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The Evolution of Closed-Loop Supply
Chain Research

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The Evolution of Closed-Loop Supply Chain Research

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Abstract

The purpose of this paper is to introduce the reader to the field of closed-loop supply chains with a strong business perspective, i.e., we focus on profitable value recovery from returned products. It recounts the evolution of research in this growing area over the last 15 years, during which it developed from a narrow, technically focused niche area to a fully recognized sub-field of supply chain management. We use 5 phases to paint an encompassing view of this evolutionary process for the reader to understand past achievements and potential future OR research opportunities.

Keywords : *closed-loop supply chains, reverse logistics, remanufacturing, value-added recovery*

1. Introduction

Closed-loop supply chains (CLSC) focus on taking back products from customers and recovering added value by reusing the entire product, and/or some of its modules, components and parts. Over the last 15 years closed-loop supply chains have gained considerable attention in industry, as well as academia. This paper serves as an overview of this evolution from a business perspective and makes some observations about future research needs. It is not intended to be a comprehensive review of published literature. Rather, based on our close collaboration with companies and researchers in this field, we provide our personal (and perhaps biased) perspective.

Today we define closed-loop supply chain management as *the design, control and operation of a system to maximize value creation over the entire life-cycle of a product with dynamic recovery of value from different types and volumes of returns over time*. This is clearly a business definition. Fifteen years ago, the definition given by a practitioner or researcher would have been operational and technical. This paper will describe this evolution. Our discussions are restricted to value-added recovery from a purely business perspective. However, we note that product recovery and reuse do serve as the foundation for the development of industrial systems that are both economically and environmentally sustainable.

Closed-loop supply chains have enormous economic potential. The remanufacturing sector is presently larger than the US domestic steel industry in terms of sales and employment with annual sales in excess of \$53 billion (Lund 1996). Large retailers, such as Home Depot, can have return rates of 10 percent of sales, or higher, due to liberal returns policies. The total value of returns can easily run in the hundreds of millions of dollars for a single retailer. Stock et al. (2002) estimate the annual costs of commercial returns in excess

of \$100 billion. Currently very little, if any, value is recovered by the manufacturer. Our experiences with a computer network equipment manufacturer showed that over 700 million dollars of perfectly operational recovered products were destroyed. Hewlett-Packard estimates that returns cost them as much as 2 percent of total outbound sales (Guide et al. 2006). Less than half of the value of those product returns is being recovered. To make matters even worse, personal computer manufacturers have short life-cycle products that can lose 1 percent of their value per week and have high return rates (Guide et al. 2006). These types of products represent a huge challenge for value recovery. A slow reverse supply chain that takes 10 weeks to put the returned product back on the market translates to a loss of (approximately) 10 percent of the total value in that product. This far exceeds many profit margins on consumer electronics, so a computer manufacturer is well advised to develop competencies in fast recovery systems.

This paper is structured as follows. We first present some fundamentals to understand closed-loop supply chain operations. Section 3 introduces our business perspective. Sections 4 to 8 paint the evolution of research in this field through a set of 5 phases. They describe the natural progression from a technical engineering-dominated perspective to a holistic business model view. Please note that these phases should neither be taken as strictly chronological, nor should they be viewed parts of a literature review. They merely serve as different lenses through which we offer the reader our personal view on the evolution of this field. Finally, we summarize the evolution of closed-loop supply chains in Section 9, and make some observations about future CLSC research.

2. Closed-Loop Supply Chain Fundamentals

Closed-loop supply chains may be viewed with a focus on the type of returns or on activities. We will present both perspectives, since both add to an overall understanding of CLSCs.

Product returns may occur for a variety of reasons over the product life-cycle. Commercial returns are products returned to the reseller by consumers within 30, 60 or 90 days after purchase (Tibben-Lembke 2004 provides a much finer-grained discussion of various types of commercial returns). End-of-use returns occur when a functional product is replaced by a technological upgrade. End-of-life returns are available when the product becomes technically obsolete, or no longer contains any utility for the current user. As an illustrative example, consider the mobile telephone. In the US, consumers may return a mobile phone to the airtime provider for any reason during a 30-day period after purchase (a commercial return). Further, 80% of mobile phone users upgrade their perfectly functional mobile phones annually, making their previous models available as an end-of-use return. Finally, some users of mobile phones only relinquish their phone when it is no longer supported by the airtime provider and it becomes available as an end-of-life return (e.g., the technology is obsolete). There are also repair and warranty returns that occur throughout, and even beyond, the product life-cycle. It should be clear that for consumer electronics alone, there are billions of returned products annually in the US, and therefore, enormous potential for value recovery.

Product recovery activities include used product acquisition, reverse logistics, product disposition (sort, test and grade), remanufacturing/repair, and remarketing (Guide and Van Wassenhove 2002). For example, in order to recover end-of-use mobile phones, the first step is to have access to sufficient quantities of the right quality phones at the right price (product acquisition). The acquired mobile phones must be transported to a recovery facility (reverse logistics) where they are tested, sorted and graded (product disposition) prior to selecting the best product recovery option (remanufacturing, repair, parts recovery, material recycling or disposal). Assuming the optimal recovery option for a given mobile phone is remanufacturing, that phone then needs to be sold in a secondary market (remarketing).

By combining our two views, we can link product return types to specific recovery activities. For each type of product return there is a most attractive recovery option. Commercial returns have barely been used and are best reintroduced to the market as quickly as possible. The majority of these returns require only light repair operations (cleaning and cosmetic). End-of-use returns may have been used intensively over a period of time and may therefore require more extensive remanufacturing activities. The high variability in the use of these products may also result in very different product disposition and remanufacturing requirements. Ideally, one would like to acquire end-of-use products of sufficient quality to enable profitable remanufacturing. End-of-life products are predominantly technologically obsolete and often worn out. This makes parts recovery and recycling the only practical recovery alternatives (assuming one wants to avoid landfill). Summarizing, there are natural return-recovery pairs: consumer returns→repair, end-of-use returns→remanufacture, and end-of-life returns→recycle. Of course, there are many exceptions, but our industrial experience shows these are the dominant pairings.

Before we proceed, it may be useful to reiterate that this paper describes our personal view on value-added recovery activities from a pure business perspective. This automatically excludes a number of important subjects. Among others, we do not discuss green or sustainable supply chain issues and we do not address end-of-life recycling and landfill avoidance (see, for example, the feature issue of the *Journal of Operations Management* **25**(6) focused on supply chain management in a sustainable environment). Likewise, we do not discuss repair systems and installed base management. Furthermore, we also exclude the literature on return avoidance and secondary markets for retail goods (see Tibben-Lembke 2004 for an overview). Many authors have provided excellent contributions to all these (and other) topics one could include in a wider definition of closed-loop supply chain management. But our focus here is on value-added recovery activities and we provide our own perspective

instead of engaging in a literature review. This implies by no means a value judgment about the superiority of one worldview over another. It does, however, allow for a focused exposition of an opinion, i.e. a forum piece.

3. A Business Perspective on Closed-Loop Supply Chains

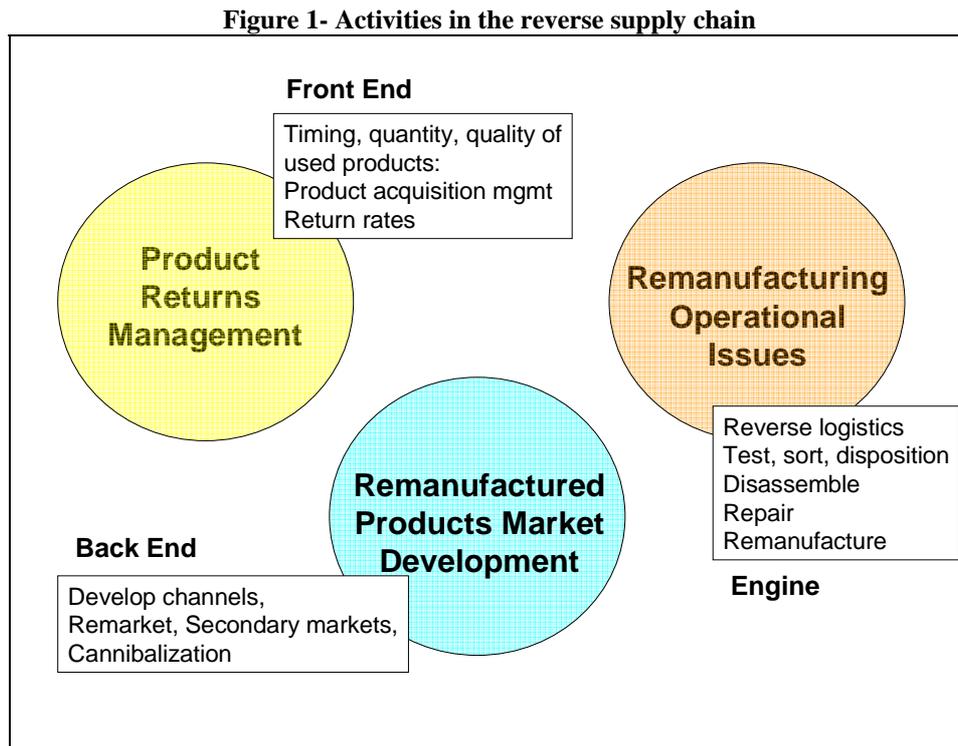
Taking a traditional *activity-based view* of the reverse supply chain shows the key activities with a focus on individual tasks (Figure 1). The bulk of research on reverse supply chains focuses on technical and operational issues. Obviously, remanufacturing makes no sense if technical/operational bottlenecks cannot be removed, so a focus on the technical activities would seem a likely place for initial research attention. Even in the event that remanufacturing is technically feasible, the potential value recovery must exceed the costs of recovery operations. This is a necessary, but not sufficient condition. To make remanufacturing economically attractive, one also needs adequate quantities of used products of the right quality and price, at the right time, as well as a market for the recovered products. In other words, one needs to go far beyond the technical and operational boundaries and take a global business process perspective.

In order to move to a *process flow perspective*, we distinguish three sub-processes (Figure 1): product returns management (Front End), remanufacturing operational issues (Engine) and remanufactured products market development (Back End). Since any one of these three sub-processes can be a bottleneck, the following questions that enable a process view should be asked:

- Does anyone want to buy remanufactured products (remanufactured products market development)?
- Can value be recovered from returns at a reasonable cost (remanufacturing)?

- Is there sufficient access to used products (product returns management)?

Our experiences suggest that very often it is not technical constraints that matter, but rather the lack of a market for remanufactured products, or the lack of used products of sufficient quality at the right price and the right time.

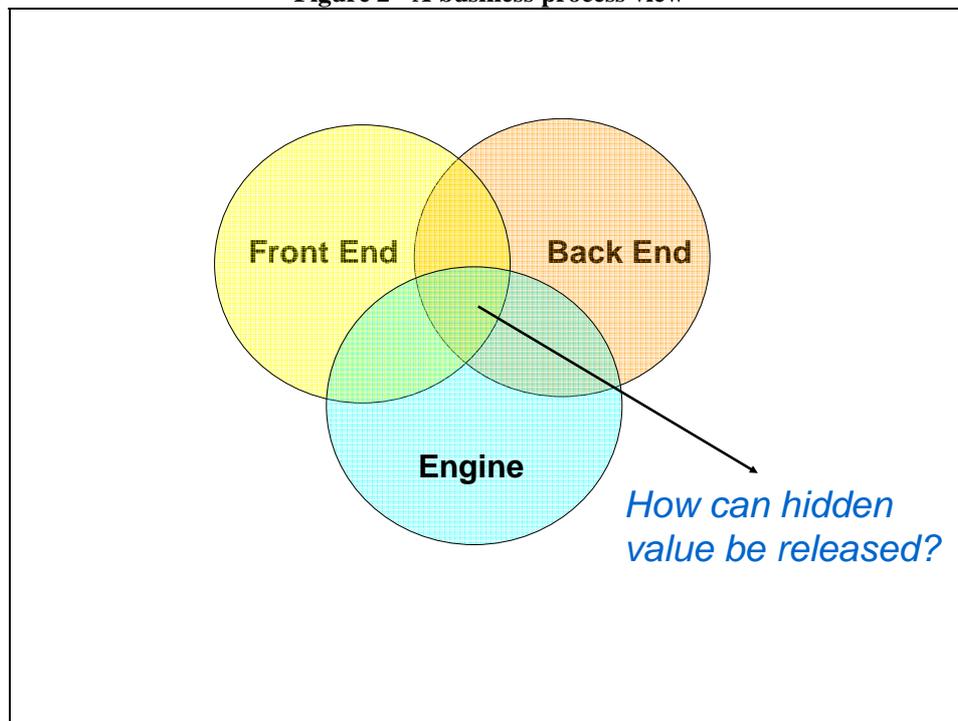


In order to take a *business perspective*, we need to recognize that only when the three sub-processes are managed in a coordinated fashion can the value in these systems be fully realized. A lack of access to used products, or technical remanufacturing issues, or marketing and sales' fear of market cannibalization can inhibit, or prevent, profitable closed-loop supply chains. In order to make CLSCs more attractive from a business or value creation perspective, all bottlenecks should be removed and the sub-processes smoothly integrated (Figure 2). Only then can the hidden value be released from the system.

Research on CLSCs has evolved from examining individual activities to considering the entire reverse supply chain process, to finally considering closed-loop supply chains as a potentially profitable business proposition. Our discussion could end here; however, it makes

sense to now revisit the evolution of closed-loop supply chain research in more detail, keeping this preview in mind. In order to provide a meaningful understanding of the evolution of CLSC research, we are going to simplify things by introducing a number of phases. Our discussion begins with a preview of the five phases.

Figure 2 - A business process view



The five phases of CLSC research build upon one another in a cumulative fashion in that each phase adds new perspectives, but also deepens the study of the issues of the previous research. We repeat that these phases should not be viewed as chronological but rather as different lenses applied by researchers over time. Many of these phases are concurrent. We use them mainly as a vehicle to convey our personal perspective on the field and as a pedagogical tool for the reader. The five phases are:

- Phase 1 – The golden age of remanufacturing as a technical problem
- Phase 2 – From remanufacturing to valuing the reverse logistics process
- Phase 3 - Coordinating the reverse supply chain

- Phase 4 – Closing the loop
- Phase 5 – Prices and Markets

Phase 1 clearly refers to an activity focus mainly geared at the engine (reverse logistics and remanufacturing). Phases 2 and 3 shift the focus to a process management perspective and extend attention to the front and back end activities. CLSCs are typically not controlled by a single actor. Our experience shows that reverse supply chains often involve many more independent players than forward supply chains. Indeed, one of the key issues in designing, managing and controlling CLSCs is the additional complexity that arises from this large number of actors in a decentralized system. Phase 4 moves from a static process management and coordination perspective to a dynamic one. It concentrates on dynamic system design over the entire product life-cycle. In Phase 5, the problems of consumer behavior and product valuation are finally recognized. These are critical aspects previously neglected by operations management researchers dominated by operations research and industrial engineering backgrounds. We now proceed with a more detailed exploration of each of the five phases.

4. Phase 1: The Golden Age of Remanufacturing

Remanufacturing was, in the early 1990s an almost completely neglected research area, despite the size of the industry. Robert Lund's early estimates of the size of the remanufacturing industry at this time suggested it was larger than what remained of the domestic US steel industry in terms of employment and gross sales (Lund 1996). Despite this fact, most academics dismissed remanufacturing as insignificant, with no relevance for the larger business community. As the editor of a major decision sciences journal told one of us in the early 90s, 'nobody cares and the issues are not mainstream research'. Fortunately, not

all journal editors felt this way, Professor Graham Rand, editor at the *Journal of the Operational Research Society* at the time encouraged submissions addressing remanufacturing issues.

Remanufacturing has existed for centuries, typically for high value and low volume items, such as locomotive engines and aircraft (product life extension). The primary difficulty in remanufacturing large, complex items is the scale of the problem. Products are often composed of tens of thousands of components and parts. The disassembly, remanufacturing and re-assembly of such products is a technical challenge with respect to shop flow control, adequate testing of critical parts (for safety reasons), and coordination of parts at the re-assembly point. The earliest work by R. Lund (1984) at the World Bank viewed remanufacturing as a pathway for developing nations to get technical know-how and also touted the energy savings from remanufactured goods (compared to production from virgin materials).

A small number of researchers worked on improving remanufacturing shop control and coordination (Guide 1996, Guide and Srivastava 1998). This early research was often sponsored by the US military where remanufacturing of expensive assets (e.g., aircraft weapons systems and aircraft carriers) is a critical concern. Remanufacturing job shops present especially difficult situations for planning and control since there are high uncertainties in routings and processing times and a need for coordination among the different shop areas (e.g., disassembly, remanufacturing processes, and reassembly) (Guide 2000). Note that this early research was driven by the need to make operations more efficient to increase profitability of the remanufacturing workshops.

In Europe, the research focus was quite different. Reverse logistics activities came about through legislation via EU directives on end-of-life products, such as the paper recycling directive, followed by many others like the end-of-life vehicle directive and the

Waste Electrical and Electronic Equipment Directive (WEEE). These directives were essentially geared at proper recycling and landfill avoidance. Under these circumstances companies naturally focused on ways to minimize the financial impact of compliance. Therefore, researchers logically studied subjects such as design for disassembly (de Ron and Penev 1995), or design of minimum cost recycling networks and the reduction of environmental impact (Bloemhof-Ruwaard et al. 1996, Fleischmann et al. 2001). Please note that we do not further discuss the many excellent contributions in this research stream driven by the environmental take-back directives of the EU (e.g., Dekker et al. 2004), since our focus is on value-added recovery from a profit perspective.

It is important to emphasize the early research on CLSCs took two fundamentally different approaches: *market-driven* (profit maximization) and *waste-stream* (cost minimization). These different world views naturally led to very different research interests in the US and Europe. However, some companies in Europe, such as Xerox, decided to be proactive and go beyond legislation. Xerox took a business economics perspective when it introduced its 'green' line of remanufactured copiers. This led to major changes in the production-distribution network as well as in other functions, such as design and marketing and sales (Thierry et al. 1995). Studying the developments at Xerox, a group at Erasmus University Rotterdam (NL) realized that remanufacturing was not only about minimizing the cost of compliance, but rather a more fundamental business and value creation issue. It was after this point that a small core of researchers on both sides of the Atlantic begin to focus on value creation.

The research focus during this golden age of remanufacturing was clearly on getting the engine right (reverse logistics, product disposition, and remanufacturing). It may best be described as (1) focused on cost minimization (either to improve profitability or reduce the cost of compliance) and (2) activity-oriented. By activity-oriented, we mean a focus

exclusively on a particular activity such as disassembly, shop floor control, or production-distribution network design. In the US, this literally meant extending the life of a fighter jet. In Europe, it meant compliance to legislation at minimum cost of establishing the necessary recycling networks.

The key findings from the golden age of remanufacturing were as follows. An understanding of the complicating characteristics of remanufacturing and reverse logistics, and the differences with traditional operations management activities (Guide 2000). The characterization of common activities in reverse supply chains (Guide and Van Wassenhove 2001). The identification of different types of products returns with their specific impact on the reverse supply chain (Thierry et al. 1995, Guide and Van Wassenhove, 2001). Two things became clear during this phase. First, there were many new and interesting operations management problems to solve and, second, remanufacturing was more than a niche area.

5. Phase 2: From Remanufacturing to Valuing the Reverse Logistics Process

Building on Phase 1, researchers introduced two new avenues to exploring CLSC issues. In fact, these two approaches represent the major research themes of this phase. The first uses a classic OR activity optimization approach (Dekker et al. 2004). It focuses on inventory control systems (Inderfurth 1997, van der Laan et al. 1999, Toktay et al. 2000, DeCroix 2006, DeCroix et al. 2005, DeCroix and Zipkin 2005, Ferrer and Whybark 2001), reverse logistics networks (Fleischmann et al. 2001, Fleischmann et al. 2003), hybrid manufacturing/remanufacturing (Aras et al. 2006), value of information (Ferrer and Ketzenberg 2004, Ketzenberg et al. 2006), lot sizing for remanufacturing (Atasu and Cetinkaya 2006, Tang and Teunter 2006, Golany et al. 2001, Beltran and Krass 2002), and remanufacturing shop/line design (Kekre et al. 2003, Ketzenberg et al. 2003, Souza et al.

2002). The second, and the one we have long advocated, takes a business management view. It requires connecting the sub-processes (Product returns management, Remanufacturing operational issues and Remanufactured products market development) and exploring this area from a business perspective (Guide and Van Wassenhove 2001, Guide et al. 2003).

Phase 1 introduced a duality between the US market-driven approach and the European waste-stream driven approach. Phase 2 introduced another duality between OR-based activity optimization and a business economics approach. The OR research community, primarily REVLOG (an EU-sponsored research consortium consisting of 6 universities), made a tremendous contribution to the definition and solution of new OR problems. These problems arose from the additional specifics of product return activities. As an example, consider a traditional inventory problem with the additional option of sourcing with remanufactured components (van der Laan et al. 1999). This research provided the necessary building blocks for this new discipline.

A small group of researchers, working closely with industry, took the business economics approach in an effort to help resolve the larger CLSC profitability issues which were not well enough understood. The business economics approach sought to show managers how to make reuse a financially attractive option by identifying the drivers of profitability (Guide and Van Wassenhove 2002). One of the primary drivers of profitability being a product acquisition management system that proactively sources used products at the optimal price and quality (Guide and Van Wassenhove 2001, Guide et al. 2003, Aras et al. 2004, Galbreth and Blackburn 2006).

At the end of phase 2, we had roadmaps for studying a new field. OR provided a lens for understanding the technically interesting issues in subfields such as inventory control, or reverse logistics network design. The business economics approach allowed insights into the business process challenges to release value.

6. Phase 3: Coordinating the Reverse Supply Chain

This is where the business economics perspective linked up with other approaches in modern operations management research (e.g., game theory and contracting). Game theory models helped to understand the strategic implications of product recovery. Contracting is of great importance in CLSCs since they typically have an increased number of actors (e.g., third party contract providers for reverse logistics, product disposition, remanufacturing and remarketing). Examining the entire process exposed huge information asymmetries and incentive misalignment issues in the reverse supply chain, hence the research interest in coordination issues (for an example see Yadav et al. 2003). Phase 3 is the breakthrough of the process and value view advocated by the business economics approach and the extension of research beyond just operational issues. It put a strategic lens on the front end (e.g., product acquisition management), as well as the back end (e.g., channel design).

Savaskan et al. (2004) analyzed the problem of who (retailer or manufacturer) should collect the returned products under monopoly and competitive situations. If a firm does not properly organize its access to used products, it cannot benefit from remanufacturing. Therefore, the manufacturer has an interest in aligning incentives for this purpose. Debo et al. (2005) examined incentive alignment from the other end. Remanufacturing requires durable components. However, the supplier has no incentive to increase durability if remanufacturing by the OEM translates to lower sales volumes of the components. In general, there is a trade-off for the OEM between the cost of investing in durability and reduced production costs for future generations. There is an additional coordination problem introduced by allowing the benefits from component reuse to be earned by the OEM at the expense of the supplier.

Ferguson et al. (2006) took the collection issue a step further by acknowledging return rates can be influenced, extending the system to the behavior of the reseller which can be

affected by the right incentives. This introduces marketing elements to the field and illustrates the increased scope of CLSC research.

The outputs of phase 3 provided greater understanding of downstream channel design issues (Majumder and Groenevelt 2001, Savaskan et al. 2004), upstream durability decisions (Debo, et al. 2005), the role of trade-ins (Ray et al. 2005), the interactions between new and remanufactured products (Ferrer and Swaminathan 2006) and reduced reseller return rates (Ferguson et al. 2006).

Phase 3 established CLSCs as a full-fledged supply chain sub-field using a business economics approach to product returns. The research increasingly appeared in top journals and editors started to actively solicit papers (e.g., the recent double issue of *Production and Operations Management* 15(3&4) on CLSCs and the feature issue of *Computers & OR* 34(2) on reverse logistics). The research community acknowledged that CLSCs are not just simple extensions of existing supply chain management knowledge.

7. Phase 4: Closing the Loop

At this phase, the research emphasis is on global system design for profitability. The dominating view was that product returns cost money and, therefore, firms must always minimize the costs of returns (Stock et al. 2002). This view stemmed from the belief that product returns were a nuisance, or worse, trash. Conventional wisdom demanded efficiencies since it wasn't realistic to spend money on trash. Our experiences with Hewlett-Packard and Robert Bosch Tools, NA suggested otherwise. We rapidly learned that smart firms were spending money in order to make money. We found that a great deal of product

returns (especially commercial returns) aren't trash, but that if slow, cost-efficient, processes are used, the remaining value is soon gone; leaving the firm with nothing but costly trash.

Considering time value is critical when product life-cycles are short. For example, the life-cycle of a PC is 3-4 months and its value deteriorates at 1 percent per week. Clearly, speed is important, and a failure to consider time in the design of the closed-loop supply chain will be costly (Blackburn et al. 2004, Guide et al. 2006). The drivers for CLSC system design are the volume of returns, the marginal value of time and the quality of returned products. Time sensitive products, like PCs, require a responsive (decentralized) CLSC. Products with low time sensitivity, such as power tools, are best served by a cost-effective (centralized) CLSC. The key trade-off is between the opportunity cost of value decay and economies of scale.

The research emphasis in this phase had a big picture focus. Business relevance and impact are related to getting things right up-front in the design phase. Front end, engine and back end of the system should be integrated. These sub-processes are not independent: the collection rate and the life-cycle determine how durable the product should be. It is easy to over-design a product when the return (collection) rate is low and the life-cycle is short. In the first case, many expensively designed products do not return and therefore cannot be reused. In the second case, the products cannot be reused since they are obsolete and no longer sold on the market. The interesting point here is that this is independent of the cost savings of the pure remanufacturing activities. This shows that the system design depends on the interrelationships between collection rate, durability and life-cycle and these relationships are neither intuitive nor linear (Geyer et al. 2007).

True closed-loop design focus for business relevance is the key. This requires an integrated perspective on the acquisition front end (collection rates), the engine (durability design decisions affecting the remanufacturing operations) and remarketing back end (the

life-cycle and time value of the product). This integrated design perspective has major implications for all functions and contradicts common wisdom such as the need for centralized economies of scale return logistics. It also implies the recognition of many independent actors that need to be coordinated in order to unleash the potential business value.

There are many different return types and volumes during, and even after, the product life-cycle for which one needs to find innovative ways to recover value. As an example, early in the life-cycle, commercial returns may be best used to fill warranty demands. Whereas, at the end of the life-cycle, product returns may best be used to meet future demand for repair parts after regular production has ceased. Closing the loop also dictates a dynamic focus on profitability, or value creation, over the entire product life-cycle, considering all types of product returns.

Summarizing, several new insights arose in phase 4. First, a return is not just a return; there are different types of returns over the life-cycle and products have different time sensitivities. Second, minimizing the costs of returns is not always the right perspective. Third, putting insights 1 and 2 together is necessary to maximize value over the entire product life-cycle. Phase 4 is about the correct perspective at the time of system design which determines, to a large degree, the business success of a system. This represents a fundamentally new path for research and questions many of the previous assumptions about centralization of facilities, durability and product life-cycles. Cost minimization is not the key business objective and sometimes firms must spend money (e.g., on product durability or responsiveness) to make money.

8. Phase 5: Prices and Markets

Phase 5 tackled the last barriers to unleashing the true value potential in CLSCs: fear of market cannibalization and returned product valuation. Market cannibalization by remanufactured goods is ‘common wisdom’ at many (if not all) of the OEMs we’ve worked with (including Hewlett-Packard, and Cisco) and this makes remarketing recovered products a tough sell. Up to this point in time, CLSC researchers had assumed either perfect substitution (complete cannibalization), or secondary markets (no cannibalization), and the real world rarely operates in this fashion. Granted, products such as single-use cameras and refillable containers are perfect substitutes, while remanufactured mobile phones and PCs are normally sold on parallel secondary markets. However, the point here is that implementation of models can be blocked by a justified fear of cannibalization since in reality most markets are a mix of the two extreme cases and research needs to acknowledge that.

The back end of a closed-loop supply chain system is traditionally outside operations management boundaries. Therefore, the problem of cannibalization has only recently been addressed in OM studies (Atasu et al. 2005, Guide and Li 2007). Preliminary results show that some remanufactured branded consumer products do not seem to cannibalize new sales and may serve as a strategic deterrent to low cost competitors (Ferguson and Toktay 2006).

Up to Phase 4, researchers had also ignored product diffusion over the life-cycle. Diffusion patterns of the new product dictate the timing and quantity of product returns, i.e., the life-cycle of the remanufactured product. The diffusion patterns of the new and remanufactured product are clearly not independent since the remanufactured product sales can cannibalize new product sales, which in turn influences return patterns (Debo et al. 2006). This introduces interesting new dynamics and research questions like the optimal timing of remanufactured product introduction on the market. The addition of diffusion insights, along

with cannibalization, increases the credibility of our research results to the business community. We note that the diffusion and cannibalization issues also introduce the need for careful incentive alignment with the sales force. Rewards for selling new products are typically larger than for remanufactured ones and this puts a constraint on the perceived profitability of remanufacturing operations.

In the same vein, valuing product returns is problematic since it obviously also determines perceived profitability from remanufacturing. There is no agreement in practice on how returned products should be valued and the accounting literature has not addressed this problem. In practice there are two extreme views. Fatalists regard product returns as a loss. By charging an artificially high transfer price for the returned product to the remanufacturing department, the latter indeed has a hard time making a profit. It makes product recovery operations cost centers where managers can, at best, lose less money by improving operations. Optimists regard product returns as a sunk cost (transfer price is the acquisition cost) and a potential source of profit. In many cases a firm can sell the products for a much higher price than the sum of the acquisition and remanufacturing costs. The two views lead to fundamentally different attitudes and behaviors since one focuses on cutting one's losses, while the other maximizes profitability. Depending on the view a firm takes, its beliefs about the viability of actively engaging in remanufacturing will clearly differ, as well as its willingness to invest in it. Whereas cannibalization is a real issue, in addition to being an emotional one, in accounting terms there is no discussion. Fatalists are plainly wrong and the problem is really to change incorrect accounting habits in industry. Research into these issues has barely started. We refer to Toktay and Wei (2005) for a preliminary discussion.

Phase 5 has begun to link other disciplines (i.e., marketing and accounting) to the OM perspective. If prices and markets are not fully understood, they become barriers, no matter how well the operational system is designed. This research phase has barely begun to

investigate these issues. A thorough understanding clearly requires an inter-disciplinary approach. Unfortunately, this is hampered by a current lack of interest from the accounting and marketing research communities.

9. The Road Forward

This paper has discussed the evolution of CLSCs from a technical focus on individual activities to a discipline taking a holistic business process approach to releasing value from product recovery. We used five phases to describe this evolution. They mainly served as a pedagogical vehicle to improve understanding. Obviously, these phases did not really happen in an exact chronological order and were overlapped in time. While new perspectives emerged, the old ones were given further in-depth attention. One can think of this as building a sand cone with a set of layers built on top of one another, which collectively have shaped a new discipline. CLSCs are rapidly growing in importance in industry, and this is one of the rare fields where academic research is ahead of industrial practice. There are huge opportunities for increased impact with great unsolved problems ahead (Flapper et al. 2005).

Summarizing our 5 phases, we started with providing a framework for analysis, identifying common activities and types of returns in CLSCs, and some dominant return-recovery activity pairs. For example, end-of-use returns are normally best recovered via remanufacturing. Phase 1 research focused on individual activities in the reverse supply chain and established key differences with traditional OR problems in production and inventory control. For example, in CLSCs, supply of used products is constrained by sales of new products, whereas supplies in traditional models are unlimited. In Phase 2, one set of researchers further developed the OR/IE stream, focusing on solving the newly identified problems. However, some researchers shifted their attention from a local cost minimization

perspective to a business process view in an attempt to identify the drivers of profitability. Phase 3 acknowledged the multitude of actors in the reverse supply chain and tackled the resulting coordination and incentive alignment issues. It enlarged the research perspective to include upstream durability decisions and downstream channel design issues. Phase 4 took an integrative approach to the design of CLSCs, with a focus on profitability over the entire life-cycle. It identified the value of time as an important driver of the reverse network design, and analyzed integrating all product returns over the entire life-cycle of the product. Finally, phase 5 extended research attention outside of the traditional comfort zone of OR-based operations management, integrating accounting issues such as returned product valuation and marketing issues like cannibalization. Throughout the phases of its evolution, CLSC research moved from solving isolated OR sub-problems, in what was essentially a poorly structured and unmapped field, to getting a grip on the key drivers of profitability in CLSCs. Simultaneously, CLSCs have become increasingly important in industrial practice, given diminishing life-cycles, commoditization of products and decreasing profit margins. Poorly designed reverse supply chains with no link to the forward business may rapidly destroy value.

Many challenging OR problems have been defined, but remain unsolved. Hence, this is a fruitful area for development of more sophisticated OR models. These models should not necessarily be more complex, but rather more integrative, linking various disciplinary perspectives to provide practical solutions to the design, control and operation of profitable CLSCs. However, as experience has shown, given a rich area for the development of OR models does not mean that industry relevant issues are the ones that academics will pursue. In particular, we've seen a wealth of manuscripts focused on slight technical refinements to existing OR models, or that address artificial problems (e.g., end-of-use returns paired with remanufacturing). A focus on technical extensions can trap research in a cycle where each

successive model yields a more elegant solution, but with little or no connection to the larger business issues (i.e., profitable business models). At best, these paths of research reduce our potential impact on business practice and, at worst, could make the area irrelevant. OR models are needed that keep the business model perspective rather than optimizing an isolated part of the problem.

Academics should become familiar with industrial CLSC practice and current problems. Researchers can easily become engaged with firms currently struggling with planning, organizing, and controlling their CLSCs. Another pathway to understanding industry relevant issues is to partner with another academic who has contacts and experience with practitioners. Working with industry is difficult and time consuming, but the potential rewards are enormous. We also note that many of the previously reported industry relevant issues remain unaddressed by academic research (Thierry et al. 1995, Guide 2000, Guide and Van Wassenhove 2001).

Finally, there is a strong need for interdisciplinary research with marketing (e.g., cannibalization) and accounting (e.g., valuation) to validate the assumptions that many of the early models are based on. Many assumptions, such as perfect substitution, are rapidly becoming institutionalized and this can reduce modeling efforts to elegant solutions addressing non-existent problems.

We acknowledge that the works of many people and groups have not been explicitly recognized in our description of the evolution of CLSC research. The reason for this is somewhat simple: we can best discuss what we know well (our work) and this helps us think more clearly and, hopefully, receive useful feedback from others. After all, this is an opinion piece and not a literature review. Once again, this paper does not imply a value judgment on the quality or relevance of (other) research work on CLSCs, although we do of course believe that it is important to keep a business focus in any work that claims to be relevant to industry.

The early work by Rogers and Tibben-Lembke (1999) clearly identified the key role of logistics in commercial returns and documented many practices and Tibben-Lembke (2004) discusses the development of secondary markets for retail goods. We would be remiss if we didn't mention several groups we have both been fortunate enough to be involved with. First, the early workshops organized by S.D.P Flapper and Ad de Ron at Eindhoven University of Technology (NL) brought together European and US researchers in 1996 for *First International Symposium on Reuse* and again in 1999 for a second meeting (de Ron and Flapper 1996, 1999). The REVLOG working group, led by Erasmus University Rotterdam (1997-2002), brought together researchers from across the EU to work on reverse logistics problems from an OR perspective (Dekker et al. 2004). Finally, we need to mention the series of workshops on *Business Aspects of Closed-Loop Supply Chains*, of which we organized the first four (2001-2005) with support from the Carnegie Bosch Institute and the US National Science Foundation. These workshops led to a number of collaborative research efforts, including a book (Guide and Van Wassenhove 2003), several feature issues of journals (*Interfaces* **33**(6), *California Management Review* **46**(2) and *Production and Operations Management* **15**(3&4)), and many papers. Many other authors have contributed to the development of CLSC research from a variety of perspectives. Rogers and Tibben-Lembke (1999) and Stock et al. (2002) clearly recognized the strategic value of reverse logistics and Lund (1984) explored the technical problems in remanufacturing. We do believe that we were the first to take a business perspective on CLSCs and that our approach has lead to relevant research and useful managerial insights. It is clear that CLSC research has matured over the years and has become a main stream sub-area in the supply chain field.

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