DECISION SUPPORT IN REVERSE LOGISTICS AND CLOSED-LOOP SUPPLY CHAINS

An overview of exclusive challenges in reverse logistics operations and areas where decision support tools are needed.

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Economic gain, reduction of disposal costs, compliance with environmental legislations, and pressure from customers and competition are among various reasons why a business may get involved in reverse logistics activities. In this article, we discuss why many of the decision support tools that are used in a forward supply chain cannot be directly applied to a reverse chain. We then identify specific areas in a reverse channel where decision support is needed and explain how simulation modeling can be a powerful tool in optimal decision making in closed loop supply chains. This article is intended for third party logistics providers as well as operations managers in businesses that deal (or will deal) with reverse logistics in any form.

Background

The importance of closed-loop supply chains has dramatically increased over the past few years, mainly due to the rising awareness about resource scarcity and waste reduction. The adoption of "Waste of Electrical and Electronic Equipment (WEEE) Directive" in 2003 and the "Circular Economy Package" in December 2015 by the EU further defines clear objectives in order to reduce landfilling and to increase recycling and reuse by 2030 [1,2]. Among its directives, the Circular Economy Package aims to reduce landfilling to a maximum of 10 % of municipal waste and to recycle over 65 % of municipal and packaging waste by 2030[1].

Aside from compliance with environmental regulations, from a strictly business point of view, producers are now faced with environmentally conscious consumers who demand products with minimal carbon footprint. Having a green image appeals to this increasingly growing customer base. On the other hand, customer returns (B2C returns) generate yet a different flow of used/new products from the end user to the manufacturer. A liberal and uncomplicated return policy gives retailers (especially the online retailers) a competitive advantage, increasing sales volume as well as customer loyalty. Here, timely and optimal return handling enables retailers to re-capture the value in their product.

After-sales services, or "after market", is another area where reverse logistics activities can greatly contribute to value creation for businesses. In a competitive market, where the products from different brands become more and more similar with regards to the technical features that they offer, companies can differentiate themselves by providing more efficient, customer friendly after-sales support and repair services. In this context, reverse logistics operations (including product-warranty logistics and service-parts logistics) play an important role in increasing revenues as well as customer satisfaction and loyalty.

It is, however, worth noting that closing the supply chain through resale, repair, remanufacturing, and eventually material recovery will inherently increase the total amount of transportation within supply chains and hence the total amount of CO_2 emissions and transportation costs. Simultaneously, repair/recycling operations do not come without environmental footprint, since they also consume energy. Furthermore, suboptimal and poorly planned reverse logistics activities can turn into major cost drivers for companies. Therefore, to be both profitable and sustainable, it is crucial to invest in careful planning and optimization of reverse logistics activities, which in turn explains the importance of decision support tools.

In this article, we consider closed loop supply chains from an economic point of view. We will identify the areas where strategic, tactical, or operational decisions are needed in order to:

- Minimize the costs of compliance with governmental regulations;
- Create value and increase revenues;
- Decrease environmental foot-print of reverse logistics operations.

We will explain where and why decision support tools for the forward chain are not necessarily suitable for the reverse channel. Finally, we will discuss why simulation modeling is a powerful customizable tool to support decision making in closed-loop supply chains.

Specific challenges in a reverse supply chain

As the economy shifts towards resource efficiency and waste prevention, activities such as refurbishing, repair, and remanufacturing become necessary. The European Working Group on Reverse Logistics (REVLOG) defines "reverse logistics" as follows [3]: "The process of planning, implementing, and controlling backward flows of raw materials, in-process inventory, packaging and finished goods, from a manufacturing, distribution or use point, to a point of recovery or a point of proper disposal." Table 1 lists a few examples of industry sectors where some form of value recovery has already been established and proven profitable.

The schematic in Figure 1 shows a simplistic view of the flow of goods and materials in forward and reverse supply chains. More specifically, the graph shows activities that are almost exclusive to reverse supply chains. These activities may include, but are not limited to, the following:

- Acquisition, collection, and transport of used (as well as hazardous) goods;
- Sorting, testing, and inspection;
- Choosing the proper value recovery process;
- Disassembly;
- Warehousing.

To carry out such activities, a wide range of operations such as logistics, inventory management and control, production planning and scheduling, procurement, and lot sizing must be involved and coordinated.

Some of the decision support tools which have been used for years in the forward supply chain can still be applied to the reverse chain with some adjustments. But the following unique characteristics make decision making in the reverse supply chain distinct from the forward channel:

- Greater supply uncertainty (uncertainty in timing, quality, and quantity of returned goods);
- Greater demand uncertainty;
- Low economical value of used/returned goods.

In this regard, we have identified several areas in a reverse supply chain where a decision support tool could prove valuable to the operations manager (see Table 1).

1. Acquisition of Used Items

In a reverse supply chain, the customer becomes the supplier. More often than not, companies that are involved in value recovery must create incentives such as buy-back options or deposit fees in order to encourage users to return end-of-life or end-of-use products, and to avoid their products ending up in the waste stream or in storage. Assuming that such incentives are already in place, acquiring the used goods includes two distinct activities:

- Collection
- Transportation

Collection and transportation of used items are often outsourced to the same third-party logistics provider (3PL) that distributes new products. The 3PL has thus the freedom to optimize the overall transportation costs for deliveries and collections, while satisfying a desired service level. Below we discuss some optimization potentials for these activities.

1.1. Network Design and Vehicle Routing

A simple closed-loop supply chain consists of manufacturing plants, warehouses, customers, collection centers, inspection and test centers, etc. A strategic decision is whether to design an integrated network that from the beginning encompasses both forward and reverse logistics activities or to add the reverse network subsequently, to a pre-existing forward network. The problem of routing the transportation vehicles and the amount of goods flow can be addressed simultaneously with the location allocation problem. It has been shown that the optimal strategy strongly depends on return rates and the cost structure for each specific industry sector [4].

A similar problem is faced by product warranty support and service providers (also known as warranty logistics), where one has to decide about the location of service centers and spare part warehouses depending on the service demand in each region and the corresponding service capacity at each center.

1.2. Collection Policy

An important difference between the forward and the reverse supply chain is the low economical value of

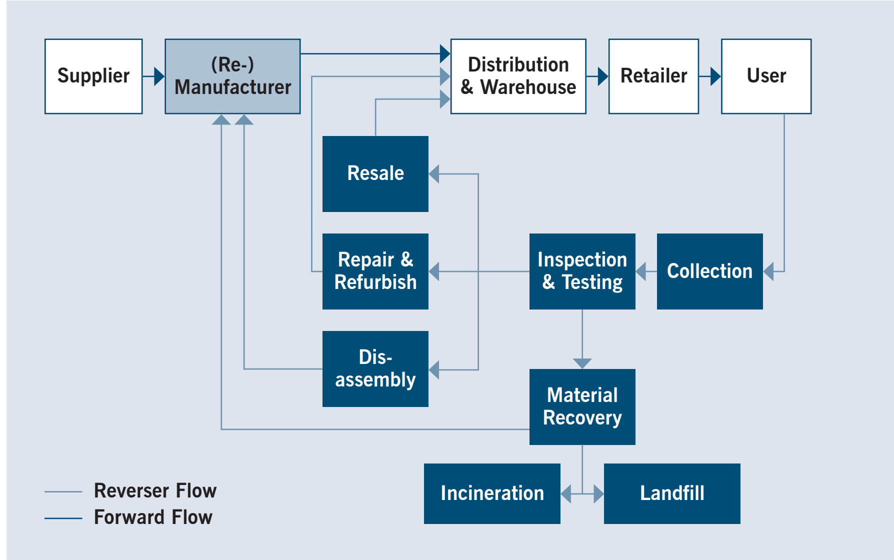

Figure 1: A simplified schematic of possible activities in a closed-loop supply chain.

1 The reader is further referred to the special issue of the VNL Logistics Innovation Magazine on "Sustainability as Business Model", published January 2016.

Industry Sector	Firm/Organization	Value Recovery Process
Copiers	Xerox, Canon, HP, Océ	Remanufacturing
Automotive components	Volkswagen, Daimler Chrysler (Germany) Cardone (USA)	Remanufacturing used components and resale as new spare parts
Automotive spare parts	VASSO (CH)	Dismantling, testing, and resale
Personal computers	IBM Global Asset Recovery Services (GARS)	Remanufacturing
Medical devices	Itris Tradmed AG (CH)	Repair & resale
Transportation containers	Palettenrecycling Dunder GmbH & Co. (Germany)	Repair & resale
Tires	Goodyear Inc. (USA)	Retreading
Single-use medical instruments	Stryker's Sustainability Solutions (USA)	Reprocessing
Construction waste	ARV (CH)	Material recovery
Batteries	BATREC Industries AG (CH)	Material recovery
Textile	TEXAID Textilverwertungs AG (CH/Germany)	Resale and/or down-cycling
Textile	H&M Group (Sweden)	Recycling fibers
Mobile phones	Recommerce (France)	Refurbishing & Resale

Table 1: Examples of successful value recovery operations in different industrial sectors.

the used goods compared to new ones. As opposed to delivering new orders which normally takes place within a short time frame (for instance the "same-day delivery" option), collection of used items need not be quick; Thus it can be postponed to a later date when the volume of the used items is so large that it is causing overspill from the containers at the collection site, or large enough to justify transportation costs. Therefore, there is some degree of freedom in planning the collection activities which is generally not present in the delivery of new goods. Several different collection policies can be considered with the goal of minimizing variable transportation costs:

– Smart drop off sites with automatic monitoring of containers;
– Periodic collection with optimized collection frequency;
– Collection on-demand (no later than a given date).

1.3. Sector Design and Fleet Size Optimization

Another way to optimize the cost of collection activities includes dividing the entire service region into sectors. A periodic schedule is then developed for each sector in order to minimize the initial fixed investment costs in vehicles and crew (fleet size) as well as the variable periodic routing costs, for a desired customer service level.

1.4. Combining Deliveries and Pickups

A third party logistics provider should also decide whether or not to combine drop off and collection activities, in order to reduce empty rides. For example whether to pick up used items by the same truck after all the deliveries are made and the truck is empty (i.e. backhauling), or alternatively, to mix deliveries with pickups.

Also, in case of source separation, the co-collection of two or more different items becomes an option and a possible area of cost optimization (for instance, the co-collection of used clothes and shoes). This might further lead to decisions regarding the use of multi compartment vehicles.

2. Lot-Sizing Decisions for Repair/Remanufacturing

This type of decisions are most relevant for remanufacturing shops or service centers with inventories of repairable spare parts. Remanufacturing facilities and service centers usually keep two separate inventories:

– Inventory of serviceable goods that can immediately satisfy customer demand;
– Inventory of recovered/repairable items that can be remanufactured (or repaired) by going through some extra process.

In addition, when demand cannot be satisfied solely through remanufacturing or repair, new products should be procured in batches and added to the serviceable inventory. Here, the remanufacturing (or repair) batch-sizing and the number of the new products that should be ordered, as well as the timing of these activities must be coordinated. While for each of these inventories the classical trade-off between set-up costs for remanufacturing (or repair) and holding costs (= cost of carrying inventory) applies, lot-sizing/batching decisions are further complicated by having to decide between two modes of supply, given that one of the sources (i.e. recovered products) has limited capacity and cannot be controlled by the manager. In a spare part facility with repair, additional complications can arise because of the uncertainty in repair time for various modules with various defects.

3. Inventory Management

In a forward supply chain, where demand is always positive, inventory management is concerned with the following questions:

– When to review stocks?
– When to order?
– How much to order?

In addition, in a closed-loop supply chain, inventory management has to deal with highly variable and uncertain recovery flows. When there are two modes of supply (for example for remanufacturing), the usual inventory management decisions are further complicated by having to select a replenishment source (where to replenish from?), since the two sources may not only differ in item availability but also in per-unit cost, supply reliability, and lead times (dual or multi-sourcing).

Furthermore, the flow of recovered items disrupts the monotonic behavior of the inventories between regular stock reviews and replenishments. This could cause inventory levels that are too high for satisfying a desired service level. This means inventory management may also need to decide on a proper disposal strategy (= when and how much to dispose?) in order to bound the total inventory in the system from above. Obviously, disposal costs per batch should then be considered. In addition, depending on the return rate and the processing activities that should be done on recovered material, another important choice is between *push and pull* strategies for the recovery process. In the push strategy, recovered items are processed and added to the serviceable inventory as soon as they enter the system, whereas in the pull strategy recovery process is done only when recovered items are needed to satisfy demand.

Decision support tools

Driven by the growing urgency of resource and environment conservation as well as compliance with new legislation, the scientific community has made great advances in developing mathematical optimization algorithms that support decision making in various stages of a closed-loop supply chain [5,6]. Logistics (including intralogistics), as the enabling process that is present in almost every step of a closed-loop supply chain, has received special attention. These theoretical tools for optimal decision making solve complicated mathematical and statistical problems and must often make limiting, simplifying assumptions to derive analytical solutions. However, these assumptions do not usually hold in practice. Realistic supply chains often contain dynamic, non-deterministic, strongly correlated processes, as well as nonlinear elements, which prevent the direct application of analytical models to the practical problems faced by the industry. Furthermore, such generic methods need customization to address practical needs within each specific industry/business-model/country.

In this context, modeling and simulation is a valuable alternative to the analytical approach. In contrast to analytical methods, simulation modeling can accommodate rather specific conditions and requirements that are present in a practical situation. Among several existing simulation paradigms, discrete-event simulation has been widely applied in logistics and supply chain management. Discrete-event-simulation models are extensively used to support decision making in areas such as inventory control, production planning, scheduling [7], fleet dispatching, resource planning, etc. Different processes in a supply chain along with the business-specific rules that govern them can be precisely modelled in a discrete-event-simulation model. In addition, any performance metric of the system that is desired by management can be defined and measured. Another advantage of discrete-event-simulation models is that they can model not just a single process but the supply chain as a whole and hence the interdependencies between processes. To support decision making, various scenarios (including the best and worst case) can be evaluated by simulating the model and the relationship between decision parameters and the performance of the system can be deduced. This process, also known as "simulation-based optimization", determines near optimal values for the decision parameters and is best suited for complex dynamic systems with uncertainties.

Conclusion

As societies become more aware about the importance of resource conservation, governments impose stronger environmental regulations to avoid waste and to encourage repair, remanufacturing, and reuse. On the other hand, taking responsibility for the whole product life-cycle, as well as effective after-sales services create a competitive advantage and an additional income source for businesses. To achieve these goals managers need to analyze and control complex dynamic systems under uncertainties and to balance various competing criteria. The reverse chain is inherently more complicated than the forward chain, mainly due to additional processes that are exclusive to reverse channels and the greater uncertainty that exists both on the supply and market sides. Here, modeling and simulation provide strong decision support tools that can be customized to answer unique and practical questions about reverse logistics for each industry sector.

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