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Reverse Logistics – Capturing Value in the Extended Supply Chain

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Abstract

Product flows in today's supply chains do not end once they have reached the customer. Many products lead a second and even third or fourth life after having accomplished their original task at their first customer. Consequently, a product may generate revenues multiple times, rather than a single time. Capturing this value requires a broadening of the supply chain perspective to include new processes, known as 'reverse logistics', as well as multiple interrelated usage cycles, linked by specific market interfaces. Coordinating the successive product uses is key to maximizing the value generated.

In this chapter, we review the field of reverse logistics. We discuss its opportunities and its challenges and indicate potential ways for companies to master them. We highlight what makes reverse logistics different from 'conventional' supply chain processes, but also point out analogies, and explain how both views can be integrated into an extended supply chain concept. We illustrate our discussion with examples of reverse logistics practice at IBM.

1. Introduction

Conventional supply chain perspectives consider a set of processes, driven by customer demand, that convey goods from suppliers through manufacturers and distributors to the final customers. However, this is not where the story ends. Physical goods do not simply vanish once they have reached the customer. Nor does the value incorporated in them. Therefore, many goods move beyond the conventional supply chain horizon, thereby triggering additional business transactions: used products are sold on secondary markets; outdated products are upgraded to meet latest standards again; failed components are repaired to serve as spare parts; unsold stock is salvaged; reusable packaging is returned and refilled; used products are recycled into raw materials again.

The set of processes that accommodate these goods flows, which can often be interpreted as running 'upstream' in a conventional supply chain scheme, is known as 'reverse logistics'. Examples are manifold. Two categories, however, form the basis of the growing importance of reverse logistics throughout the past decade, namely return agreements for excess products and extended producer responsibilities.

The first category refers to a customer's right to return a purchased product and be refunded. Due to their increased channel power, retailers have been able to negotiate the

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right to return excess stock to manufacturers. Supply chain management analyses have shown that this type of return contracts can, in fact, be beneficial for both the manufacturer and the retailer. Thereby, the manufacturer's benefit hinges on larger expected sales volumes (Tsay et al. 1998). Similarly, consumers often have the legal right to return products within a certain period after purchase. This factor is gaining particular importance in the context of e-business, where customers cannot physically inspect products prior to purchasing. All of the above cases confront companies with returns of technically 'new' though possibly outdated products. Subsequent options differ by case. In the simplest case, products may simply be restocked. Other products may require repackaging or thorough inspection. Yet other products are salvaged through outlet channels. However, even in the case of simple restocking, effective administration and efficient handling of returns often constitute serious challenges.

The second category of reverse logistics activities that have drawn much attention is related to used products. Increasingly, companies are held responsible for the entire life-cycle of their products. By this token, several countries require companies to take back and recover their products after use by the customer. A well-publicized example concerns the recent directive on Waste of Electrical and Electronic Equipment (WEEE) of the European Union (see European Commission 2004). Even in less regulated environments, such as the U.S.A., increasing disposal costs drive companies to offering used product take-back as a customer service. At the same time, companies have been recognizing the value potential of used products. In particular, many high-end products from the business market are still valuable in other market segments, even after a few years' use. Similarly, used products may contain valuable components that can serve as spare parts. This value potential renders used products attractive not only for the original manufacturer but also for specialized third parties. In either case, this business requires novel supply chain processes that include the former 'user' as a 'supplier'.

In the past decade, reverse logistics has grown to a significant business sector. Most logistics service providers offer reverse logistics as one of their core competences. A quick search on the Internet yields links to a host of reverse logistics programs. Many leading original equipment manufacturers (OEMs) are engaged in product recovery initiatives and highlight them in their company reports.

At the same time, reverse logistics has also gained recognition in the academic community. Many leading supply chain management conferences feature dedicated sessions on this topic. The number of related articles published in academic journals has been growing exponentially. Several renowned international journals have recognized the topic through special issues (e.g., *Interfaces* 33(4), 2003; *Production and Operations Management* 10 (2+3), 2001; *California Management Review* 46(2), 2004). Recent books on reverse logistics include research monographs, textbooks, and case collections (e.g., Rogers and Tibben-Lembke 1999; Guide and Van Wassenhove 2003; Dekker et al. 2003; Flapper et al. 2004).

In this chapter, we review the field of reverse logistics. We discuss its opportunities and its challenges and indicate potential ways for companies to master them. We highlight what makes reverse logistics different from 'conventional' supply chain processes, but also point out many analogies, and we explain how both views can be integrated into an extended supply chain concept. As a basis for our discussion, we draw on two sources.

First, we review key results from the academic literature. Second, we complement them with illustrations of reverse logistics practice at IBM.

Throughout our analysis, we take a supply chain management perspective and we emphasize the need for differentiation. The main lesson learned from supply chain management concerns the benefits of a holistic view: Rather than trying to optimize individual business processes separately, companies need to coordinate processes along the entire chain, based on their underlying common goal, namely satisfying customer demand. Applied to our field of analysis, this implies that decisions in reverse logistics should consider the entire scope ranging from the original customer, as the source of product returns, to the future market for these products. In the subsequent sections, we highlight how current business practice still deviates from this ideal, in particular by focusing predominantly on either the supply or the demand side. In fact, one can take the supply chain management impetus even one step further by considering the 'original' chain and the 'reverse logistics' chain together. In this view, reverse logistics simply becomes a particular set of processes in an extended overall supply chain. In the literature, this extended chain is often denoted as 'closed-loop supply chain' (Guide and Van Wassenhove 2003). In the subsequent sections we highlight implications of this extended view and its link with novel business models, such as the shift from a physical-product orientation to a service orientation.

A second aspect that we believe deserves particular emphasis is the distinction of different reverse logistics environments. It is not surprising that early reverse logistics literature focused on basic common elements, thereby leaning towards a 'one size fits all' approach. However, as the field is maturing, a more detailed view is in order. While sharing a common set of processes, different reverse logistics environments entail different priorities, different preferences, and different trade-offs and therefore require different managerial decisions. We highlight these distinctions in our discussion.

The remainder of this chapter is structured as follows. Following this introduction, Sections 2 and 3 consider supply and demand interfaces in reverse logistics, respectively. The next two sections address the supply chain design that links these interfaces. Section 4 focuses on location decisions, while Section 5 zooms in on temporal coordination of reverse logistics processes. Section 6 summarizes our view on this field. We start each section with a general discussion and then illustrate it with IBM practice.

2. The Supply Side – Reverse Product Flows

As a first step to highlighting opportunities in extended supply chains, we take a closer look at the supply side, that is, at the potential sources of 'reverse' product flows. In line with the discussion in the previous section, we interpret this notion rather broadly and consider all flows that surpass the conventional supply chain scheme, i.e. from suppliers via manufacturers and distributors to the customer. This view encompasses, in particular, the two cases highlighted in the introduction, namely returns of excess products to the previous supply chain member (also known as 'commercial returns') and returns of discarded used products (also known as 'end-of-life returns'). However, the scope of our discussion is much broader and also includes, e.g., reusable product carriers, such as pallets, and boxes, rotable spare parts, and leased equipment. In many cases, these products move to an upstream supply chain stage. Yet the terms ‘returns’ and ‘reverse’ are primarily symbolic and should not be interpreted as necessarily going back to the original sender.

In the literature, several schemes have been proposed for classifying this diverse collection of extended product flows. In a previous contribution, we have grouped these flows into five broad categories, namely (i) end-of-life returns, (ii) commercial returns, (iii) warranty returns, i.e. failed products submitted for repair, (iv) production scrap and by-products, and (v) reusable packaging material (Fleischmann 2001). De Brito and Dekker (2003) classify reverse flows based on two dimensions, namely the supply-chain stage at which they occur (production, distribution, or use) and the sender’s reason for disposing of the product. They argue that returned products are either defective or their original purpose has become redundant. It is worth pointing out that the boundaries of the latter category are somewhat blurred since they actually refer to the owner’s relative valuation of keeping the product versus disposing of it. If only the incentives are high enough, he will be willing to give up the product. For a given product, the challenge for companies engaged in reverse logistics is, of course, to identify those sources to which they have to offer relatively little incentives.

As for the sender, one can also distinguish different drivers for the receiving party. The literature commonly lists economic, commercial, and legal motives. The most obvious driver for acquiring products is their future market value. Alternatively, product take-back may be a customer-service element which supports sales in the original channel. At the same time, companies can often exploit such a policy to showcase themselves as environmentally conscious. Finally, companies may simply have the legal obligation to take their products back, as discussed in the introduction. It is worth emphasizing, however, that even in the latter cases companies may eventually find opportunities for exploiting returned products as valuable resources. We discuss this aspect in detail in the next section.

Another important insight from the literature concerns the fact that reverse product flows arise, in principal, at all supply chain stages (de Brito and Dekker 2003). Each stage in the process implies different product characteristics - and thereby a different market potential. Products returned at the final stage are, by definition, used. In contrast, products returned during the distribution phase are technically new – although they may be commercially outdated. Similarly, it is worthwhile distinguishing sources in the business market from those in the consumer market. Business markets typically offer larger volumes of homogenous, relatively high-end products, whereas products are much more dispersed in the consumer market. Obviously, these differences heavily impact potential costs and revenues. Again, we follow up on these implications in the next section.

To make the above theoretical concepts specific, we illustrate their implementation at IBM. The electronics industry has been one of the key sectors of reverse logistics developments. The combination of a huge market volume, short product life-cycles, and a potential of repair processes results in a large potential supply for reverse logistics. At the same time, this large volume also entails significant environmental concerns. Therefore, it is no coincidence that electronic products have been playing a prominent role in the discussions of extended producer responsibility, such as the WEEE directive (see above). The fact that life-cycles of electronic equipment are determined primarily by technological progress, rather than by physical failure, represents both an opportunity and a challenge. On the one hand, many ‘end-of-life’ products are still in good working condition and may therefore find another useful application. On the other hand, quick depreciation puts this option under significant time pressure (see Blackburn et al. 2004).

Recognizing the impact of product returns, IBM has bundled their management in a dedicated business unit Global Asset Recovery Services (GARS), a subdivision of its Corporate Finance organization. GARS worldwide operations are subdivided in three geographies, namely the Americas (North, Mid, and South), Europe, Middle East, and Africa (EMEA), and Asia Pacific. Together, these operations handled some 1.5 million units of returned equipment in 2003, of which the vast majority are personal computers (PCs), including non-IBM brands. High-end mainframes and mid-range server equipment account for a smaller fraction of the return volume. GARS operates primarily in the business market. Its core supply consists of end-of-lease equipment, which is owned by its mother organization Corporate Finance. Other fractions of returns stem from ‘old-for-new’ buy-back initiatives and from commercial returns by supply-chain partners. In a growing number of countries, IBM also offers its customers the option to return end-of-life used equipment. Returns from the consumer market play a more subordinate role and are primarily driven by legal requirements, such as the WEEE directive. In the next section, we discuss the potential value of these different streams.

In addition to returned equipment, IBM also manages reverse logistics processes for replaced components that can be repaired and used as service parts. For a detailed discussion of these processes we refer to Draper and Suanet (2004).

3. The Demand Side – Remarketing

Having considered the supply side of reverse logistics, we now turn to the other end of the chain, namely potential market demand. Arguably, this is the single most important factor determining the profitability of any reverse logistics program. Therefore, carefully and systematically considering potential options is vital. Creativity plays an important role at this point.

The most straightforward option is simply to resell the obtained products, possibly in a different than the original market segment. In this case, the reverse logistics chain essentially provides a broker function. While this alternative preserves a maximum of the original value added, its overall profitability may be limited. For products with a significant market value the original owner can be expected to claim at least a part of this value. This holds in particular for the consumer market where online market places, such as e-bay, facilitate extensive ‘second-hand’ trading. In the business market, the value added of the broker function as an intermediate between supply and demand tends to be larger. Furthermore, reselling may be a viable option for products that are still in the possession of the OEM, such as commercial returns and lease returns. In all of these cases, technological progress tends to put significant pressure on the throughput time.

Other market opportunities require additional value-adding steps, such as repair, upgrading to a more recent technological level, or even extensive remanufacturing. In a few cases, these recovered products are indistinguishable from the original products and therefore serve the same market. Disposable cameras are a well-known example of such a situation (Toktay et al. 2000). In most cases, however, recovered products are seen as distinct and address a specific market segment of price-sensitive customers that choose this product variant in exchange for a price discount. Under these circumstances, it is important to take into account potential demand shifts from new to recovered products, so-called ‘demand cannibalization’ (Debo et al. 2001).

It is worth emphasizing that product sales, in all their variants, are not the only potential opportunities for recapturing value from reverse product flows. Other options, which are often overlooked, are linked to earlier stages of the original value chain. For example, even products which by themselves are no longer remarketable may still prove valuable on a component level. Recovered components may serve as spare parts, internally or externally, or sometimes as new production input. While in many cases the market value of a product exceeds the value its components and therefore reselling the product as a whole is more profitable a priori than component recovery, exceptions to this seemingly intuitive rule should not be overlooked. Component commonality across product generations, long-term service requirements, and high procurement costs for components late in the life-cycle may shift the balance in favor of the component value.

Moving further back in the original value chain leads to the material content of returned products. Recycling aims at reclaiming these materials. Relatively low raw material prices limit the value potential of this route. Therefore, recycling tends to be profitable only for a few material fractions, notably precious metals. Consequently, it serves as a means for absorbing at least some of the costs of reverse logistics and for avoiding disposal costs, rather than being a driver for initiating new reverse logistics programs. Again, however, exceptions do exist, as illustrated by several nylon-recycling projects in the chemical industry (Realff et al. 2004). In general, such initiatives rely on large scale operations that seek to exploit economies of scale.

In conclusion, reverse product flows may generate value on a product, component, or material level. In general terms, this value may materialize either in the form of cost reductions, by substituting original supply chain inputs, or in the form of revenue increases, by opening new markets. This distinction plays a role in the design of the reverse logistics process, as we discuss in the next section. Despite all of the aforementioned opportunities, it goes without saying that not all reverse product flows are valuable. Some of them represent significant disposal costs in the first place. Therefore, supply control is an important task. However, we repeat that the line between burden and opportunity also depends on a company’s creativity and vision to recognize and generate potential markets.

IBM’s asset recovery operations illustrate many of the aforementioned reuse options. The priority is on reselling equipment as a whole. To this end, high and mid-range products generally require some reconfiguration, often on the basis of specific customer orders. The products are sold through IBM’s regular sales organization as certified remanufactured equipment. A portion of this stream is also sold through business partners and brokers.

For the PC sector, IBM uses a somewhat different channel and does not resell products directly to the customer. Instead, GARS tests these products and then auctions them off in large batches to brokers, who sell them through to specific market segments, for example in Eastern Europe. Other products are donated to schools and charities, sometimes entailing tax credits. Overall, IBM is able to resell some 80% of the PCs returned from the business market.

In a following step, GARS screens the remaining equipment for valuable components. In particular, it supplies spare parts to IBM's own service division. The potential of this so-called 'dismantling' channel relies on the fact that service requirements typically extend well beyond two or three years, the typical duration of a lease contract. In addition, there are few alternative sourcing options for parts towards the end of the service horizon (see also Draper and Suanet, 2004). For a detailed discussion of the dismantling channel we refer to Fleischmann et al. (2003). In addition, GARS also sells recovered components to external brokers.

Finally, GARS breaks down the remaining returned equipment into some 50 different material fractions and sells them to specialized recyclers. While precious metals generate some additional revenues, other fractions are sold at a cost.

The above options concern returns from the business market. Returns from the consumer market are less valuable to IBM, given their quantity, quality, and product range. Therefore, IBM often participates in industry-wide solutions for this market sector, as for example in the Dutch ICT take-back program (ICT Milieu 2004). These systems typically rely on material recycling.

4. Designing the Reverse Logistics Process

The previous two sections highlighted the sources of and potential market outlets for 'reverse' product flows. The task of reverse logistics is to link these two market interfaces, as illustrated in Figure 1. The literature groups the processes that provide this link into a few generic steps (Fleischmann, 2003):

- *Acquisition* (or *collection*) refers to the initial transaction by which a company gains possession of the products;
- *Grading* (or *disposition* or *inspection*) denotes the sorting of the product stream into fractions of different quality and their allocation to different reuse options;
- *Re-processing* includes all transformation processes that prepare products for their future use;
- *Re-distribution* means the delivery to a new market.

The collection of these processes forms a supply chain of its own right. Consequently, the individual steps should be coordinated, based on their common underlying goal, namely generating a maximum of value. As in any supply chain, this requires decisions on, among other things, the allocation of processes to different actors, their geographical location and connection through transportation, and the timing of their execution. We address these issues in what follows.

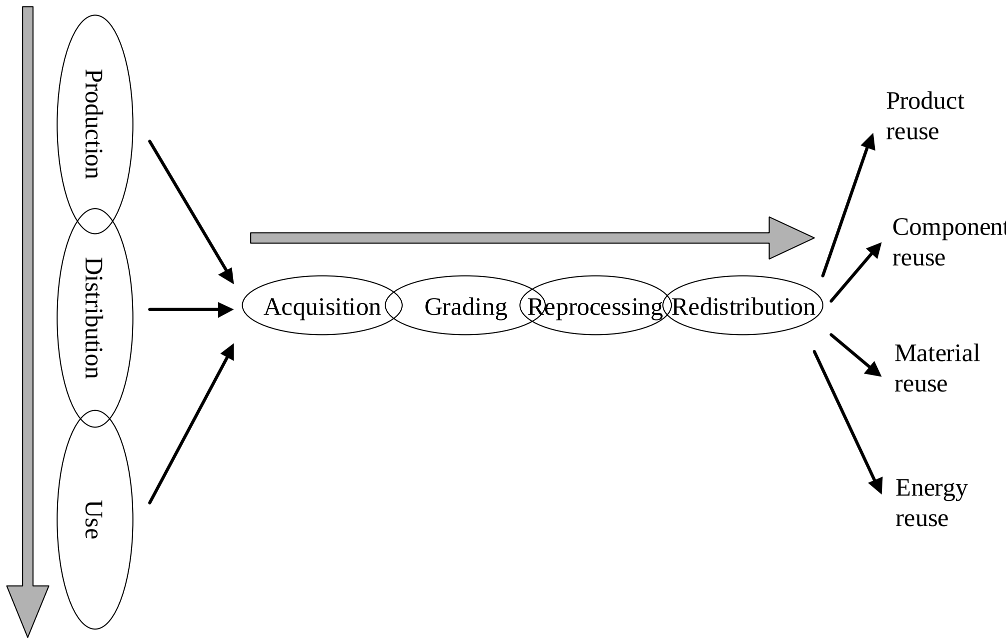

Fig.1 The Reverse Logistics Chain

Comparing the above 'reverse chain' with conventional supply chains, two processes deserve special attention, namely the acquisition and the grading steps, which differ from conventional sourcing and supply. We devote a separate subsection to each of these processes below. In contrast, the roles of re-processing and re-distribution essentially resemble those of traditional production and distribution operations.

Another aspect that deserves extra emphasis is the fact that the 'reverse chain' is not isolated but, by definition, builds on some preceding 'original' chain. Similarly, additional chains may follow. Figure 2 illustrates this view. In some cases, successive chains may literally form a closed-loop that repeats itself. In many other cases the different chains serve different markets. In any case, however, they extend the traditional supply chain framework to a framework that includes multiple use stages. Given their interrelation, supply chain management thinking suggests that the individual chains should be considered as one entity and be coordinated such as to maximize their overall performance. One example that illustrates these interrelations concerns the original product design, which obviously influences all subsequent uses. Through 'design for reuse' or 'design for disassembly' companies explicitly take multiple use cycles into account, in particular by exploiting modularity (Krikke et al. 2004). From a supply chain management perspective, the 'use' stages play a particularly important role since they actually generate the chain's revenues. Managing these stages therefore is a critical lever for coordinating the extended chain as a whole. We return to this issue in our subsequent analysis.

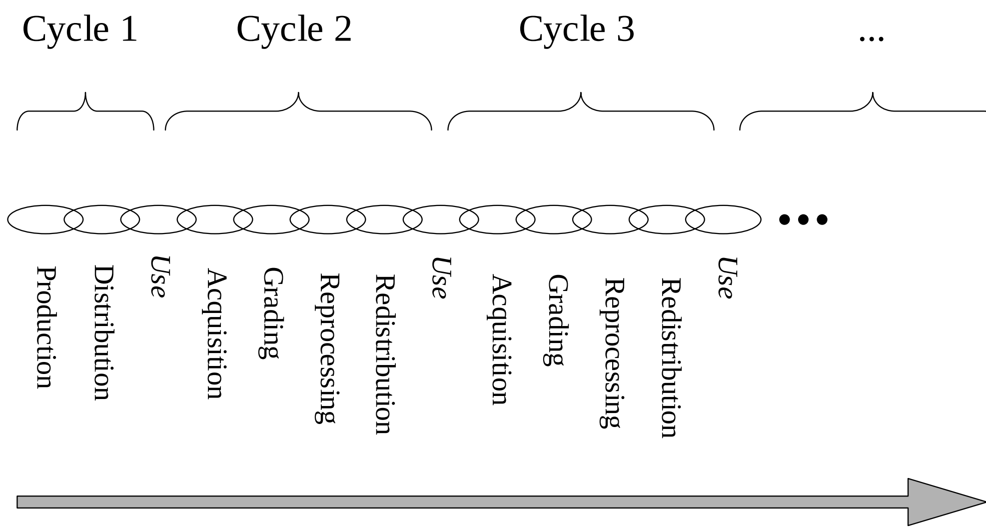

Fig.2 The Extended Supply Chain

4.1 Take-Back Strategies

In Section 2 we listed sources of reverse product flows. The next question is how companies can use these sources to obtain their desired inputs. Comparing the aforementioned sources with traditional suppliers reveals a number of structural differences. In a traditional buyer-supplier relation, the buyer simply orders the desired quantity at a given price. In a reverse logistics setting, the buyer's choice is often more limited since supply is a derivative of a preceding supply chain cycle (see Figure 2). Supply may therefore not be available in the desired quantity or quality. What is more, some transactions may be supply driven rather than demand driven. That is, a supply push partly replaces a demand pull. This relationship is the most obvious for commercial returns and in the case of extended producer responsibilities, which simply oblige companies to take back what customers return. However, even in economically-driven reverse logistics initiatives many companies to date follow a rather reactive approach. While this is a logical choice in some cases, it reflects a lack of awareness in others. In conclusion, the sourcing challenge in reverse logistics is twofold: getting what you want and avoiding what you do not want.

One way to approaching this challenge more proactively is by influencing supply through financial incentives, that is by offering buy-back prices differentiated by product type and quality and dynamically updating them. It is worth noting the particular market mechanism of this setting. Instead of a supplier offering products at a given price, we have a buyer soliciting for products at a given price.

However, the potential of innovative concepts reaches much further. In particular, novel approaches exploit the interrelation between the different phases of the extended supply chain (see Figure 2). Rather than losing sight of their products once they reach the customer and then rediscovering them later through reverse logistics, companies may rather monitor the entire underlying process. This opens the way to a conscious trade-off between costs and revenues, and thereby to maximizing the overall value of a product. Note that this approach, which is also known as 'installed-base management' (see van Nunen and Zuidwijk 2004), matches well with the ongoing trend from a physical-product focus to a service focus: selling mobility rather than cars, connectivity rather than mobile phones, and documenting-capabilities rather than copiers. Leasing is a classical implementation of this concept. Service contracts are another example. Selling services whereas keeping the physical products in their own possession, enables companies to optimize the use of these products, by deciding on replacements, maintenance, upgrading, and disposal. Advancing information-technology capabilities further facilitate these decisions by routinely providing rich sets of relevant data regarding, e.g., product wear, usage statistics, and market profiles. As an aside we note that these developments also entail challenging issues regarding security and confidentiality. While to date few if any reverse logistics programs fully exploit these capabilities, we expect them to mark the future development of this field.

Let us return to the case of IBM. As discussed, the majority of the products managed by IBM's asset-recovery organization originates from expiring leases. In principal, these product returns are known in advance, based on the lease portfolio. However, actual return dates and quantities deviate from a simple one-to-one projection, since customers may request contract extensions and, in particular, since they may purchase the product when the lease expires. All in all the actual return process, of both leases and other types, is largely customer driven. Only in a few exceptional cases does GARS actively seek to take back a specific product. Besides customer preferences, actions in IBM's original sales channel are another factor that determines product returns, for example through 'old-for-new' exchanges.

All in all, these different factors result in a fairly stable supply rate to IBM's asset recovery operations, with some slight seasonal fluctuations, driven for example by customers' budget cycles. In general, customers are responsible for shipping returned products to a national IBM return center. From there on, GARS is taking responsibility for further processing.

4.2 Grading and Disposition

In contrast with traditional supply, reverse logistics flows, in general, consist of a heterogeneous mix of products of different quality and value. Therefore, the reverse chain typically includes some type of grading and sorting process, which determines the status of the individual products and assigns them to corresponding reuse options. This process is of prime importance as a means of quality control. In addition, its design has a significant impact on the performance of the reverse supply chain and therefore merits specific discussion at this point.

The degree of centralization of the grading and sorting process gives rise to a trade-off. As usual, centralization tends to reduce investment costs by exploiting economies of scale. In the case of the grading process this regards testing-equipment and the required skills to operate it. On the other hand, de-central grading close to the source may reduce transportation costs by separating waste, which ought to be disposed locally, from valuable products, which merit further processing. What is more, de-central grading provides earlier supply information and may thereby speed up the recovery process as a whole. Blackburn et al. (2004) point out that this effect acts, to some extent, in the opposite way of postponement. While in traditional supply chains *delaying* product differentiation creates an option value, *revealing* product differences *earlier* creates value in reverse logistics.

Many of today's reverse logistics programs choose for a centralized grading and sorting process. In line with our argumentation in Section 4.2, we see information technology as a factor that may reverse this choice. Remote access to detailed product data reduces the need for physical inspection and corresponding investments and may partly substitute physical flows by information flows.

IBM's asset recovery process involves a two-step grading process. The first step is based solely on nominal product type and model, rather than on individual product identity. GARS selects the types and models that qualify for further use. The selection criteria are dynamically updated, based on market developments. The selected products then undergo detailed individual tests at a central recovery facility.

4.3 Location and Network Design

Designing a logistics network for the extended supply chain involves decisions on where to locate the aforementioned transformation processes, notably grading and re-processing, as well as intermediate storage processes, and at what capacity levels. At the same time, corresponding transportation links need to be established. The previous subsections highlight some of the particular issues regarding these decisions. In addition, many of the traditional trade-offs also apply in this particular supply chain context. These include economies of scale both in transportation and in facility investments, consolidation versus responsiveness, and labor cost savings versus transportation.

Given these analogies with conventional supply chain environments, it comes as no surprise that most of the corresponding decision support models in the literature closely follow up on traditional network design models. In particular, many authors have proposed variants of mixed integer linear programming (MILP) facility location models that include 'reverse' supply chain processes (Fleischmann et al. 2003). A few more fundamental extensions include stochastic modeling elements to account for the significant uncertainty that is typical of many 'reverse' supply chains (Realff et al. 2004). However, in many cases it appears that the benefits of these more involved modeling approaches are limited compared, e.g., to simple scenario analyses. This conclusion hinges on the well-known 'robustness' property of network design decisions, in the sense that moderate demand changes do not require a fundamental network re-design. Besides, transportation differences of a few hundred kilometers rarely are a decisive factor on a global scale.

A factor that deserves specific mentioning when it comes to logistics network design for the extended supply chain is potential synergies between different processes. This concerns, in particular, the relation between 'forward' and 'reverse' processes, such as distribution and collection, or original manufacturing and re-processing. For example, combining inbound and outbound transportation may increase vehicle capacity utilization. Similarly, co-locating manufacturing and remanufacturing operations may give rise to economies of scale. On the other hand, separating these processes allows for a more tailored network design, and thus a trade-off has to be made.

In many of today's business examples we observe that companies take a hierarchical approach, in the sense that they give priority to designing the traditional 'forward' supply chain processes and only later fit in reverse logistics processes. Given the interrelations between these sets of processes one may wonder whether this successive approach is in fact appropriate or whether an integrated design of the overall process chain would be superior. In a previous study we have shown that, with respect to the logistics network design, in many cases there is no need to deviate from the common hierarchical approach (Fleischmann et al. 2003). It is again the aforementioned robustness property that allows one to decompose the overall network design into two separate parts. Exceptions include those cases, in which recovered product content substitutes 'virgin' supply and both streams differ significantly in their cost structure. This applies, for example, to the substitution of pulp wood from Scandinavia by recycled paper from Western Europe in paper production.

The above general considerations and trade-offs are also reflected in IBM's asset recovery network. Besides the aforementioned national return centers where returns are selected and consolidated, GARS operates two major recovery facilities in the EMEA region, each for a specific product range. These are located in Montpellier, France, for the server equipment and in Mainz, Germany, for all other product ranges. These facilities host the final grading operations, the actual remanufacturing and subsequent storage, as well as component disassembly and material separation. Currently, PC operations are subcontracted to a service provider, while other operations are carried out in-house. To achieve economies of scale, all transportation operations are subcontracted to a single provider that is also responsible for the 'forward' distribution shipments.

The network structure in the other geographical regions, i.e. America and Asia Pacific, closely resembles that in EMEA. Specifically, GARS operates two product-specific facilities in the U.S.A., in addition to central facilities in Canada and Brazil, as well as in Japan and Australia. The number of facilities in each region, and thus the degree of centralization of the recovery operations, is a major strategic choice. In contrast, the exact location of these facilities is largely historically determined, based on available competencies and infrastructure. This illustrates once more the common hierarchical network design approach discussed above.

5. Inventory Management and Value of Information

Another important element of the supply chain design, besides the geographical location of the various processes, is their inter-temporal coordination. This relates to the location of inventory buffers, which decouple the individual processing steps. Traditional supply chain management commonly distinguishes inventories according to their supply chain function, such as cycle stock, seasonal stock, and safety stock. All of these functions also play a role in the extended supply chain. Moreover, inventories assume an additional role in this context, which is driven by the mismatch between exogenous supply and demand. Since, in general, customers do not return products exactly at the moment that these can be resold, companies build up inventories of re-marketable products, which we denote as 'opportunity stock'. The effect is similar to that of forward buying in response to a temporary price discount.

An important choice in any supply chain design concerns the location of the customer-order decoupling point, i.e. the borderline between make-to-stock and make-to-order processes. In the extended supply chain, each usage cycle contains an additional such decoupling point on the supply side (see Figure 3). This point indicates how far in the process chain a returned product moves upon its arrival. Analogous with traditional terminology one might denote the processes after and before this point as 'make-*from*-stock' and 'make-*from*-supply' processes, respectively. Needless to say, both decoupling points may coincide in a single inventory buffer.

A related, but not identical, supply chain characteristic concerns the border between supply-push and demand-pull processes. In particular, it is important to decide whether the re-processing stage, which typically represents the main value-adding activity of the extended chain, is to be push or pull-driven. In the former case, one processes returned products as they become available, whereas in the latter case one postpones value-adding activities until demand materializes. In a study on IBM's component-dismantling operation we highlighted that the appropriate choice depends primarily on how certain one is of future demand for the product in question (Fleischmann et al. 2003). In case of a serious risk of not finding a demand, and thus of wasting the reprocessing expenses, it is advisable to postpone any costly re-processing until more demand information becomes available. In all other cases, postponing the re-processing operation comes down to trading higher safety stock levels against lower holding costs per unit, which in sum leads to slight inventory cost savings at best.

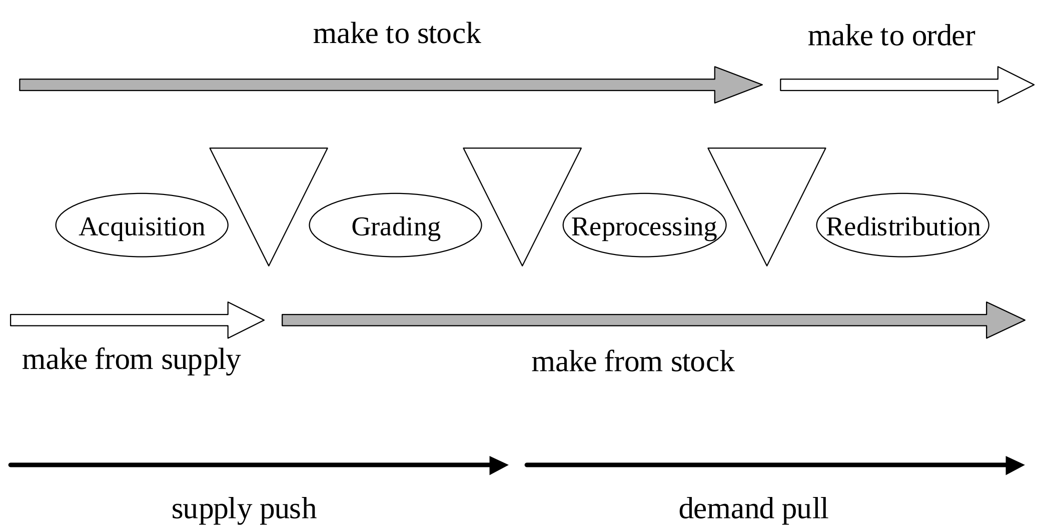

Fig.3 Inventory Buffers in the Reverse Logistics Chain

The management of seasonal stocks and cycle stocks in the extended chain does not appear to differ essentially from traditional environments. The literature provides several variants of economic-order-quantity (EOQ) models for lot-sizing decisions in product recovery operations (Minner and Lindner 2003). In contrast, choosing appropriate levels of safety stock and opportunity stock is more challenging. A significant body of literature addresses this issue (see, e.g., van der Laan et al. 2003). What complicates the matter in the first place is the additional uncertainty on the supply side of the extended chain. Higher overall uncertainty typically implies the need for higher safety stock buffers. A second complicating factor concerns the fact that returned product content and new products and components often serve as substitutes, as for example in IBM's service operations. In this situation, one needs to coordinate multiple alternative supply sources with different characteristics in terms of cost, reliability, and lead times, in such a way as to minimize overall costs (see also Draper and Suanet, 2004). One can distinguish two approaches for integrating market returns into the planning of such a supply system. Most commonly in current practice we found a conservative, reactive approach, which only takes returns into account after they have actually occurred. The downside of this 'safe' approach is that it may create excessive inventories of unneeded returns. The alternative is to proactively incorporate expected future return flows into the current planning, for example when ordering new components. We have illustrated that such a proactive planning can significantly reduce inventories, even though it requires additional safety buffers to protect against supply uncertainty (Fleischmann et al. 2003).

Inventory management critically depends on the available information about future supply and demand, and thus in particular on forecasting. Just as in traditional supply chains, managing the extended chain requires projections of future demand. Expert assessments and statistical tools provide a basis for such estimates. What is more particular is the forecasting requirement on the supply side of the reverse logistics chain. In the literature, different methods have been proposed for estimating future product returns, which form the basic resource of the extended chain (Toktay et al. 2003). Simple methods treat the return flow as an autonomous process and apply the same statistical techniques as in demand forecasting. More advanced methods explicitly capture returns as a consequence of a previous supply chain cycle (see Figure 2). From this perspective, the key is to estimate the time a product spends in the market. Since this approach requires demand information from the previous supply chain cycle it is particularly appealing to OEMs that collect and recover their own products. Yet, even if historical demand information is available it may be non-trivial to determine the actual time that a product spent in the market. While the sales history of a high-end product in the business market may be well documented, this is not the case, in general, for commodities such as PCs, disposable cameras, or even softdrink bottles. However, as discussed previously, advances in information technology are about to change this picture. The ever more widespread and cheaper availability of digital storage devices, such as RFID-tags, provides the basis for tracking detailed product data even for simple commodities. Heineken's 'Chip-in-crate' project nicely illustrates this development. In this pilot project, the Dutch brewer equipped a set of its reusable beer crates with an electronic chip that is read whenever the crate passes through the bottling line (van Dalen et al. 2004).

As discussed in Section 4.1, the impact of this new wealth of information reaches much further than providing a basis for more reliable forecasting. For example, it may replace forecasts by real-time actual data. Moreover, it allows companies to realize an active acquisition management, that is to manage the supply side of the extended chain rather than to accept it as purely externally given.

These quickly expanding possibilities raise the question which type of information is the most critical for enhancing the extended supply chain and how to quantify its actual benefits. A stream of literature on the 'value of information' focuses mainly on inventory cost savings through the reduction of uncertainty (Toktay et al. 2003). Yet it appears that other benefits of advanced product information are even much larger. In particular, information helps identify potential supply and demand and thereby enables valuable transactions that otherwise would not have been realized at all. Pricing decisions are another issue that is closely related to this type of information. Finally, supply and demand information is key to supply chain design decisions such as capacity investments. In our opinion, a systematic and detailed analysis of the factors that determine this broader 'value of information' is one of the primary current research mandates in this field.

In order to position IBM's asset recovery processes in the above inventory management framework we need to distinguish several channels. As discussed in Section 4.1, the supply of returned products is essentially customer driven. For the PC product range this supply push extends all the way to the re-processing operation, i.e. the testing of the returned PCs. In fact, even the re-selling by means of auctioning can be characterized as a push operation. In this way, safety stocks and opportunity stocks can be limited. Since return rates turn out fairly stable, seasonal stocks do not play an important role either. Inventory occurs mainly as cycle stock at the end of the operation while waiting for a sufficient auctioning batch to accumulate. For higher product ranges, the push-pull border lies further upstream in the process. For these products, the required reconfiguration depends on specific customer requests and is therefore carried out in a make-to-order fashion in most cases. Consequently, the major inventory buffer contains preliminarily tested equipment awaiting reconfiguration. Only for a limited product range, full testing and reconfiguration are carried out immediately after receipt, in order to have the products available for fast re-sale. In both of these channels, IBM uses supply forecasts mainly on a medium-term aggregated level to adjust capacities. In contrast, short-term forecasting turns out to be difficult, even for leased equipment (see Section 4.1).

Also IBM's supply of service parts from dismantled machines is push-driven. Available parts which match projected future demand are moved through their specific recovery process and are then stored ready-to-use until actually being deployed in the service network. Again, supply forecasts are mainly used in the long-term planning, namely the expected contribution of different supply sources during the product lifecycle. Besides for cost calculations, this information is important, for example, for deciding on the size of the final production order at the time that production of new parts is phased out.

6. Conclusions

Product flows in today's supply chains do not end once they have reached the customer. Many products lead a second and even third or fourth life after having accomplished their original task at their first customer – or after this customer changed his mind and returned them. Initially, many of these additional products flows were driven by ecological arguments, namely waste reduction, and by customer service obligations. Consequently, many have seen product returns as a cost factor in the first place. In the meantime however, companies have started recognizing the potential value of these flows. Instead of a single time, a product may generate revenues multiple times, possibly in different markets.

Capturing this value requires a broadening of the supply chain perspective. This broader view includes new processes, such as the collection of products from the market and the grading of these products according to their quality and future value. More importantly, it includes multiple interrelated usage cycles, linked by specific market interfaces. Coordinating the successive product uses is key to maximizing the value generated.

To date, many companies deal with product returns in a purely reactive manner. While in some cases it does, indeed, make good sense to give unlimited priority to the initial product market this strategy is shortsighted in many other cases. Maximizing a product's lifetime value requires a more proactive attitude. In particular, it requires a good understanding of the interrelations between different phases of the product lifecycle. Market incentives can then help assign the product to its most valuable use at each time.

Information technology is a key enabler of this integral approach. Timely availability of detailed product, process, and market data allows companies to manage the corresponding processes in a conscious way. The current realization of extended supply chains is still in its early stages. Their potential is huge.

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