

A closed loop supply chain network design problem with multiple recovery options

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Introduction

Supply chain network design (SCND) is a challenging strategic issue for any company since it involves long-term decisions and high capital investment (see e.g. (Owen & Daskin, 1998) and (Melo, et al., 2009) for an overview of network design and facility location literature). Classical SCND problems include only forward flows, i.e. flows from suppliers to end customers. However, nowadays, many companies have to manage reverse flows of end-of-use products, containers, packages, etc. that move in the opposite direction of the traditional flows. Returns collected from customers may be directed in different ways depending on their quality and the possibility of reusing them. One of the most used recovery options is recycling, which is beneficial if different component materials (e.g. precious metal, steel, aluminum, plastic, etc.) can be separated and reused at a reasonable cost and without environmental harm. Another recovery option is to resell the returned products to secondary markets, if the items are still in good condition and if an active secondary market for used equipment exists. Another value-added operation, which can generate profit from returned products is remanufacturing. Remanufacturing processes include disassembly, cleaning, repairing, replacing parts and reassembly. Finally, if it is not possible to regain value from returned products, companies should dispose of them in a way to reduce harm to the environment.

Literature review

The integration of reverse flows in SCND led to the development of two types of problems: a- reverse logistics (RL) network design problems that aim at locating reverse facilities such as collection and sorting centers and b- closed loop supply chain (CLSC) network design problems, which consider both forward and reverse flows in a same network and decide of the location of both distribution and collection facilities. The readers are referred to (Akçali, et al., 2009) and (Govindan, et al., 2015) for recent reviews on RL and CLSC network design models and related solution approaches. Many of the previous works have assumed that the input parameters of the problem are known with certainty (see e.g. (Easwaran & Üster, 2010)). Other works have considered the uncertainty of customer demand and return rates (see e.g. (Listes, 2007), (El-Sayed, et al., 2010) and (Francas & Minner, 2009)) or prices and costs (see e.g. (Salema, et al., 2007) and (Ramezani, et al., 2013)). Another criterion for classifying the existing literature is the number of recovery options

taken into account in the model. For instance, (Easwaran & Üster, 2010) considered only remanufacturing in their CLSC network design model, where all collected returns are directed to remanufacturing plants, before being reintegrated into the forward channel. (Salema, et al., 2006) studied the network of an office document company located in Spain, where collected papers are returned to production plants to be remanufactured. The authors considered also the possibility of product disposal at disassembly centers. Other papers such as (Yongsheng & Shouyang, 2008), (Soleimani, et al., 2013) and (Alumur, et al., 2012) considered multiple recovery options for the products returned by customers. (Yongsheng & Shouyang, 2008) modeled a CLSC network where returns can be either remanufactured or reinserted in the market after a repair step. The authors compared costs when only the remanufacturing option is considered and when both repair and remanufacturing options are taken into account. (Soleimani, et al., 2013) combined recycling, repair and remanufacturing in a same model where revenues and disposal rates are predetermined. (Alumur, et al., 2012) modeled a multi-stage RL network design problem where the decision maker can decide the amount of products to be recycled, remanufactured or sold to secondary markets, given the revenue from each option.

Although the research on RL and CLSC network design has attracted the attention of a growing number of researchers in the past decade, only a few papers have integrated different recovery alternatives to deal with returned products. The consideration of different recovery alternatives would improve the practical relevancy of RL and CLSC network design models as in real life, the quality of returns might vary significantly. Furthermore, most of the existing literature in this field have assumed known and certain input parameters, while only 25% of the previous papers have studied models that include uncertainties (Govindan, et al., 2015). Demand and return rates are the most considerable uncertain parameters and only a few papers have included the uncertainty of other factors such as prices and costs. In real life, companies might face, however, high uncertainties in demand, return rates, returned products' quality, revenues, prices and costs, at the same time. This should be taken into account when making the strategic decisions of forward and reverse center location. Therefore, we propose in the present work to overcome these limitations of the existing literature by developing a new mixed integer linear programming model, which integrates different possible options for product recovery and considers the uncertainty of various parameters. The network that we study includes hybrid manufacturing/remanufacturing facilities, dedicated distribution and collection centers as well as hybrid collection/distribution centers. It manages forward flows from manufacturing sites to customers as well as reverse flows collected from customers (see Figure 1). Reverse flows are shipped to collection centers where they are sorted, then processed to one of the possible recovery options, which are remanufacturing, reselling to a secondary market, recycling or disposal. The objective of the proposed model is to determine the best locations for collection/distribution centers in a way to maximize the total profit of the company.

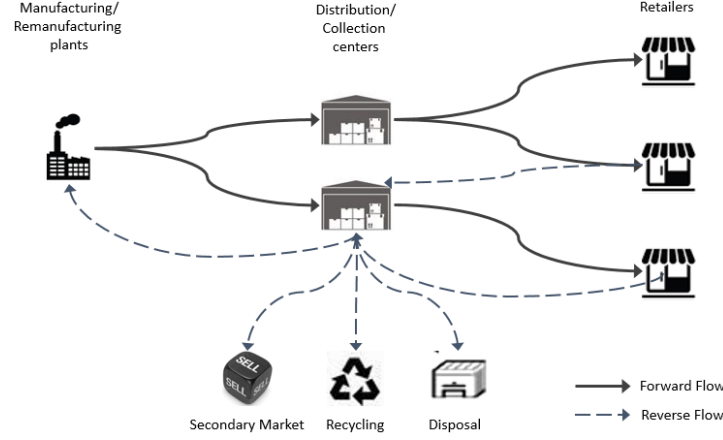


Figure 1: Structure of the CLSC network

Major findings and practical implications

In the first part of our numerical experiments, we carry out an extensive sensitivity analysis using the deterministic version of the model and realistic input data. We study the impact of the input parameters' variation on the network structure, the reverse service level (proportion of honored returns) and the overall profit. The computational experiments show how the presence of penalties over non-collected returns affects the location decisions and the reverse service level. In many of our tests, the high reverse service level observed is not due to the high profitability of the reverse business but is only due to the penalties incurred in case the required returns are not satisfied. Furthermore, when the target return rate (expressed as a proportion of forward demand) increases, the number of dedicated collection centers (CC), the reverse service level as well as the overall profit increase, even in the case where the penalty is set to zero. This first observation shows that the reverse business becomes more profitable when the quantity of returns made by customers is higher. On the other hand, the sources of profit in the reverse business considered relate to remanufacturing opportunities as well as to recycling and sales to the secondary market. Therefore, we study the impact of varying the related parameters. The results show that when the remanufacturing cost does not exceed a given proportion of the manufacturing cost, all the return requests are honored (i.e. reverse service level at 100%) both in the case with penalty and without penalty. This suggests that up to this limit, the reverse business remains profitable. Above this limit, the reverse service level decreases when the remanufacturing cost increases until reaching 0%. Similar conclusions hold for revenues from recycling and secondary markets. Under a given limit, the overall profit and reverse service level start decreasing when the revenues decrease, until reaching 0%. Thus, a limit of profitability of the reverse business can be defined for each of the studied parameters, by considering the value for which the reverse service level reaches 0%. The numerical experiments also highlight the sensitivity of the model output to the proportion allocated to each recovery option. Different values from 0 to 1 are tested in order to observe the changes in the profit, reverse service level and network structure. This sensitivity suggests a further analysis using a stochastic setting.

In the second part of the numerical experiments, we develop a two-stage stochastic program considering the uncertainty of return rates, remanufacturing costs, revenues as well as the proportions of returns to be allocated to each recovery option. The latter type of uncertainty accounts for the uncertainty of returned products' quality. Locations of distribution and collection centers are considered as first stage decisions while forward and return flows are considered as second stage decisions, i.e. made after a certain scenario of the problem parameters is realized. We conduct a scenario-based analysis to illustrate the impact of uncertainty on expected revenues and to measure the value of the stochastic model (VSS). Using different replications of randomly generated scenarios (we used 120 scenarios), we show that the stochastic solution is stable in terms of profit and network structure. The VSS is strictly positive in all the tests and shows an increase when the penalty over non-collected returns increases. In other words, the benefit of using a stochastic model instead of a deterministic counterpart is higher when there is more obligation for product recovery (for instance because of strict legislation).

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