JJMIE

Volume 6, Number 1, Feb. 2012
ISSN 1995-6665
Pages 87 - 102

Jordan Journal of Mechanical and Industrial Engineering

Perspectives in Reverse Supply Chain Management(R-SCM): A State of the Art Literature Review

Arvind Jayant*[,a], P. Gupta[a], S.K.Garg[b]

[a]Department of Mechanical Engineering, Sant Longowal Institute of Engineering & Technology, Longowal, Punjab, India
[b]Department of Mechanical Engineering, Delhi Technological University, Delhi-110042

Abstract

Environmental and economic issues have significant impacts on reverse supply chain management and are thought to form one of the developmental cornerstones of sustainable supply chains. Perusal of the literature shows that a broad frame of reference for reverse supply chain management is not adequately developed. Recent, although limited, research has begun to identify that these sustainable supply chain practices, which include the reverse logistics factors, lead to more integrated supply chains, which ultimately can lead to improved economic performance. The objectives of this paper are to: report and review various perspectives on design and development of reverse SC, planning and control issues, coordination issues, product remanufacturing and recovery strategies, understand and appreciate various mechanisms available for efficient management of reverse supply chains and identify the gaps existing in the literature. Ample opportunities exist for the growth of this field due to its multi-functional and interdisciplinary focus. It also is critical for organizations to consider from both an economic and environmental perspective. The characteristics of RSCM provided here can help the researchers/practitioners to advance their work in the future.

Keywords: Reverse supply chain management; Remanufacturing; Recycling; Reverse logistics

1. Introduction

Reverse logistics, which is the management or return flow due to product recovery, goods return, or overstock, form a closed-loop supply chain. The success of the closed-loop supply chain depends on actions of both manufacturers and customers. Now, manufacturers require producing products which are easy for disassembly, reuse and remanufacturing owing to the law of environmental protection. On the other hand, the number of customers supporting environmental protection by delivering their used products to collection points is increasing [1]. According to the findings, the total cost spent in reverse logistics is huge. In order to minimize the total reverse logistics cost and high utilization rate of collection points, selecting appropriate locations for collection points is critical issues in RSC/reverse logistics. Reverse logistics receive increasing attention from both the academic world and industries in recent years. There are a number of reasons for its attention. According to the findings of Rogers and Tibben-Lembke (1998), the total logistics cost amounted to $862 billion in 1997 and the total cost spent in reverse logistics is enormous that amounted to approximately $35 billion which is around 4% of the total logistics cost in the same year. The concerns about energy saving, green legislation and the rise of electronic retaining are increasing. Also, the emergence of e-bay advocates product reuse. Online shoppers typically return items such as papers, aluminum cans, and plastic bottles whose consumption and return rates are high. Although most companies realize that the total processing cost of returned products is higher than the total manufacturing cost, it is found that strategic collections of returned products can lead to repetitive purchases and reduce the risk of fluctuating the material demand and cost.

Research on reverse supply chain has been growing since the Sixties and research on strategies and models on RL can be seen in the publications in and after the Eighties. However, efforts to synthesize the research in an integrated broad-based body of knowledge have been limited [9]. Most research focuses only on a small area of RL systems, such as network design, production planning or environmental issues. Fleischmann et al. [2] studied RL from the perspectives of distribution planning, inventory control and production planning. Carter and Ellram [3] focused on the transportation and packaging, purchasing and environmental aspects in their review of RL literature. Linton et al. [4] studied the interactions between sustainability and supply chains by considering environmental issues regarding product design, product life extension and product recovery at end-of-life. Realff et al. [5] have also reviewed the literature on RL published between 1995 and 2005 by focusing on management of the recovery, distribution of end-of-life products, production planning and inventory management, and supply chain management issues. To consider the stock of the past

* Corresponding author. e-mail: arvindjayant@rediffmail.com

research, Fleischmann et al. [6] and Fleischmann [7] their literature review suggested seven opportunities for further research. First, they proposed the use of closed-loop network design and the integration of facilities between forward and backward flow. Second, they suggested including more comprehensive facility location models to examine the impact of uncertainty on reverse logistics network design via scenario and parametric analysis. Third, they suggested the development of stochastic model for reverse logistics network on real time basis. Fourth, they recommended the assessment of the impact of product recovery network on transportation. Fifth, they also suggested the analysis of multi-agent characters in a reverse logistics network by revealing the underlying incentives of collectors, intermediaries and processors. Sixth, they proposed to investigate the impact of inventory management techniques such as risk-pooling and postponement on reverse logistics network design. Finally, they suggested investigating the impact of global supply chain issues such as taxation and cross-border waste transportation on the design of product recovery network. The need for more complex objective functions; reverse logistics network and robust stochastic models have also been suggested in the literature by many authors.

The review presented in this paper extends the review to consider important features of reverse logistics such as product acquisition, pricing, collection of used products, RL network structure vis-à-vis the integration of manufacturing, and remanufacturing facilities of location of facilities for inspection and consolidation activity. The literature review covers published research until 2009. A further literature review of the recent research papers focuses mainly on reverse logistics design will provide an overview of the overall progress of the research and identify further research opportunities. The main objective of this paper is to review literature addressing various issues related to reverse logistics/closed loop supply chain during the period 1990-2009 and then to identify future research opportunities. This paper specifically identifies and reviews papers which addressed the research opportunities suggested by Fleischmann et al. [6] and [7]. Chanintrakul et al, [8] and Pokharel and Mutha [9]. Altogether we found more than 100 papers published during the period 1990-2009. For each paper we identify the applied modeling method and assumptions, i.e., time period, commodity-product flow, network level, open or close-loop structure, objective function, uncertainty type and other model constraints. With this systematic approach we are able to review the progress and contribution of the recent research papers and identify new issues for further research. The rest of the paper is organized as follows. In the next section research methodology is discussed. In Section 3 on ward, the results of review are presented section wise with research directions for the future research. Each section is divided further into subsections to highlight various factors that are important to this research. The paper ends with conclusions and some thoughts on further research.

2. Review Methodology

We have adopted content analysis method for literature review [9]. Content analysis is an observational research method that is used to systematically evaluate the symbolic content of all forms of recorded communication. This method also helps to identify the literature in terms of various, thereby creating a realm of research opportunities. Al-Mashari and Zairi [10] used content analysis to analyze the implementation of SAP R/3 for re-engineering the supply chain using enterprise resource systems. Gallivan [11] adopted content analysis methodology to examine case studies of open source software projects in the research on balance between trust and control in a virtual organization. Content analysis was also used by Byrd and Davidson [12] to examine the impact of information technology on supply chain; and by Ellinger et al. [13] in their research on the transportation industry in the US. Recently, Marasco [14] also used a similar method for review of literature on third party logistics. The review is limited to the published literature including white papers and literature obtained from electronic sources. Search engines were used to explore Science Direct, Emerald Insight, Springer and Inderscience databases for literature. Keywords such as ‘green supply chain’, ‘product returns’, ‘product recovery’, ‘reverse logistics’, ‘end-of-life products’, ‘closed-loop supply chains’, ‘recycling’, ‘remanufacturing’ were used to find related literature. The publications were found in the areas of logistics management, production and operations management and business logistics. The references cited in each relevant literature were examined to find out additional sources of information. In this research, 7 reports and 113 journal publications have been reviewed.

3. Research on Reverse Supply Chain Network Design

Recently, a considerable number of case studies have been reported which address the reverse supply chain network design in the product recovery and remanufacturing context. Table 1 is given in appendix 1 and table 1 summarizes the papers related to design of reverse supply chain networks and relevant issues and a details of abbreviation used in the table 1 are given in table 2. Several researchers have studied the design of RL network focusing on their cost effectiveness. Studies have concluded that for recycling of the returned products, logistics costs account for a large share of the total costs [15]. RL requires high investment and a high portion of logistics costs. The RL cost can vary from 4% (Rogers, 2001) to 9.49% [15-16] of the total logistics cost. In the retail and manufacturing sectors, it is estimated that RL accounts for about 5–6% of the total logistics cost. Transportation of used products is the most challenging issue in RL as smaller return quantities and variability in product types Increase the transportation costs. Biehl, Prater, and Realff [18] emphasize on the need for collection centers in a reverse production system to help in maximizing collection of returned products. Reimer, Sodhi, and Jayaraman [19] have developed truck sizing models for collection of wastes and transporting them to recovery centers. Min, Ko, and Ko [20] have developed a mixed integer non-linear programming model to determine the exact length of holding time for spatial and temporal consolidation at the initial collection points to minimize the total RL costs.

A review on various quantitative models for RL networks is given by Fleischmann et al. [21]. The location of collection points in a RL system has been examined by Bloemhof-Ruwaard, Fleischmann, and van Nunen [22]. Fleischmann, Beullens, Bloemhof-Ruwaard, and van Wassenhove [23] have presented a generic MILP model considering a single product flow between incapacitated facilities and reprocessing as a product-recovery option.

Table 3: Literature Based on Various Issues of RL Design.

Contents	Literature
Modeling of uncertainty	Pati et al. (2008) (Shih, 2001; Krikke et al., 2003). (Fleischmann et al., 2001), (Shih, 2001), refrigerator (Krikke et al., 2003), (Schultmann et al., 2003), LPG-tanks (le Blanc et al., 2004), (Salema et al., 2006), (Salema et al., 2007), (Pati et al., 2008), carpet recycling (Realff et al., 2000, 2004), Krikke et al. (2003), Du and Evans (2008) (Srivastava, 2008), (Lee and Dong, 2008).
Reverse supply chain network with stochastic model	Pohlen and Farris (1992), Kolbin (1977), (Listes, 2002, 2007) (Listes and Dekker, 2005), Wojanowski, Verter, and Boyaci (2007), Gupta, and Kamarthi (2004)
Impact of transportation on RL design	Ferrer & Whybark, 2000, Nagurney and Toyasaki, 2005; Chen et al., 2007, Hammond and Beullens, 2007. (Min et al., 2006a), (Min et al., 2006b) (Min and Ko, 2008). De Brito and Dekker (2004, Nagurney and Toyasaki (2005), Chen et al. (2007), Hammond and Beullens (2007)
Simulation model for RSC	Frank et. Al.(2006), Kara et al. (2007), Biehl et al. (2007)

Jayaraman, Patterson, and Rolland [24] have proposed a MILP model by considering the reverse flow of goods. Pochampally, Gupta, and Kamarthi [25] have proposed a physical programming approach to identify potential recovery facilities in a region where reverse supply chain is to be established. Savaskan, Bhattacharya, and van Wassenhove (2004) have proposed a product-recovery strategy depending on who collects the used products.

Table 2: Abbreviation.

S.No.	Parameters	Abbreviation
1.	Model	SIM=Simulation ,LP = linear programming model, MILP = mixed integer linear programming model, MINLP = mixed integer non-linear programming model, NE = network equilibrium model, ST = stochastic model, SM = simulation model, OT = other models)
2.	Solution method	GA=Genetic Algorithm,EX = exact solution method, HE = heuristics method, MHE=Multi-heuristics method
3.	Period	S = single-period, M = multi-period
4.	Product commodity	S = single, M = multiple
5.	Levels	S = single, T = two, M = multiple
6.	Recovery Option:	S = single recovery option, M = multiple recovery options
7.	Issue	MI=Multiple Issues SI=Single Issue
8.	Constraints	MC=multi-Constraints ,SC=Single Constraint
9.	Network structure	(OL = open-loop, CL = closed-loop)
10.	Model objectives	S = single, M = multiple, CM = cost minimisation,PM = profit maximization, RM = risk minimization, OT = others such as environmental impact minimization, total tardiness of cycle time minimization, etc.

namely the manufacturer; the retailer; or a designated third party. The findings suggest that optimal results are achieved when the retailer collects the returned products. However, the authors consider the flow of goods in only a two echelon system i.e. retailer and manufacturer. De Koster, de Brito, and van de Vendel [26] have investigated the factors contributing to RL network decisions by considering inbound and outbound flows, the transport routes, the return volume, choice of receiving warehouse and the market location for returned products. The authors recommend that retailers that supply to stores should collect the returned material to the distribution centre using the same truck which delivered the products. Also, retailers that handle a high volume of returns should unload and sort returns in a separate area in the distribution centre.

Lu and Bostel [27] have also developed an incapacitated model for RL. Pohlen and Farris [28] have investigated the reverse distribution channel structure in plastics recycling and analyzed the compaction and routing issues related to transportation in the RL process. Spengler, Puchert, Penkuhn, and Rentz [29] have developed a model based on linear activity analysis to determine locations and capacities of recycling facilities for reprocessing byproducts of steel industries. Barros, Dekker, and Scholten [30] have proposed a logistics network for recycling of polluted sand by using MILP to determine the optimum number, capacities, and locations of the depots and cleaning facilities in the network. Louwers, Kip, Peters, Souren, and Flapper [31] have proposed a RL network model to determine appropriate locations and capacities for collection, preprocessing and redistribution facilities of carpet wastes. Realff, Ammons, and Newton [32] have proposed a multi-period MILP model for carpet recycling. Their model analyzes a set of alternative scenarios identified by the decision maker and provides a near optimal solution for network design. Schultmann, Zumkeller, and Rentz [33] have developed a recycling network for the German automotive industry by minimizing the travel routes between dismantling centres and reprocessing facilities. The authors solve their network model by using linear programming and meta-heuristics methods. Beamon and Fernandes [34] have developed an integer programming model for a four echelon reverse supply chain by assuming infinite storage capacities and same holding costs for recovered and new products. The authors assume that the remanufactured products are of the same quality as that of the new products. Therefore remanufactured products can be sold in the same condition as new ones to meet the market demand. Kusumastuti, Piplani, and Lim [35] have presented a multi-objective and multi-period MILP model for RL network design for modularized products. The model determines the number of existing forward flow facilities to be used and the number of dedicated facilities to be setup for handling return flows. The authors have not considered the use of new modules in remanufactured products. Salema, Povoa, and Novais [36] have proposed a MILP model to analyze the problem of closed loop supply chains. They consider multi-product returns with uncertain behavior but limit their consideration of demand for returned products to factories and not to secondary markets or spare markets. Thus a supplier network which may be required to remanufacture a new product to meet the market demand is not considered. Also, this model is not suitable for modular products.

Wojanowski, Verter, and Boyaci [37] have developed a stochastic model to analyze the network structure for product returns under a refundable-deposit scheme. They show that the success of the profitability of the network depends on the accessibility of the customers to the collection centers. Zhou, Naim, and Wang [38] analyzed the battery recycling practices in China and identified its obstacles and weaknesses. They recommend legislative actions, technical guidance and administrative resources, and cost-effective recycling and RL infrastructure to improve the system. Kroon and Vrijens [39] have considered the design of a logistics system for used plastic containers. They propose a MILP model to determine the number of containers required to run a five echelon system under consideration, the appropriate service, and distribution and collection fee per shipment for empty containers and location of depots for empty containers. Berger and Debaillie [40] have proposed a model for extending a production/distribution network with disassembly centers to allow the recovery of used products. The authors consider each plant and distribution centers with fixed locations and capacities, but determine the location and capacity of the disassembly centers based on a multi-level capacitated MILP model.

Few researchers discussed the aspect of supply planning in RL considering modular structure of products and address the problem of scheduling supplies of new modules from suppliers to meet the demand after a certain recovery of modules from the returned products. The authors present a MILP model for maximizing the cost savings by optimally deciding which quantity of products/ modules are to be refurbished and which are to be outsourced from the suppliers. Min, Ko, and Ko [41] have proposed a single objective, nonlinear, mixed integer programming model to provide a minimum cost solution for network design of product-recovery systems. Their proposed model considers trade-offs between freight rate discounts and inventory cost savings due to consolidation and transshipment. The authors perform sensitivity analysis on the holding period to determine the optimal length of holding time for consolidation and the collection centers. The model indicates that as the maximum holding period increases the RL costs decreases, but the overall network structure remains stable. The authors noticed dramatic cost saving in total RL costs after setting the maximum holding period at three days. Research is also done in areas of product disassembly planning (Guide, Jayaraman, & Srivastava, 1999; Gungor & Gupta, 1998; Lambert, 2002; Mok, Kim, & Moon, 1998), vehicle routing and planning in reverse logistics (Alshamrani, Mathur, & Ballou, 2007; Dethloff, 2001) and the pricing of a ‘‘remanufactured” product (Heese, Cattani, Ferrer, Gilland, & Roth, 2005).

Teunter, Van der Laan, and Inderfurth [42] have compared the performances of different methods for setting the holding cost rates in average cost inventory models with reverse logistics. Jayaraman et al. [43] have also proposed a model for location of remanufacturing and distribution facilities by optimizing the quantities for remanufacturing, transshipment and stocking. Pati, Vrat, and Kumar [44] have formulated a mixed integer goal programming model for analyzing paper recycling network. The model assumes five echelons and studies the inter-relationship between cost reduction, product quality improvement through increased segregation at the source, and environmental benefits through waste paper recovery. The model also assists in determining the facility location, and route and flow of different varieties of recyclable wastes. Shih [45] have proposed a MILP model to determine the optimal collection and recycling system for end-of-life computers and home appliances. The model helps to determine the location for storage and treatment facilities. Walther and Spengler [45] have developed a model for the treatment of electrical and electronic wastes in Germany. This model optimizes the allocation of discarded products, disassembly activities and disassembly fractions to participants of the treatment system. Ravi, Ravi, and Tiwari [46] presented an ANP based decision model to analyze the options in RL for end-of-life computers and link them to the determinants, dimensions and enablers of RL. Kara, Rugrungruang, and Kaebernick [47] have modeled the collection of end-of-life electrical appliances with high degree of uncertainty in quality and quantity of the returned products. The authors suggest that low costs can be achieved when local councils act as collectors. Fernandez and Kekale [48] have studied the implications of modular product architecture on RL strategies. They discuss that modular structure of a product affects the decision making in terms of destination for returned products or its modules. Krikke, van Harten, and

Schuur [49] analyzed a RL network for photocopiers with a fixed supplying processes and disassembly. The authors propose a MILP model to determine optimal locations for the preparation and reassembly operations. The modular nature of computer monitors is considered in RL by Krikke, van Harten, and Schuur [50] to find a profit-optimal product recovery and disposal strategy for each of the six types of monitors considered in the study. Their strategy includes options of partial disassembly, mixed and separate recycling. Frank, Basdere, Ciupek, and Seliger [51] have developed an optimization model for planning of capacities and production programs for remanufacturing of mobile phones. Their model considers modular nature of the product and considers reuse; component retrieval; material recycling; and disposal as the four possible options for recovery of products or its modules. The authors have also included an external procurement activity (suppliers) to satisfy the market demand. The process capacities and the remanufacturing program are determined by the optimization model. They have developed a simulation model to help in determining the required transport and storage capacities, and the performance of the remanufacturing system.

3.1. Contributions, Applications and Limitations:

After investigating more than 50 papers the review shows that the design of RL network is an important research problem as the circumstances leading to the model development could be unique. The research emphasizes on the reduction of RL costs through the choice of locations and capacities. The research also shows that remanufacturing of products and their sale in secondary markets are important considerations being studied for different types of returned products. While some researchers have focused mainly of used products only, others have recognized that used products do contain modules with different qualities. Kusumastuti et al. [35] and Franke et al. [51] have considered modular architecture of the returned products for remanufacturing operations. While Franke et al. [51] have considered new module suppliers for the remanufacturing of new products; Kusumastuti et al. [35] have considered multi-product configurations of returned products. In table 3 papers related to parameters investigation on reverse logistics has been listed.

3.1.1. Modeling of Uncertainty:

Furthermore, several authors began to investigate the impact of uncertainty on reverse logistics network design for large-scale problems solved by robust MILP models with exact algorithms, decomposition algorithms and heuristics algorithms and large-scale and dynamic problems solved by MINLP model with heuristics algorithms. Notably, Kirk et al. [49], Du and Evans [51] and Patti et al. [44] have started to investigate multi-objective MILP models. In addition, two papers have begun to take environmental regulation and technological issues into account. Furthermore, many of the proposed models were applied in different industrial and product sectors, i.e., copier remanufacturing and paper recycling [52], end-of-life home appliances and computer (Shih, 2001), refrigerator (Krikke et al., 2003), spent batteries (Schultmann et al., 2003), LPG-tanks (le Blanc et al., 2004), copier remanufacturing (Salema et al., 2006), office document company (Salema et al., 2007), paper recycling[44], carpet recycling (Realff et al., 2000, 2004), home appliances, computer, mobile phone and car (Srivastava, 2008), and end-of-lease computer products [1].

3.1.2. Modeling of Dynamic systems:

There are very few papers which use stochastic models to solve reverse logistics network design problems. Theoretically, a stochastic model is more flexible in dealing with uncertainty compared with an MINLP model via sensitivity and parametric analysis. However, Kolbin [53] argued that a stochastic model has a number of disadvantages including unstable outputs due to random values of parameters, huge computational effort and computational intractability. This may explain why we found only three papers which established comprehensive models to cope with return and demand uncertainty in terms of quantity. These models assumed a single-commodity flow and two-level reverse logistics network. The proposed models were further applied for electronic equipment remanufacturing industry [54-55] and sand (from demolition waste) recycling industry [56].

3.1.3. Impact of Transportation on Product Recovery:

Though there are only three papers, they laid the foundations for the research of the impact of the transportation issues in terms of consolidation and channel selection decisions (direct and indirect shipment). Particularly, the proposed models have coped with products returned from online sales [57], products returned from online and retail sales [58] and mail catalog or online sales business via third-party logistics company [59]. De Brito and Dekker [60] mentioned that there are three main classifications of agents in reverse logistics and closed-loop supply chain as follows; forward supply chain actors (as supplier, manufacturer, wholesaler and retailer), specialized reverse chain actors (such as jobbers, recycling specialists, etc.) and opportunistic actors (such as charity organizations). Each of players within forward and/or reverse channels may have particular operations objectives and constraints. Moreover, each of them may have different competition and/or collaboration behaviors with other agents in the same or different tiers.

To analyze the behavior of agents in reverse logistics network, Nagurney and Toyasaki [61], Chen et al. [62] and Hammond and Beullens [63] proposed a network equilibrium model for reverse logistics recycling network by using the variational inequality (VI) approach. All proposed models addressed single-period and single-commodity flow problem for the recycling waste of electric and electronic equipment (WEE). The proposed models consider an open-loop system with four-tiered network comprised of four agents including the sources of electronic waste, the recyclers, the processors and demand markets (Nagurney and Toyasaki,[61]; Chen et al.,[62]) and a closed-loop system with a two-tiered network and two agents including manufacturers and consumer markets[63].

3.1.4. Application of Simulation for RL Network Design:

A very few authors presents the overview of the simulation models for reverse logistics network design appeared in literature during the last two decades. Overall, few simulation models were proposed to analyze the impact of various network design parameters on the operational performance of reverse logistics systems. The objective of the simulation models was to investigate which possible design variables are important for a reverse logistics network design. For example, Biehl et al. [64] took potential design variables such as the number of collection centres, collection rates, type and set up of information technology for forecasting and control systems, recycling rates and return rates into account in order to assess how the US carpet industry would able to meet a 40% diversion from landfills by 2012. In addition, Kara et al.[65] considered design variables including the number and type of participants in the system, number and location of the disassembly centre, collection points, return rate and characteristics of the material flow and product characteristics in order to design a cost effective reverse logistics networks for taking back end-of-life white goods. It can be seen that both papers considered many realistic characteristic of reverse logistics network and return uncertainty into account. In summary, both papers addressed a single-item flow with multi-period. Biehl et al. [64] investigated closed-loop and two-level network structure while Kara et al. [65] considered open-loop and multi-level network structure. Regarding the model results, both simulation models were able to provide several crucial managerial recommendations for the improvement of reverse logistics network.

3.2. Research Gaps in Reverse Logistics Network Design & Development:

Despite many profound contributions of the researchers, these papers (models) are still faced with some limitations:

- All of the proposed models considered few elements of return and/or demand uncertainty left out other elements of risk and uncertainty in terms of quantity, quality and timing
- All of the proposed papers have not included more realistic assumptions, i.e., multi-objective, multi-period, multi-commodity flow, capacitated, closed-loop network structure into a single model
- Though a number of the heuristics solution methods were proposed, there is no computational time performance comparison between the proposed models and other heuristics solution methods.
- The models only investigated the element of return uncertainty in terms of quantity but ignored the risk and uncertainty in terms of quantity, quality and timing.
- All of the proposed models did not consider reverse logistics capacities and basic operations requirement
- All of the proposed models only considered single-commodity flow while only Hammond and Beullens [63] addressed closed-loop system and the two-tiered network.
- The authors took only return and demand uncertainty in terms of quantity into account but they have not included other elements of return and/or demand uncertainty in terms of quantity, quality and timing into account
- The authors employed only genetic algorithms to calculate outputs; however, there are several heuristic algorithms that might provide the same results with better computation time
- All of the models though applied two-level network structure only considered single objective instead of multiple objectives.
- The proposed models only considered return and demand uncertainty in terms of quantity but there are other elements of return and/or demand uncertainty in terms of quantity, quality and timing to be included.

4. Remanufacturing Issues in Reverse Supply Chain

In this section, we identify the problems with current descriptions of remanufacturing and their planning and control issues. As observed by Volmann et al. [66], an aggregate production plan should provide as close a match as possible between the model and the real world. Management must clearly define key objectives in order to develop advanced manufacturing systems. The development of formal production planning and control systems for remanufacturing is still in its infancy. Many firms simply use tools and techniques designed for traditional manufacturing operations. Previous research has shown that the production planning and control requirements for remanufacturing are unique [67]. Consequently, planners must consider a variety of complicating factors. Examples of the research addressing various aspects of remanufacturing are shown in Table 4. A complete review of this research stream is offered in both Fleischmann [52] and Guide and Jayaraman [67]. Currently, there is a relatively small but growing body of literature devoted to production planning and control for remanufacturing. Many of the models developed are based on a specific product type or a hypothetical scenario. In Table 4, we can see that much of the research has been grounded in actual remanufacturing systems. However, with the exception of Thierry et al. [68], the past research addresses a single aspect of remanufacturing using a single example, e.g. models for inventory control based on automotive parts remanufacturing. Further, the past work has been focused on producing operations research models and there have been a very limited number of attempts to structure the field.

Table 4: Recent Remanufacturing Researches.

Author	Product Type	Research Focus
Kara et al., 2007	Automotive parts	Recovery strategy
Kim et al. (2006)	-------------	Remanufacturing cost
Seitz and Peattie, 2004	Automobile	Product take back
Guide et al(2003)	-------	Demand forecasting
Guide and Jayaraman, 2000	Mobile phone	Uncertainty
Krikke et al., 2001	Toner cartridges	Distribution issues
Toktay et al. (2000)	Single-use cameras	Inventory control policies
Krikke et al. (1999)	Photocopiers	Facility location and network design
Jayaraman et al. (1999)	Cellular telephones	Product returns management
Guide and Srivastava (1998)	Jet engine components	Short-term scheduling policies
van der Laan (1997)	Automotive parts	Inventory control policies
Thierry et al. (1995)	Photocopiers	Case study
Kelle and Silver (1989)	Refillable containers	Forecasting returns

Our purpose in Table 4 is to show that the research efforts to date have been focused primarily on analytical modeling. van der Laan [69] discusses independent demand inventory control policies as it relates to automotive parts. The independent demand inventory models can be classified as periodic and continuous review models. Kelle and Silver [70-71] considered the forecasting of returns of reusable containers in which the planner must forecast the core availability (a core is an item available for repair or remanufacture) that depends on the product's stage in its life cycle. van der Laan et al. [69] discusses a number of options for independent demand inventory control models using automobile part and photocopiers for examples. Guide and Srivastava [72] report on scheduling policies for remanufacturing shops using information from turbine jet engine remanufacturing. Jayaraman et al. [73] develop a location model for remanufacturable products and ground the model with information provided by a mobile telephone remanufacture. Krikke et al. [49] consider a number of alternatives for the design of a reverse logistics network for photocopiers in Western Europe. Toktay et al. [73] consider the problem of predicting return flows for single-use cameras. As the previous research shows, many studies have considered specific portions of the remanufacturing processes to support the development of a detailed operations research model. There is a clear gap in rich descriptive reports of remanufacturing systems from a planning and control standpoint. The work by Thierry et al. [68] examines several examples of product reuse and provides a series of managerial insights. Their research examines the operations of a number of firms engaged in product recovery management. One of the key managerial implications identified by Thierry et al. [68] is that product recovery management has the potential for large influences on production and operations management activities.

Previous research has reported different systems and techniques for gathering cores for remanufacturing. A common observation is that off-lease and off-rent products are an important source of used products for remanufacturing. Thierry et al. [68] have come to the conclusion that this type of return is more predictable than other types of returns due to the additional information that is available to the remanufacturing company. In the automotive industry, there is widespread use of ‘‘exchange cycles’’ where products are only sold if a core is given back [74]. In this scenario you first have to act as a supplier of a core in order to become a customer of a remanufactured product. Other reported systems are voluntary systems where the supplier freely returns the used products/cores to a remanufacturer, or where the cores are bought from core brokers or end customers. The company Lexmark uses a ‘‘prebate’’ program giving a discount on a product if the customer agrees to return the product after use; this program prohibits the customers from returning or selling their used products to other companies.

Guide et al [74] present a number of management propositions on what to focus on when trying to balance the supply and demand for remanufacturing. Regarding core acquisition, one of the most important issues is to focus on identifying different sources of cores and rating them according to their characteristics. Forecasting core availability is critical in order to balance supply and demand. This reduces the need to purge the system of excess cores and reduces stock-outs of unavailable units. Managers should also try to synchronise return rates with demand rates, since doing so will lower the overall uncertainties in the system and lead to lower overall operating costs [75]. According to Jayaraman et al [76], there are three crucial limitations that a remanufacturing firm needs to overcome: limited access of cores leaving the use phase, limited feasibility of product remanufacturing, and limited market demand for the secondary output from remanufacturing. Furthermore, a challenge that remanufactures need to tackle is the fact that market demands for remanufactured products and the disposal of used products does not always overlap. This is often referred to as, the problem of balancing supply of cores suitable for remanufacturing and the demand for remanufactured products. The reasons for returning used products are many. In theory, there are four basic types of returns:

- End-of-Life Returns. These are returns that are taken back from the market to avoid environmental or commercial damage. These used products are often returned as a result of take back laws.
- End-of-Use Returns. These are used products or components that have been returned after customer use. These used products are normally traded on an aftermarket or being remanufactured.
- Commercial Returns. These returns are linked to the sales process. Other reasons for the returns include problems with products under warranty, damage during transport or Product recalls.
- Re-Usable Components. These returns are related to consumption, use or distribution of the main product. The common characteristic is that they are not part of the product itself, but contain and/or carry the actual product; an example for this kind of return is remanufactured toner cartridges (Krikke et al., 2001).

4.1. Contributions, Applications and Limitations:

The issue of forecasting for used product returns has proven to be a difficult challenge for the remanufacturing industry. The return of mainly mechanical products is dependent on factors such as age and use of the product, whereas electrical products tend to have a more random pattern of failure. Vacone et al. [77] report that different IT-based systems are used for keeping control over the products during use; two examples of these technologies are remote monitoring devices that communicate usage data and Radio Frequency Identification tracking systems used for keeping track of the installed base. Rogers and Tibben-Lembke [78] characterize good gate keeping as ‘‘the first critical factor in making the entire reverse flow manageable and profitable’’. Another important characteristic in the closed-loop supply chain is the need for a well-functioning reversed logistic network [67]. For example, reversed logistic networks for product recovery have been modeled by Kara et al. [65], with the aim to calculate the total collecting costs in a predictable manner. Kim et al. [79] also present a closed-loop supply chain model for remanufacturing to minimize the total cost of remanufacturing. Furthermore, the reverse supply chain and remanufacturing processes are dependent on what type of relationship the remanufacturer has with the original equipment manufacturer (OEM).Remanufacturers are often categorized into three categories: original equipment remanufacturers, contracted remanufacturers and independent remanufacturers (IRs). OEMs are in fact manufacturers that perform their own remanufacturing as a part of their company group, whereas CRs have a contract with OEMs to perform remanufacturing for them. In the last category, remanufactures work independently from the manufacturers, and often as competitors in the same market. The type of remanufacturing category has a major impact on the supply of spare parts and cores. The relationship perspective has the starting point that the important issue is the mutual exchange of value that occurs during an existing relationship between different parties.

4.2. Research Gaps in the Literature Related to Remanufacturing Strategies:

Despite many profound contributions, literature in the segment having many gaps that needs to be addressed by the researchers and models are still faced with some limitations:

- Although there are a lot of studies on various specific areas of remanufacturing, only a few research studies have focused on the development of a general framework and mathematical model about remanufacturing system
- Absolute shortage of integrated models which includes remanufacturing with OEM. More research needed on integrated modes which include reverse and forward channels simultaneously.
- Performance measurement system for the integrated manufacturing models which includes reverse and forward channels is still awaited.

5. Inventory Control and Coordination Issues in RSCC

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 [80]. 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 Figure1).

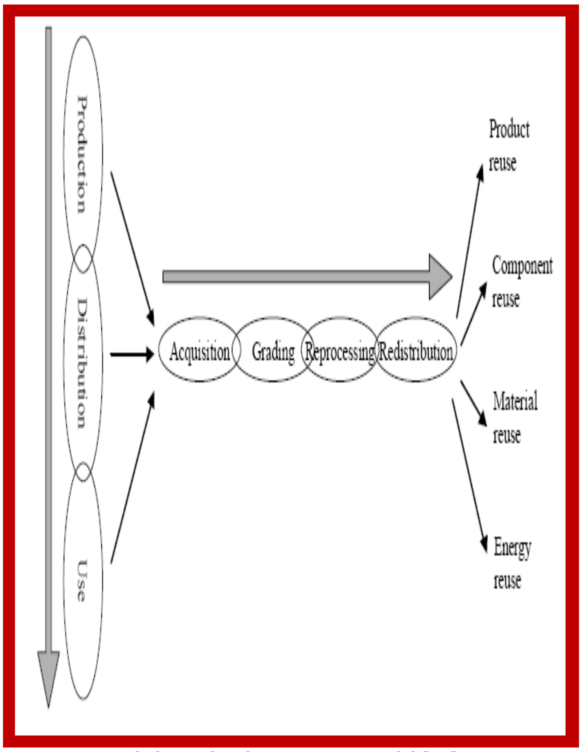

Figure1: Extended Supply Chain Generic Model [80].

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.

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 [81]. In contrast, choosing appropriate levels of safety stock and opportunity stock is more challenging. A significant body of literature addresses this issue. 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. 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 [82].

5.1. Contributions, Applications and Limitations:

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 [83]. 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).

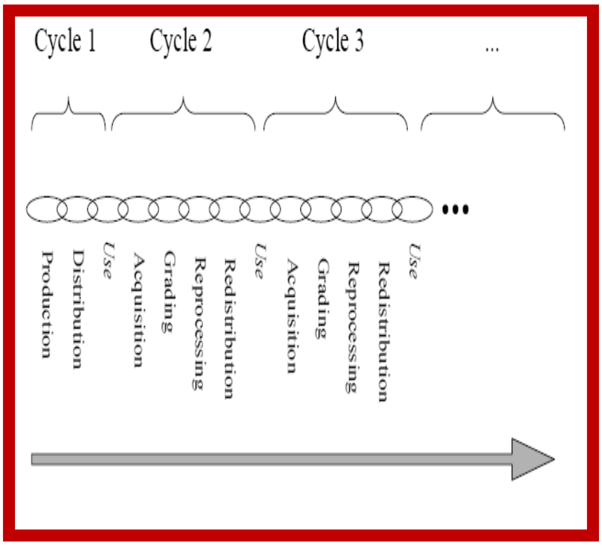

Figure2: Extended Supply Chain [80].

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 soft drink 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 [85].

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 [84]. 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.

6. Reverse Supply Chain/Reverse Logistics out Puts

Pricing the remanufactured product for sale is a complex and challenging issue [85] due to stochastic returns and demands. This makes it difficult to determine the price of a remanufactured product vis-à-vis new products. The groupings of literature under RL outputs are given in Table 4.

6.1. Pricing and Competition:

Researchers have studied the relationship between markets for new and remanufactured products and developed models to determine the optimum selling price for remanufactured products and parts. The competition between original equipment manufacturers (OEMs) and local remanufacturers not only affect the supply of used products but also the price of the remanufactured product [86-87-88-89]. They found that OEMs are in a better position to offer remanufactured. Products at a lower price than those offered by local remanufacture. Ferguson and Toktay [90] have discussed strategies used by OEMs to deter the entry of independent remanufactures. Substitution of new products by remanufactured products is discussed by Bayindir et al. 91]. Researchers have also recommended early entry of OEMs in RL to gain first mover advantages and to learn significant engineering capabilities and product disassembly knowledge [92].

6.2. Coordination Support:

Coordination in RL is also discussed by the authors. Some authors have discussed the importance of communication to help in quick and early disposition of returned products and also assisting in remanufacturing planning [93-95]. Some authors have suggested the use of information support systems to assist in coordination [96-97].

6.3. Customer Relation:

The benefits of RL on customer relationship such as improved customer retention and customer satisfaction through liberalized returns policies is analyzed by Fuller et al.[98], Turner et al.[99], Wise and Baumgartner [100], Sarkis et al.[101], and Mollenkopf et al.[102]. Amini and Retzalff-Roberts [103] suggest reduction in cycle time of providing refunds and exchanges to customers as a way of enhancing customer service quality. Daugherty et al. [97] suggest the use of information technology for better customer relations and enhanced service.

Table 4: Literature on Reverse Logistics Out Puts (Pokharel & Murtha, 2009).

Contents	Literature
Product pricing	Ferrer and Swaminathan (2006), Vorasayan and Ryan (2006), Karakayali et al. (2007), Mitra (2007), Vadde et al. (2007)Purohit (1992), Purohit and Staelin (1994), Majumder and Groenevelt (2001), Guide et al. (2003), Choi et al. (2004), Bayindir et al. (2005), Ferguson and Toktay (2005), Debo et al. (2005), Yalabik et al. (2005), Yao et al. (2005), Bhattacharya et al. (2006),
Competition	Goldsby and Stank (2000), Majumder and Groenevelt (2001), Sahay et al. (2003), Richey et al. (2004), Ferguson and Toktay (2005), Heese et al. (2005), Ferrer and Swaminathan (2006), Savaskan and vanWassenhove (2006),Webster and Mitra (2007)Porter and van der Linde (1995), Shrivastava (1995), Newman and Hanna (1996), Russo and Fouts (1997), Marien (1998),
Coordination	Fleischmann et al. (2000, 2001), Fleischmann (2003), Hess and Meyhew (1997), Chouinard et al. (2005), Daugherty et al. (2005), Yalabik et al. (2005), Aras et al. (2006), Atasu and Cetinkaya (2006), Ketzenberg et al. (2006), Kongar and Gupta (2006)
Customer relation	Sarkis et al. (2004), Daugherty et al. (2005), Mollenkopf et al. (2007), Srivastava (2007)Fuller et al. (1993), Turner et al. (1994), Amini and Retzalff-Roberts (1999), Wise and Baumgartner (1999), Daugherty et al. (2003),
Reverse Supply chain	Choi et al. (2004), Kim et al. (2006), Reimer et al. (2006), Bakal and Akcali (2006), Debo et al. (2006), Georgiadis et al. (2006), Tang and Teunter (2006)Guide et al. (1997a,b), Bras and McIntosh (1999), Guide (2000), Veerakamolmal and Gupta (2000), Inderfurth and Teunter (2001),

6.4. Reverse Supply Chain:

An understanding of reverse supply chain is also explored by the authors. Scheduling arrivals of new modules, storing or disposing excess recovered modules are some of the factors analyzed by researchers [104-105]. Research is also carried to analyze capacity planning techniques and material planning systems in a remanufacturing environment [104]; Ferrer and Whybark [106]. A few authors have also discussed the aspect of supply planning by considering the modular structure of products [107].

7. Concluding Remarks and Future Research Directions

This paper presents a comprehensive literature review of the journal papers on reverse logistics/closed loop supply chain published in last two decades. We have used a holistic perspectives approach to study the research on the various issues related to design and development of reverse logistics system/reverse supply chain systems. After surveying more than 100 papers, we have to come on this conclusion that the research in RL is multifaceted and distinguishes itself from forward logistics. The review also shows that research publications on RL are increasing specially after 2004 and therefore it shows the growing recognition of RL as a driver of supply chain and logistics. We have used content analysis approach [108] in this paper to study the research in reverse logistics and its impact on forward supply chain unctioning. Overall, the reviewed papers applied models such as linear programming, non-linear programming, MILP, MILNP, network equilibrium model, stochastic model and simulation model to deal with the above research issues.

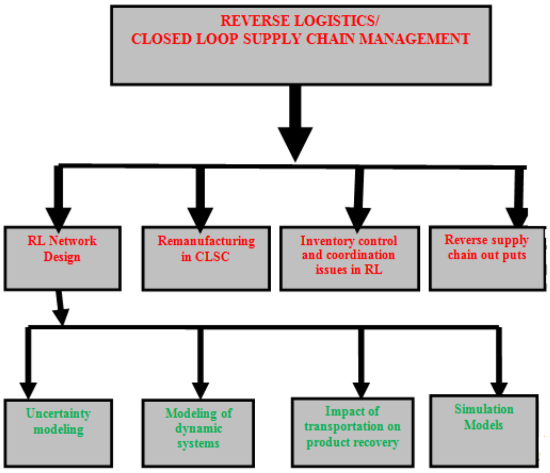

Figure 3: Shows The Eight Major Streams Covered by our Literature Review.

Figure 3 shows the eight major streams covered by our literature review with regards to the issues being addressed during the review period 1990-2009, the impact of design of reverse logistics network channel functions in isolation was most popular issue among the academician and practice , while the rest of the research issues received relatively less attentions. Particularly, we found a lot of contributions to the understanding of the impact of uncertainty on reverse logistics network design because return and demand uncertainty in terms of quantity, quality and timing have now been investigated [109]. The rest of the research issues, though received relatively less attention, have already given the foundations for future research.

The review presents reverse supply chain from a systems perspective. It can assist the decision maker in key operational and strategic decision making, for example, integrating manufacturing, distributors, remanufacturing operations and 3PL providers, evaluating end-of-life options for returned products, or setting up a returns policy. RL involves a paradigm shift in terms of product, that is, from "cradle-to-grave" to "cradle to cradle". Arising from the above, we propose some important directions in RL research. We have found that the research can be strengthened in assessing the stochastic nature of supply and demand and the yield from a remanufacturing process. More generic models have to be developed to tackle this type of situation so that better networks can be designed to facilitate RL [108].

The objective of this study was to encourage and provide researchers with future research directions in RSCM for which empirical research methods are appropriate. In addition, the research directions suggested in the paper address several opportunities and challenges that currently face business managers operating in RSCs. Studies using survey-based research methods are complementary to existing research in that they are used to develop generalizations about a representative group of firms, to clarify predominant and critical issues in the RSC and to explain the current business environment and managerial behavior [110]. In addition, most studies have focused on the retailer (with consumer product returns) or the remanufacturer (with process concerns). We believe there are several opportunities to conduct survey-based research along all tiers of the RSC. There are many opportunities for future research using empirical-based research methods in RSCs.

Arising from the above, we propose some important directions in RL research

Future research could measure organizational commitment as it has been defined in social exchange theory and test its relationship to operational performance Although the relationship between organizational commitment and RSC performance is implied in several studies [9,23,65,66], research has not addressed how organizational commitment and the form of the investments influence operational performance.

The second direction of research should be development of performance measurement mechanism to investigate remanufacturing influences on production, planning & control in the RSC. We are only beginning to develop an understanding of the constraints in remanufacturing that challenge our traditional PP&C systems. Previous work on traditional PP&C systems, recent PP&C case studies in RSCs and normative research on remanufacturing systems provide a good foundation for future work. To extend our current understanding of the difficulties of using PP&C systems with both remanufacturing and new products, empirical research can be used to audit the applicability of PP&C systems in different remanufacturing environments and the PP&C system's influence on performance.

The third direction of research should be in terms of pricing of products based on quality of the returned products. Good quality products require less number of processes in terms of inspection, and less number of new parts for remanufacturing; this can possibly lead to higher value extraction to the remanufacturer. Therefore, designing a good pricing policy for the acquisition of used products should be strengthened. Liang et al. [85] have proposed an option theory method for acquisition pricing based on anticipated demand. However, the authors do not explicitly consider network design and the remanufacturing process [108]. Therefore, integration of models from acquisition of used products to the sale of remanufactured products should be considered.

The fourth area of research could be selection of return facility like, 3PL provider, in-house or centralized returns center with cost effective manners. The results of a study by Autry et al. indicated that managers perceived higher levels of environmental regulatory compliance when reverse logistics was carried out in-house rather than being outsourced. In Lieb et al., the results suggested that Western European managers outsourced to third-party logistics (3PL) providers because they perceived flexibility as a primary benefit, whereas U.S. manufacturers outsourced to 3PL providers to reduce and control costs, as well as to improve productivity and service. Both parties perceived that using third-party providers reduced costs, although Western European companies perceived this improvement to be more significant. The alignment of competitive priorities with the returns facility selection decision should be further developed and explored.

The fifth area of research could be in terms of management of collection centers. These centers should be attracted to work with the OEM and remanufacturers on a long term basis. This requires multi-period transactions between the OEM and the remanufacturers.The challenge would be to use similar concepts by incorporating obsolescence and fluctuating lead times in a RSC situation.

The sixth area of research could be research on the impact of uncertainty on reverse logistics network design, though investigated many different elements of uncertainty, lacks considerations of the element of risk and multiple objectives. Also, the comparison of heuristics algorithms solution methods is often ignored. There is a need of future models should consider a multi-objective model which takes multi-period, multi-commodity flow, capacitated and closed-loop network structure problem into account and there is a need for comparison of the proposed solution method with other heuristics, e.g., GA, ANN, Lagrangrian relaxation, tabu search and scatter search.

The seventh area of research could be development of stochastic models for reverse supply chain network applied more comprehensive models to cope with return and demand uncertainty in terms of quantity but they lack considerations of multi-level or multi-commodity models and other elements of uncertainty. Despite the call for more stochastic modeling by Sasikumar and Kannan [111], there is still limited research in this area.

To sum up, the development of closed loop supply chain conceptual and quantitative models is one of the most imperative research areas of reverse logistics research because of the need to address the uncertainty of supply and the dynamic interactions between forward and reverse flows. Our literature review updates and complements the literature reviews by Fleischmann et al. [112], Fleischmann [113], Carol et al. [110], Pokharel et al. [108] and Chanintrakul et al. [109]. Our review concludes that there have been a gradual increased of efforts in modeling of reverse supply chain/closed loop supply chain network but there is a need for incorporating more realistic and complicated assumptions in terms of time period, commodity-product flow, network level, open or close-loop structure, objective function, uncertainty type and other model constraints.

Acknowledgment

The authors would like to put on record appreciation to the anonymous referees for their valuable suggestions, which have enhanced the quality of the paper over its earlier version.

References

[1] Lee, D-H. and Dong, M. (2008) ‘heuristic approaches to logistics network design for end-of-lease computer products recovery’, Transportation Research Part E: Logistics and Transportation Review, Vol. 44, No. 3, pp.455–474.

[2] Fleischmann M, Bloemhof-Ruwaard JM, Dekker R, van der Laan E, van Nunen JAEE, van Wassenhove LN. Quantitative models for reverse logistics: a review. European Journal of Operational Research 1997; 103(1):1–17.

[3] Carter CR, Ellram LM. Reverse logistics: A review of the literature and framework for future investigation. Journal of Business Logistics 1998; 19(1):85–102.

[4] L.N. (2003) ‘Concurrent product and closed-loop supply chain design with an application to refrigerators’, International Journal of Production Research, Vol. 41, No. 16, pp.3689–3719.

[5] Realff, M.J., Ammons, J.C. and Newton, D.J. (2004) ‘Robust reverse production system design for carpet recycling’, IIE Transactions, Vol. 36, No. 8, pp.767–776.

[6] Fleischmann M, Krikke H, Dekker R, Flapper S. A characterization of logistics networks for product recovery. Omega 2000; 28:653–66.

[7] Fleischmann, M. (2003). ‘Reverse logistics network structures and design’, in V.D.R. Guide Jr. and L.N. Van Wassenhove (Eds.), Business Aspects of Closed-Loop Supply Chains: Exploring the Issues,

[8] Chanintrakul et.al(2009), ‘Reverse logistics network design: a state-of-the-art literature review’, International Journal of Business Performance and Supply Chain Modeling, Vol.1,issue1, pp.61-81Carnegie Mellon University Press, Pittsburgh, PA, Vol. 2, pp.117–148.

[9] Shaligram Pokharel, Akshay Mutha,(2009) ‘Perspectives in reverse logistics: A review’, Resources, Conservation and Recycling 53 (2009) 175–182

[10] Al-Mashari M, Zairi M., “Supply-chain re-engineering using enterprise resource planning (ERP) systems: an analysis of a SAP R/3 implementation case”. International Journal of Physical Distribution&LogisticsManagement 2000; 30(3–4):296–313.

[11] Gallivan M. Striking a balance between trust and control in a virtual organization: a content analysis of open source software case studies. Information Systems Journal 2001; 11(4):277–304.

[12] Byrd T, Davidson N. Examining possible antecedents of IT impact on the supply chain and its effect on firm performance. Information and Management 2003; 41(2):243–55.

[13] Ellinger A, Lynch D, Hansen J. Firm size, web site content, and financial performance in the transportation industry. Industrial Marketing Management 2003; 32(3):177–85.

[14] Min, H., Ko, H-J. and Ko, C.S. (2006a) ‘A genetic algorithm approach to developing the multiechelon reverse logistics network for product returns’, Omega, Vol. 34, No. 1, pp.56–69.

[15] Bloemhof-Ruwaard J, Fleischmann M, van Nunen J. Reviewing distribution issues in reverse logistics. In: Speranza MG, Stahly P, editors. New trends in distribution logistics. Springer–Verlag; 1999. p. 1999.

[16] Daugherty P, Richey R, Genchev S, Chen H. Reverse logistics: superior performance through focused resource commitments to information technology. Transportation Research Part E 2005; 41:77–92.

[17] Daugherty P, Richey R, Hudgens B, Autry C. Reverse Logistics in the Automobile Aftermarket Industry. International Journal of Logistics Management 2003; 14(1):49–62.

[18] Biehl, M., Prater, E. and Realff, M.J. (2007) 'Assessing performance and uncertainty in developing carpet reverse logistics systems', Computers & Operations Research, Vol. 34, No. 2, pp.443–463.

[19] Reimer, B., Sodhi, M.S. and Jayaraman, V., 2006, Truck Sizing Models for Recyclables Pick-up, Computers & Industrial Engineering Vol. 51 (4): 621–636, 2006.

[20] Min, H., Ko, H-J. and Ko, C.S. (2006a) 'A genetic algorithm approach to developing the multiechelon reverse logistics network for product returns', Omega, Vol. 34, No. 1, pp.56–69.

[21] Fleischmann M, Bloemhof-Ruwaard JM, Dekker R, van der Laan E, van Nunen JAEE, van Wassenhove LN. Quantitative models for reverse logistics: a review. European Journal of Operational Research 1997; 103(1):1–17.

[22] Bloemhof J, van Nunen J. Integration of environmental management and SCM. ERIM Report Series Research in Management 2005; ERS-2005-030-LIS.

[23] Fleischmann M, Beullens P, Bloemhof-Ruwaard JM, vanWassenhove LN. The impact of product recovery on logistics network design. Production and Operations Management 2001; 10(2):156–73.

[24] Jayaraman, V., Patterson, R.A. and Rolland, E. (2003) 'the design of reverse distribution networks: models and solution procedures', European Journal of Operational Research, Vol. 150, No. 1, pp.128–149.

[25] Piyawat Chanintrakul,Adrian E. Coronado Mondragon, Chandra Lalwani and Chee Yew Wong (2009) 'Reverse logistics network design: a state-of-the-art literature review', Int. J. Business Performance and Supply Chain Modeling, Vol. 1, No. 1, 2009 61

[26] De Koster M, de Brito M, van Vendel M. How to organize return handling: an exploratory study with nine retailer warehouses. International Journal of Retail and Distribution Management 2002; 30(8):407–21.

[27] Lu, Z. and Bostel, N. (2007) 'A facility location model for logistics systems including reverse flows: the case of remanufacturing activities', Computers & Operations Research, Vol. 34, No. 2, pp.299–323.

[28] Pohlen, T. L. and T. M. Farris (1992),"Reverse logistics in plastic recycling",International Journal of Physical Distribution and Logistics Management, Vol 22, No7, pp. 35-47

[29] Spengler, T., H. Puchert, T. Penkuhn, O. Rentz. 1997. Environmental integrated production and recycling management. Eur. J. Oper. Res. 97 308–326.

[30] Bayindir Z, Dekker R, Porras E. Determination of recovery effort for a probabilistic recovery system under various inventory control policies. Omega 2006; 34(6):571–84.

[31] LouwERs, D., B. J. Kip, E. PETERS, F. SOUREN, AND S. D. P. FLAPPER (1999), "A Facility Location Allocation Model for Re-Using Carpet Materials," Computers and Industrial Engineering, 36, 4, 855-869.

[32] Realff, M.J., Ammons, J.C. and Newton, D.J. (2004) 'Robust reverse production system design for carpet recycling', IIE Transactions, Vol. 36, No. 8, pp.767–776.

[33] Schultmann, F., M. Zumkeller, and O. Rentz. 2006. "Modeling reverse logistic taskswithin closed-loop supply chains: An example from the automotive industry,' European Journal of Operational Research", vol. 171, no. 3, pp. 1033-1050.

[34] Beamon, B.M. and Fernandes, C. (2004) 'Supply-chain network configuration for product recovery', Production Planning & Control, Vol. 15, No. 3, pp.270–281.

[35] Kusumastuti, R.D., Piplani, R., Lim, G.H., 2008. "Redesigning closed-loop service network at a computer manufacturer: a case study," International Journal of Production Economics, Special Issue on Sustainable Supply Chain Management, Vol. 111 (2), 244-260.

[36] Salema, M. I. G., Barbosa-Povoa, A. P., & Novais, A. Q. (2007). An optimization model for the design of a capacitated multi-product reverse logistics network with uncertainty, European Journal of Operational Research, 179, 1063–1077.

[37] Wojanowski, R., V. Verter and T. Boyaci, "Retail-Collection Network Design under Deposit-Refund", Computers & Operations Research, Vol. 34, No. 2, pp. 324-345, 2007.

[38] Zhou, L., Naim, M.M. and Wang, Y. (2007), "Soft systems analysis of reverse logistics battery recycling in China", International Journal of Logistics: Research and Applications, Vol.10, No.1, pp. 57-70.

[39] Kroon, L. and Vrijens, G., (1995), "Returnable containers: and example of reverse logistics", International Journal of Physical Distribution & Logistics Management, Vol.25, No., 2, pp. 56-68.

[40] Bergstrom RY. (1993), "An annotated essay: environmental affairs", Production, Vol.105 No. 4, pp.36–41.

[41] Min, H., Ko, H-J. and Ko, C.S. (2006a) 'A genetic algorithm approach to developing the multiechelon reverse logistics network for product returns', Omega, Vol. 34, No. 1, pp.56–69.

[42] Teunter, R.H., E.A. van der Laan, and K. Inderfurth (2000). "How to set the holding cost rates in average cost inventory models with reverse logistics", OMEGA the International Journal of Management Science 28:409-415, 2000

[43] Jayaraman, V., Guige, Jr. VDR., & Srivastava, R. (1999). A closed-loop logistics model for remanufacturing. Journal of the Operational Research Society. 50, 497–508.

[44] Pati, R.K., Vrat, P. and Kumar, P. (2008) 'A goal programming model for paper recycling system', Omega, Vol. 36, No. 3, pp.405–417.

[45] Walther and Spengler (2005) "Facility location planning for treatment of large household appliances in

Spain” International Journal of Environmental Technology and Management , Issue: Volume 8, Number 4 / 2008 Pages: 405 - 425

[46] V. Ravi, Ravi Shankar, and M. K. Tiwari, Selection of a reverse logistics project for end-of-life computers: ANP and goal programming approach, , International Journal of Production Research, 2007,

[47] Kara, S., Rugrungruang, F. and Kaebernick, H. (2007) ‘Simulation modeling of reverse logistics networks’, International Journal of Production Economics, Vol. 106, No. 1, pp.61–69.

[48] Fernandez I, Kekale T. The influence of modularity and clock speed on reverse logistics strategy: implications for the purchasing function. Journal of Purchasing and Supply Management 2005; 11:193–205.

[49] Krikke, H. R., van Harten, A., Schuur, P.C. (1999). "Business case Oce: Reverse logistic network re-design for copiers." OR Spektrum 21: 381-409.

[50] Krikke, H. 1998. Recovery strategies and reverse logistic network design. Ph.D. thesis, University of Twente, Enschede, The Netherlands.

[51] Du, F. and Evans, G.W. (2008) ‘A bi-objective reverse logistics network analysis for post-sale service’, Computers & Operations Research, Vol. 35, No. 8, pp.2617–2634.

[52] Fleischmann M, Krikke H, Dekker R, Flapper S. A characterization of logistics networks for product recovery. Omega 2000; 28:653–66.

[53] Kolbin, V.V. (1977) Stochastic programming, D. Reidel Publishing, Dordrecht. Krikke, H.R., Bloemhof-Ruwaard, J.M. and Van Wassenhove,

[54] Listes, O. (2002) ‘A decomposition approach to a stochastic model for supply-and-return network design’, (No. EI 2002-43), Working paper, Econometric Institute, Erasmus School of Economics, The Erasmus University Rotterdam, Rotterdam.

[55] Listes, O. (2007) ‘A generic stochastic model for supply-and-return network design’, Computers & Operations Research, Vol. 34, No. 2, pp.417–442.

[56] Listes, O. and Dekker, R. (2005) ‘A stochastic approach to a case study for product recovery network design’, European Journal of Operational Research, Vol. 160, No. 1, pp.268–287.

[57] Min, H., Ko, H-J. and Ko, C.S. (2006a) ‘A genetic algorithm approach to developing the multiechelon reverse logistics network for product returns’, Omega, Vol. 34, No. 1, pp.56–69.

[58] Min, H., Ko, C.S. and Ko, H-J. (2006b) ‘The spatial and temporal consolidation of returned products in a closed-loop supply chain network’, Computers & Industrial Engineering, Vol. 51, No. 2, pp.309–320.

[59] Min, H. and Ko, H-J. (2008) ‘The dynamic design of a reverse logistics network from the perspective of third-party logistics service providers’, International Journal of Production Economics, Vol. 113, No. 1, pp.176–192.

[60] De Brito, M.P. and Dekker, R. (2004) ‘A framework for reverse logistics’, in R. Dekker, M. Fleischmann, K. Inderfurth and L.N. Van Wassenhove (Eds.), Reverse Logistics: Quantitative Models for Closed-Loop Supply Chain, Springer, Berlin, pp.1–27.

[61] Nagurney, A. and Toyasaki, F. (2005) ‘Reverse supply chain management and electronic waste recycling: a multitiered network equilibrium framework for e-cycling’, Transportation Research Part E: Logistics and Transportation Review, Vol. 41, No. 1, pp.1–28.

[62] Chen, H-K., Chou, H-W. and Chiu, Y-C. (2007) ‘On the modeling and solution algorithm for the reverse logistics recycling flow equilibrium problem’, Transportation Research Part C: Emerging Technologies, Vol. 15, No. 4, pp.218–234.

[63] Hammond, D. and Beullens, P. (2007) ‘Closed-loop supply chain network equilibrium under legislation’, European Journal of Operational Research, Vol. 183, No. 2, pp.895–908.

[64] Biehl, M., Prater, E. and Realff, M.J. (2007) ‘Assessing performance and uncertainty in developing carpet reverse logistics systems’, Computers & Operations Research, Vol. 34, No. 2, pp.443–463.

[65] Kara, S., Rugrungruang, F. and Kaebernick, H. (2007) ‘Simulation modeling of reverse logistics networks’, International Journal of Production Economics, Vol. 106, No. 1, pp.61–69.

[66] Vollmann TE, Berry WL, Why bark DC, Jacobs FR. Manufacturing planning and control for supply chain management. New York, NY: McGraw-Hill Irwin Publishing;

[67] Guide V. Production planning and control for remanufacturing: industry practice and research needs. Journal of Operations Management 2000; 18:467–83.

[68] Thierry, M. S., M; Van Nunen, J.; Van Wassenhove, L. (1995). "Strategic issues in product recovery management." California Management Review 37(2): 114-135.

[69] Van der Laan E, Salomon M, Dekker R, van Wassenhave L. Inventory control in hybrid systems with remanufacturing. Management Science 1999; 45(5):733–47.

[70] Kelle, p. And silver, e. (1989a). Forecasting the returns of reusable containers. Journal of Operations Management, 8(1):17–35.

[71] Kelle, p. And silver, e. (1989b). Purchasing policy of new containers considering the random returns of previously issued containers. IIE Transactions, 21(4):349–354.

[72] Guide V, Srivastava R. Inventory buffers in recoverable manufacturing. Journal of Operations Management 1998; 16:551–68.

[73] Toktay, L.B. and L.M.Wein, S.A. Zenios. 2000. Inventory Management of Remanufacturable Products. Management Science 46 (11) 1412-1426.

[74] Guide Jr. VDR. Production planning and control for remanufacturing: industry practice and research needs.

[75] Jayaraman, V., V. D. R. Guide, Jr., R. Srivastava. 1999. A closed-loop logistics model for remanufacturing. J. Oper. Res. Soc. 50 497–508

[76] Jayaraman, V., R. A. Patterson, E. Rolland. 2003. The design of reverse distribution networks: Models and solution procedures. Eur. J. Oper. Res. 150 128–149

[77] Rogers, D. S., R. Tibben-Lembke. 1999. Going Backwards: Reverse Logistics Trends and Practices. Reverse Logistics Executive Council, Reno, NV.

[78] Kibum Kim,Iksoo Song, Juyong Kim, Bongju Jeong.Supply planning model for remanufacturing system in reverse logistics environment. Computers & Industrial Engineering, 51 (2006), p279~287.

[79] Fleischmann, M., Bloemhof-Ruwaard, J.M., Beullens, P. and Dekker, R. (2004) 'Reverse logistics network design', in R. Dekker, M. Fleischmann, K. Inderfurth and L.N. Van Wassenhove (Eds.), Reverse Logistics: Quantitative Models for Closed-Loop Supply Chain, Springer, Berlin, pp.65–94.

[80] Minner S, G. Lindner (2003): Lot sizing in product recovery decisions, in: Dekker R., M.

[81] Fleischmann, K. Inderfurth, and L. van Wassenhove (eds.), Reverse Logistics. Quantitative Models for Closed- Loop Supply Chains, Springer, Berlin, 157–179.

[82] Fleischmann M, van Nunen J, Grave B. Integrating closed-loop supply chains and spare-parts management at IBM. Interfaces 2003; 33(6):44–56.

[83] Toktay, B., Wein, L., Stefanos, Z., 2000. Inventory management of remanufacturable products. Management Science 46, 1412-1426.

[84] Van Hoek R. and Erasms I. (2000), "From reversed logistics to green supply chains", Logistics Solutions Issue, Vol. 2, pp. 28-33.

[85] Enterprise information system project selection with regard to BOCR. International Journal of Project Management. Liang and Li, 2007.

[86] Majumder P, Groenevelt H. Competition in remanufacturing. Production and Operations Management 2001; 10(2):125–41.

[87] Debo L, Toktay B, van Wassenhove L. Market segmentation and product technology selection for remanufacturable products. Management Science 2005; 51(8):1193–205.

[88] Ferrer G, Swaminathan J. Managing newand remanufactured products. Management Science 2006; 52(1):15–26.

[89] Webster, Scott, and Supriya Mitra (2007) .Competitive strategy in remanufacturing and the Impact of take-back laws. Journal of Operations Management 25, 1123.1140

[90] Ferguson M, Toktay B. The effect of competition on recovery strategies. Production and Operations Management 2006; 15(3):351–68.

[91] Bayindir Z, Dekker R, Porras E. Determination of recovery effort for a probabilistic recovery system under various inventory control policies. Omega 2006; 34(6):571–84.

[92] Shrivastava, P. (1995), "Environmental technologies and competitive advantage", Strategic Management Journal, Vol.16 (Special issue, Summer), pp. 183–200

[93] Autry C, Daugherty P, Richey R. The challenge of reverse logistics in catalog retailing. International Journal of Physical Distribution and Logistics Management 2000; 31(1):26–37.

[94] Ayres R, Ferrer G, van Leynseele T. Eco-efficiency, asset recovery and remanufacturing. European Management Journal 1997; 15(5):557–74.

[95] Bakal I, Akcali E. Effects of random yield in reverse supply chains with price sensitive supply and demand. Production and Operations Management 2006; 15(3):407–20.

[96] Chouinard M, D'Amours S, Ait-Kadi D. Integration of reverse logistics activities within a supply chain information system. Computers in Industry 2005; 56:105–24.

[97] Daugherty P, Richey R, Hudgens B, Autry C. Reverse Logistics in the Automobile Aftermarket Industry. International Journal of Logistics Management 2003; 14(1):49–62.

[98] Fuller J, O'Conor J, Rawlinson R. Tailored logistics: the next advantage. Harvard Business Review 1993; 71:87–98.

[99] Trebilcock, B., (2002), "Warehouses unplugged", Logistics management and distribution report, Vol. 41, No. 2, pp. 51-54.

[100] Amini M, Retzalff-Roberts D. Reverse logistics process reengineering: improving customer service quality. Issues in Supply Chain Management 1999; 5(1):31–41.

[101] Sarkis J. (2003), "A strategic decision framework for green supply chain management", Journal of Cleaner Production, Vol. 11, pp. 397-409.

[102] Maloney, D., (1999), " The power of returnable containers", Modern Materials Handling, Vol. 54, No. 8, pp. 53-55.

[103] Wise, R., and Baumgartner, P. 1999. Go Downstream: the New Profit Imperative in Manufacturing. Harvard Business Review: 133-141.

[104] Guide V, Kraus M, Srivastava R. Product structure complexity and scheduling of operations in recoverable manufacturing. International Journal of Production Research 1997a; 35:3179–99.

[105] Guide V, van Wassenhove L. Managing product returns for remanufacturing. Production and Operations Management 2001; 16(2):142–55.

[106] Ferrer G, Why bark C. Material planning for a remanufacturing facility. Production and Operations Management 2001; 10:112–24.

[107] Choi T, Li D, Yan H. Optimal returns policy for supply chain with e-marketplace. International Journal of Production Economics 2004; 88(2):205–27.

[108] Shaligram Pokharel, Akshay Kiran Mutha, 2009, Perspectives in reverse logistics: A review, Journal of Resources, Conservation and Recycling, 53(4):175-182.

[109] Chanintrakul, P., Mondragon, A.E.C., Lalwani, C., Wong, C.Y., 2009. Reverse logisticsnetwork design: a state-of-the-art literature review. International Journal of Business Performance and Supply Chain Modeling 1, 61–81.

[110] Carol Prahinskia and, Canan Kocabasoglub (2006), Empirical research opportunities in reverse supply chains. Omega 34 (2006) 519 – 532

[111] G.Kannan, P. Sasikumar and S. Narendran (2008) Comments on the erratum to The spatial and temporal consolidation of returned products in a closed-loop supply chain network , Computers & Industrial Engineering, Vol. 54, No. 4, pp. 1087-1090.

[112] Fleischmann M, Krikke H, Dekker R, Flapper S. A characterization of logistics networks for product recovery. Omega 2000; 28:653–66.

[113] Fleischmann M, van Nunen J, Grave B. Integrating closed-loop supply chains and spare-parts management at IBM. Interfaces 2003; 33(6):44–56.

Appendix 1

Table 1 Summary of Reviewed Papers Based on Reverse Supply Chain Design.

References	Model	Solution methodology	Period	Commodity flow	Level	RL Structure	Model objectives	Constraints	issues	Recovery option
Mutha et al. (2009)	MILP	Sim	M	M	M	OL	M	MC	MI	M
Lee and Dong (2008)	MILP	HE	S	S	T	CL	M	SC	MI	S
Pati et al. (2008)	MILP	EX	S	M	M	OL	M	SC	MI	S
Srivastva (2008)	MILP	EX	M	M	M	OL	M	SC	MI	S
Biehl et al. (2007)	MILP	HE	S	S	T	CL	M	SC	MI	S
Lieckens and Vandaele (2007)	MINLP	HE	S	S	S	OL	M	SC	MI	S
Ko and Evans (2007)	MINLP	HE	M	M	T	CL	M	SC	MI	S
Lu and Bostal (2007)	MILP	HE	S	S	T	CL	M	SC	MI	S
Salema et al. (2007)	MILP	EX	S	M	M	CL	M	SC	MI	S
Lieckens and Vandaele (2007)	MINLP	HE	S	S	S	OL	M	SC	MI	S
Boyaci et al. (2007)	MILP	HE	S	S	T	CL	M	SC	MI	S
Wang et al. (2007)	MINLP	HE	S	S	S	OL	M	SC	MI	S
Salema et al. (2006)	MILP	EX	S	M	T	CL	M	SC	MI	S
Jayaraman et al. (2006)	MILP	EX	S	M	M	CL	M	SC	MI	S
Min, et al.(2006b)	MINLP	HE	S	S	S	OL	M	SC	MI	S
Rentz et al. (2006)	MILP	HE	S	S	T	CL	M	SC	MI	S
Seliger et al.(2006)	MILP	Sim	M	M	M	OL	M	MC	MI	M
Hwang, et al. (2005)	MILP	EX	S	M	M	CL	M	SC	MI	S
Fernandez and Kekale (2005)	MILP	EX	S	M	M	CL	M	SC	MI	S
Piplani et al(2004)	MILP	EX	S	M	M	CL	M	SC	MI	S
Beamon and Fernandes (2004)	MILP	EX	S	M	M	CL	M	SC	MI	S
Jayaramanet al(2003)	MILP	HE	S	S					MI	S
Bloemhof et al (2001)	MILP	EX	S	M					MI	S
Fleischmann et al (2001)	MILP	EX	S	S					SI	