Reverse Supply Chain: Literature Review and Models

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Abstract

A supply chain (SC) consists of all parties involved, directly or indirectly, in fulfilling a customer requestas defined in Chopra & Meindl (2007). This includes supplier, manufacturer, distributors, retailer, and customer. In addition, all the functions and departments within each organisation are included in the SC. Supply Chain Management (SCM) is the coordination between all these parties and functions for the advantage of the whole supply chain. This coordination requires flow of products (in the direction of customers), funds (in the direction of suppliers) and information between different parties.

Keywords: Reverse Supply Chain, Mathematical Models, Sustainability

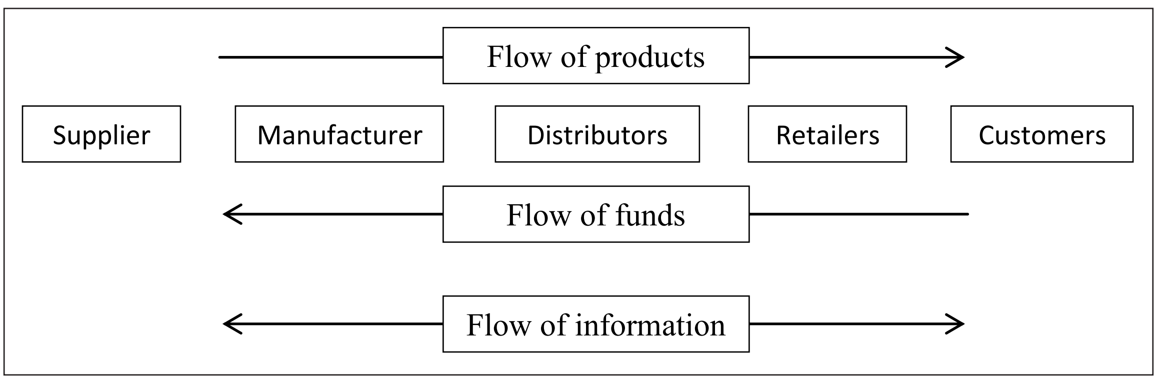
Introduction

A supply chain (SC) consists of all parties involved, directly or indirectly, in fulfilling a customer requestas defined in Chopra & Meindl (2007). This includes supplier, manufacturer, distributors, retailer, and customer. In addition, all the functions and departments within each organisation are included in the SC. Supply Chain Management (SCM) is the coordination between all these parties and functions for the advantage of the whole supply chain. This coordination requires flow of products (in the direction of customers), funds (in the direction of suppliers) and information between different parties. This can be observed in Figure 1.

The interest of SCM started in 1980s and increased obviously in 1990s. The organisations went behind this new concept as they realised that the competition and battle on market share is no more determined by only the product quality. The market is now controlled by how far the organisations can spread their products and how much they can provide the customers with values and satisfy their needs.

In reversed supply chain (RSC) another flow of products in the opposite direction exists. This flow occurs for many reasons; either to return, repair, or recycling a product. The first two reasons arise from obligations on the firm towards customer satisfaction and provide at the same time feedback about the products quality. Customer

Figure 1: Different Flows in SC



satisfaction means reputation of the firm and market value of its products which increases the loyalty of the customers towards the organisation and leads to sales functions support and profit increase as well. Recycling was found to be beneficial to the firm in two directions; it reduces the amount of required raw materials which reduces the cost, and at the same time helps in the proper disposal of some pollutant materials which also increases the credibility of the organisation as the environmental concerns are getting more critical every day.

In 1991, the Federal Republic of Germany passed an Ordinance on the Avoidance of Packaging Waste. It places the whole responsibility on industry for managing its waste, including the costs of collecting, sorting, and recycling waste. It requires that industry pays for the waste management costs industry if it does not take back its packaging waste (Rousso & Shah,1994).

RSC was defined by Stock as "the role of logistics in product returns, source reduction, recycling, materials substitution, reuse of materials, waste disposal and refurbishing, repair, and remanufacturing" (from the Council of Logistics Management's definition of logistics). Rogers & Tibben-Lembke (1999) defined reverse logistics as: the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing or creating value or proper disposal.

The differences between SC and RSC are usually the random supply rate, the uncertainty in the products retrieved quality, the irregular required production processes, the non-uniform pricing, the variety of products locations, and the unpredictable inventory requirements.

The remainder of the paper is organised in sections; each addresses a related topic to the RSC. First, decision making in RSC is classified in second section. Then, information sharing and how it supports decision making is discussed in third section. In fourth section inventory management and control importance in RSC is addressed. Fifth section explains the difference between RSC and closed- loop SC and a survey of mathematical models is presented. Sustainability in SCs is introduced in sixth section. Next section shows various applications of RSC in industry. Finally the paper is concluded in the eighth section.

Decision Making in RSC

According to Talluri & Baker (2002), supply chain problem decisions can be classified into three categories: strategic, tactical, and operational decisions.

- Strategic decisions are usually long term and involve the design of SC for the next years. Determining its size and structure; i. e. the locations and number of facilities, suppliers, manufacturers, distributors, and warehouses. For RSC design collecting centres and recycling facilities are added to the structure.
- Tactical decisions are the planning strategies that will guide the SC for the next months and up to one year. Including transportations strategies, inventory policies subcontracting, purchasing and production policies, and the flow of goods within the SC. Collecting strategies, promotions, and selection of collected products for RSC.
- Operational decisions are the short term planning orders based on day-to-day or week-to-week decisions. Production schedules, routing, handling orders, and storage activities. In RSC inspecting collected products, disassembly, reuse, recycle, or dispose decisions based on retrieved products quality.

Information Sharing

Information sharing between different components of SC supports better decision making for the benefits of all players. The application of Information Technology (IT) improved the performance of supply chains through increasing the accuracy and the speed of information sharing.

Olorunniwo & Xiaoming (2010) studied the impact of IT on the company performance in reverse logistics. They investigated the current IT types used, the operational attributes derived from IT and the collaboration, and information sharing on the performance of the reverse logistics. Their results showed that the use of IT is necessary to improve the reverse logistics performance and this improvement is a function of the IT attributes. However, no specific IT leads to better performance.

Nativi & Lee (2012) considered a supply chain with a manufacturer and two different suppliers: a recycled-material and a raw-material supplier where decisions are made individually to satisfy the demand and reduce the cost. The demand, returns, and collection lead time are stochastic. They investigated the impact of implementing Radio Frequency Identification (RFID) in the SC on attaining higher environmental and economic benefits. They used simulation-based analysis to show the advantages of RFID through real-time monitoring and improved information sharing. The results showed that although there are economic benefits, they are not significant compared to the environmental benefits.

Inventory Management

Inventories are distributed all over the supply chain in the form of raw material, work in process, components and finished products at suppliers, manufacturing plants, warehouses, retailers, and in transportations. They compose about 20 to 60 percent of the organisation assets (Bhatt & Borgesa, 2005). Therefore inventory management is considered a key element for the SCM success. With the integration between forward and RSC; inventory control gained even more interest. The return flow of products increased not only the inventory size but also the difficulty of control. Because this flow is entirely random in size, quality, and time, it needs different methods for handling and control.

Fleischmann & Kuik (2003) considered a single inventory point facing independent stochastic demand and stochastic item returns which are independent of demand and may be directly reused. They derived an optimal policy structure and an explicit expression of the cost function. A transformation made on the classical inventory theory for the case of return flows. Fixed order costs, convex shortage, and holding costs are considered with an objective to minimize the average cost per time.

Jonrinaldi & Zhang (2013) proposed a mixed integer nonlinear programming model for production and inventory control in a supply chain consists of multiple raw materials suppliers, multiple parts suppliers, a manufacturer, multiple distributors, and multiple retailers. They assumed that each type of parts and raw materials can be provided from more than one supplier in finite horizon period. They considered reuse option for collecting used products from end customers by a third party to return the collected parts to a manufacturer. They considered that returned products can be disassembled to become parts which are as good as new parts and can be used again into new finished products.

Models in Open and Closed-Loop Supply Chain

Sasikumar & Kannan (2008) classified the reverse distribution into open and closed loop supply chain. The difference is whether the products can be returned to the original producer through the integration of forward and reverse supply chain, or the return products are used in other industries. Following a survey on models used in reverse and closed-loop SC, Table 1 classifies the literature based on type of supply chain and the used model.

Mathematical Models in RSC

Pati *et al.* (2008) proposed a mixed integer goal programming model with multi-objectives which are; reduction of reverse logistics cost, improvement of product quality, and environmental benefits. The multi-itemmulti-echelon multi-facility model can determine the facility location, route, and flowas well.

Lee & Dong (2009) developed a two-stage stochastic programming model for multi period reverse logistics network design and proposed sampling method with a heuristic algorithm. They demonstrated the significance of the developed stochastic model as well as the efficiency of the proposed solution method using numerical experiment.

Table 1: Survey of Models in Reverse and Closed-loop SC

	Reverse SC	Closed-Loop SC
Mathematical Model		Chung (2008) Alfonso-Lizarazo (2013)
Heuristic	Barros (1998) Lee &Dong (2008)	
Stochastic Programming Model	Lee &Dong (2009)	
Mixed Integer Linear Programming	Achillas (2010) Alumur (2012)	Kannan (2010) Wang &Hsu (2010)
Mixed Integer Nonlinear Programming		Ko & Evans (2007) Jonrinaldi & Zhang (2013)
Mixed Integer Goal Programming	Pati (2008)	
Stochastic Mixed Integer Linear Programming		El-Sayed (2010)
Genetic Algorithm		Ko & Evans (2007) Wang &Hsu (2010) Kannan (2010)
Tabu-Search	Lee &Dong (2008)	
Review	Biehla (2007) Chan (2012)	

Achillas *et al*. (2010) formulated a mixed integer linear programming model to minimize the reverse logistics cost. The model considers the existing infrastructure collection points and the recycling facilities. The study is initiated to determine the optimal path of waste electrical and electronic equipment through the network.

Alumur *et al*. (2012) presented a mixed integer linear programming model to maximize the profit with multi-period settings. They considered multi-commodity and used reversed bill of material to track product return.

Mathematical Models in Closed-loop SC

Ko & Evans (2007) presented a mixed integer nonlinear programming model for the design of a dynamic integrated distribution network of a multi-period two-echelon multi-commodity capacitated network design problem for optimizing the forward and reverse network. A genetic algorithm-based heuristic was presented and tested in a set of problems by an exact algorithm.

El-Sayed *et al*. (2010) proposed a multi-period multi-echelon forward-reverse logistics network design under risk. They formulated the problem in a stochastic mixed integer linear programming (SMILP).

Chung *et al*. (2008) analyzed an inventory system with forward-reverse material flow supply chain. A multi-echelon inventory system with remanufacturing capability was proposed and a closed-loop supply chain inventory model was developed.

Wang & Hsu (2010) proposed model for the closed-loop logistics planning by formulating a cyclic logistics network problem into an integer linear programming model. Due to NP-hard nature of the model, a Genetic Algorithm, which is based on spanning tree structure, was developed.

An Integer Linear Programming Model

It can be noticed that integer linear programming is commonly used in modeling SC. In this section a simplified model from Pochampally, Nukala, & Gupta (2008) is illustrated. The model aims to select the best used product which attains the maximum profit out of selected group of used products. The profit function is modified to include the probability of missing or broken components. It is opposing to the following two assumptions that may cause risk of making a bad choice of product: every component of the chosen used product will be reused and all components are in their original multiplicities.

The profit function consists of five terms: total resale value, total recycling revenue, total reprocessing cost, total disposal cost, and collecting cost. It is influenced by the number of components, the probability of broken or missing components, the percentage of recyclable content in each component, the weight of each component, the disassembly time of each subassembly in the product, and the difficulty of disposing component.

Maximize $Z = R_{rsx} + R_{rsx} + R_{rcx} - C_{rpx} - C_{dx} - CC_x$

Subject to X_{xy} or 1 for all x and y

Sustainability in SCM

As defined in World Commission on Environment and Development (1987), sustainable development is "a development that meets the needs of the present without compromising the ability of future generations to meet their own needs".

Seuring & Muller (2008) offered a literature review on sustainable supply chain management taking 191 papers published from 1994 to 2007 into account. They defined sustainable supply chain management as "the management of material, information, and capital flows as well as cooperation among companies along the supply chain while taking goals from all three dimensions of sustainable development, i.e., economic, environmental, and social, into account which are derived from customer and stakeholder requirements".

Linton *et al*. (2007) provided a background to better understand the interaction between sustainability and supply chains. They explained that sustainability must integrate issues and flows that extend beyond the core of supply chain management.

Hassini *et al*. (2012) reviewed sustainable supply chain management research in the last decade and analyzed it from different perspectives. They also proposed a unified conceptual frame-work and provided performance measures.

Dues, Tan, & Lim (2013) studied the overlap of Lean and Green.They recommended strategies for companies to integrate Green practices in the company's Lean SCM to fit environmental considerations. They made a comparison between Lean and Green based on purpose, focus, customer satisfaction, and all stages along the SC; from product design, raw material sourcing, and manufacturing, to storage and transportation. They have found that there are common elements like waste reduction, lead time reduction, and service level enhancement between Lean and Green. They concluded that a Lean environment assists Green implementation and the integration of Lean and Green practices will bring benefits to companies.

Application of RSC in Various Industries

Many industries attained great achievements through the integration of forward and reverse supply chains.

Barros *et al.* (1998) considered the sand recycling as reverse logistics management problem and proposed a two-level location model for optimisation using heuristic procedures. A case study was investigated as the construction industry in Netherlands produces huge amount of waste products per year.

Biehla *et al.* (2007) simulated carpet reverse supply chain and designed an experiment to analyse the impact of the system design and environmental factors on the operational performance of the system.

Lee & Dong (2008) discussed the products recovery in computer industry by developing a deterministic programming model for managing logistics flows. They developed a heuristic approach, decomposed the problem into location-allocation problem, and revised network flow problem. A tabu search algorithm was applied to obtain the improved solution of shipping the returned products.

Kannan *et al.* (2010) presented a study considering lead recovered from the spent lead-acid batteries for producing new battery. They developed a multi-echelon, multi-period, multi-product closed loop supply chain network model for product returns. They proposed a mixed integer linear programming model and proposed genetic algorithm (GA) heuristic as a solution methodology.

Chan *et al.* (2012) investigated the reverse logistics activities of the automobile industry and the feasibility of reusing vehicle materials. They provided a framework for those activitiesand showed that most of the parts and components are feasible for reversing back into the supply chain.

Alfonso-Lizarazo *et al.* (2013) studied the impact of closed-loop supply chain concept in the area of agro-industry. They proposed a mathematical model to optimize the profit and the energy and operational cost in a case study about palm oil.

Conclusion and Future Work

The paper addressed related issues to RSC, surveyed different classes of mathematical models used in RSC, and showed that many industries have made great benefits from the application of RSC. It could be perceived that reverse supply chain is considered as obligations from governments and burdens on organisations. However, recycling can be beneficial in many ways. It reduces the cost of raw materials by reusing the components from returned products. At the same time it aids in the proper disposal of some pollutant materials which increases the reputation of the firm as customer's awareness towards environmental concerns increases. Reputation of the firm and market value of its products will increase and the loyalty of the customers towards the organisation and leads to sales functions support and profit increase as well.

The expansion of supply chains beyond boarders and the increase of product varieties and trade volume require extraordinary development in mathematical models. This development is intended for supply chain design models; to be more realistic, deal with the special products characteristics, and consider multi-objective optimisation problems. Most of research was directed to single economical objective optimisation function. The future work is tobuild a mathematical model that includes multi-objective functions and shows the tradeoff between the economical objective and other qualitative objective functions, i.e. sustainability, waste reduction and service level, to improve the supply chain design. Other directions that consider uncertainty and involve multi-product distribution are open for research as well.

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