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CLOSED-LOOP SUPPLY CHAINS

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Closed-Loop Supply Chains

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1. INTRODUCTION

There are numerous examples and cases available of products that are being reused via remanufacturing or recycling, or combinations of reuse activities (Thierry et al.1995, Krikke et al.1999, Guide 2000, Toktay et al 1999, Fleischmann 2000). However, these products and their supply chains are not all the same with respect to a number of critical dimensions, including product acquisition, reverse logistics, inspection, testing and disposition, remanufacturing, and distribution and selling of the remanufactured product. In the following sections we document a number of diverse products that are presently being remanufactured and describe their supply chains. After each case, we summarize and discuss the distinguishing features of the supply chains. Finally, we discuss the management of each of the different supply chain systems, and identify the key research issues.

2. SUPPLY CHAINS FOR REFILLABLE CONTAINERS

Xerox Copy/Print Cartridge Return Program

Xerox introduced their program for copy/print cartridge returns in 1991 and, at present, it covers 80% of the toner/print cartridge line. In 1998 Xerox expanded the program to include the recycling of waste toner from high-speed copier and commercial production publishing systems. The return rate for cartridges in Europe and North America was greater than 60% for 1998. This equates to over 2.86 million kilograms of material remanufactured or recycled just from cartridges. Xerox reports avoiding almost 23 million kilograms of landfill because of their reuse programs. The cartridges are designed for remanufacturing and recycling of materials not fit for remanufacture.

Customers return the cartridges by placing the spent cartridge into the packaging used for a full cartridge and attaching a prepaid postage label provided by Xerox. The returned cartridges

are cleaned, inspected, and then parts are reused or materials recycled. The full cartridges are then distributed through normal distribution channels to customers. The final cartridge product containing remanufactured parts or recycled materials is indistinguishable from cartridges containing exclusively virgin materials. Figure 1 shows the supply chain, in simplified form, for a cartridge. Xerox is presently testing the use of 'ecoboxes' to allow bulk returns from high volume users in Europe. Xerox will arrange for regular pick-ups of the boxes by its own carrier network. A bulk returns process allows each high volume user to batch cartridges and may lower the returns costs absorbed by Xerox (the information in this section was obtained from Xerox 1999).

Insert Figure 1 Here

Kodak Single-Use Cameras

Kodak started their program to reuse their single-use camera line in 1990. The first stage of the program was to re-design the cameras so that parts could be reused and film reloaded. The entire line of single use cameras may be remanufactured or recycled and the amount of materials per camera that are reusable range from 77-80%. The second stage involved forging agreements with photofinishers to return the cameras to Kodak after consumers had turned them in for processing. Kodak now enjoys a return rate greater than 70% in the United States and almost 60% worldwide. Since 1990, Kodak has reused over 310 million cameras, and has active programs in over 20 countries.

The process flow for the reuse of cameras, after the sale of the camera, starts with the consumer returning the camera to a photofinisher to develop the film. The photofinisher then batches the cameras into specially designed shipping containers and sends them to one of three

collections centers. Kodak has entered into agreements with other manufacturers (Fuji, Konica, and others) of single-use cameras that allow for the use of common collection centers. At the collection center, the cameras are sorted according to manufacturer and then by camera model. After the sorting operations the cameras are shipped to a subcontractor facility where the cameras are cleaned of packaging materials, disassembled, and cleaned. Some parts are routinely reused, some are removed (batteries) and the frame and flash circuit board are carefully tested. These sub-assemblies are then shipped to one of three Kodak facilities that manufacture single use cameras. At the Kodak facility, the cameras are loaded with film and a fresh battery (flash models only), and finally new outer packaging. The final product is now distributed to retailers for resale. The final product containing remanufactured parts and recycled materials is indistinguishable to consumers from single use cameras containing no reused parts. Figure 2 shows the supply chain network for reusable cameras (the information in this section was developed from Kodak 1999).

Insert Figure 2 Here
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3. CHARACTERISTICS OF REFILLABLE CONTAINER CLOSED-LOOP SUPPLY CHAINS

These products, toner/printer cartridges and single-use cameras, are both containers required to sell the contents. Consumers do not distinguish between a new and a remanufactured/reused product since the purpose of buying the container is to gain access to the contents, which are toner ink and film, respectively. Additionally, the customer also has no way of determining, aside from labeling, whether the container has been remanufactured or that it contains reused materials. The returned containers in both cases are blended with new

materials so there is no distinguishing between new and reused products. This is possible because the technology is extremely stable for toner/print cartridges and single-use cameras. The markets for the remanufactured products are exactly the same as for the new products since the two are indistinguishable. The characteristics of the supply chain for container reuse are listed in Table 1. The volumes are very high, in the millions for both products, and the annual returns quantities are stable or have a known growth rate. In both cases the OEM controls the reverse logistics network and the reuse alternatives.

Characteristic
Commodity goods
Containers for consumables
High volume
Low variance
Non-distinguishable products
Simple products
OEM controlled
Short lead times

Table 1 - Characteristics of Closed-Loop Supply Chains for Refillable Container

4. SUPPLY CHAINS FOR INDUSTRIAL REMANUFACTURING - COPYMAGIC

Industrial remanufacturing is mechanical item remanufacturing and accounts for the majority of remanufacturing operations in the United States (Guide 2000). Xerox reports that over 90% of their copier equipment is remanufacturable and that using remanufactured parts has enabled Xerox to reduce landfill materials by over 300 million kilograms since 1998 (Xerox 1999). Xerox has redesigned its photocopier lines using modular design principles to allow for part and component reuse.

Thierry et. al (1995) describes in detail the product recovery processes used by a multinational photocopier manufacturer (nicknamed "CopyMagic") and we present an overview of the reuse processes and the product characteristics. CopyMagic brings new products to

markets and takes back used products from customers. The majority of the return flows are from expired lease agreements, although some used products may be purchased to ensure sufficient quantities of used products. After products are returned there are several alternatives for product reuse: repair, cannibalization, recycling, and remanufacturing. A product may be used for any or all of the above reuse options. For example, a product may be disassembled and some parts cannibalized for use as spares, other parts may be repaired and reused, some other parts fully remanufactured, and parts worn beyond higher-order reuse recycled. The most appropriate level of reuse for products, components, and parts should be driven by economics, e.g. the most revenue-effective reuse option.

CopyMagic does all remanufacturing operations in-house and uses a common production line for both new and remanufactured products. The use of existing production facilities greatly reduced start-up costs for remanufacturing, but has the disadvantage of complex production planning and control. Remanufactured products may be offered as technical upgrades, or with original technology, and this has enabled CopyMagic to exploit additional market segments. Product design relies heavily on modular design concepts to allow for inter-changeable parts and components between models and product lines, in addition to allowing technical upgrades. Products designed for remanufacturing are also easier to repair and service, allowing for better customer relations. The firm has been able to reduce the number of suppliers because of common design platforms and components. A disadvantage to remanufacturing is that suppliers with better quality parts may have lower sales volumes since their parts may be reused more frequently.

The marketing of remanufactured products is complex and CopyMagic has had to tightly control the quality of remanufactured products, and convince customers that the quality of

remanufactured products is the same as a new product. However, the company has an enhanced image due the 'green image' of reused products.

The additional complexities of product reuse has caused CopyMagic to design and implement new information systems to forecast and track product returns, analyze the returns for yields and the condition of products, modules, and parts, and to track the performance of remanufactured units. The supply chain (illustrated in Figure 3) required for these activities is more complex to plan, monitor and control. In Figure 3 we show the remanufacturer as being physically separate from the manufacturer. In the case of third party remanufacturing this is standard practice. However, Xerox and Ocè both use a common facility for new and remanufactured products. Where a common facility is used, new and remanufactured parts are mixed to produce end items. In this case the distinction between manufacturing and remanufacturing is not physical, but simply to illustrate the different flows of components and parts.

Insert Figure 3 Here
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5. CHARACTERISTICS OF CLOSED-LOOP SUPPLY CHAINS FOR INDUSTRIAL REMANUFACTURING

Xerox and CopyMagic are in the minority in industrial remanufacturing since less than 5% of remanufacturing in the United States is done by OEMs (Guide 2000). Additionally, both Xerox and CopyMagic rely heavily on leasing to enable the firms to forecast the timing and quantities of product returns. Product returns from leasing, for non-OEM remanufacturers, represents less than 5% of total returns and this makes the tasks of forecasting product returns timing and quantities much more difficult. This forecasting problem manifests itself as product

imbalances since matching return rates with demand rates is complex and difficult. OEMs have another distinct advantage in the area of product design, since most products must be designed for reuse, i.e., a modular design and clearly labeled materials. The volume of returns in the case of value-added remanufacturing is significantly less than for container reuse.

Marketing is more complex for the remanufactured products since customers may require significant education and assurances to convince them to purchase remanufactured products. Market cannibalization is also a significant concern since little is known about how remanufacturing sales affect new products sales.

Characteristic
High variances
Stable production technology
Limited volumes
Modular design
Imbalances in supply and demand
Cannibalization

Table 2 - Characteristics of Closed-Loop Supply Chains for Industrial Remanufacturing

6. CLOSED-LOOP SUPPLY CHAINS FOR THE REUSE OF CONSUMER ELECTRONICS

Our last case discusses the reuse of consumer electronics equipment and details the supply chain and remanufacturing operations.

Cellular Telephone Reuse at ReCellular, Inc.

ReCellular, Inc., was founded in 1991 in Ann Arbor, MI by Charles Newman to trade new, used, and remanufactured cellular handsets. The business grew from a venture that provided cellular telephones for leasing and alternative sources for handsets were required to reduce costs (hence the discovery of the used handset market). ReCellular is a trading operation that refurbishes cellular phones when necessary to add value for existing orders, and buys and

sells wireless handsets of all technologies. At present, ReCellular estimates it has remanufactured over 1.3 million cellular phones. One of the goals of the company is to be the “first in the second” in the wireless exchange plan. The company offers remanufactured (refurbished) products as a high quality, cost effective alternative to new cellular handsets. Customer services include: grading and sorting, remanufacturing, repackaging, logistics, trading, and product sourcing (all services are specific to cellular handsets and accessories). ReCellular operates globally with a presence in South America, the Far East, Western Europe, Africa, the Middle East, and North America. The company has plans to expand operations to provide better coverage throughout the world.

The cellular communications industry is a highly dynamic market where the demand for telephones changes daily. Demand may be influenced by the introduction of new technology (e.g., digital and analog), price changes in cellular airtime, promotional campaigns, the opening of new markets, churn (customers leaving present airtime providers), and the number of new cellular telephone manufactured. Additionally, there is no worldwide standard technology (e.g., Europe uses GSM, but the United States does not support this wireless technology) that necessitates dealing in a number of often-disparate technologies and standards. These global differences makes regional activities difficult since there may be no local market for certain types/models of phones, requiring a firm to manage global sales and procurement. Additionally, cellular airtime providers may limit the number of telephones supported by their system and the dropping of a phone model by a major carrier can greatly affect a local market. These factors make competition for an original equipment manufacturer challenging. However, a company offering used or remanufactured equipment faces numerous factors affecting the supply of used cellular phones. The same factors that complicate demand affect the availability of used

handsets. Further, identifying and taking actions to reduce the uncertainties in the reverse flows as early as possible is an important issue in this business. The supply of used handsets is a volatile market, with volumes and prices in a constant state of flux. Supply uncertainty is not a complication faced by traditional OEMs.

In order to fully understand the nature of the market, both forward and reverse flows of materials must be considered. Figure 4 shows the supply chain system for cellular telephone reuse. The forward movement of materials consists of the traditional flows from suppliers to manufacturers, manufacturers to airtime providers (retailers in this case since the sale of a cellular phone is tied to airtime activation) and airtime providers to the customers. The reverse flows are more complex. Remanufacturers of cellular telephones do not collect handsets directly from the end user, but rather rely on airtime providers or a variety of third-party collectors (we discuss the specifics of product acquisition in the next section). Airtime providers and third-party collectors act as consolidators who then broker the units to remanufacturers. ReCellular then sorts and grades the handsets, and sells the handsets as-is or remanufactured to airtime providers and third-party dealers working with airtime providers. Some handsets may be obsolete or damaged beyond higher-order recovery and these products are sold to scrap dealers and recyclers (note this flow may come from both remanufacturers and third party collectors). Recyclers recover polymers and other materials in the handset assemblies, and base materials in batteries. Scrap dealers may separate the handsets into materials and resell individual parts for reuse in other applications and offer the other sorted materials to recyclers. Suppliers may then purchase the recycled materials for use in new products.

The acquisition of used telephones is central to the success of a remanufacturing firm. The nature of product acquisitions is driven by what future demands (unknown) will be for

phones. The lead times for delivery after used phones have been purchased are often lengthy and subject to a large amount of variability. This has caused remanufacturers to have stocks on-hand to compete for sales. ReCellular obtains used phones in bulk from a variety of sources, including cellular airtime providers and third-party collectors. Third-party collectors are often charitable

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Insert Figure 4 Here
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foundations (e.g., the Wireless Foundation: http://www.wirelessfoundation.org) that act as consolidators by collecting used handsets and accessories from individuals. Cellular airtime providers also act as consolidators by collecting used phones from customers who have returned the phones at the end of service agreements, or customers upgrading to newer technology. Both these and other sources worldwide may offer a variety of handsets and accessories in varying condition for a wide range of prices and quantities. Due to the low cost (approximately $0.50 per phone using air transport) of bulk transportation of phones using a worldwide network of suppliers of used phones is practical and cost-efficient. No individual returns are accepted since the channels required for direct returns from the consumer have too high a cost to be effective at this time. Obtaining the best grade of used products for the best price is one of the keys tasks necessary for the success of ReCellular. Deciding on a fair price to offer for the used phones is a difficult and complex task. At present, the acquisition staff devotes much of their time to identifying reliable and reputable sources of used phones and establishing a working relation with these suppliers. New suppliers usually require a physical visit to ensure the quality of the used phones.

The value of a used handset is highly dependant on future market demand for that particular model either in remanufactured or as-is form. The present demand for a graded as-is

used cellular phone or a remanufactured phone is known for that instant in time, but due to the highly dynamic nature of the industry, these prices are not stable. The market forces discussed earlier may cause the value of a particular model of phone to drop or rise with little warning. An additional factor is that the selling price for remanufactured phones tends to drop over time, making the used phones a perishable product.

This nature of the product reuse market necessitates a fast, responsive supply chain that identifies sources of used phones for a fair price, and future buyers of these phones in either graded as-is or remanufactured condition. Additionally, the system must procure the phones in a timely manner, sort and grade the telephones, have the capability to rapidly remanufacture the phones to order, and provide a fast accurate transportation method to ensure timely delivery of the phones. ReCellular is developing an e-commerce site strictly for business to business in order to facilitate matching suppliers and buyers of equipment. The present e-commerce site shows the current stocks (model, price, grade, and quantity) available and what models are needed (but not the prices offered). The site is being upgraded to allow real-time transactions by sales and procurement agents. Future considerations also include using the e-commerce site to facilitate on-line auctions for used and remanufactured products.

7. CHARACTERISTICS OF CLOSED-LOOP SUPPLY CHAINS FOR CONSUMER ELECTRONICS REUSE

The volume of cellular telephones in use worldwide is enormous, with over 55 million cellular subscribers in the United States alone (U.S. Central Intelligence Agency 2000). One of the first requirements for a remanufacturer in this environment is global coverage. Since the rate of technology diffusion is different for each country in the world, phones, which may be

technically obsolete in Norway, may be current technology in Ecuador. This imbalance in the diffusion of technology makes having global operations and intelligence crucial for a profitable operation. Tightly tied to the concept of global markets is the problem of acquisition, or obtaining the best-used product for the best price. The prices for cellular telephones are highly dynamic and are based on future expected prices for remanufactured handsets. The problem is further complicated by the market for graded, as-is cellular telephones where a selling is price is known, as opposed to an expected price in the future for a remanufactured item.

Cellular telephones are perishable items because of the high clockspeed in new product development. Electronics industries have the highest clockspeed, an average of 18 months, and this makes responsive systems crucial to making a profit. Remanufacturers cannot afford to remanufacture to stock in this environment since the value of the items drops daily.

Characteristic
Dynamic spot markets for supply and demand
High volumes
Perishable good
Cascade reuse opportunities (worldwide market)
High information requirements
High variability

Table 3 - Characteristics of Supply Chains for Consumer Electronics Reuse

8. MANAGEMENT OF CLOSED-LOOP SUPPLY CHAINS

In the simplest terms all closed-loop chains do have a common set of activities. The recovery process consists of several highly inter-related sub-processes: product acquisition, reverse logistics, inspection and disposition (consisting of test, sort and grade), reconditioning (which may include remanufacturing) and distribution and selling of the recovered products. However, the previous cases illustrate that while there are common processes, not all closed-loop supply chains are alike. Each different supply chain system has different characteristics and

management concerns. Table 4 highlights the differences in the three forms of closed-loop supply chains we discussed in this chapter. In the following subsections we discuss each of the sub-processes for the different types of closed-loop supply chains.

	Product Acquisition	**Reverse Logistics**	**Test Sort Grade**	**Recondition**	**Distribution And Selling**
Refillable Containers ⇒ Toner cartridges	Easy	Easy	Easy	Easy	Easy
Industrial Remanufacturing ⇒ Copiers	Intermediate	Hard	Hard	Hard	Hard
Consumer Electronics Reuse ⇒ Cellular Phones	Hard	Intermediate	Easy	Easy	Intermediate

Table 4 - Key Distinctions Between Closed-Loop Supply Chains

Refillable Container Closed-Loop Supply Chains

Product acquisition refers to product acquisition management, and is actually a number of related processes (Guide and Van Wassenhove 2000). First, product acquisition management determines whether reuse is a value-creation activity for a specific firm. Second, if reuse activities are profitable, to maximize revenue the appropriate method for managing product returns should be selected. Third, operational issues, such as facility design, product planning and control policies, inventory policies, are dependant on the method selected to manage product returns. Fourth, product acquisition management activities help identify and develop new markets for reused product, and to balance the return rates with market demands. We are concerned here primarily with the second and fourth product acquisition processes, selection of the appropriate method for managing product returns, and balancing return rates with market demands. In the case of single-use cameras, the OEM controls the returns process by using cash incentives to motivate the photofinisher to return the empty cameras to Kodak's reuse facility. Xerox also directly controls the returns process for print/toner cartridges. Xerox supplies each

customer with a pre-paid mailer and appeals to customers to send back the spent cartridge. Both strategies are extremely successful at ensuring constant volumes of containers, and are examples of market-based returns strategies. Market-based strategies are active strategies to encourage product returns, in contrast to waste stream systems where returns are passively accepted from the waste stream (Guide and Van Wassenhove 2000). Both firms enjoy stable returns flows with predictable volumes each period.

Balancing return and demand rates in a refillable container closed-loop supply chain is a relatively easy process, in part because the customer cannot differentiate between reused and new products. We do not mean that the processes involved in balancing return and demand rates are simplistic (see Tokay, et al. 1999 for a complete discussion of this process), but rather that the process is simple in comparison with the other types of closed-loop supply chains. The technology contained these products is stable and there are very limited secondary markets available for the used containers. There are secondary markets for the refilling of printer cartridges and single use cameras, these are small localized operations that are considered more of a nuisance since the remanufacturing may be sub-standard and damage the firm's reputation. The returned products are mixed with new (replacement) materials as needed and then repackaged and sent back out through traditional distribution channels. There is no need to segment demand by product type (remanufactured vs. new) or for a manufacturer to consider market cannibalization.

Reverse logistics activities are the processes required to move the products from the end user to the facility where reuse activities will take place. In both examples of refillable containers, these sets of activities are simple. The photofinisher acts as a consolidator for Kodak and eliminates the need for Kodak to deal with individual customers. Xerox has minimized their

contact with end-users by using a pre-paid mailer, which the customer may then use to arrange for pick-up and transportation. Fleischmann (2000) provides a complete discussion of reverse logistics networks and their characterization.

The disassembly, test and inspection processes and the remanufacturing processes for refillable containers are simple. The product itself is simple and the costs are low, products that may be questionable may be recycled with little or no concern about replacement materials. Finally, the distribution and selling processes are simple since traditional distribution networks are used and the customer base is the same as for new products.

Industrial Remanufacturing Supply Chains

We summarize the key factors for success in Table 5. Of the closed-loop supply chains, the industrial remanufacturing sector is most likely the best documented, but the most difficult to plan, manage, and control.

Product acquisition activities for industrial remanufacturing may be based on leasing, in which case the product will be either returned at the expiration of the lease, or the lease renewed with the same item. Product acquisition in the case of leasing may be viewed as relatively simple, however, only a small number (5%) of industrial remanufacturers report using leasing (Guide 2000). Remanufacturers report using a number of other techniques (deposits, rebates, and cash refunds) with varying degrees of success and this indicates that the problem of obtaining sufficient quantities is more difficult than for refillable containers.

Keys to Success – Industrial Remanufacturing Closed-Loop Supply Chains
• Ability to forecast and control the timing, quantity, and quality of product returns (IS)
• Design for reuse (recycle, repair, and remanufacture) (engineering)
• Customer education (remanufactured as good as new)
• New relationships with suppliers (fewer parts & components, and design)
• Complex production planning and control problems

Table 5 - Key Factors Industrial Remanufacturing

Balancing return and demand rates for industrial remanufacturing is more difficult since there are distinct and separate markets for new and remanufactured goods. Customers may require the newest technology or may simply perceive remanufactured products as inferior. These separate markets may affect the distribution and selling of remanufactured products. Market cannibalization may be a concern for manufacturers providing remanufactured products and, as a result, the retail markets may be disparate. The reverse logistics process is most often very difficult since the remanufacturer must arrange for pick-ups from many geographically diverse facilities. Many used industrial items are also regarded as hazardous waste and must be treated as such during transportation. The process of testing, sorting, grading and inspection is time consuming and complex, with the possibility of a single product containing tens of thousands of parts and components. The screening process must be rigorous since products of poor quality may be expensive to remanufacture, or dangerous to reuse. The remanufacturing/reconditioning processes are most often complex and difficult to plan, manage and control (Guide 2000).

Consumer electronics reuse

These types of closed-loop supply chains may hold the greatest promise due to the volume of products available for reuse, but at the same time these types of supply chains represent some of greatest challenges. We list the key factors for success in Table 6.

Keys to Success – Consumer Electronics Closed-Loop Supply Chains
• Ability to forecast and control the timing, quantity, and quality of product returns in a global market (IS)
• Fast response (perishable items)
• e-Commerce to identify buyers and sellers
• Identify and exploit cascade reuse
• Identify and exploit technology diffusion differences

Table 6 - Keys to Consumer Electronics

Product acquisition is very hard for this form of closed-loop supply chains. The products are used globally, but the rate of technical diffusion is different in various geographic areas. This requires that a successful operation will have worldwide collection and distribution markets and these markets will not be the in the same geographic areas. Supply and demand rates and prices are extremely volatile. The products are also perishable items since the value of a remanufactured item may drop daily because of the rapid rate of technological progress and the rate of technology diffusion. There are also multiple options for reuse since products may be sold in graded as-is condition or remanufactured. Each option has a different selling price which is quite dynamic.

However, there are several of the major processes that may be characterized as easy to intermediate. The nature of the products, very few mechanical parts, makes them simple to test, sort and grade, and remanufacture/recondition. The reverse logistics processes are somewhat hard to coordinate since there are so many national borders with customs regulations to manage. However, the handsets are small and light and may be shipped in bulk with commercial air carriers for an inexpensive price (approximately $0.50 as of the summer of 2000). The distribution and selling processes involve a number of different nations, and requires knowledge of the cellular technology in use and the airtime providers. The selling process is, for reasons discussed previously, tightly intertwined with the acquisition process.

9. CONCLUSIONS AND RESEARCH ISSUES

There are a number of unique structures for closed-loop supply chains. These different structures all require a set of common activities: product acquisition, reverse logistics, test, sort and grade, remanufacturing /reconditioning, and distribution and selling. The successful

management of the various activities does not always involve the same actions from supply chain to supply chain. It is crucial for managers and researchers to understand the differences and the implications of these differences. One of the basic research needs is a continuing refinement of the documentation, categorization, and understanding of the different forms of closed-loop supply chains. Other pressing research needs are those activities shown in Table 5 to be 'hard'. Finally, we hope that holistic models will be developed that reflect the complex nature of the interactions.

REFERENCES

Fleischmann, Moritz (2000), *Quantitative Models for Reverse Logistics*, Rotterdam, The Netherlands: Erasmus University Rotterdam Ph.D. Thesis.

Guide, V. Daniel R., Jr. (2000), 'Production planning and control for remanufacturing: Industry practice and research needs', *Journal of Operations Management*, **18**, 467–483.

Guide, V. Daniel R., Jr. and Luk N. Van Wassenhove (2000), *Managing Product Returns for Remanufacturing*, Fontainebleau, France: INSEAD Working Paper 2000/35/TM/CIMSO.

Kodak (1999), *1999 Corporate Environmental Report*, Rochester NY: The Kodak Corporation.

Krikke, Harold, A. van Harten and P. Schuur (1999), 'Business case Océ: Reverse logistics network re-design for copiers', *OR Spektrum*, **21**, 381-409.

Thierry, Martijn, Marc Salomon, Jo Van Nunen and Luk Van N. Wassenhove (1995), 'Strategic issues in product recovery management', California Management Review, **37**, 114-135.

Toktay, Beril, Lawrence Wein and Stefanos Zenios (2000), 'Inventory management of remanufacturable products', forthcoming in *Management Science*.

U.S. Central Intelligence Agency (CIA) (2000), *The World Fact Book 2000*, Washington, DC: The United States Central Intelligence Agency.

Xerox, (1999), *1999 Environment, Health and Safety Progress Report*, Webster, NY: The Xerox Corporation.

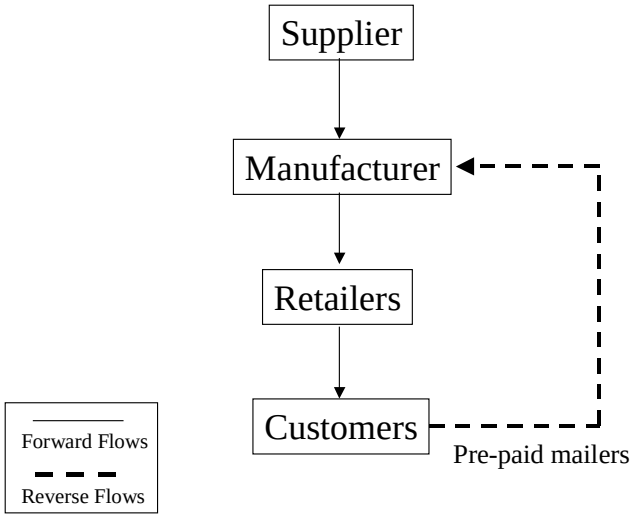


Figure 1 – A Closed-Loop Supply Chain for Cartridge Reuse

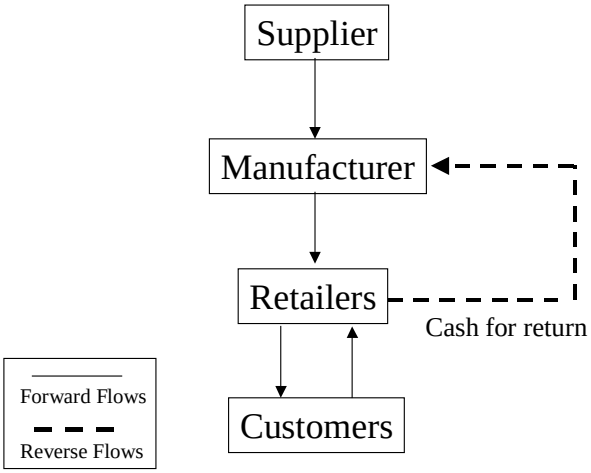


Figure 2 – A Closed-Loop Supply Chain for Single-Use Cameras

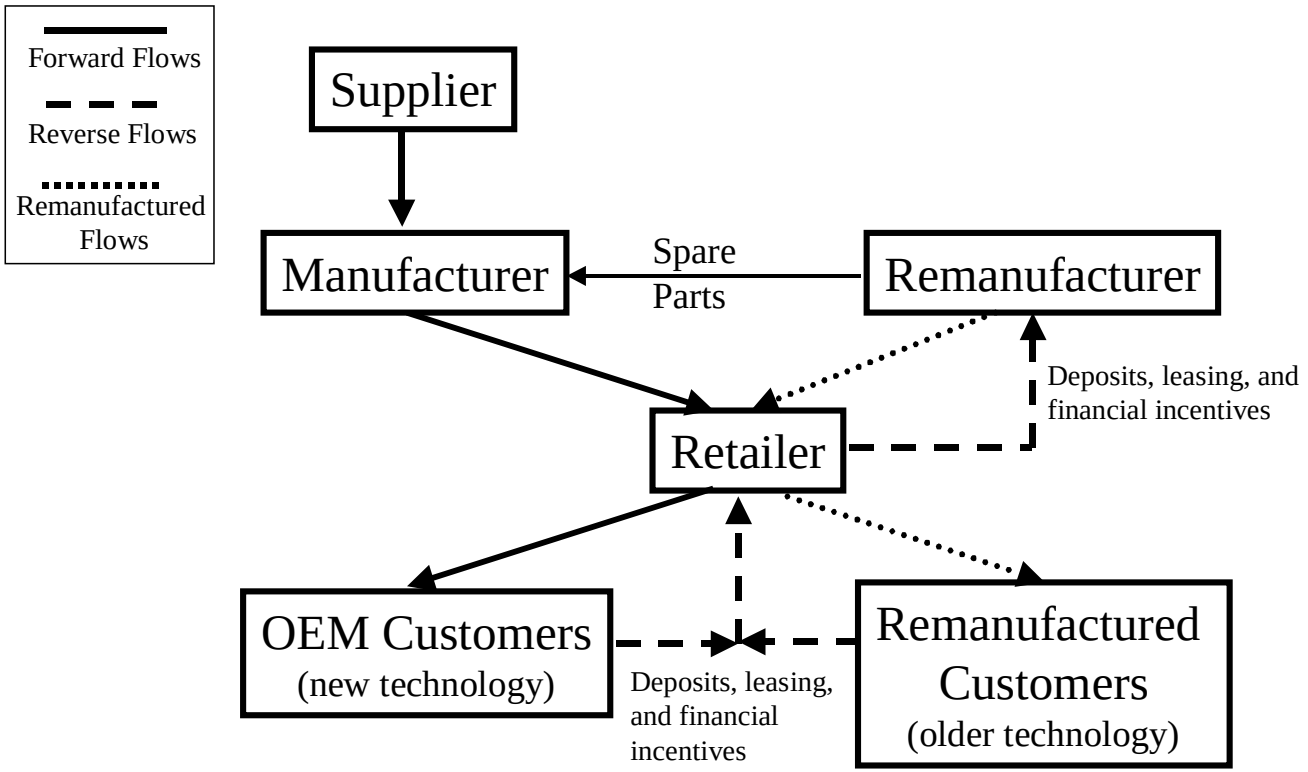


Figure 3 – A Closed-Loop Supply Chain for Photocopiers

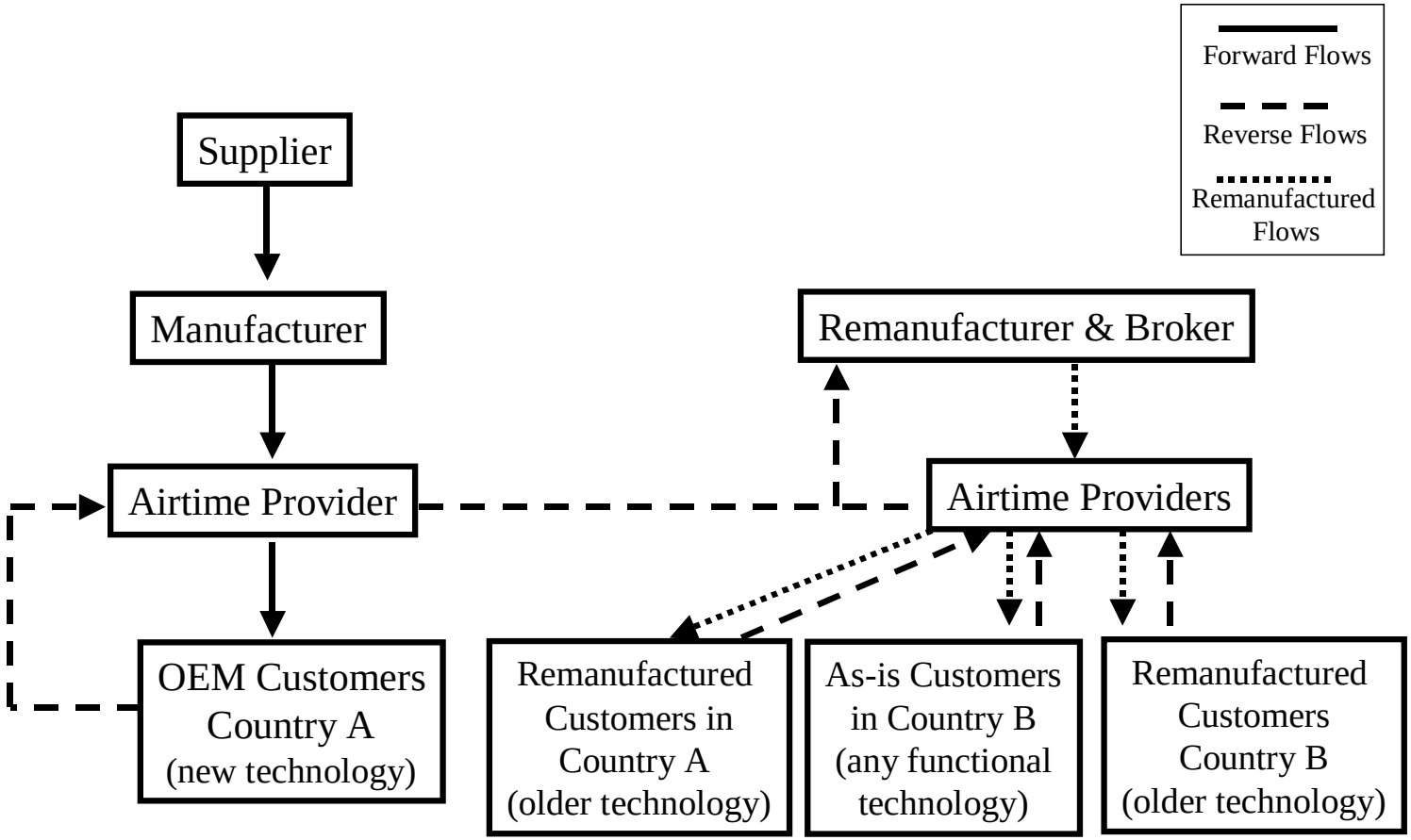


Figure 4 – A Closed-Loop Supply Chain for Cellular Telephones