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A fuzzy multi-objective optimization model for sustainable reverse logistics network design

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ABSTRACT

Decreasing the environmental impact, increasing the degree of social responsibility, and considering the economic motivations of organizations are three significant features in designing a reverse logistics network under sustainability respects. Developing a model, which can simultaneously consider these environmental, social, and economic aspects and their indicators, is an important problem for both researchers and practitioners. In this paper, we try to address this comprehensive approach by using indicators for measurement of aforementioned aspects and by applying fuzzy mathematical programming to design a multi-echelon multi-period multi-objective model for a sustainable reverse logistics network. To reflect all aspects of sustainability, we try to minimize the present value of costs, as well as environmental impacts, and optimize the social responsibility as objective functions of the model. In order to deal with uncertain parameters, fuzzy mathematical programming is used, and to obtain solutions on Pareto front, a customized multi-objective particle swarm optimization (MOPSO) algorithm is applied. The validity of the proposed solution procedure has been analyzed in small and large size test problems based on four comparison metrics and computational time using analysis of variance. Finally, in order to indicate the applicability of the suggested model and the practicality of the proposed solution procedure, the model has been implemented in a medical syringe recycling system. The results reveal that the suggested MOPSO algorithm overtakes epsilon-constraint method from the aspects of quality of the solutions as well as computational time. Proper use of the proposed process could help managers efficiently manage the flow of recycled products with regard to environmental and social considerations, and the process offers a sustainable competitive advantage to corporations.

1. Introduction

Reverse logistics (RL) is one of the significant areas discussed in subjects related to logistics and management of supply chain in various industries. Because of the great effects on customer relationships, reverse logistics and logistics related to operational capabilities should be regarded as a managerial priority (Liu, 2014; Bouzon et al., 2016). RL is a general term that covers a wide area, including all operations related to re-using of goods and materials. The efficient management of these operations can improve the system of distribution and collection of goods and materials. Generally, the aim of RL is to manage reverse currents; that is, the backward currents in the supply chain (Álvarez et al., 2007). RL includes all logistical activities that are related to resource reduction, recycling, replacing, re-using the materials, and dissolving the wastes (Stock, 1992).

Over the past decade, companies have been challenged with the complicated issues of customer returns; accordingly, RL developed much more as a set of models and techniques to manage these issues. The rapid growth of RL activities has heightened the levels of social and environmental degradation (Henriques and Sadorsky, 1996) and, consequently, has drawn the attention of academic researchers and industrial practitioners to find a solution for these problems.

One of the most important objectives facing the researchers is to design a RL network that can minimize the costs, and simultaneously can consider green and social issues. Incorporation of green strategies and sustainability in logistics can be the keys to address these problems (Murphy and Poist, 2000). In a broader vision, in addition to providing green products and services for customers, green logistics (GL) considers the overall logistics of an item's flow.

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In other words, not only do the entities in the supply chain have to be green in their own logistics operations, but also they have to cooperate with each other with regard to green considerations. In this approach, RL is a primary issue of GL, and cannot be designed by simply considering economic aspects. Hence, in a sustainable way, environmental factors have to be considered as well (Zhou et al., 2000; Björklund et al., 2012; Hervani et al., 2005; Zhang et al., 2015). In addition, companies must care about their social responsibility. This implies that companies, besides making profit, have to think about conformity with legal necessities, ethical principles, and esteem for people and communities in all of their activities (Pai et al., 2015).

Thus, the term sustainability is used when environmental and social factors are taken into account in addition to economic aspects. Seuring and Muller (2008) defined sustainability as "the designing and employing human systems as well as industrial systems in order to use natural resources and to make sure that the normal cycles do not reduce the quality of life and future economic opportunities and also do not have any negative impact on social conditions, human health, and ecosystem." Every company and their individuals need to develop themselves with regard to the health and safety of all creatures, to a cleaner environment, and help to ensure a safe and balanced society (Kotzee and Reyers, 2016).

Today's companies take a range of different approaches in their pursuit of sustainability as they attempt to make their supply chains more responsive to the environment and society. Effective RL programs have great potential in helping them attain these goals, because sustainability and RL are interconnected. Hence, designing the supply chains with optimized RL can help them enhance resource recovery, reduce returns, integrate shipments, and adjust transportation administration (Lee and Lam, 2012).

Many researchers trying to explore the relationships linking sustainability and green supply chain in RL (Govindan, 2015; Rostamzadeh et al., 2015). Most of the previous research has focused on social and green issues through closed-loop supply chain, but integrating RL in the design of green and sustainable supply chains has rarely been considered (Govindan et al., 2015a,b,c, 2016; Govindan and Cheng, 2015). In a quantitative approach, this integration can be done by adding some decision variables, objective functions, and constraints into mathematical models (Govindan et al., 2015b; Soleimani and Govindan, 2015). Therefore, the contribution of this paper is to integrate the green and sustainability issues in RL. In this study, a sustainable reverse logistics network design (SRLND) is presented. The minimization of the present value of costs, the minimization of environmental impacts, and the maximization of social responsibility are the objective functions to consider the three aspects of sustainability. Social responsibility is considered as increasing the career opportunities and reducing harms at work. In order to minimize the environmental impacts, the eco-indicator 99 methodology is used, which is a way for estimating the environmental impacts of a supply chain network (Pishvaee and Razmi, 2012; Pishvaee et al., 2012).

Network design problems are classified as NP-Hard problems and the duration of the solution process is increased exponentially according to the size of the problem (Aras et al., 2008; Fattahi et al., 2015). Consequently, the problem of multi-objective RL network design is an NP-Hard problem. In order to solve this problem in an acceptable length of time, meta-heuristic algorithms should be used. The result of solving the multi-objective RL network design problem with a meta-heuristic algorithm is the production of non-dominated Pareto optimal solutions for decision-makers. By using meta-heuristic algorithms, all possible solutions for the problem are obtained and the decision-makers can make their final decision based on comparison metrics and comprehensive data.

The rest of this paper is organized as follows. In Section 2, the literature in this area of research is reviewed. In Section 3, the problem is defined and the model is formulated. In Section 4, the solving methodology and comparison metrics are discussed. Section 5 is dedicated to experimental results. Finally, in Section 6, the conclusions are presented and suggestions for future research are provided.

2. Literature review

In this paper, we attempt to propose a model for a RL network design problem, regarding green and sustainability issues and use a meta-heuristic algorithm to solve the model. Consequently, the focus of the literature survey in this study is subdivided into three sections: (1) RL mathematical models for supply chain (SC); (2) Green and sustainable RL and SC; and (3) The applications of meta-heuristic algorithms in RL and SC.

2.1. RL mathematical models for supply chain

In this section, some RL mathematical models for SC and the solving methodologies have been reviewed. Fleischmann et al. (1997) did one of the first studies on various characteristics and improvements in RL system. They separated the subject into three major parts: production management, inventory management, and distribution management. Then they elaborated on the implications of re-using efforts per each part, studied the models suggested in the previous researches, and offered several suggestions for future researchers. Minner (2001) mixed internal and external product returns and their improvement with the problem of certainty inventory control in the SC. He then solved the problem by a concave minimum optimization method and stated that the re-using of products creates the surplus inventory. He concluded that when the complete concurrence among various supply conditions is expensive (considering the characteristics of SC in terms of processing time, level of services, and inventory costs), the creation of surplus inventory is inevitable.

In solving the problem of reverse logistics recycling balance, Chen (2012) mainly focused on the balance in conditions that the prices of the market and recycling flows have interactive effects and the flows of input and output recycled materials in the SC are not balanced. Lee and Chan (2009) offered an RL network based on radio frequency identification (RFID) technology. Their aim was to find a model for the optimization of product output. They suggested that RFID could be used for the counting of stored items in storage points and for sending signals to the returning center. Das and Chowdhury (2012) offered a recycling, logistics model for various electronic product wastes in order to minimize the overall processing costs. Their model consisted of four recycling phases: collection, separation, recycling, and repair. The final site included a dumping point, primary market, and secondary market. They found that the transportation costs constitute a major part of recycling costs. Therefore, they concluded that the reduction of transportation costs is the best way to reduce the overall costs of the system.

Nikolaou et al. (2013) presented a combinatorial model for the social responsibility of companies and sustainability in the RL system on the basis of a complete operational framework. Their framework included combinatory mathematical indices for the evaluation of social responsibility in RL. Their work can enhance the companies' performance in social responsibility throughout reverse logistics processes. Ramezani et al. (2013) developed a model to design a forward and reverse asymmetric logistics system. They suggested a process for optimizing the quality, profit, and customer responsiveness as the objective functions in their model.

Suyabatmaz et al. (2014) presented two modeling methods for the stochastic RL system design to handle the uncertainties in the problem. One addressed the design of a distribution network and another considered the development of a generic