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Fuzzy multi-objective sustainable and green closed-loop supply chain network design

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ABSTRACT

This article addresses a design problem of a closed loop supply chain, including suppliers, manufacturers, distribution centers, customers, warehouse centers, return centers, and recycling centers. The problem entails three choices regarding recycling, namely, product recycling, and components recycling raw material recycling. Modeling this chain is carried out by accounting for environmental considerations, total profit optimization, and reduction of lost working days due to occupational accidents, we well as maximizing responsiveness to customer demand. In order to solve the model, genetic algorithm has been used and multiple scenarios with different aspects have been studied. Solving this model provides decisions regarding opening or closing of each of the components of the network and the optimal product flow among them. The results prove the feasibility of the presented model and the applicability of the developed solution methodology.

1. Introduction

In recent years, due to governmental regulations as well as the ever-increasing attention to environmental impacts and preserving natural resources, reverse logistics and closed loop supply chains have come to the forefront of agendas by researchers and decision-makers. A classic or forward (progressive) supply chain consists of a network of suppliers, manufacturers, and distributors that is formed to produce and deliver a specific product or service. Reverse logistics involves all the matters related to collecting the used products, controlling and collecting them, as well as recycling, reprocessing, refurbishing, and disposing of them. If both forward and reverse supply chains are considered simultaneously, the resulting network is referred to as closed loop supply chain (Govindan, Soleimani, & Kannan, 2015). These concepts guide organizations to make conscious decisions on their products – whether they have reached their end-of-life or have been used – to either recycle or dismount them. In order to design such a chain, it is necessary for the organization to plan for the design of their reverse logistics network as well as their forward supply chains. Also, the increase of the attention to the environmental and societal outcomes has led to the coining of concepts such as green and sustainable supply chains.

In various industries, as well as in academic publications, as conventional selection criteria, an acceptable trade-off between cost and quality have been proposed and considered among suppliers. The mere means by which firms can stand out from the competition is to reduce operational costs and to improve the quality of services while taking into account the economic and social matters related to their respective supply chains (Özkır & Başlıgil, 2013). This also highlights the need for organizations to designing a sustainable close loop supply chain network to increase their overall competitive advantage. According to the new definition, a closed loop supply chain entails the design, control, and implementing of a system to maximize value creation in the lifetime of a product, with a dynamic value generation from different returned products over time (Govindan et al., 2015).

A green supply chain is a supply chain in which environmental considerations have been addressed during its design. For instance, new raw materials would have higher prices if their manufacturing process has lower energy consumption. Recycled materials would have lower buying price while their processing has higher energy consumption (Su, 2014). Implementing sustainable supply chain management is a key enabler that pressures organizations to reduce their negative environmental impacts, and results in increased social and economic benefits (Zailani, Jeyaraman, Vengadasan, & Premkumar, 2012). Also, the reduction of the destructive environmental impacts should be considered as an aim in the supply chain. The CO_2 emission indicator is widely used

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to quantitatively identify the environmental impacts, and could be used in modeling supply chains. Several other indicators are also considered in studying the environmental impacts, including the amount of energy consumption, solid waste, water consumption, and water waste. These indicators are analyzed in an article by Ahi and Searcy (2015).

The social responsibility of firms has also various dimensions. The dimensions are categorized by the International Standardization Organization (ISO) in ISO26000 into six major groups, including human rights, workforce issues, the environment, proper working conditions, customer care, and societal development. In general, there are three types of decision variables including strategic (e.g., locating, capacities, etc.), tactical (e.g., allocation, planning, etc.), and operational (e.g., order size, inventory, etc.) (Chopra & Meindl, 2007). Designing the logistics network as a strategic decision in organizations has a remarkable impact on the effectiveness of supply chains. In the closed loop supply chain problem, simultaneously, two decisions – including locating facilities and the flows between them – are considered.

Dealing with the problem of designing and planning a closed loop supply chain as a NP-hard problem requires an efficient approach to provide a reliable solution in a logical time, specially, in problems with realistic dimensions. Prior articles which have attempted to provide new solutions to the problem confirm this (Soleimani, Seyyed-Esfahani, & Shirazi, 2013). As a result, using different precise and imprecise approaches have been overviewed. In larger dimensions and in more complex problems, using precise approaches are extremely time-consuming or impossible. In order to provide a solution for these types of problems, innovative approaches could be used to reach an acceptable solution in a relatively shorter time.

The components of the closed loop supply chain considered in this study include customers, factories, distribution centers, warehouses, and recycling centers. This chain has three forward levels and three reverse levels, which will be modeled with a multi-objective fuzzy approach. The model reviewed in this article, is a multi-product, multi-level, multi-periodic model which includes almost all activities from the suppliers to the recycling centers and customers.

The new approach of the developed model of this study considers components and raw materials simultaneously. The products consist of several components which can be disassembled and used as a unit or be recycled as raw materials. For example, a bicycle is made of several components including frame, saddle, front set, wheels, pedals and chains. There is a huge market in selling such components.[1] On the other hand, the components which are not in an acceptable quality of recovering and selling in second markets can be recycled to the metals and rubbers so as to be used as raw materials.[2] Various similar instances can be mentioned in the automotive industry, electronic, and computer equipment. This approach made the proposed multi-product model so complicated, especially in terms of solving large-scale instances with metaheuristic approaches. Strictly speaking, a multi-product, multi-components, multi-material model is developed in this study as a more practical model.

In the following, and in the second section of this article, a literature review is provided followed by a thorough explanation of the model in Section 3. Section 4 includes the solution and the suggested algorithm. In Section 5, different scenarios are overviewed and the numerical results from solving the model are analyzed and interpreted. Finally, in Section 6, the results of this article are presented and future research areas are suggested.

[1] http://www.bicycling.com/bikes-and-gear-features/lifestyle/where-sell-your-used-cycling-gear.

[2] http://www.ibike.org/environment/recycling/.

2. Literature review

2.1. Closed loop supply chain design

The design of a closed loop supply chain is a problem that has been given much academic attention in the recent years. In general, most of the existing research is single objective in which mainly the objective function consists of minimizing the fixed costs of setup, operations, and transportation (Pishvaee, Rabbani, & Torabi, 2011).

Pishvaee, Farahani, and Dullaert (2010) and Pishvaee, Kianfar, and Karimi (2010) provided a robust linear complex planning model for minimizing the cost of transportation and the fixed setup costs in a multilevel reverse logistics network using simulation algorithms. Following the mentioned study, Pishvaee et al. (2011) presented a robust linear complex planning model with the objective functions of minimizing cost and maximizing the level of responsiveness, in which for reaching a set of robust results, a multi-objective mimetic algorithm is used.

In 2013, three rather related papers can be mentioned here; Ramezani, Bashiri, and Tavakkoli-Moghaddam (2013) provided a multi-object model for the problem of an integrated logistics network under the conditions of uncertainty with the objective of maximizing profit, customer responsiveness, and quality. Amin and Zhang (2013) considered a closed loop supply chain network with multiple manufactures, warehouses, demand markets and products. They used linear integer planning to reduce the total cost. In their work, the effect of uncertainty on demand and returns in networks is considered using contingency planning. Özkır and Başlıgil (2013) used fuzzy logic to model the activities in a closed loop supply chain in a multi objective fashion. They applied the model to investigate the effects of the quality and quantity of returned products on customer satisfaction and supply chain profitability. The objectives of this model include maximizing service levels, maximizing buyer and seller satisfaction in the chain, and decreasing the total cost in the supply chain.

Ramezani, Kimiagari, Karimi, and Hejazi (2014) considered a closed loop supply chain with decentralized decision makers including raw material suppliers, manufactures, and retailers which directly collect recycled products from the market. They studied the convergence of suggested algorithms which could include the effects of competition, investment on distribution centers, as well as profits and returns. The reviewed model in this research is a multi-objective model for designing an integrated logistics network under uncertainty with the objective to maximize profits, customer responsiveness, and quality. Finally, Alshamsi and Diabat (2015) utilized a mixed-integer linear programming in reverse logistics using a case study approach.

2.2. Sustainable and green supply chain

Attention to the concepts of sustainable and green supply chains has been on the rise in the recent years, and many researchers have included environmental and social responsibility issues in their studies. Paksoy, Özceylan, and Weber (2010) provided a multi-objective linear model to minimize costs and CO_2 emissions in supply chains. Millet (2011) studied the elements in achieving a sustainable supply chain which simultaneously considers economic, social, and environmental issues. Kannan, Diabat, Alrefaei, Govindan, and Yong (2012) considered carbon emissions as the decision variable in their suggested model. In their research, they considered a reverse logistics network in the plastic industry and modeled it as a linear integer planning problem. Pishvaee, Razmi, and Torabi (2012) and Pishvaee, Torabi, and Razmi (2012) considered minimizing costs and maximizing social impacts in their