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Journal of Managerial Issues; Fall 2007; 19, 3; ABI/INFORM Global
pg. 436

JOURNAL OF MANAGERIAL ISSUES
Vol. XIX Number 3 Fall 2007: 436-452

Enhancing Product Recovery Value in Closed-loop Supply Chains with RFID

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The downstream movement of goods from the manufacturer to the retailer for sale to consumers is referred to as a forward supply chain. When consumers return their purchases to the retailer for a refund, a repair or a recall, an upstream movement of goods occurs from the retailer to the manufacturer. This upstream movement of product returns is termed a reverse supply chain (often called reverse logistics) (Tibben-Lembke and Rogers, 2002). Closed-loop supply chains refer to the integration of both forward and reverse supply chain activities (Guide *et al.*, 2003).

Closed-loop supply chains are a key component of sustainable business operations and they have begun to receive increased attention from both practitioners and academicians. This interest is driven by legislative environmental regulation for companies that operate in the European Union and by economic factors for companies in the United States. Additionally, companies exporting to Europe will also have to abide by these laws and adjust their business practices to be environmentally friendly (Guide *et al.*, 2003).

For U.S. manufacturers, product returns have expanded from a limited volume of high-value goods to a large variety of low-value goods, due to shorter product life cycles and lenient return policies at retailers (Tibben-Lembke and Rogers, 2002; Guide *et al.*, 2003). Rogers and Tibben-Lembke (2001) estimated overall customer returns for general merchandise in the U.S. to be approximately 6% of sales, which in 1999 would have been over $38 billion worth of returned goods. These proliferations of product returns have increased costs for manufacturers since they typically must credit the retailer and then determine the most cost-effective way to dispose the returns (Blackburn *et al.*, 2004). It should be noted that recovered parts and components often can be used to reduce production costs and to provide a cheap source of parts for service repairs (Toffel, 2004). Furthermore, the Supply Chain Council has identified the management of product returns as one of five key supply chain processes (SCOR, 2005). Hence, the development of effective and efficient, strategically managed closed-loop supply chains is becoming more important to practitioners.

Chopra and Meindl state "Information is crucial to supply chain performance because it provides the foundation on which supply chain processes execute transactions and managers make decisions" (2004: 482). To be useful in aiding supply chain decisions, information must be accurate, accessible in a timely manner, and be of the right kind (Chopra and Meindl, 2004). A relatively new information-sharing technology being utilized in the supply chain is radio frequency identification (RFID). Radio frequency identification is a data acquisition and storage method, which promises numerous supply chain benefits: improved speed, accuracy, efficiency and security of information sharing across supply chain (Jones *et al.*, 2004). Additional benefits realized are: (1) reduced storage, handling and distribution expenses, (2) increased sales through reduced stock outs, and (3) improved cash flow through increased inventory turns and improved utilization of assets (Kärkkäinen, 2003).

The major drivers behind RFID implementation are retailers such as Wal-Mart and the U.S. Government. In January 2005, Wal-Marts' top 100 suppliers were required to tag all pallets and cases they shipped to Wal-Mart distribution centers. The next top 200 suppliers were to tag all pallets and cases by January, 2006 and all suppliers by the end of 2006 (*RFID Journal*, 2004). Other early retail adopters of RFID technology include The Gap, Woolworth's, Prada, Benetton, and Marks & Spencer (Wilding and Delgado, 2004c). The U.S. Department of Defense required its 43,000 suppliers to put RFID tags on pallets, cases and on any single item with a cost of more than $5,000 beginning January 1, 2005 (Collins, 2004a). In addition, the U.S. Food and Drug Administration (FDA) has called for the implementation of RFID technology to track the distribution of prescription medicine in order to protect the medical supply chain from counterfeit drugs. Companies in the health care industry will have to tag pallets and cases by 2007 to meet the FDA's goal (FDA, 2004).

Though the literature on closed-loop supply chains has discussed a large number of integrated aspects and value recovery options, none of these articles have described the use of RFID in a closed-loop supply chain. The purpose of this article is to introduce RFID technology in closed-loop supply chains to practitioners and academicians. This review will offer useful guidance for companies which plan to implement RFID and we expect it to provide the motivation for future research in this emerging area.

The article is organized as follows. We first define a closed-loop supply chain, discuss its key characteristics and describe all the available value recovery options. Next, we discuss how RFID systems work and provide the motivation for utilizing RFID in closed-loop supply chains. We then discuss how RFID can be effectively used to enable decision making during the return process and to enhance value recovery. Lastly, we offer our concluding remarks, suggestions for further research on RFID systems, and implementation advice for practitioners.

CLOSED-LOOP SUPPLY CHAINS

Closed-loop supply chains have become an important area of focus for both practitioners and researchers due to the potential benefits from integration of the forward and reverse supply chains. The differences between forward and reverse supply chains make the integration challenging and necessitates an understanding of the characteristics of a closed-loop supply chain.

Characteristics of a Closed-loop Supply Chain

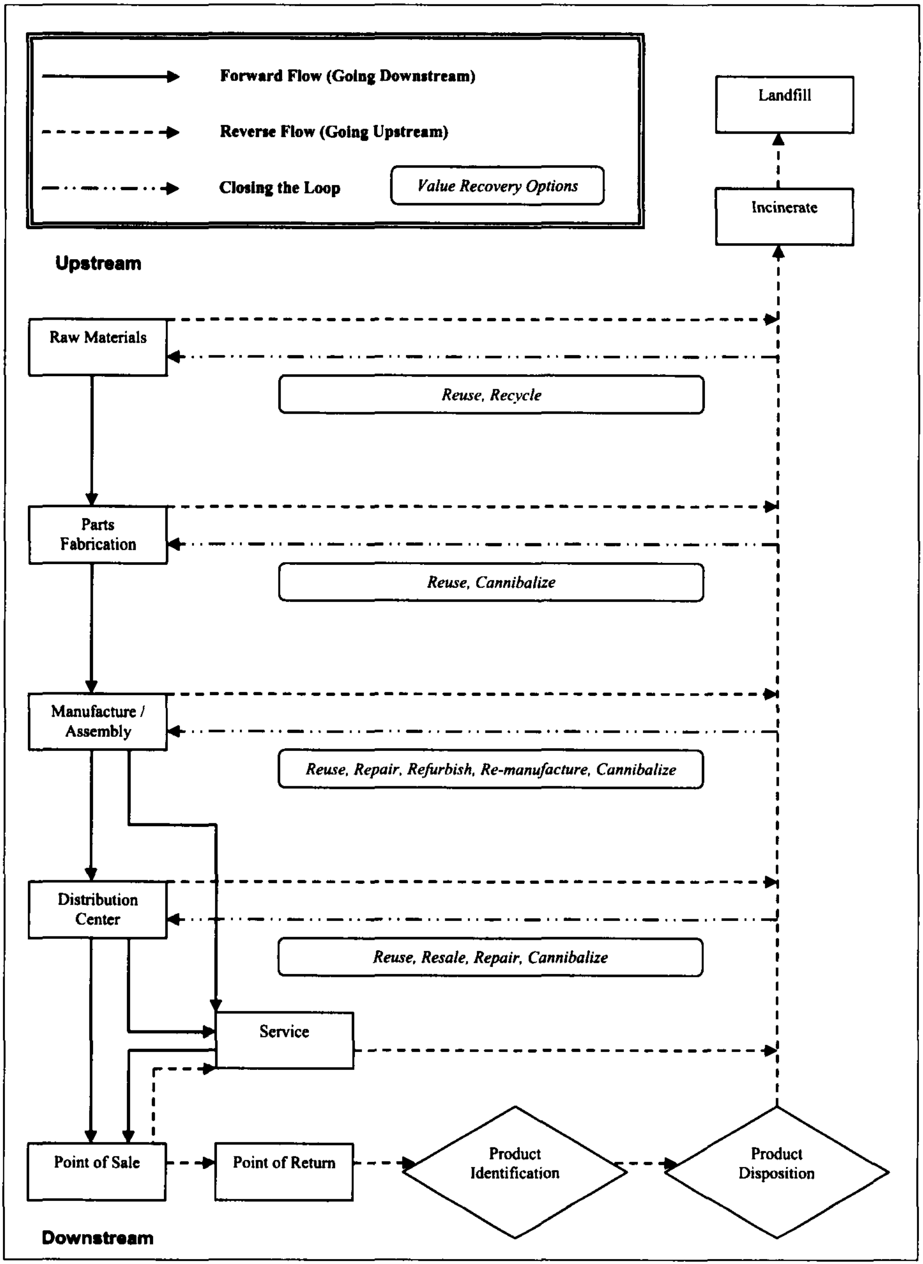
Based on the work of Thierry *et al.* (1995) and Krikke *et al.* (2004) a general view of a closed-loop supply chain is presented in Figure 1. Key characteristics of Figure 1 are the supply chain entities, decision points, and value recovery options that close the loop between the forward and reverse supply chains. Depending on the firms' business model, different supply chains might exist for different product lines. In addition, the forward and reverse supply chains could operate in different channels, and a firm can potentially belong to several supply chains within the same industry. Therefore, some additional discussion concerning Figure 1 is warranted.

The majority of consumer goods are purchased at retail locations, but sales can also originate from paper catalogs, at call centers or over the Internet. Capital goods such as customized manufacturing equipment may be purchased directly from the manufacturer, thereby skipping the distribution center. We separate the point of return from the point of sale because not all products are returned to the original seller. Examples include community recycling centers, third-party service calls, and automotive scrap yards. We consider the service entity in our network to be a location where service technicians are dispatched from to perform maintenance and/or repairs at the customer's site. Byproducts from the service call initiate the reverse flow for product recovery, and the decision steps of product identification and product disposition are performed by the technician.

The process of product identification occurs *before* product disposition. Accurate product identification can eliminate return fraud by proving where and when a product was purchased. Product disposition determines where to send a returned item in order to either maximize value recovery and/or reduce the environmental impact of disposal. Some products might require testing in order to (hopefully) determine the correct final destination of the return.

We show reverse flows that originate from all entities in the forward supply chain. Van Nunen and Zuidwijk (2004) identified product returns that are initiated by: customers

Figure 1
A Closed-loop Supply Chain



Based on Thierry *et al.* (1995) and Krikke *et al.* (2004).

(warranty, service, end-of-use), distribution centers (product recalls, obsolete goods, redistribution of goods), and manufacturing facilities (raw materials surplus, re-work, production scrap). Product returns from retailers include damage in transit, expired date code, discontinued product, seasonal product, high and/or imbalanced retailer inventories and retailer going out of business (Tibben-Lembke, 2002). Of course, all entities in the supply chain generate return flows as a normal by-product of conducting business operations (paper, packaging material, beverage containers, etc.). We assume that value recovery options for return flows emanating from supply chain entities do not need to go through an identification and disposition process.

Value Recovery Options in Closed-loop Supply Chains

Depending on the type of product returned, its condition and its anticipated future demand, a variety of value recovery options are available. Value recovery options include direct reuse, direct resale, repair, refurbish, re-manufacture, cannibalize, and recycle (Thierry *et al.*, 1995; Krikke *et al.*, 2004). The following discussion is based on Thierry *et al.* (1995) and Krikke *et al.* (2004).

Direct reuse items are also known as reusable assets. They are capital assets owned by the company and must be tracked throughout the supply chain, recovered when emptied, checked for damage, and repaired and/or cleaned if necessary. Totes, dollies, and containers are used to hold finished goods, components, and raw materials. They are used to facilitate transportation and handling along the supply chain. Reusable assets also include refillable containers, such as beer kegs, glass soda bottles, and drink syrup containers. Often these assets are returned to the manufacturer to be refilled and redistributed. Direct resale items are often products that have been returned to the point of sale by consumers. However, they can also include overstock and end-of-season products returned by retailers to distributors. Direct resale items need to be inspected for damage, and cleaned and repackaged if necessary. Consumer returns can be returned to either the inventory at the location they are returned to or sent back to the warehouse for redistribution.

Products returned for repair, refurbishment or re-manufacturing undergo a disassembly and reassembly process to fix or upgrade the product. Products returned for repair are brought to working order by fixing or replacing broken parts, and the output is an original product. A product that is returned for refurbishment is in working order at the time it is returned. It is inspected and critical modules are fixed or replaced, while outdated parts and modules may be upgraded. The output is an updated version of the original product. Products that are re-manufactured have all critical components and modules replaced with current technology, and the output is a new product that meets or exceeds the original quality standards. A re-manufactured machine costs significantly less than a new machine. Repair, refurbishment, and re-manufacturing all create a waste stream of removed parts that can be directed to a closed-loop supply chain for further value recovery.

Cannibalization is a disassembly process that focuses on the select retrieval of potentially reusable parts for repair or refurbishment and raw materials for recycling. A high-volume, efficiently run cannibalization operation has the potential to create a reliable internal parts supplier. Products that are recycled are reduced to the material level and cleaned if necessary. High-quality materials can be used to make original parts, while lower grades are used to make items that do not need to meet a high standard. Non-recoverable items from the value recovery processes are incinerated or land-filled. In Figure 1 we show incineration and landfill as reverse supply chain destination options. We do not consider incineration and land-filling to be value recovery options because the end result is that the item is removed from the supply chain.

RADIO FREQUENCY IDENTIFICATION

The origins of RFID technology can be traced to laboratory research in the 1940s that focused on reflected power communication. Its commercial use began in the 1980s, primarily in railroad and trucking industries (Landt, 2001). These applications used battery powered active RFID tags and proprietary systems to track and manage capital assets, such as rail cars and cargo ship containers (Dinning and Schuster, 2003).

The expansion of RFID into the supply chain has been due to the reduction in the cost of RFID technology through the use of non-battery powered *passive* tags. These passive tags can be used to replace bar codes as a means of gathering information within the supply chain. Radio frequency identification can be used to identify products at item level, can be read with no requirement for line of sight and can operate in harsh environments, where dirt, dust and moisture conditions can affect other types of Automatic Data Capture Systems, such as bar codes and light-emitting devices. Moreover, multiple tags can be read simultaneously, and tags can also be programmed easily. In addition, tags are capable of carrying more information than bar code technology, thus enabling RFID to store additional information such as location, move history, destination, expiration date and environmental conditions (temperature, moisture, etc.) (Wilding and Delgado, 2004a, 2004c).

According to Tersine intensive competitive pressures force firms to eliminate wasteful and time-consuming activities that do not add value to the product (Tersine, 2004). Radio frequency identification has the potential to increase the level of visibility and communication in the supply chain. This information can be used in decision making to eliminate non-value-adding activities, strengthening the competitiveness of the supply chain.

The RFID System

All RFID systems are comprised of three main components: (1) the RFID tag, or transponder, which is located on the object to be identified and is the data carrier in the RFID system, (2) the RFID reader, or transceiver, which may be able to both read data from and write data to a transponder, and (3) the back-end database which associates records with data collected by readers (Jones *et al.*, 2004). Figure 2, adapted from Dinning and Schuster (2003), shows how an RFID system works.

First, a unique identifier, such as an Electronic Product Code (EPC), is embedded into the microchip in a tag. The microchip can also incorporate functionality beyond simple identification and include integrated sensors, read/write storage, encryption and access control. The tag is then attached to an item, case or pallet. As the item/case/pallet moves into the scanning range of the reader, the reader sends out electromagnetic waves that form a magnetic field when they "couple" with antenna on the RFID tag. The tag draws power from the magnetic field and uses it to power the microchips' circuits. The microchip then modulates the signal received in accordance with its identification or programmed code and transmits or reflects a radio frequency signal. The modulation is in turn picked up by the reader, which decodes the information contained in the transponder and, depending upon the reader configuration, either stores the information, acts upon it, or transmits the information to the host computer via the communications port (Jones *et al.*, 2004).

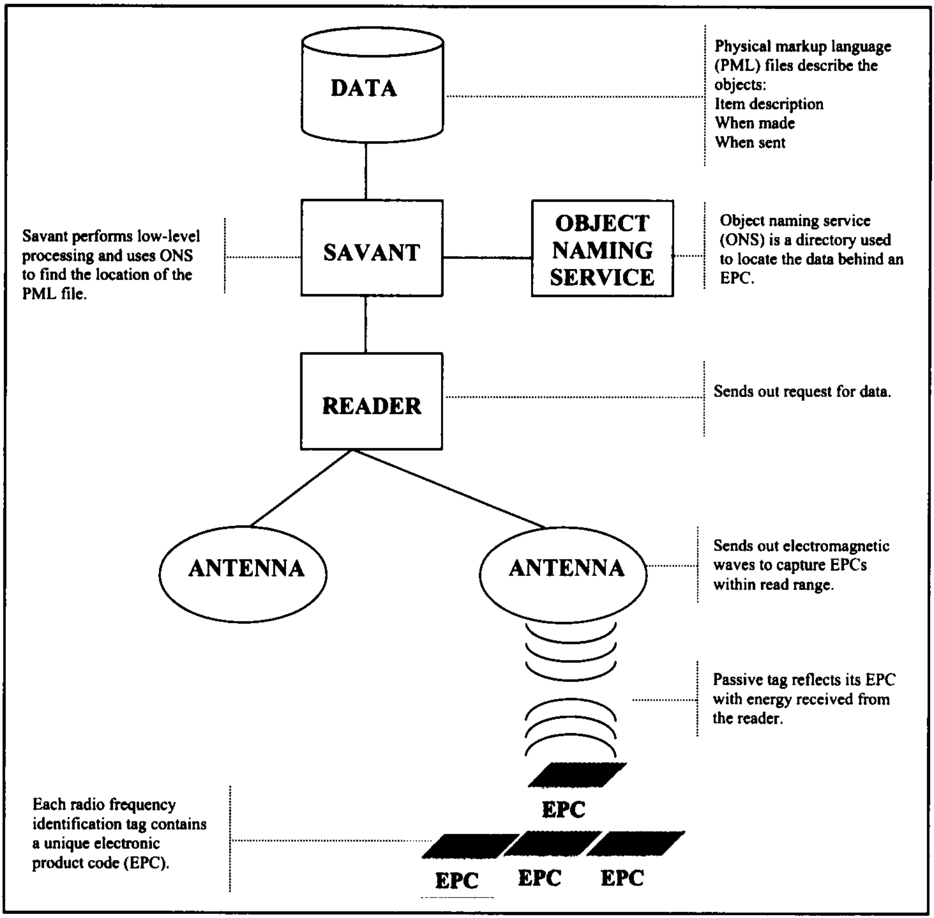
The decoding process in an RFID system is carried out by Savant, a lower-level software application developed by the MIT Auto-ID Center to handle data. When the reader picks up a signal, Savant uses the EPC on the tag to contact the Object Naming Service (ONS). The ONS can be on a local network or on the Internet, and it is similar to the domain name service that associates an Internet provider address with a domain name. The ONS serves as a directory that locates the server containing the information for the item being scanned. That information is collected by Savant, and then communicated to the databases and supply chain applications requiring the information. The communication format for the data is physical markup language (PML). Physical markup language is based on the extensible markup language (XML, popular in e-commerce transactions), which has the ability to describe physical objects, processes and environments in a standardized way (Angeles, 2005; Dinning and Shuster, 2003).

Closing the Loop with RFID

In an effective and efficient closed-loop supply chain, all processes (forward and reverse) need to be coordinated, which requires accurate and timely information. Guide *et al.* state "*Managers must take actions to reduce uncertainty in the timing and quantity of returns, balance return rates with demand rates, and make material recovery more predictable. Managers must also plan for the collection of products from end users. The use of information systems with new production-planning and control techniques makes management of those activities more predictable*" (2000: 125).

Several authors have mentioned the use or potential use of RFID and related technology in the closed-loop supply chain. Fleischmann *et al.* believe that "*information management is the key to creating an efficient closed-loop supply chain*" (2003: 55) and that RFID can be used to actively manage product returns. Krikke *et al.* (2004) mention using RFID to improve the quality of data and reduce the amount of manual data transfer of information in the supply chain in order to enable a Product Data Management system. Van Nunen and Zuidwijk (2004) feel that future improvements in closed-loop supply chains will be driven by technological developments such as RFID that will

Figure 2
A RFID System



Adapted from Dinning and Schuster (2003).

allow low-cost remote monitoring of information for a wide range of products and their processes. These processes include source, make, delivery, use, return, and recovery.

THE IMPACT OF RFID IN THE CLOSED-LOOP SUPPLY CHAIN

Radio frequency identification implementation brings about many potential impacts on a closed-loop supply chain, and companies in various supply chain positions may reap different benefits from RFID applications. Radio frequency identification can be used to track the movement of items through the supply chain in real-time. This provides higher visibility for inventory and assets in the supply chain (Seideman, 2003) and facilitates better management of inventory and logistics (Jones *et al.*, 2004). Radio frequency identification also improves the safety and security of the supply chain through improved track and trace, more efficient recall management, better expiration date management and reductions in shrinkage (Chappell *et al.*, 2003). Hence, a higher level of detailed analysis can be done to guide the management and synchronization of the supply chain. Increased synchronization enables collaborative planning, forecasting, and replenishment (CFPR) activities beyond the typical buyer-seller relationship. In addition, RFID technology can also be used to enhance value recovery.

When products are returned, RFID can be used to accurately identify the point of sale and the specific model of the product. Accurate product identification will make the disposition process more efficient and speed up the value recovery process. Radio frequency identification tags could also contain valuable information on how the product was utilized by the customer, which can be used to estimate the quality level(s) of the return. This increased transparency and efficiency will facilitate the integration of return flows into the forward flows.

For example, suppose a truckload of machines is to be returned from a disposition center to the original equipment manufacturer (OEM) for either refurbishment or cannibalization. As the truck leaves the disposition center, the contents are scanned and the information is relayed to the OEM. Knowing the lead time for delivery, the OEM can begin planning the disassembly and refurbishment schedules. Forecasts of recoverable parts from cannibalization can be used to reduce the number of new parts needed to refurbish the machines, thereby reducing purchasing costs. Since cannibalized parts will be used in the refurbishment process, the disassembly and refurbishment schedules will need to be coordinated. Downstream customers can be notified of potential completion dates for refurbished machines, and upstream recyclers can be notified of raw materials availability, thereby reducing their purchase of more expensive virgin raw materials and facilitating their planning process. More efficient value recovery will reduce disposal waste, thereby benefiting society as a whole.

We now discuss in more detail the use of RFID to enable product identification and product disposition, and to enhance value recovery. In our discussion we assume that tagging is done for individual items that meet a value threshold determined by the supply chain entity that is either responsible for the recovery of the item or stands to gain from a value recovery option.

Enabling Product Identification

Before a product return is sent upstream for value recovery the product needs to be accurately identified and the correct disposition decision needs to be made. Due to lenient return policies for consumer goods by retailers, product returns at retail locations are increasing (Rogers and Tibben-Lembke, 2001; Guide *et al.*, 2003). Most retailers have a no-questions-asked policy concerning returns since they want to keep customers happy and speed up the line at the customer service counter. Currently, a retail store cannot be 100% certain that the return was indeed sold by the store or even by the retail chain which the store is part of. It is estimated that fraudulent returns cost retailers and the manufacturers who often have to take back the returns billions of dollars annually. Fraudulent returns can be stolen at various points along the supply chain or purchased below full retail value at outlet stores and returned to retail stores for full refunds (O'Connor, 2004).

The serial number portion of the EPC on a tag is reserved to identify the unique product item and has the capacity to uniquely identify nearly 69 billion items for a single stock-keeping-unit (Brock, 2001). Since a tagged item can be monitored throughout the supply chain, the tags EPC is logged onto the company database when the company assumes ownership of the item. When an RFID-tagged item is sold or shipped to the customer, the tag can be locked so it cannot be written over. When the item is returned, the customer service representative can scan the tag and reconcile the item with the stores' records to determine the validity of the tag. The use of RFID to validate the item removes the proof-of-purchase from the customer and places it on the item. This system could also be used to effectively protect against returns of counterfeit items. In addition, the EPC code can be used to correctly identify returns of products that have undergone various model changes. These could include household appliances, kitchen equipment, electronics, and auto parts. In this scenario, automatic product identification can speed up the disposition process.

Enabling Product Disposition

After a product has been validated as a genuine return, a decision must be made regarding where to send the product to maximize value recovery. Correct product disposition requires knowledge of the value recovery options available. However, the employees processing the returns might not have this knowledge, especially in the retail environment. A survey on reverse logistics practices by Rogers and Tibben-Lembke (2001) found that nearly 70% of respondents used a central returns center (CRC) for processing returns. A CRC sorts and disposes all returns and is often located upstream from the point of return.

The benefits of a CRC are an increase in the percentage of value recovered, improved efficiencies and a gain in product information in regards to the best disposition. An obvious disadvantage of a CRC is the transportation and handling cost of product that should have been disposed of when it was returned. An additional drawback of a CRC is that product recovery lead times can increase. Blackburn *et al.* (2004) recommend disposition as early as possible in the reverse channel in order to avoid unnecessary processing expenses and to speed up the recovery of products with significant value. Recovery speed is critical for products such as electronics that have a high marginal value of time (MVT) or machines that can be cannibalized for repair or refurbishment operations. Products with high MVT rapidly lose value as they spend time in the reverse channel (Blackburn *et al.*, 2004). Savaskan *et al.* (2004) conjecture that for manufacturing returns, the supply chain entity that is closest to the customer is the most effective point of return.

Radio frequency identification technology can improve the efficiency of the disposition process by enabling disposition at the point of return instead of at a CRC. When the tag is read to validate the return of the item, the reader can also retrieve the product information over the Internet. The system can then automatically select the value recovery option or activate a decision support system to aid in the selection of a value recovery option. The system can also recommend immediate disposal (Parlikad *et al.*, 2003).

A key obstacle to maximizing the value from product recovery is that information associated with the product is often lost after the sale. This information includes product identity, components composition, and current state. The current state of a return is based on the operating conditions the product was used under and any maintenance performed. This obviously impacts the structural composition of the materials and the quality of the components.

An active or semi-active tag can be used to capture information on product usage and such information can be used to improve the accuracy of the estimated residual value of the return (Parlikad *et al.*, 2003). For example, the Robert Bosch Group installs an Electric Data Log (EDL) in power tools with electric motors to optimize the end-of-life product recovery. The EDL collects information on a set of parameters measured during the use of the product that influence the life expectancy and therefore recovery value of the motor. The information on the EDL is retrieved via wireless data transmission using a light emitting diode (LED) and the measurements have proven to be more reliable in evaluating returned tools compared to the cost of testing (Klausner *et al.*, 1998). The performance characteristics of a LED are similar to a bar code and it is foreseeable that low-cost RFID tags can be used to efficiently transmit information from the EDL.

The information collected on product usage can be forwarded to the manufacturer's new product development team to help them improve product quality (Gross *et al.*, 2003). The specific benefits of sharing knowledge of part usage and failure include improved part design, lower redesign cost of a new replacement part, reductions in failures and repair costs, and improved customer service (Mabee *et al.*, 1999). Information on usage and part failure can also be used to develop preventive maintenance and part replacement schedules.

Enhancing Value Recovery with RFID

Assuming that at the point of return the correct disposition has been made, the product will undergo a value recovery process that maximizes both the financial benefit to the firm and the economic benefit to society. As previously discussed, value recovery options include direct reuse, direct resale, repair, refurbish, remanufacture, cannibalize, and recycle. Since repair, refurbishing, remanufacturing and cannibalization all require some degree of disassembly, we group these options under the section of disassembly. We now discuss the use of RFID to enhance the value recovery process.

Direct Reuse. RFID tags are used to track and control company-owned reusable assets (totes, dollies) similar to the way pallets and cases are tracked in the forward supply chain. A September 2003 survey by Forrester Research on physical assets found that only 52% of the 172 responding firms saw a business case for collecting asset data. And, only 35% of the firms collected in-depth data on the identity of their physical assets (Radjou, 2004). However, there are several examples in the literature that describe the implementation benefits of using RFID to track and control reusable assets.

Scottish Courage, one of the largest brewers in the UK, tagged 1.9 million kegs with low frequency, read/write tags. Some of the reported benefits were a reduction in keg losses from 4% to 2%, the identification and elimination of "unofficial supply chains," and a reduction in distribution overheads due to fewer distribution errors (Wilding and Delgado, 2004b).

The food division of London-based retailer Marks & Spencer deployed RFID tags to track reusable plastic trays contained in plastic dollies. Annual throughput of plastic trays is approximately 85 million and 70% of the product line is perishable. Marks & Spencer implemented a pilot study that replaced bar codes with RFID tags on 3.5 million trays that could be stacked and read through a doorway reader. The reported benefits include an 83% reduction in read time for each tagged dolly, a 15% reduction in shrinkage, a reduction in lead time which allowed for improved postponement, and improved product management due to near real time tracking (Wilding and Delgado, 2004b).

A 2002 pilot study by retailer Woolworth's in the UK to track 16,000 dollies resulted in the identification of supply chain inefficiencies, a reduction in shrinkage that was equal to 1.8% of sales, reductions in receiving and claims processing labor, improved utilization of totes and dollies, and a reduction in inventory levels with an improvement of product availability and customer service (Wilding and Delgado, 2004b).

Direct Resale. Direct resale is typically an option for commercial returns that are linked to the sales process at a retail location. Once the product has been correctly identified from the EPC and inspected for damage, the value recovery option is fairly straightforward. If the product is not damaged it can be returned to the retail store or to the warehouse for distribution to another retail location. If the packaging is damaged it can be returned upstream to the warehouse or the manufacturer for repackaging and tracked with RFID in the same manner as items are tracked in the forward supply chain. We are unaware of any direct resale applications of RFID.

Disassembly. Returns that are dispositioned for repair, refurbish, remanufacture and cannibalize will require some degree of disassembly during the value recovery process. As mentioned in our discussion on product disposition, an Electric Data Log (EDL) can be used to collect information on the recovery value of parts, components and materials that make up the return. For repair, refurbish and re-manufacture this information can be used to determine which parts or components need to be replaced. Replacement can be based on the known failure or on the expected failure of a part. Product information that can improve the efficiency of the disassembly can be stored on a product "passport."

Spengler and Schröter (2003) described a recycling passport developed by electrical and electronic equipment maker Agfa-Gevaert, based in Munich, Germany. The passport contains comprehensive information on Agfa-Gevaert's products that recyclers can access via the Internet to assist them in their recycling operations. The passport contains color-coded schematic drawings of the product, material weights, and advice on disassembly and hazardous substances (Spengler and Schröter, 2003). Radio frequency identification can be used to enhance the disassembly process by automatically accessing the passport through the EPC as the unit enters the workstation. The specific disassembly procedure and information on part recovery options (salvage for reuse, recycle or dispose) can be displayed on a monitor. When the product moves to the next disassembly station, inventory records for salvaged parts and recyclable materials can be updated for planning purposes.

We are unaware of any applications of RFID which are currently being used to improve the efficiency of a disassembly process. And, we know of only one example in the literature describing the use of RFID in a re-manufacturing process. Airgate Technologies, based in Allen, Texas, discussed a pilot study using passive RFID tags at a Dallas-based automotive-component re-manufacturer of alternators and power-steering pumps. Bar codes could not be used to identify products prior to painting; production workers had to visually identify the painted units before applying a bar code that was read at downstream assembly stations. Identification errors were usually discovered when the customer opened the box, resulting in customer dissatisfaction and return costs. Since the painting process does not affect an RFID tag, the tag can be attached to the component before painting, thereby ensuring accurate product identification (Collins, 2004b).

Recycling. It is unclear how RFID can be used to improve the collection and sorting efficiency of a recycling operation. Community recycling programs, such as in the state of Delaware, use color-coded bins so residents can easily sort their recyclable materials at collection centers. Plastic bottles have a material identification number on the bottom which aids the sorting process. Aluminum, copper and other metals that are collected by scrap yards are graded and separated before they are weighed, and industrial byproducts that can be recycled are often routed to a container for safe storage or to a designated area in the warehouse. And, large retail and grocery stores often have a corrugated box compactor in the shipping/receiving area.

To our knowledge there are no published examples of RFID implementations in recycling operations. However, RFID systems can be used to track and control the trucks and containers used to transport the reverse flow of recyclable materials. The security features of RFID can be used to protect against theft, and movement information can be used by production planners to allocate resources and schedule conversion processes.

Implementing an RFID Enabled Closed-loop System

There is a significant potential for the use of RFID systems in product recovery. Its use to track and control reusable assets can be expected to expand as more stringent environmental legislation is passed. Moreover, RFID can be used in the disassembly process much the same way it is currently used for new product manufacturing. Mabee *et al.* (1999) provided an extensive list of design attributes for re-manufacturing assessment. Radio frequency identification can be used to enable and increase the efficiency of several of these attributes, including: accurate identification; disassembly time, steps and layout; analysis of part or component quality (through the EDL); cleaning or repair procedures; and accurate identification after reassembly.

Currently, the use of RFID in closed-loop supply chains is dominated by item tagging for reusable assets that will have a unique EPC code over their lifetime. This dominance is due to control issues, low return volatility and low product complexity. The company owns the assets and obviously has a vested interest in minimizing the costs associated with these assets. Though the implementing company bears the financial burden of the RFID system, they control the assets and the data associated with the asset. Since the information is internal it is easier to use the data to improve operations and the cost of integration with external entities can be avoided. In addition, product disposition is known. Accurate tracking of the assets as they move along the supply chain helps to reduce the level of return volatility. Lead times can be stratified for different process steps and a higher level of measurement accuracy can be attained. Product complexity is low for reusable assets because they are designed for utility, which facilitates product identification. Due to the low levels of return volatility and production complexity, we postulate that RFID deployment for reusable assets will yield significant short-term benefits.

Direct resale items and products that require some degree of disassembly (repair, refurbish, re-manufacture and cannibalize) will have varying levels of return volatility and product complexity. The higher the return volatility and product complexity, the greater the difficulty of implementing RFID in these value recovery options. But the impact of RFID to enhance these options could possibly be significant due to the potential of RFID to aid in product identification, product disposition, and disassembly. In addition, value recovery options that require disassembly have the potential to yield valuable information on product usage, which can be used for new product development or product improvement. We postulate that RFID deployment for direct resale items and products requiring some degree of disassembly will yield significant long-term benefits, and these benefits will increase as return volatility and product complexity increase. In addition, we postulate that these benefits will be greater for products that have a high marginal value of time.

CONCLUSION

In this article we have discussed the importance of "closed-loop supply chain management" and the benefits of implementing RFID systems in it. As RFID system cost decreases and standards become clearer it is predicted that RFID tags will gain widespread acceptance in all types of supply chains. Suppliers and manufacturers should look at the mandates from retailers and government agencies as a business opportunity to improve the visibility, security and efficiency of their own business processes and to take control of their supply chain.

Rohm and Milne state "business strategy involving the Internet must be developed in concert with existing business practices, structures, and channel relationships" (2003: 480). Because RFID is an Internet-based technology the biggest benefits of RFID implementation will come from solutions across the entire supply chain. But it is difficult to implement because of the disputes regarding sharing the cost and benefits between manufacturers, logistics providers, distributors and retailers. The proliferation of tag use also raises serious concerns regarding privacy issues. Moreover, successful RFID implementation will require a change in culture, process, and technology within and across organizations.

One of the major problems associated with the literature on RFID is the lack of empirical examples of RFID in the closed-loop supply chain. Currently, the only examples we have been able to identify that describe a closed-loop application and provide performance metrics have been for reusable assets. This lack of empirical examples is a limitation of this article.

Due to the infancy of both RFID and closed-loop supply chains, research is needed to identify best practices and applications that integrate RFID and closed-loop supply chains. Research is particularly needed for value recovery options that require disassembly due to the greater long-term benefits these options have for organizations.

For practitioners, the implications of this article are that initial RFID projects should focus on internal closed-loop supply chains for reusable assets. Reusable assets have a high level of controllability and low levels of product complexity and return volatility. For other value recovery options, the focus should be on items with low levels of product complexity and return volatility, and a high marginal value of time. The organizational learning from these early projects can then be expanded to products with increasing complexity and return volatility. Those firms deploying closed-loop supply chains will assume a leadership role in sustainable operations, which can then be leveraged for competitive advantage.

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between exploration, exploitation, distinctive competencies associated with radical innovation, and distinctive competencies associated with incremental innovation, we find full support for one of our hypotheses and partial support for the other. Our results suggest that persons holding different positions in a firm (from CEO to Production Worker) are likely to validly respond to our scale items, that respondents reliably envision the two constructs that we measure as separate entities, and that these separate entities related mostly as hypothesized to various distinctive competencies.

Enhancing Product Recovery Value in Closed-loop Supply Chains with RFID 436

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Closed-loop supply chains' integration of the forward and reverse supply chains is an emerging area of interest as firms seek to reduce costs of returns, increase profits through value recovery and meet more stringent environmental standards. Closed-loop supply chains have a higher level of complexity than stand alone forward supply chains or reverse logistics networks due to the uncertainty in the timing, location, quantity and quality of returned goods. This uncertainty inhibits effective and efficient product recovery operations and hence has an adverse impact on the value of recovered products. A key to reducing the uncertainty in closed-loop supply chains is accurate and timely information. Radio Frequency Identification (RFID) technology has the potential to provide such information. The purpose of this article is to introduce how RFID is and can be utilized by the various participants in a closed-loop supply chain. We also describe how RFID can be used to enable decision making during the return process and to enhance the various value recovery options in a closed-loop supply chain. In addition, we provide direction for the implementation of RFID systems in closed-loop supply chains.