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A possibilistic solution to configure a battery closed-loop supply chain: Multi-objective approach

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ABSTRACT

Closed-loop supply chain (CLSC) is a prominent concept emphasizing on both economic and environmental aspects. Since a CLSC comprises of forward and reverse supply chains, there are a variety of internal and external factors associated with its total expected profit. In a forward flow, volatility in transportation cost, holding cost, and forecasting the market's demand are the most challenging issues for decision makers, while determining the rate of returned products and efficiency in recycling the returned products are crucial parameters to predict in reverse flow. In this paper, it is aimed to develop and apply a fully fuzzy programming (FFP) method to determine the possible upper, middle, and lower ranges of profit for a multi-echelon battery CLSC with multi-components, multi-product in multi-period under imprecise information. In addition, we extend the proposed model to multi-objective to consider the green factors related to plants and battery recovery centers. Fuzzy analytic network process (Fuzzy ANP) is utilized to alter the qualitative measurements to the measurable parameters. Then, distance technique and ε-constraint method are utilized for solving the multi-objective problem. We illustrate the application of the model in Vancouver, Canada using maps.

1. Introduction

Decision makers often encounter challenges about uncertainty in optimization of models. Those alterations stem from either internal or external factors affecting model's profit or cost. In other words, most of the factors are not deterministic, and decision makers are supposed to reconcile their decisions with such uncertainties. In this sense, fuzzy programming (FP) plays a prominent role in optimization problems. If we suppose that all parameters and decision variables are imprecise, the FP can be developed to a fully fuzzy programming (FFP) case. In this study, it is intended to apply FFP to address the probable uncertainty in elements of a battery closed-loop supply chain (CLSC). A CLSC has reverse and forward streams together (Amin & Zhang, 2012). The forward flow is about sending the products and parts from suppliers to producers, distributors, and final customers. On the other hand, some elements such as collection and recycling centers participate in a reverse supply chain (Amin & Baki, 2017; Das & Dutta, 2016; Mirakhorli, 2014; Özceylan, 2016; Soleimani, Govindan, Saghafi, & Jafari, 2017).

1.1. CLSC literature review

Amin, Zhang, and Akhtar (2017) examined a CLSC network concentrated on a tire remanufacturing system. The reason was high incentive of tire remanufacturing due to profit and responsibility for protecting environment. They aimed to maximize the profit of the network. Besides, they applied decision-tree methodology to obtain net present value of the CLSC in case of uncertainty in demands and returns of tires by customers in a CLSC in Toronto. Chen, Wang, Wang, and Chen (2017) believed that reducing carbon dioxide emission should be prioritized in implementing the sustainable strategy in a CLSC. For such reasons, two objectives including minimization of total cost and carbon emission reduction were applied for the multi-objective CLSC. A deterministic mixed integer linear programming (MILP) was applied as the methodology. According to their findings the enterprise should use an appropriate recycling strategy to reach an efficient economic situation in case of applying the carbon emission regulation. Özceylan, Demirel, Çetinkaya, and Demirel (In press) examined CLSCs in automotive industry, since many manufacturers are supposed to collect and recycle their end-of-life products. They employed deterministic linear programming to address their multi-echelon, multi-products, multi-period model. Similarly, Shimada and Wassenhove (In press) considered the effect of recycling law on CLSC in home appliances and computer industry

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in Japan. Al-Salem, Diabat, Dalalah, and Alrefaei (2016) employed an optimization model to minimize the total cost related to forward and reverse logistic networks. The non-linear objective function was linearized by performing the piecewise method. According to their findings, significant cost saving can be achieved because of integration the forward and reverse flows which leads to a CLSC. Kaya and Urek (2016) maximized the profit in a CLSC. They also developed a heuristic for the proposed multi-echelon model. Soto, Chowdhury, Allahyari, Azab, and Baki (2017) applied a Mixed Integer Non-linear Programming (MINLP) to formulate a multi-period inventory lot sizing network.

Talaei, Moghaddam, Pishvaee, Bozorgi-Amiri, and Gholamnejad (2016) utilized MILP to design a CLSC considering environmental issues such as rate of carbon dioxide emission. In addition, they examined their proposed model under uncertainty of demand and variable cost by utilizing a robust fuzzy programming. Kisomi, Solimanpur, and Doniavi (2016) proposed an integrated model considering robust optimization theory in account of addressing uncertain environment related to supply chain configuration and supplier selection. They compared the obtained results with the deterministic model and utilized sensitivity analysis to validate their proposed model. Ruimin, Lifei, Maozhu, Peiyu, and Zhihan (2016) utilized a robust multi-objective model to examine a CLSC under uncertainty of demand and cost parameters in the realistic network. The intention was minimization of the total cost and environmental impacts of the CLSC simultaneously. Xu et al. (2017) introduced a novel global reverse supply chain emphasizing on uncertainty of waste collection, carbon emission, and some issues existing in global supply chain such as exchange rate and transportation cost. Sifaleras and Konstantaras (2017) developed a new VDN heuristic algorithm to address the multi-product dynamic lot sizing network in reverse logistic. Mohammed, Selim, Hassan, and Syed (2017) developed a CLSC model determining the total carbon footprint in a CLSC and the total incurred cost. They applied robust optimization approach to consider multiple scenarios.

Sifaleras and Konstantaras (2015) proposed a General Variable Neighborhood Search (GVNS) metaheuristic algorithm for solving the multi-product network. Vahdani and Mohammadi (2015) introduced a bi-objective optimization model for minimizing the total cost and waiting time in a queue. They applied a hybrid solution method according to stochastic programming and robust optimization. Dutta, Das, Schultmann, and Fröhling (2016) introduced a recovery model for a multi-period CLSC with the aim of improving rate of returned products by utilizing the buy-back offer. Feitó-Cespón, Sarache, Piedra-Jimenez, and Cespón-Castro (2017) employed a stochastic programming along with a multi-criteria programming to consider various objectives to manage the uncertainty in a sustainable supply chain network. They also proposed a performance indicator with the aim of evaluating the obtained solution and reducing the effects of uncertainty on decision making. Jeihoonian, Zanjani, and Gendreau (2017) applied a two-stage stochastic mixed-integer mathematical formulation to address uncertainty in quality of the returned products in a CLSC. A scenario reduction method was utilized to manage various scenarios in their proposed model.

Subulan, Taşan, and Baykasoğlu (2015) applied a fuzzy goal mathematical model to solve a fuzzy multi-objective, dynamic network for a tire CLSC. They expressed that recycling and remanufacturing should be taken more seriously in account of growing the environmental effects of used products. Shakourloo, Kazemi, and Javad (2016) applied a multi-objective mathematical model along with fuzzy analytic hierarchy process to examine their proposed CLSC. They aimed to optimize the number of products providing by suppliers along with number of returned products which are supposed to be remanufactured. Pham and Yenradee (2017) described that supply chain performance is affected by design of its network. They claimed that considering facility location to design the supply chain may make the model more complicated. For such reasons, they introduced an alternative approach to design the supply chain network.

Some specifications of related literatures such as sources of uncertainty, multi-product, type of products, multi-period, multi-objective, mathematical programming approach, and real locations are categorized in Table 1.

1.2. Aims and contributions of research

In this study, a multi-objective CLSC model is introduced for a battery recycling network under uncertainty of demand, return, selling price, and the costs associated with purchasing raw materials, transportation, production, holding, disposal (variable costs), opening plants, retailers, and recovery centers (fixed costs). In this research, it is aimed to maximize the total profit as the first objective, in addition to maximizing the green performance of the plants and the battery recovery centers as the second objective. It is intended to apply real transportation costs to evaluate the effects of uncertainty and volatility in fuel prices on the network. To this aim, fuel consumption rate is obtained from the fuel consumption guide (Natural Resources Canada, 2014), and monthly average retail price of gasoline in Vancouver for 2016–2017 are considered. Based on our knowledge, this study is the first examination that takes into account a battery CLSC design and optimization in Vancouver. The FFP method is utilized to calculate the triangular fuzzy profit, and green performance separately, and thereafter it is tried to find the trade-off surface of the solutions. The proposed methodology is helpful to determine the optimal CLSC network under imprecise information.

The key research points of this study are as follows:

- Designing and optimizing a CLSC network of battery in Vancouver, Canada considering related organizations.
- Developing and applying an FFP method to evaluate the impacts of several sources of uncertainty on the CLSC network.
- Utilizing solution approaches to solve the problem and determine the trade-off surface of the multi-objective model.
- Assuming real distances in the proposed multi-echelon CLSC through Google Maps for estimating real transportation costs.
- Developing and applying a fuzzy ANP model to estimate the qualitative factors in the model.

Section 2 is devoted to the problem statement. Then, the problem is formulated and solved through utilization of the FFP method in Section 3. Thereafter, the proposed model is developed to multi-objective by utilization of fuzzy ANP in Section 4. We solve the fuzzy multi-objective model in Section 5. The ε-constraint method for verifying the results of the distance method is applied in Section 6. Lastly, Section 7 is dedicated to the conclusions.

2. Problem statement

Growing concerns associated with battery recycling exist because of the incremental demand by households and industries as their power resources. Some comprehensive plans are helpful to collect used batteries; otherwise, left batteries in environment may harm humans and species due to the toxic materials. Although there is no threat to human health associated with battery's usage, a battery will become dangerous when it is discarded improperly or ended up in landfills due to spreading out its chemical material into soil and groundwater. Call2Recycle has been recognized as the premier stewardship organization in North America. Call2Recycle does not believe that just collecting battery is good enough, besides it is important to optimize the recycled portion of the used