouse. All three factors are categorised into low, medium and high levels. These factors and settings lead to a $3 \times 3 \times 3$ design or 27 runs. We performed 10 replications per run for a total of 270 simulations. The replications were conducted in order to gain a reliable measure of the central tendency of the performance of the model since the individual task processing times for the operator's tasks performed was a random variable. For our simulation runs, the task processing times were sampled from a triangular distribution formulated from data collected during the site visits.

In the experimental context, the simulated warehouse typically experiences a total daily arrival of 18,000–22,000 cases of product each during each 8-h shift. The warehouse is also assumed to operate 8–12 h per day, and is staffed operationally by a team of direct laborers, such as loaders, palletisation operators, forklift operators and quality assurance clerks who perform specific processing tasks subject to the task time data collected. Cases of product arrive to the warehouse at constant inter-arrival rates of two seconds each for this study. For each working day, a 10-h receiving time window for all receiving processes (by truck, by conveyor or by railcar) each working day. Warehouse operations in the model terminate after processing of the last arriving case of a typical day.

We summarise the average case processing costs for the design discussed above. The results offer initial insights on the returns processing in the warehousing context for RFID operability versus bar code operability. Table 4 reports the average processing costs and overall average labour utilisation rates for each of the 27 cells represented in the run design. In general, the processing costs and labour utilisation rates display an increasing trend as process complexity rises for the traditional barcode technology environment. Conversely, the rate of increase and overall trend in labour cost, under the RFID setting, was less in relative terms. Additionally, the lower labour utilisation rates suggest that there may be several hidden advantages regarding direct labour requirements for RFID over Barcode. These results, however, must be viewed in light of the acquisition, installation, training, system integration and the maintenance costs of RFID. These costs vary across industries and between specific warehousing environments.

Figure 3 represents the case of a fully enabled RFID context while Figure 4 represents a fully enabled barcode setting. Our focus is on the returned goods processing function and is expressed in processing cost (dollars) per case. Figure 3 depicts the cost per case for the proportion of returned goods received (EXPV3) versus low, medium and high degrees of homogenous pallets (EXPV2). Processing cost for homogenous pallets (high HPAL) was less than $0.04 per case for low volume returns processing up to $0.0525 per case for high volume (15%) returns processing rates. Processing costs for mixed pallets (medium HPAL) was $0.0425 per case for low volume returns up to $0.0525 per case for high volume (15%) returns processing rates. For low HPAL

Table 4. Simulation results table.

EXPV1 inbound receiving complexity	EXPV2 (HPAL) pallet confign. complexity	EXPV3 product returns complexity	Case processing cost (RFID)	Average labour utilisation (RFID), %	Case processing cost (Barcode)	Average labour utilisation (Barcode), %
LOW	Low	Low	$0.0420	33.6	$0.0610	49.9
LOW	Low	Med	$0.0449	39.1	$0.0669	45.1
LOW	Low	High	$0.0540	46.0	$0.0770	48.9
LOW	Med	Low	$0.0425	38.2	$0.0600	51.0
Low	Med	Med	$0.0473	42.8	$0.0700	51.4
Low	Med	High	$0.0525	40.6	$0.0740	51.6
Low	High	Low	$0.0400	40.1	$0.0590	52.8
Low	High	Med	$0.0482	32.5	$0.0638	53.2
Low	High	High	$0.0525	30.6	$0.0755	53.2
Med	Low	Low	$0.0470	30.6	$0.0685	54.2
Med	Low	Med	$0.0534	42.4	$0.0712	54.3
Med	Low	High	$0.0643	29.1	$0.0902	57.3
Med	Med	Low	$0.0478	44.8	$0.0677	58.8
Med	Med	Med	$0.0539	28.6	$0.0803	60.6
Med	Med	High	$0.0594	31.7	$0.0876	60.8
Med	High	Low	$0.0439	28.8	$0.0691	61.0
Med	High	Med	$0.0569	25.2	$0.0859	61.2
Med	High	High	$0.0585	43.0	$0.0917	61.9
High	Low	Low	$0.0524	40.8	$0.0777	63.6
High	Low	Med	$0.0632	36.3	$0.0895	66.7
High	Low	High	$0.0710	36.8	$0.1078	70.7
High	Med	Low	$0.0560	44.3	$0.1018	71.2
High	Med	Med	$0.0691	46.5	$0.1140	74.6
High	Med	High	$0.0792	37.8	$0.1214	67.8
High	High	Low	$0.0650	27.6	$0.1415	73.6
High	High	Med	$0.0868	39.5	$0.1620	66.4
High	High	High	$0.0917	32.8	$0.1724	62.4

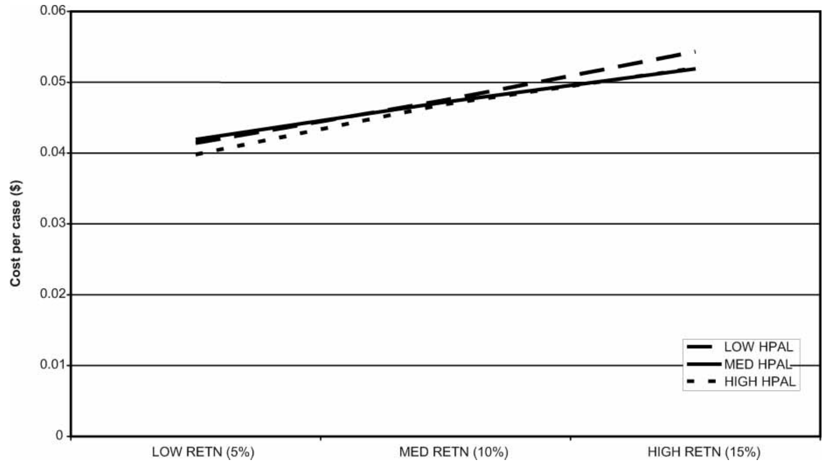

Figure 3. Pallet configuration *vs*. proportion of product returns in RFID context.

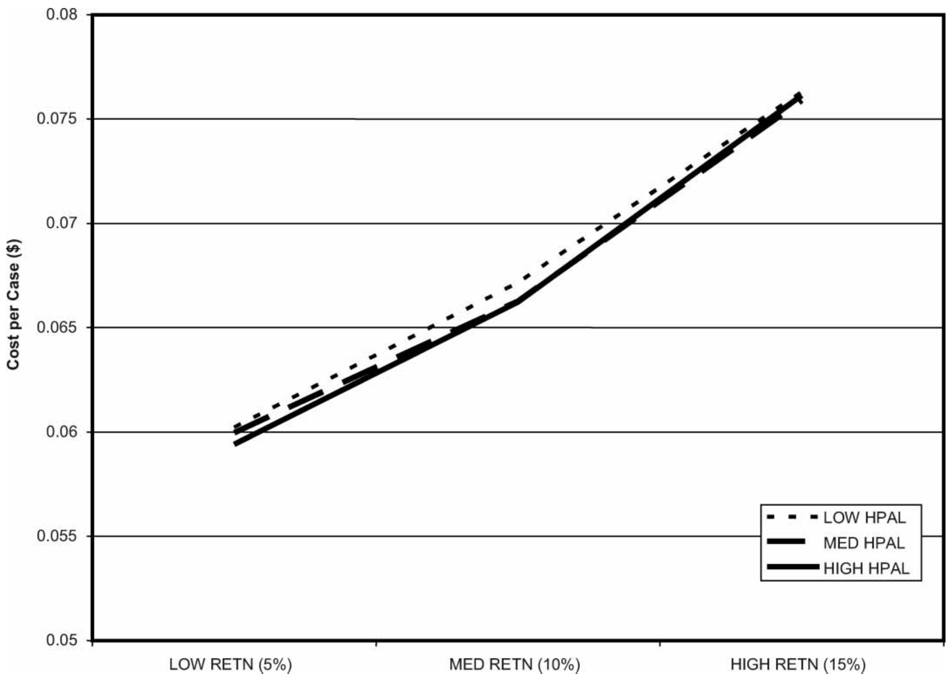

Figure 4. Pallet configurations *vs*. proportion of product returns in barcode context.

settings, processing cost ranged from a low (for 5% returns) of $0.042 per case to a high (for 15% returns) of $0.054 per case. Figure 4 illustrates the results in the barcode context. Processing costs for homogenous pallets (high HPAL) ranged from $0.059 per case for low volume returns to $0.0755 per case for high volume processing rates. For medium HPAL, processing costs varied between $0.06 per case for low volume returns to $0.074 per case for high volume processing rates. Finally, for low HPAL, processing costs varied from $0.061 per case to a high of $0.077 per case.

Clearly, adopting RFID (Figure 3) is beneficial compared to the barcode context (Figure 4). The results from our large-scale simulation point to two major conclusions. First, we conclude that manufacturer's with high value, low volume goods (*e.g.* high-tech consumer electronics) will benefit more from RFID than those with lower value, high-volume goods (*e.g.* consumer products). Second, the greater a manufacturer's order fulfillment complexity in the warehouse (*e.g.* value-added services, product returns), the greater the opportunity to gain benefits from adopting RFID.

These findings illustrate the promise of RFID assisting with the integration of returned goods processing in the warehouse and with a lower cost structure than barcode. From the point of view of value added in the reverse-channel, due to RFID technology over barcode technology, the average cost per case reduced from 0.077 to 0.054, a reduction of 0.023 or 30%. This implies that β_{Aq} reduced to 0.7. Assuming similar reductions in β_{tsd} and β_{ts}, the value added due to use of RFID technology on the reverse channels in the US will be of the order of \$10.8 billion (30% of 36 billion). The benefit of using RFID is more pronounced when a distribution channel has to handle customer returns. Returned products have to be inspected, verified for customer credit, refurbished or remanufactured, and then returned to the supply chain to satisfy future demands. The amount of rework and refurbishing is dependent on the incoming quality levels of the returned products. Most warehouses and distribution channels do not have a clear visibility of the contents of the pipeline of return channels. Another potential use of RFID is the use of RFID tags; this would help in the visibility of the return channels. Although the study is not intended to be the definitive study, initial experience with the model suggests that further research is warranted. RFID-tagged goods enhance the visibility of returned products in the CLSC by allowing their integration into operations planning. This in turn creates additional information flows which allow for web-based collaboration for returned goods processing between supply chain participants.

5. Conclusion

Product returns can significantly affect a firm's bottom line. Considerable values can be derived from recovered products. Current reverse supply-chain systems are cumbersome and incur significant costs in managing returns and salvaging value. It is critical for managers to take stock of the high costs involved in the reverse supply chain and realise that many of these costs can be mitigated through the use of sound information systems and through collaboration with supply-chain partners. Since the reverse supply chain involves several steps, opportunities exist to design systems using the latest IT, to save costs at every step and at every interface between supply-chain partners. It is imperative that firms collaborate to share and integrate necessary information in the reverse supply chain in order to utilise timely and correct information.

The emerging importance and relevance of reverse logistics requires careful execution and management of return flows along the reverse logistics supply chain. Besides the development of new design, planning and control of existing ERP and APS systems, electronic marketplaces seem to have tremendous potential to effectively manage return flows in the supply chain.

References

Andriesse, F.G., 1999. Successful implementation of reverse logistics in Philip Morris. *In*: A.R. Van Goor, S.D.P. Flapper and C. Clement, eds. *Handbook of reverse logistics*. Deventer, The Netherlands: Kluwer.

Angeles, R., 2005. RFID technologies: Supply-chain applications and implementation issues. *Information systems management*, 22 (1), 51–65.

Borriello, G., 2005. RFID: Tagging the world. *Communications of the ACM*, 48 (9), 34–37.

Connaughton, P., 2006. Taking control of your aftermarket supply chain. Forrester Research Article: Massachusetts.

De Brito, M., Dekker, R., and Flapper, S.D.P., 2003. Reverse logistics – a review of case studies. *ERIM report series research in management*, Rotterdam.

Eckfeldt, B., 2005. What does RFID do for the consumer? *Communications of the ACM*, 48 (9), 77–79.

Ferrer, G. and Ketzenberg, M., 2004. Value of information in remanufacturing complex products. *IIE transactions*, 36 (3), 265–277.
Fleischmaan, M., Bloemhof-Ruwaard, J.M., Dekker, R., Van der Laan, E.A. Van Nunen, J.A.E.E. and Van Wassenhove, L.N., 1997. Quantitative models for reverse logistics: a review. *European journal of operational research*, 103, 1–17.
Guide, Jr.,V.D.R., Jayaraman, V., and Srivastava, R., 1999. The effect of lead time variation on the performance of disassembly release mechanisms. *Computers and industrial engineering*, 36, 759–779.
Guide, Jr.,V.D.R., Jayaraman, V., Srivastava, R. and Benton, W.C., 2000. Supply chain management for recoverable manufacturing systems. *Interfaces*, 30 (3), 125–142.
IBM Websphere Workbench © version 4.2.4, International Business Machines, Inc. 2006.
Johnson, M.R. and Wang, M.H., 1995. Planning product disassembly for material recovery opportunities. *International journal of production research*, 33, 3119–3142.
Jayaraman, V., Guide, V.D.R. and Srivastava, R., 1999. A Closed-Loop Logistics Model for Remanufacturing. *Journal of operational research society*, 50 (5), 497–508.
Jayaraman, V. and Luo, Y., 2007. Creating competitive advantages through new value creation: A reverse logistics perspective. *Academy of management perspective*, 21 (2), 9–27.
Keen, P. and Mackintosh, R., 2001. The Freedom Economy: Gaining the M-commerce Edge in the Era of the Wireless Internet, New York: McGraw-Hill.
Kokkinaki, A., Dekker, R., Van Nunen, J., and Pappis, C., 2000. An exploratory study on electronic commerce for reverse logistics. *Supply chain forum: An international journal*, 1, 10–17.
Kumar, K., 2001. Technology for supporting supply chain management. *Communications of the ACM*, 44 (6), 58–61.
Linton, J.D. and Johnson, D.A., 2000. A decision support system for planning remanufacturing at Nortel Networks. *Interfaces*, 30 (6), 17–31.
Linton, J.D. and Jayaraman, V., 2005. A framework for identifying differences and similarities in the managerial competencies associated with different modes of product life extension. *International journal of production research*, 43 (9), 1807–1829.
Linton, J.D., Klassen, R., and Jayaraman, V., 2007. Sustainable supply chains: An introduction. *Journal of Operations Management*, 25 (6), 1075–1082.
Meijer, H.W., 1998. Cannon Benelux and reverse logistics. *In*: A.R. Van Goor, S.D.P. Flapper and C. Clemant, eds. *Handbook of reverse logistics*. Deventer, The Netherlands: Kluwer.
Meyer, H., 1999. Many happy returns. *The journal of business strategy*, 20 (4), 27–31.
O'Connor, M.C., 2004. Ending retail scams with RFID. *RFID journal* [Online] November Available from: www.rfidjournal.com/article/articleview/1260/.
Rogers, D. and Tibben-Lembke, R., 1999. Going backwards: Reverse logistics trends and practices. Reverse Logistics Executive Council.
Sodhi, M.S., and Knight, W., 1998. Product design for disassembly and bulk recycling. *Annals of CIRP,* 47 (1), 115–118.
Souza, G.C., Ketzenberg, M., and Guide, D., 2002. Capacitated remanufacturing with service level constraints. *Production and operations management*, 11 (2), 231–248.
Stock, J.R., 1992. *Reverse logistics.* Oak Brook, IL: Council of Logistics Management.
Toktay, B., Wein, L., and Stefanos, Z., 2000. Inventory management of remanufacturable products. *Management science*, 46, 1412–1426.
Van der Lann, E., Dekker, R., Salomon, M. and Ridder, A., 1996. An (S, Q) inventory model with remanufacturing and disposal. *International journal of production economics*, 46–47, 339–350.
Van der Laan, E., Salomon, M., Dekker, R., and Van Wassenhove, L., 1999. Inventory control in hybrid systems with remanufacturing. *Management science*, 45, 733–747.
Van Hillegersberg, J., Zuidwijk, R., Van Nunen, J., and Van Eijk, D., 2001. Supporting return flows in the supply chain. *Communications of the ACM*, 44 (6), 74–79.
http://www.internetretailer.com/internet/marketing-conference/35906-dealing-returns.html