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A carbon footprint-based closed-loop supply chain model under uncertainty with risk analysis: A case study

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ABSTRACT

The management of products' end-of-life and the recovery of used products has gained significant importance in recent years. In this paper, we address the carbon footprint-based problem that arises in a closed-loop supply chain where returned products are collected from customers. These returned products can either be disposed of or be remanufactured to be resold as new ones. Given this environment, an optimization model for a closed-loop supply chain (CLSC) in which carbon emission is expressed in terms of environmental constraints, i.e., carbon emission constraints, is developed. These constraints aim to limit the carbon emission per unit of product supplied with different transportation modes. Here, we design a closed-loop network where capacity limits, single-item management and uncertainty on product demands and returns are considered. First, fuzzy mathematical programming is introduced for uncertain modeling. Then, the statistical approach to the possibility to synthesize fuzzy information is utilized. Therefore, using a defined possibilistic mean and variance, we transform the proposed fuzzy mathematical model into a crisp form to facilitate efficient computation and analysis. Finally, the risk caused by violating the estimated resource constraints is analyzed so that decision makers (DMs) can trade off between the expected cost savings and the expected risk. We utilize data from a company located in Iran.

Introduction

Currently, due to the existence of a competitive global market, it is necessary for enterprises to work together to enhance their adaptive ability and viability in the market, which will help them achieve common goals such as minimizing the total costs and the delay of deliveries in the whole chain (Fazlollahtabar et al., 2013; Roy et al., 2004; Li et al., 2008). Three main flows exist in the chain: the material flow, the information flow, and the fund flow. The coordination and integration of these flows across enterprises is called supply chain management (SCM) (Fazlollahtabar et al., 2012). Production and all aspects of logistics, such as transportation, warehousing and inventories, have created large environmental problems, such as global warming and climate changes (Dekkera et al., 2012). The Department of the Environment, Transport and the Regions (DETR; formed by the combination of the Department of the Environment and Department of Transport in 1997 by the Secretary of State for the Environment (UK cabinet position)) found that CO_2 is present in the atmosphere in significant quantities,

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estimating that among greenhouse gases, it accounts for two thirds of global warming (Department for Transport, 2000). The integration of the SCM concept with the issue of environmental protection confirms the sharp decline in pollution problems (Wang and Gupta, 2011). Research on this approach has received considerable attention recently and has led to the creation of a new research agenda: green supply chain management (GSCM). Most current research on GSCM has had a tendency to focus on reverse logistics and closed-loop supply chains, such as the studies conducted by Blumberg (2005) and Pochampally et al. (2009). In reverse logistics/closed-loop supply chain (CLSC) systems, a product returns to the manufacturer after use and can be repaired or remanufactured to be delivered again to the end consumers. With well-managed reverse logistics, environmental protection can be achieved by minimizing the total costs in the whole closed-loop supply chain. Most previous studies have focused on reverse logistics and only formulated models corresponding to this field. Some researchers have presented closed-loop models, but they have not considered the relation between forward and reverse flows in their proposed models (Fleischmann et al., 2001; Salema et al., 2007; Uster et al., 2007). These models often assume the unlimited capacities for the reverse logistics, which is not a valid assumption for representing real situations. In real-life situations, the distribution center (DC) also plays a role as a collector in a recovery system. Therefore, the capacity of the DC is restricted to both distribution and collection. The closed-loop supply chain is characterized by these interactions. With the lack of such relations, the model can be separated into two parts independently and become a supply chain that includes forward and reverse chains but not a loop.

A few studies proposed closed-loop models with realistic assumptions (Mohajeri and Fallah, 2014). The authors of these studies proposed a comprehensive closed-loop model with crisp parameters for logistics planning considering profitability and ecological goals. They achieved the ecological goal of reducing the overall amount of CO_2 emitted from journeys.

Closed-loop supply chain networks naturally work in an uncertain and dynamic environment due to the demand, land filling and recovery rates (Wang and Hsu, 2010a). Indeed, inaccurate forecasts of these parameters cause increases in various types of financial risks and in the risks related to the collection and recovery amounts. Thus, risk management has an important role in controlling the uncertainty level in optimization problems (Subulan et al., in press). To cope with uncertainties, various dynamic, probabilistic and stochastic programming approaches have been developed by relatively few researchers (Fahimnia et al., 2013). Wang and Hsu (2010a) highlighted that appropriate models that aim to handle the uncertainty in CLSCs are still lacking.

Pishvaee et al. (2010b) developed a stochastic programming model for a CLSC network design using a scenario-based stochastic approach. They considered demands, the quantity and quality of returns and the variable costs as uncertain parameters. El-Sayed et al. (2010) developed a multi-period, multi-echelon and multi-stage stochastic program for an integrated forward-reverse logistics network design while assuming the demands of customer zones to be stochastic. Because of the some disadvantages of stochastic programming, such as the difficulty related to the availability of historical data in most real-case problems and complex modeling, fuzzy set theory can be used as an alternative framework to model the uncertain parameters based on managerial judgments and experimental data (Pishvaee and Torabi, 2010; Zhao et al., 2012). Subulan et al. (2012) developed a fuzzy mixed integer programming model with non-linear constraints for medium-term planning in a CLSC with a remanufacturing option. Pishvaee and Razmi (2012) developed a multi-objective possibilistic mixed integer programming model for an environmental supply chain network design. They used a possibilistic programming approach to handle imprecise parameters such as lower-cost items, demands, return quantities and the facilities' capacities.

In this study, we construct a closed-loop supply chain network design (CLSCND) that is more applicable in real-world problems. First, based on the best mechanism to reduce carbon emissions from freight transport concluded in Mohajeri and Fallah (2014), we optimize the proposed closed-loop model in an uncertain situation. Due to the capability of fuzzy presentation to engage uncertain factors, fuzzy numbers are used to describe these uncertain factors. Thus, the proposed fuzzy closed-loop model is configured.

Second, applying the statistical approach to possibility, we find a way to synthesize fuzzy information. In the framework of fuzzy programming, the possibilistic mean and variance are formulated to transform the proposed fuzzy closed-loop model into a crisp form to facilitate efficient computation and analysis. Thus, the proposed interval closed-loop model is configured in this phase.

Third, given this uncertain environment, we find that the development of a decision-support procedure is essential for actual management practice. Therefore, the decision maker's (DM) preference is taken into account in the proposed interval model formulation. Thus, the proposed preference closed-loop model is configured.

Finally, with the definition of expected risk of resource utilization though the defined parameter θ, a trade-off mechanism is developed to allow DMs to evaluate the expected cost and the expected risk.

To our knowledge, this study is the first in which the closed-loop SCND problem under uncertainty decides on the emission of carbon. The remainder of the paper is organized as follows. In Section "Literature review", the literature of closed-loop supply chain problems is reviewed. The problem description is presented in Section "Problem description". The methodology, including the procedure to transform the fuzzy numbers into crisp numbers, is fully explained and justified in Section "Methodology". In Section "The proposed closed-loop modeling for uncertain logistics", a mathematical programming model of the green supply chain logistics in an uncertain situation is developed. In Section "A case study", the case study of an uncertain GSC to illustrate the effectiveness of the proposed model and the risk analysis is given. Finally, Section "Conclusion" concludes the paper and proposes future research.