An Integrated Hybrid Approach for Circular supplier selection and Closed loop Supply Chain Network Design under Uncertainty

Kannan Govindana, b, *, Hassan Minac, Ali Esmaeili c, Seyed Mohammad Gholami-Zanjani d

a China Institute of FTZ Supply Chain, Shanghai Maritime University, Shanghai 201306, China
b Centre for Sustainable Supply Chain Engineering, Department of Technology and Innovation, University of Southern Denmark, Odense M, 5230, Denmark
c School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran
d School of Industrial Engineering, Iran University of Science and Technology, Tehran, Iran

A R T I C L E   I N F O

Article history:
Received 2 March 2019
Received in revised form 1 September 2019
Accepted 5 September 2019
Available online 12 September 2019
Handling Editor: Cecilia Maria Villas Boas de Almeida

Keywords:
Circular supplier selection
Circular closed-loop supply chain
Order allocation
Analysis network process
DEMATEL
Fuzzy theory

A B S T R A C T

In recent decades, reverse logistics has garnered considerable attention since it recovers value of returning products, satisfies environmental requirements, and pays attention to customers’ rights. Suppliers, as the first layer of the supply chain network, pose a great impact on environmental pollution. Therefore, in this paper a hybrid approach of fuzzy analysis network process (FANP), fuzzy decision-making trial and evaluation laboratory (FDEMATEL), and multi-objective mixed-integer linear programming (MOMILP) models are developed for circular supplier selection and order allocation in a multi-product circular closed-loop supply chain (C-CLSC) considering multi-depot, capacitated green routing problem using heterogeneous vehicles. In this regard, a mathematical model concerning an inventory-location-routing problem is developed that minimises cost and shortage simultaneously and also deals with imposed uncertainties. A fuzzy solution approach is proposed to simultaneously incorporate uncertainty and to change the multi-objective model into a single-objective model. To motivate the practical aspect of the proposed model in real world applications, we applied the model to an automotive timing belt manufacturer. The obtained results indicate that the proposed model is cost efficient and environmentally friendly for CLSC network designs.

© 2019 The Authors. Published by Elsevier Ltd. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

1. Introduction

As the result of intense globalisation, fierce competition and also customers’ awareness, many firms are strategically rethinking ways to control their environmental footprints. Being an eco-friendly organisation is no longer a competitive advantage, but it is a necessity to remain commercially viable and attractive to its stakeholders. In this regard, research on quantifying and controlling the environmental impacts of business operations has received a considerable deal of attention (Olsthoorn et al., 2001). On the other hand, firms are experiencing a pressing need to incorporate the circular economy (CE) into their supply chain network (Geisdoerfer et al., 2017; European Commission, 2015). CE tries to keep products and materials at the highest possible utility in both environmental and technical perspectives. This concept heads toward zero waste that aims to return the useful ingredients to the environment to enhance the natural resources (EMF, 2017). These steps provide advantages for SCM in terms of sustainability. Incorporating CE into SCM could extend the boundary of sustainability through reducing the need for virgin materials, which contributes to circulation of resources (Genovese et al., 2017; Shankar et al., 2017).

Although integrating CE in SCM is in its infancy, in recent years, an increasing number of studies pay more attention to integrating forward and reverse flows to transform supply chains into circular and closed models (Mardan et al., 2019; Darbari et al., 2019). In this stream, including recycling, disassembly, and reuse activities, there are several implications when it comes to incorporating environmental considerations into the traditional supply chain design (Ghayebloo et al., 2015; Li et al., 2018). Environmental issues are critical to understand and manage from several points of view such as regulatory requirements and corporate social responsibility (Tate et al., 2010; Govindan et al., 2018). Several well-known
organisations such as Kodak, Xerox, and General Motors have a central focus on their reverse logistics with respect to legislative requirements, economic benefits, and reputation (Üster et al., 2007). According to Cardoso et al. (2013), design of forward and reverse flows in separation will have devastating impacts on the overall supply chain’s performance. Thus, in order to develop sustainable solutions which are commercially viable and environmentally friendly, decisions about forward and reverse flows must be made jointly (Fleischmann et al., 2001; Pishvaee and Torabi, 2010).

Decision making in supply chain management should be done with the estimation of different types of costs. It is of high importance to understand the fundamental nature of costs in order to determine which to take into account with its particular behaviour. This estimation generally depends on what we want to do. In the CLSC context, economy of scale for procurement is considered as de-carbonisation and cost reduction opportunities. Economies of scale happen when marginal costs fall as activity level increases. Therefore, procurement purchase costs are less as purchase quantity rises. Lower rates usually stem from better utilization of available resources of the suppliers.

In this paper, we propose a novel hybrid approach on the basis of the FANP, FDEMATEL, and MOMILP models for supplier selection and order allocation focusing on the inventory-location-routing problem in the CLSC context considering demand uncertainty. First, suppliers are evaluated regarding the essential criteria using the FANP and FDEMATEL approaches. Accordingly, the MOMILP model is developed to design a CLSC under uncertainty, considering multi-product, location routing problem, economies of scale and inventory optimisation assumptions.

This paper makes several contributions. First, a strategic-operational level hybrid approach is developed based on FDEMA-TEL, FANP, and mathematical programming for circular supplier evaluation, selection and order allocation. As far as the authors are concerned, this is the first attempt to investigate circular supplier selection. Second, demand uncertainty is introduced into the design of the CLSC. Third, a unique linearisation approach is developed and practiced in the solution approach. Finally, the proposed approach has been applied in an automotive timing belt network in Iran. To achieve these goals, the present research addresses the following main research questions.

1. How could the circular supplier selection and order allocation be integrated into a CLSC network design?
2. Which criteria are suitable for circular supplier selection?
3. Which method is appropriate for weighting the criteria and prioritizing the suppliers?

The remainder of this paper is organised as follows. In Section 2, a literature review is provided on CLSCs with a focus on analysing the methodological approaches and objective functions. Section 3 presents the problem context, mathematical model development, and the linearisation method. The proposed model is tested and validated in Section 4 through an application of the model to a real world case in the automotive parts industry. Finally, conclusions are drawn and directions are given for future studies in Section 5.

2. Literature review

There are several rich survey and review studies in the field of CLSCs and reverse logistics such as Fleischmann et al. (1997), Rubio et al. (2008), Guide and Van Wassenhove (2009), Akcali and Cetinkaya (2011), Govindan et al. (2015b), Govindan and Soleimani (2017), and Govindan and Bouzon (2018). This research area is still under development and the number of research works has magnified over the last decade. Sustainability aspects of business operations and the availability and commercial viability of recycling and reuse technologies has been a dominant focus of research studies. The aim of this section is to present a brief review of the body of knowledge, relevant to our context. The first part of this section focuses on the major studies contributing to the development of CLSC research, and the section’s second part aims to summarise the works in circular supply chain. The last section aims at summarizing the relation to circular supplier selection and order allocation.

2.1. Reverse logistics and CLSC network

As one of the early efforts in reverse logistics area, Jayaraman et al. (1999) presented a mixed-integer linear programming (MILP) model to optimise the reverse flow quantities in a reverse supply chain network. The authors state that an aspect of the recoverable product environment is the recoverable manufacturing system must be developed in a way to extend the product life cycles through remanufacturing and repair processes. Fleischmann et al. (2001) were one of the pioneers in studying and defining CLSC characteristics by extending the forward logistics model into reverse logistics and incorporating the differences using the mixed-integer linear programming model (MILPM).

Several papers in this field discuss the issue of greenness and environmental issues. Pati et al. (2008) presented a mixed-integer goal programming (MIGP) model to design a multi-product paper recycling network in line with reducing reverse logistics costs. The model aims to improve product quality by increasing segregation in the source points and to achieve environmental benefits by increasing the rate of wastepaper recovery. Govindan et al. (2009) studied the tyre and plastic goods manufacturers’ supply chain by applying genetic algorithm (GA) and particle swarm optimisation (PSO) techniques. Later, Govindan et al. (2010) investigated a battery recycling supply chain in a reverse logistics setting. The authors state that although recycling products containing chemical and hazardous materials (such as lead) require more consideration, revenue generation opportunities exist when the materials are scarce. Amin and Zhang (2012) provided a mixed-integer mathematical model to design a CLSC network configuration. They presented an integrated model in two phases including a supplier selection stage in reverse logistics and a fuzzy approach to evaluate suppliers according to the defined qualitative criteria. Pishvae and Torabi (2010) introduced uncertainty and risk in CLSC by proposing a bi-objective possibilistic mixed-integer programming (MIP) model for the network design decisions in both forward and reverse flows. The presented model also integrates the strategic network design decisions along with tactical material flows to prevent the phenomenon of sub-optimality arising from separated design decisions. Similarly, Shi et al. (2011) introduced a model for CLSC network design. They investigated optimisation of a multi-product, multi-period capacitated CLSC considering uncertain parameters, including demand, return rates, recycling utilities, and other supply chain-related costs using fuzzy numbers.

A MILP model was introduced by Amin and Zhang (2013) to minimise the total costs of establishing and managing CLSCs under uncertain demand and return levels using scenario-based stochastic programming. The model was also developed to incorporate environmental factors using weighted sums and e-constraint methods.

Soleimani et al. (2017) examined a CLSC network design problem, including suppliers, manufacturers, distribution centres, customers, central warehouses, return centres, and recycling centres. Their chain modeling was designed in order to maximise meeting
customer demand, maximise total profits, and minimise the lost working days due to occupational events.

Chen et al. (2017) examined the design problem of an integrated CLSC network by taking into account chain costs and environmental concerns in the solar industry from the sustainability perspective. Their proposed model includes practical features, such as flow protection in each production/recycling unit whether in the progressive flow or in the reverse flow, expansion of capacity, and recycled parts. The results of the analysis indicate that a company must adopt a proper recycling strategy or energy-saving technology to achieve an optimal economic efficiency due to regulations pertaining to carbon emissions.

Sahebjamnia et al. (2018) developed a MOMILP model for sustainable CLSC network design in the tyre industry. The proposed model considers the environmental impacts of setting up centres, tyre processing, and transport between each level, as well as social impacts, including job opportunities and occupational injuries in order to optimise overall costs.

To date, a vast number of studies have been done on CLSCN design. However, few studies have been conducted on routing/location-routing problem in this area. Fang et al. (2017) assessed the combination of reverse logistics in a CLSC network with routing problem. Baraki and Kianfar (2017) proposed an integer nonlinear model for order allocation in a CLSC network. To this end, they used a mixed-integer non-linear programming (MINLP) model.

A MILP model to solve a location-routing problem in the CLSC network is developed by Sadeghi et al. (2019). Their routing problem was capacitated and multi-depot in which vehicles were considered heterogeneously. In addition, several transportation modes were also considered for the transfer of raw materials from suppliers to producers where the optimal transportation mode is determined by the model. In order to validate their proposed model, they implemented it in a manufacturing-distribution chain of automotive parts in Iran.

2.2. Circular supplier selection

As the first level of the network, suppliers have a noteworthy impact on the efficiency of the whole network. Around 70% of the products’ overall cost is related to the cost of purchasing raw materials from suppliers (Mizaei et al., 2018). Likewise, the utmost environmental damage is caused by suppliers and manufacturers. Consequently, selecting the right supplier can reduce both environmental damage and costs and lead to circularity of used materials. The CE imposes suppliers to provide raw materials that are technically restorative, recoverable, and regenerative and would not have negative effects on the environment (Genovese et al., 2017).

Supplier selection with complex and conflicting criteria is the matter of multi criteria decision making (MCDM) problems (Guarnieri and Trojan, 2019). MCDM problems constitute a framework for structuring decision making problems, as well as a set of methods for generating preferences among alternatives (Govindan et al., 2013; Kannan et al., 2014).

A review of the related literature indicates that many researchers have used MCDM methods to evaluate suppliers (Awasthi et al., 2018; Banaeian et al., 2018; Jain et al., 2018) and mathematical models for order allocation and lot-sizing problems (Baraki and Kianfar, 2017; Vahidi et al., 2018). However, circularity assumptions, besides a combination of these two methods, result in circular supplier selection and order allocation. In this context, just a few researches have been conducted. Witjes and Lozano (2016) proposed a procurement framework toward reducing resource utilization. They aimed at improving efficiency through lower waste generation and recycling. Similarly, Popa and Popa (2016) focused on green industrial requirements and addressed resource efficiency, but they did not use quantitative approaches in their framework.

Much research has been conducted on the greenness of supplier selection. Humphreys et al. (2003) introduced a new framework involving environmental considerations such as solid waste, chemical waste, and wastewater disposal to select the most suitable supplier. Aissaoui et al. (2007) investigated supplier selection and order allocations in a literature review. The authors provided a comprehensive review by covering the entire purchasing process that includes both parts and services, outsourcing activities, and procurement models based on E-commerce. Ho et al. (2010) reviewed the papers published between 2000 and 2008 that utilised MCDM approaches for evaluating suppliers and ordering allocation. Authors reveal that the most commonly used MCDM method is data envelopment analysis (DEA). However, the most popular integrated approach is analytical hierarchy process (AHP) with goal programming (GP). This study reveals that qualitative evaluation criteria are the most widely considered factors in supplier selection. Quality, delivery, and price are ranked respectively. Hsu and Hu. (2009) incorporated greenness issues by controlling hazardous substance management (HSM) in supplier evaluation and selection using AHP. These authors stress that the success of HSM relies on five key dimensions, including procurement management, process management, R&D management, incoming quality control, and the management system.

To evaluate green suppliers in the high-tech industry context, Lee et al. (2009) employed the Delphi method to discriminate the criteria for assessing traditional and green suppliers. The authors constructed a hierarchy to evaluate the importance of the chosen factors and the performance of green suppliers. As experts may not ascertain the importance of factors, the results of questionnaires may be prejudiced and biased. To reflect the ambiguity of experts’ opinions, the fuzzy extended analytic hierarchy process (FEAHP) was utilised to minimise any preconceptions in the experts’ opinions.

Quality function deployment (QFD) was integrated with fuzzy techniques for the evaluation and selection of suppliers by Amin and Razmi (2009). Employing QFD was beneficial as the supplier selection, evaluation, and development process was combined in one integrated framework for supplier management. In order to consider the interdependencies among the criteria in a green supplier selection problem, Hashemi et al. (2015) investigated the application of analytic network process (ANP) by employing grey rational analysis (GRA) to incorporate uncertainties in supplier selection decisions. The authors presented a novel approach by utilising ANP and improved GRA to define weights for the criteria, which was validated in the automotive industry.

Many research studies have been conducted on green supplier selection through MCDM methods. Mina et al. (2014a), Hashemi et al. (2015), Chung et al. (2016), and Tavana et al. (2017) used ANP method to calculate criteria weight and evaluate green suppliers. TOPSIS (dos Santos et al., 2019), DEA (Dobos and Vorosmarti, 2019), VIKOR (Banaeian et al., 2018), and AHP (Mavi, 2015) are commonly used methods in the literature. Moreover, some papers have provided comprehensive reviews on MCDM methods (Govindan et al., 2015a; Khan et al., 2018). Some other papers have investigated green supplier selection and order allocation problem; see Gören (2018), Lo et al. (2018), Mohammed et al. (2018), Park et al. (2018), and Kellner and Utz (2019).
Table 1 represents a summary for the body of knowledge in CLSCs that is most relevant to this research in terms of the modelling approach and objective functions.

Although supplier selection is found to be a strategic function of firms, much less research has been conducted on integrating circular specifications into supplier selection. Moreover, while it is clear that there is a positive move towards the development of models that are capable of solving a wide range of supplier evaluation and selection problems, there seems to be concerns in relation to their practicality in the real world environments and to their adaptability by the industry. Many of the models covered in this review require a significant amount of investment in data collection and analysis. Furthermore, several criteria are subject to change in the face of new business practices and technologies. Therefore, efforts must be made to transform the models to practical and simplified tools that are adaptable in the supplier management field. The next section describes the formulation of our model and our approach in filling the research gap.

3. Problem definition and the proposed approach

In this study, a two-stage optimisation model is proposed to evaluate and select the circular suppliers and, accordingly, to allocate optimal orders in the CLSC. In the first stage, which is designed at a strategic level, suppliers are assessed using a decision support system (DSS) based on a FDEMATEL and FANP. The second stage, which is linked to tactical and operational decisions, aims to model a CLSC using a fuzzy bi-objective model. Fig. 1 demonstrates the decision-making order framework.

3.1. First stage: supplier evaluation

Supplier management is a costly and time-consuming task, particularly when it comes to evaluation and selection activities. On the other hand, organisations potentially deal with a large number of suppliers for their outsourcing requirements. Hence, models that assist businesses in evaluating and selecting the best subset of suppliers in an efficient manner are in high demand.
Step 1: Extracting criteria and sub-criteria

Step 2: Weighting of criteria and sub-criteria without considering inner dependency (FAHP)

Step 3: Determining inner dependency among criteria using FDEMATEL

Step 4: Applying the inner dependency matrix in criteria weights (FANP) and calculating the final weights of sub-criteria

Step 5: Performance evaluation of each supplier for each sub-criterion and calculating the final score of suppliers

Formulation of the multi-objective linear programming model

First stage

Second stage

Fig. 1. Procedure of decision-making strategy.

Since the evaluation criteria have interdependencies, these factors should be taken into account for calculating the exact criteria weights. In the related literature (Zhang et al., 2015), the ANP and supermatrix methods are most often used to achieve this aim. However, in this research, to ease the calculation process, FDEMATEL is utilised instead of supermatrix since the latter imposes heavy computational efforts. The employed method is described through the following steps.

Step 1 In this step, the critical criteria and sub-criteria of supplier quality for the selection process are identified. An extensive literature survey was done to develop an inclusive set of criteria and sub-criteria. Furthermore, experts’ opinions were also collected to complement the criteria set from the literature and to achieve a level of practicality. The selected criteria and sub-criteria for circular supplier evaluation and selection are presented in Table 2.

For this purpose, questionnaires, with the possibility of pairwise comparison between factors, were used and experts were requested to determine the status and importance of the paired comparisons through Table 3 (Kahraman et al., 2006).

After completion of the questionnaires, the pairwise comparison matrix can be extracted. Then, the local weight of each factor is used to defuzzify and obtain each factor by means of the method proposed by Bozguna and Beskese (2007).

In this process, we assume that $\phi_{pq}$ represents the triangular fuzzy numbers located in the $p$th row and the $q$th column of the pairwise comparison matrix, and the following is accurate:

$$\sum_{q=1}^{P} \phi_{pq} = \left( \sum_{q=1}^{P} l_{pq}, \sum_{q=1}^{P} m_{pq}, \sum_{q=1}^{P} u_{pq} \right), \quad p = 1, 2, 3, \ldots, P$$

where $l$, $m$, and $u$ represent the lower, middle, and upper bounds of each triangular fuzzy number, respectively. Fuzzy synthetic extent is shown with $S_p$ and is defined through Eq. (2):

$$S_p = \sum_{q=1}^{P} \phi_{pq} \otimes \left[ \left( \frac{1}{\sum_{p=1}^{P} \sum_{q=1}^{Q} \phi_{pq}} \right)^{-1} \right]$$

Eq. (3) is enacted to obtain $\left[ \sum_{p=1}^{P} \sum_{q=1}^{Q} \phi_{pq} \right]^{-1}$:

$$\left[ \sum_{p=1}^{P} \sum_{q=1}^{Q} \phi_{pq} \right]^{-1} = \left( \frac{1}{\sum_{p=1}^{P} \sum_{q=1}^{Q} l_{pq}}, \frac{1}{\sum_{p=1}^{P} \sum_{q=1}^{Q} m_{pq}}, \frac{1}{\sum_{p=1}^{P} \sum_{q=1}^{Q} u_{pq}} \right)$$

Accordingly, the degree of possibility is determined. For example, this possibility is defined for $S_q \geq S_p$ as follows:

$$V(S_q \geq S_p) = \sup \left[ \min \left( \mu_{S_q}(x) \cdot \mu_{S_p}(y) \right) \right], y \geq x$$

Degree of possibility is obtained via Eq. (5):

$$V(S_q \geq S_p) = \begin{cases} 1 & \text{if } b_j \geq b_i \\ 0 & \text{if } a_i \geq c_j \\ \frac{1}{l_p - u_q} - \frac{1}{m_p - l_q} & \text{Otherwise} \end{cases}$$

In the next stage, the degree of possibility for convex fuzzy numbers is defined as Eq. (6):

$$d'(A_p) = \min \left[ V(S_p \geq S_k) \right], p = 1, 2, \ldots, k$$

Then, the weight vector is defined as Eq. (7):

$$W' = (d'(A_1), d'(A_2), \ldots, d'(A_p))^T$$

The obtained weight vector is normalised as Eq. (8):

$$W = (d(A_1), d(A_2), \ldots, d(A_p))^T$$

Using this approach, it is possible to obtain the local weight for the criteria and sub-criteria.

Step 3 In this step, FDEMATEL is used to determine the interdependencies between the factors. To achieve this, the following five procedures are proposed:

1. Initially, the experts were asked to schematically display the impact of factors on each other using their experience.
2. Based on the impacts demonstrated by the experts, a fuzzy direct-relation matrix should be obtained. For this purpose, questionnaires, with the possibility of pairwise comparison, were used and experts were requested to determine the status and importance of the paired comparisons through Table 3 (Kahraman et al., 2006).

After completion of the questionnaires, the pairwise comparison matrix can be extracted. Then, the local weight of each factor is used to defuzzify and obtain each factor by means of the method proposed by Bozguna and Beskese (2007).
Table 2
Selected criteria and sub-criteria for supplier evaluation.

| Criteria                  | Sub-criteria               | Description                                                                 | References                                                                 |
|---------------------------|----------------------------|-----------------------------------------------------------------------------|---------------------------------------------------------------------------|
| Circular air pollution    |                            | Consideration of decreased air pollution in procedure of recycling the       | Grisi et al. (2010); Rashidi and Saen (2018); dos Santos et al. (2019)     |
| Environmental standards   |                            | Utilization of the environmental standards in recycling the products       | Thongchattu and Siripokaprom (2010); Rashidi and Saen (2018)              |
| Eco-friendly raw materials|                            | Utilization of recyclable raw materials in producing the products         | Mangla et al. (2013); Gupta and Barua (2017)                              |
| Eco-design                |                            | Designing a product with the least environmental degradation effects and     | Hong-jun and Bin (2010); Scur and Barbosa (2017); Vieira et al. (2018);   |
| Eco-friendly packaging    |                            | Utilization of recyclable materials in packaging the products              | Rashidi and Saen (2018); dos Santos et al. (2019)                         |
| Eco-friendly transportation|                            | Utilization of clean and appropriate vehicles to distribute and collect    | Lee et al. (2009); Chatterjee et al. (2018)                                |
| Clean technology          |                            | Utilization of proper technology for recycling the returned products      | Humphreys et al. (2003); Humphreys et al. (2006)                          |
| Quality control system    |                            | Applying proper systems for increasing quality of products                 | Kuo and Lin (2012); Sari and Timor (2016)                                 |
| Previous customers'       |                            | Providing conditions to demonstrate customers' satisfaction              | Bafrooei et al. (2014)                                                   |
| satisfaction              |                            | Providing conditions to return defective products and utilization of grantee| Jinturkar et al. (2014); Mina et al. (2014a); Parkouhi et al. (2019)       |
| Quality of after sales    |                            | Application of project control and efficient ordering system              | Yadav and Sharma (2015)                                                  |
| service                   |                            | Application of methods based on scheduling and routing problem           |                                                                           |
| On-time delivery          |                            | Application of project control and efficient ordering system              | Yadav and Sharma (2015)                                                  |
| Time management           |                            | Appropriate mechanisms to reduce the processing time                      |                                                                           |
| Delivery time             |                            | Application of methods based on scheduling and routing problem           |                                                                           |

Table 3
Linguistic scales for difficulty and importance (Kahraman et al., 2006).

| Linguistic scales for difficulty | Linguistic scales for importance | Triangular fuzzy scale | Triangular fuzzy reciprocal scale |
|----------------------------------|----------------------------------|-----------------------|----------------------------------|
| Just equal                       | Just equal                       | (1, 1, 1)             | (1, 1, 1)                        |
| Equally difficult                | Equally important                | (0.5, 1, 1.5)         | (0.667, 1, 2)                    |
| Weakly more difficult            | Weakly more important            | (1, 1.5, 2)           | (0.5, 0.667, 1)                  |
| Strongly more difficult          | Strongly more important          | (1.5, 2, 2.5)         | (0.4, 0.5, 0.667)                |
| Very strongly more difficult     | Very Strongly more important     | (2, 2.5, 3)           | (0.333, 0.4, 0.5)                |
| Absolutely more difficult        | Absolutely more important        | (2.5, 3, 3.5)         | (0.286, 0.333, 0.4)              |

Table 4
Scale of determining criteria’s impacts.

| Linguistic term | Fuzzy scales |
|-----------------|--------------|
| None            | (0,0,0,1)    |
| Very low        | (0.1,0.2,0.3) |
| Low             | (0.2,0.3,0.4) |
| More or less low| (0.3,0.4,0.5)|
| Medium          | (0.4,0.5,0.6)|
| More or less good| (0.5,0.6,0.7)|
| Good            | (0.6,0.7,0.8)|
| Very good       | (0.7,0.8,0.9)|
| Excellent       | (0.8,0.9,1)  |

For step 2, weights are assigned to the criteria and sub-criteria resulting from the previous step. Afterwards, ANP is used to analyse the interdependencies that exist among the criteria. Thus, it is assumed that there is no dependency between criteria and sub-criteria. A pairwise comparison matrix is also used to define the local weight of factors.

4. The full fuzzy relation matrix is obtained in this step. Similar to the normalised direct-relation matrix ($X$), the total fuzzy relation matrix ($\tilde{X}$) is obtained using Eq. (9). Here, $I$ represents the identity matrix. Therefore, matrix $X_{ij}$ is converted into three defuzzified matrices where the first, second, and third matrices are composed of low, middle, and high entries of triangular fuzzy numbers, respectively.

$$X_1 = \begin{bmatrix} 0 & l_{12} & \cdots & l_{1n} \\ l_{21} & 0 & \cdots & l_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ l_{n1} & l_{n2} & \cdots & 0 \end{bmatrix}, \quad X_2 = \begin{bmatrix} 0 & m_{12} & \cdots & m_{1n} \\ m_{21} & 0 & \cdots & m_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ m_{n1} & m_{n2} & \cdots & 0 \end{bmatrix}, \quad X_3 = \begin{bmatrix} 0 & u_{12} & \cdots & u_{1n} \\ u_{21} & 0 & \cdots & u_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ u_{n1} & u_{n2} & \cdots & 0 \end{bmatrix}$$

purpose, experts were provided with the pairwise comparison matrix and table of linguistic scales (Table 4) to rate the impact of factors on each other.

3. Now, Eq. (9) is used to normalise the resultant matrix.

$$\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij}) \quad \text{and} \quad s = \frac{1}{\max_{1 \leq i \leq n} \sum_{j} a_{ij}} \quad \text{then} \quad \tilde{X} = s \times \tilde{A}.$$
Accordingly, the total fuzzy relation matrix is defined as follows.

\[
\tilde{T} = \tilde{X}(I - \tilde{X})^{-1} \tilde{T} = \begin{bmatrix}
\tilde{t}_{11} & \tilde{t}_{12} & \cdots & \tilde{t}_{1n} \\
\tilde{t}_{21} & \tilde{t}_{22} & \cdots & \tilde{t}_{2n} \\
\vdots & \vdots & \ddots & \vdots \\
\tilde{t}_{n1} & \tilde{t}_{n2} & \cdots & \tilde{t}_{nn}
\end{bmatrix}
\]

where \( \tilde{t}_{ij} \) is the fuzzy value of the relationship between factor \( i \) and factor \( j \), and \( \tilde{X} \) is the local fuzzy relation matrix.

5. Finally, the interdependency matrix is calculated. For this purpose, the total fuzzy relation matrix is defuzziﬁed and normalised as per Eqs. (11) and (12).

\[
\text{Defuzzy}(t_{ij}) = \frac{t_{ij}^a + 4t_{ij}^b + t_{ij}^c}{6}
\]

\[
\text{Normalized Defuzzy}(t_{ij}) = \frac{\text{Defuzzy}(t_{ij})}{\sum \text{Defuzzy}(t_{ij})}
\]

Step 4 In this step, the interdependence matrix obtained from Step 3 is applied to the weight of the factors achieved from Step 2. As the result, the weights of factors are obtained by considering the interdependencies between them. The local weights of criteria which are obtained in this step are applied to the sub-criteria so that the final sub-criteria weight can be achieved.

Step 5 Using a questionnaire, experts assigned the relevant factors to each supplier. The linguistic words and triangular fuzzy numbers associated with the linguistic terms are shown in Table 5 (Dagdeviren and Yüksel, 2010).

Finally, the mean score of experts’ opinions on each sub-criterion is calculated for each supplier. To obtain the final score of each supplier, the sum of factors’ weights multiplied by numerical values are calculated, so the suppliers who obtain the minimum score are considered as qualiﬁed suppliers.

3.2. Second stage: mathematical model

Once the evaluation and selection of qualiﬁed suppliers is ﬁnalised, we focus on the design and optimisation of the CLSC. The schematic representation of the proposed supply chain network is shown in Fig. 2.

As can be seen in Fig. 2, distribution centres purchase the required products from the selected suppliers (manufacturers), and then distribute them among the customers through optimal routes of a heterogeneous ﬂeet of vehicles. Defective products are then returned to the collection centres to be inspected and to determine their next direction. Repairable products are sent to recycling centres and, if they are not repairable, they are sent to disposal centres. The recycled products should be returned to suppliers in order to start the cycle from the ﬁrst step.

Therefore, a bi-objective mathematical model is proposed under uncertainty for the given supply chain network, where the following decision variables are included: the locations of distribution, collection, recycling, and disposal centres; the presence or absence of any relationship with the suppliers, vehicle ownership, the level of product transition between different tiers, the volume of purchase from the supplier considering the discount and economies of scale option, the degree of shortage, the storage levels in customers’ warehouses, and even the arrival time window for the vehicles to the customers’ location. The proposed model and the notations are presented in the remainder of this section.

Assumptions

- The supply chain in this study is closed-loop with the consideration of reverse logistics.
- There is only one production plant.
- The setting of the proposed supply chain is single period and multi-product.
- Determining the geographical location of customers and suppliers is not in the scope of this model.
- All centres and suppliers are considered capacious.
- The demand pattern is uncertain (fuzzy).
- The transition between levels is intended to have capacity.

Table 5

| Linguistic values for positive sub-factors | Linguistic values for negative sub-factors | Triangular fuzzy numbers | The mean of fuzzy numbers |
|-----------------------------------------|------------------------------------------|--------------------------|--------------------------|
| Very weak                               | Very strong                              | (0.0,0)                  | 0                        |
| Weak                                    | Strong                                   | (0.0,1.67,0.333)         | 0.167                    |
| Weak-Mid                                | Mid-Strong                               | (0.167,0.333,0.5)        | 0.333                    |
| Mid                                     | Mid-Strong                               | (0.333,0.5,0.667)        | 0.5                      |
| Mid-Weak                                | Weak                                     | (0.5,0.667,0.833)        | 0.667                    |
| Strong                                  | Very weak                                | (0.667,0.833,1)          | 0.833                    |

Fig. 2. The CLSC network in this study.
- The number and capacity of the vehicles involved in the distribution network is given, but the allocation of vehicles is performed by the model.
- The time required for travelling vehicles is predetermined.
- The vehicle routing problem is considered between distribution levels and demand only and the routing problem considers multiple depots.

### Variables

| Variables                                      | Description                                                                 |
|-----------------------------------------------|-----------------------------------------------------------------------------|
| YSP_{ik}                                      | Binary If the supplier $s$ is contacted for the purchase of product $i$ at price level $k$ Otherwise |
| YDIST_{df}                                    | Binary If distribution centre $d$ is established Otherwise               |
| YCLC_{fo}                                    | Binary If collection centre $o$ is established Otherwise                   |
| YRCY_{fn}                                    | Binary If recycling centre $n$ is established Otherwise                    |
| YDS_{fi}                                      | Binary If disposal centre $f$ is established Otherwise                    |
| ZV_{vf}                                      | Binary If vehicle $v$ is supplied                                           |
| Z_{vc}                                       | Binary When vehicle $v$ travels from customer $c$ to customer $c$ Otherwise |
| AT_{vr}                                      | Positive Arrival time of vehicle $v$ to customer location $c$              |
| INVP_{ck}                                    | Integer The amount of product $i$ available in the warehouse of customer $c$ |
| INVC_{ck}                                    | Integer The shortage of product $i$ (negative balance) for customer $c$    |
| FFL_{ck}                                     | Free Stock (auxiliary variable)                                           |
| X_{csil}                                     | Integer The amount of product $i$ moved from distribution centre $d$ to customer $c$ by vehicle $v$ |
| XCSCI_{cco}                                  | Integer The amount of product $i$ moved from collection centre $o$ to collection centre $o$ |
| XCLDS_{cdf}                                  | Integer The amount of product $i$ moved from collection centre $o$ to disposal centre $f$ |
| XCLR_Y_{fm}                                  | Integer The amount of product $i$ moved from collection centre $o$ to recycling centre $n$ |
| XRCY_{fon}                                   | Integer The amount of product $i$ moved from recycling centre $n$ to supplier $s$ |
| XSPDST_{isd}                                 | Integer The amount of product $i$ purchased from supplier $s$ by distribution centre $d$ at price level $k$ |

### Parameters

| Parameters                                      | Description                                                                 |
|-----------------------------------------------|-----------------------------------------------------------------------------|
| CSSPi                                        | Cost of communicating with the supplier $s$                                 |
| CSDIST_{d}                                   | Cost of establishing a distribution centre in potential location $d$         |
| CSCLa                                        | Cost of establishing a collection centre in potential location $o$           |
| CSRy_{in}                                    | Cost of establishing a recycling centre in potential location $n$            |
| CSD_{f}                                      | Cost of establishing a disposal centre in potential location $f$             |
| CSPSP_{ik}                                   | Processing cost of product $i$ by supplier $s$                              |
| CSPDST_{id}                                  | Processing cost of product $i$ by distribution centre $d$                   |
| CSPCT_{io}                                   | Processing cost of product $i$ by collection centre $o$                     |
| CSRy_{in}                                    | Recycling cost of product $i$ by recycling centre $n$                       |
| CSPD_{if}                                    | Disposal cost of product $i$ by disposal centre $f$                         |
| CSV_{hv}                                     | Cost of vehicle $v$                                                         |
| CSCSCL_{ilo}                                 | Cost of moving product unit $i$ from customer $c$ to collection centre $o$  |
| CSCSCL_{ilf}                                 | Cost of moving product unit $i$ from collection centre $o$ to disposal centre $f$ |
| CSCLRY_{fon}                                 | Cost of moving product unit $i$ from collection centre $o$ to recycling centre $n$ |
| CSRy_{in}                                    | Cost of moving product unit $i$ from recycling centre $n$ to supplier $s$   |
| CSPDST_{isd}                                 | Cost of moving product unit $i$ from supplier $s$ to distribution centre $d$ |
| CSPi_{ks}                                    | Cost of purchasing product unit $i$ from supplier $s$ at price level $k$    |
| A_{k}                                        | The upper limit of the volume of product $i$ purchased from supplier $s$    |
| CPSp_{is}                                    | Capacity of supplier $s$ for product $i$                                   |
| CPDST_{id}                                   | Capacity of distribution centre $d$ for product $i$                        |
| CPCLa                                        | Capacity of collection centre $o$ for product $i$                          |
| CPRy_{in}                                    | Capacity of recycling centre $n$ for product $i$                           |
| CPD_{if}                                     | Capacity of disposal centre $f$ for product $i$                            |
| CVH_{v}                                      | Capacity of vehicle $v$                                                    |
| DSC_{c}                                      | Distance of customer location $c$ from customer location $c$               |
| TMSC_{c}                                     | Time distance of customer location $c$ from customer location $c$ by vehicle $v$ |
| DS_{s}                                       | Distance of supplier $s$ from customer location $c$ by vehicle $v$         |
| TN_{sd}                                      | Time distance of supplier $s$ from customer location $c$ by vehicle $v$    |
| DMND_{c}                                     | Demand of customer $c$ for product $i$                                     |
| FCS_{ilo}                                    | Maximum flow of moving product $i$ from customer $c$ to collection centre $o$ |
| FCLDS_{dif}                                  | Maximum flow of moving product $i$ from distribution centre $d$ to disposal centre $f$ |
| FCLR_Y_{fon}                                 | Maximum flow of moving product $i$ from collection centre $o$ to recycling centre $n$ |
| FRCY_{fon}                                   | Maximum flow of moving product $i$ from recycling centre $n$ to supplier $s$ |
| FSPDST_{isd}                                 | Maximum flow of moving product $i$ from supplier $s$ to distribution centre $d$ |
| w_{ic}                                       | Return rate of product $i$ from customer $c$                               |
| R Pi                                         | Recycling rate of product $i$                                              |
| h_{iv}                                       | Holding cost of each product unit $i$ by vehicle $v$                       |
| f_{iv}                                       | Fuel consumption per distance unit by vehicle $v$                          |
| δ                                            | Cost of each emission unit of greenhouse gases                              |

### 3.2.1. Mathematical model

### 3.2.1.1. Objective function.

\[
\text{Min } z^{\text{cost}} = \sum_{i,k} CVH_{vi} \times ZV_{vf} + \sum_{i,k} CSSP_{is} \times YSP_{iks} + \sum_{i} CSCL_{ilo} \times YCL_{o} + \sum_{i} CSRCTY_{in} \times YRCY_{fon} + \sum_{i,d} CSDDS_{dif} \times YDST_{df} + \sum_{i,o} CSPCT_{io} \times YCLC_{fo} + \sum_{i,n} CSRy_{in} \times YRCY_{fon} + \sum_{i,d} CSPD_{if} \times XSPDST_{isd} + \sum_{i,c} FCS_{ilo} \times XCSCI_{c} + \sum_{i,r} CPCLa \times XCLDS_{cdf} + \sum_{i,n} CPSp_{is} \times XRCY_{fon} + \sum_{i,d} CPSD_{if} \times XSPDST_{isd} + \sum_{i,c} FCLDS_{dif} \times XCLDS_{cdf} + \sum_{i,o} CSPDST_{isd} \times XSPDST_{isd} + \sum_{i,n} FRCY_{fon} \times XCLR_Y_{fm} + \sum_{i,c} FSPDST_{isd} \times XSPDST_{isd} + \sum_{i,n} FRCY_{fon} \times XCLR_Y_{fm} + \delta \times \left( \sum_{i,v,c} Z_{vcc} \times DSC_{Cc} + \sum_{i,d} f_{iv} \times (Z_{ct} + Z_{ct}) \times \beta_{vd} \times DS_{vd} \right)
\]

The first objective function aims to minimise the total costs of the system. These costs include costs of vehicle supply, transportation costs, costs of product processing in each level, costs of product maintenance in customers' warehouses, cost of providing products from suppliers, and cost of producing greenhouse gas emissions.
Min \[ z_{\text{shortage}} = \sum_{i,c} \text{INVN}_{ic} \]  

The second objective function is designed to ensure shortages are minimised. 

Subject to:

\[ \sum_{i,c} X_{idec} \leq CPVH_v \times ZVH_v \forall v, d \]  

Constraint (15) states that the amount of products carried by each vehicle should not exceed capacity. 

\[ \sum_{i,c} X_{idec} \leq \text{bigm} \times \beta_{id} \forall v, d \]  

According to constraint (16), the condition for product movement to customers by vehicles is that the vehicle should be allocated to the distribution centre. 

\[ \sum_{d} \beta_{id} \leq 1 \forall v \]  

Based on constraint (17), each vehicle is allocated at most to one distribution centre. 

\[ \sum_{v} \beta_{id} \leq \text{bigm} \times \text{YDST}_d \forall d \]  

If no distribution centre has been established, no vehicle is allocated, which is included in constraint (18). 

\[ \sum_{c} Z_{vc} \leq 1 \forall v, c \]  

There is the possibility of each customer's visit from each vehicle just once, but there is the possibility of demand overlap which is shown in constraint (19). 

\[ \sum_{c} Z_{vc} = \sum_{c} Z_{vcc} \forall v, c \]  

Based on constraint (20), if a vehicle arrives to the customer location, it should leave as well. 

\[ AT_{vc} + \text{bigm} \times (1 - Z_{vcc}) \geq AT_{vc} + TM_{vcc} \forall v, c, d > 1 \]  

\[ AT_{v1} + \text{bigm} \times (1 - Z_{v1c}) \geq AT_{v1} + TM_{vdc} \times \beta_{id} \forall v, d, c > 1 \]  

Sub-tour elimination constraint has been provided by the constraint and calculation of arrival time to each customer location in constraints (21) and (22). 

\[ \sum_{i,d} X_{idec} \leq \text{bigm} \times \sum_{c} Z_{vcc} \forall v, c \]  

\[ \sum_{i,d,c} X_{idec} \leq \text{bigm} \times ZVH_v \forall v \]  

The condition for product delivery to the customer is that the customer's vehicle should be visited and this vehicle should be a purchased one that is presented in constraints (23) and (24), respectively. 

\[ \text{INV}_{ic} = \sum_{v} X_{idec} - \text{DMND}_{ic} - \sum_{o} W_{ic} \times \text{XCSCl}_{ico} \forall i, c \]  

Constraint (25) considers the stock balance in customers’ warehouses. 

\[ \text{INV}_{ic} = \text{INVV}_{ic} - \text{INVN}_{ic} \forall i, c \]  

Warehouse stock and shortages are shown in constraint (26). 

\[ \sum_{n} \text{XRCP}_{ins} + \eta_{is} \geq \sum_{k,d} \text{XSPDST}_{iskd} \forall i, s \]  

Constraint (27) sets the input and output balances for each supplier and each product. 

\[ \sum_{n,s} \text{XRCP}_{ins} \leq \sum_{n,s} \text{FRCP}_{ins} \forall i \]  

\[ \sum_{n} \text{XRCP}_{ins} + \eta_{is} \leq \text{CPSP}_{is} \forall i, s \]  

Constraints (28) and (29) show the state of transferred product is not exceeding the flow capacity between recycling centres and the supplier, and the states of processed and received products is not exceeding the capacity of each supplier, respectively. 

\[ \sum_{c,o} \text{XCSCl}_{ico} \leq \sum_{c,o} \text{FCSCl}_{ico} \forall i \]  

According to constraint (30), there is no possibility that the product movement from the customer to the collection centres exceeds the capacity flow of transfer between them. 

\[ \sum_{c} \text{XCSCl}_{ico} \geq \sum_{f} \text{XCLDS}_{idf} + \sum_{n} \text{XCLR}_{ion} \forall i, o \]  

Constraint (31) calculates the balance of products’ entry for each collection centre and product. 

\[ \sum_{c} \text{XSCL}_{ico} \geq \text{CPCL}_{io} \forall i, o \]  

Constraint (32) states that the amount of products moved to collection centres must not exceed their capacity. 

\[ \sum_{o} \text{XSCL}_{ico} = \sum_{v,d} w_{ic} \times X_{idec} \forall i, c \]  

Constraint (33) calculates the amount of products returned from customers. 

\[ \sum_{o,f} \text{XCLDS}_{idf} \leq \sum_{o,f} \text{FCLDS}_{idf} \forall i \]  

Constraints (34) and (35) state that the quantity of products transferred from collection centres to disposal centres and to recycling centres must not exceed the flow capacity between them. 

\[ \sum_{o} \text{XCL}_{ion} \leq \text{CPR}_{ion} \forall i, n \]  

Constraints (36) and (37) prevent exceeding the capacity of disposal and recycling centres. 

\[ \sum_{k,s,d} \text{XSPDST}_{iskd} \leq \sum_{s,d} \text{FSPDST}_{isd} \forall i \]  

Constraint (38) shows that the products transferred from suppliers to distribution centres must not exceed the maximum
transfer rate between them.

\[ \sum_{k,s} X_{SPDST \text{iks}} \leq CPDST_{id} \forall i, d \]  

(39)

Constraint (39) indicates the capacity constraints of distribution centres.

\[ \sum_{k,s} X_{SPDST \text{iks}} \geq \sum_{v,c} X_{vdec} \forall i, d \]  

(40)

Constraint (40) states that the amount of products transferred from the total of suppliers to distribution centres should not be less than the sum of the products delivered to the customers.

\[ A_{iks} - \text{bigm} \times (1 - Y_{SPiks}) \leq X_{SPDST \text{iks}} \leq A_{iks} + \text{bigm} \times (1 - Y_{SPiks}) \]  

(41)

Constraints (41) are presented to apply piecewise economies of scale on the purchase of products from suppliers.

\[ \sum_{k} Y_{SPiks} \leq 1 \forall i, s \]  

(42)

Constraint (42) indicates the purchase of each product from any supplier is at one price level only.

\[ X_{SPDST \text{iks}} \leq \text{bigm} \times X_{SPiks} \forall i, k, s, d \]  

(43)

\[ X_{RCYSP \text{iks}} \leq \text{bigm} \times X_{SPiks} \forall i, k, n, s \]  

(44)

Constraints (43) and (44) ensure that products can be purchased from and sent to the suppliers that are selected.

\[ X_{SPDST \text{iks}} \leq \text{bigm} \times \text{YDST}_{id} \forall i, k, s, d \]  

(45)

\[ X_{vdec} \leq \text{bigm} \times \text{YDST}_{id} \forall i, v, d, c \]  

(46)

\[ X_{CSCLio} \leq \text{bigm} \times YCL_{io} \forall i, c, o \]  

(47)

\[ X_{CLDSof} \leq \text{bigm} \times YCL \forall i, o, f \]  

(48)

\[ X_{XRCY\text{Ion}} \leq \text{bigm} \times YRCY_{io} \forall i, o, n \]  

(49)

\[ X_{XRCY\text{Ion}} \leq \text{bigm} \times YRCY_{io} \forall i, o, n \]  

(50)

\[ X_{RCYSP \text{ins}} \leq \text{bigm} \times YRCY_{io} \forall i, n, s \]  

(51)

\[ X_{XCLDSof} \leq \text{bigm} \times YDS_{if} \forall i, o, f \]  

(52)

Constraints (45)–(52) ensure that products flow to and from the only established distribution centres, collection centres, and recycling centres.

3.3. Linearisation process

According to the developed mathematical model, the term \( \beta_{id} \times Z_{vcc} \) makes the model nonlinear. So, to linearise the model, a new binary variable is defined that includes all the indices in \( \beta_{id} \) and \( Z_{vcc} \).

\[ Z_{\beta_{id} \& Z_{vcc}} \]  

(53)

Now, the nonlinear term is replaced with new variable in the objective function as follows.

\[ Z_{\beta_{id} \& Z_{vcc}} \begin{cases} 1 & \text{Binary} \\ 0 & \end{cases} \]  

4. Case study and model validation

In this section, we focus on the implementation and validation of the proposed model in an automotive parts industry involved in producing automotive timing belts. The factory is located in the Alborz Province (Iran) and includes three production lines that produce timing belts for Peugeot 405, Peugeot 206, Peugeot Pars, Samand, and Pride.

In the considered case study, automotive timing belts are produced by suppliers (plants) and sent to distribution centres. Then, they are distributed to customers’ sites (spare parts sales agencies) with the routing plans. During the sale process, some of the products may be determined as defective. Such products should be sent to either disposal or recycling centres according to their deficiency level. In the recycling centres, the defective products are repaired and re-sent for further usages. Recycling centres and disposal centres are of two activities that lead to CE in the network. This CLSC network is illustrated in Fig. 2.

In this paper, the data from production line 1 is used to validate the proposed model. Production line 1 produces three products, including the timing belts for Peugeot 405, Peugeot 206, and Peugeot Pars. The final products of this production line are then distributed to three distribution centres in the proximity of the main production plant. To collect the required data to test the model, five experts and six suppliers were contacted and relevant data collection procedures were conducted. The step-by-step implementation of the model in the case study environment is explained below.
First stage/Step 1 In this step, the evaluation criteria and sub-criteria that were obtained from the literature survey and experts’ opinions are extracted and presented. In Table 2, the selective criteria and sub-criteria are calculated using a pairwise comparison matrix between factors and Bozbura and Beskese’s (2007) method (Table 6).

Step 2 In this step, weights are assigned to the criteria and sub-criteria derived from the previous step. It is assumed that there is no interdependency between the criteria. The local weights for criteria and sub-criteria are calculated using a formula. This procedure is presented in Table 6.

Step 3 The interdependencies between the factors are played in Table 7. The matrix resulting from the previous procedure is normalised using Eq. (9) (Table 8).

4. The full fuzzy relation matrix is obtained by conversion into the three following matrices.

\[
X_1 = \begin{bmatrix}
0 & 0.545 & 0.091 \\
0.091 & 0 & 0.273 \\
0.091 & 0.091 & 0 \\
\end{bmatrix}
\]

\[
X_2 = \begin{bmatrix}
0 & 0.636 & 0.181 \\
0.181 & 0 & 0.363 \\
0.181 & 0.181 & 0 \\
\end{bmatrix}
\]

\[
X_3 = \begin{bmatrix}
0 & 0.727 & 0.273 \\
0.273 & 0 & 0.454 \\
0.273 & 0.273 & 0 \\
\end{bmatrix}
\]

5. Finally, the interdependence matrix is calculated from the defuzzification of the matrices obtained from the previous procedure. For example, calculations for the first entry of matrix are presented as follows.

\[
T_1 = X_1 (I - X_1)^{-1} \quad T_1 = \begin{bmatrix}
0.0799 & 0.6127 & 0.2655 \\
0.1283 & 0.0983 & 0.3115 \\
0.1099 & 0.1557 & 0.0525 \\
\end{bmatrix}
\]

\[
T_2 = X_2 (I - X_2)^{-1} \quad T_2 = \begin{bmatrix}
0.2648 & 0.9053 & 0.5576 \\
0.3340 & 0.3094 & 0.5358 \\
0.2894 & 0.4009 & 0.1979 \\
\end{bmatrix}
\]

\[
T_3 = X_3 (I - X_3)^{-1} \quad T_3 = \begin{bmatrix}
0.7784 & 1.6271 & 1.2242 \\
0.8058 & 0.8787 & 1.0729 \\
0.7035 & 0.9571 & 0.6271 \\
\end{bmatrix}
\]

And the interdependency matrix is as follows:

\[
\text{Defuzzy}(t_{ij}) = \frac{t_{ij}^6 + 4t_{ij}^4 + t_{ij}^2}{6} = \frac{0.0799 + 4 \times 0.2648 + 0.7784}{6} = 0.3195
\]

Step 4 The interdependency matrix obtained from the previous step is applied to the weight of factors from Step 2 as follows:

\[
\begin{bmatrix}
0.3112 & 0.5431 & 0.4267 \\
0.3685 & 0.2052 & 0.4046 \\
0.3203 & 0.2517 & 0.1687 \\
\end{bmatrix} \times \begin{bmatrix}
0.2898 \\
0.3722 \\
0.338 \\
\end{bmatrix} = \begin{bmatrix}
0.43655 \\
0.31992 \\
0.24353 \\
\end{bmatrix}
\]

Accordingly, the local weights of criteria are obtained using the interdependence matrix. Then, the local weights of criteria are applied to the local weights of sub-criteria along with the application of their interdependence matrix to obtain the global weights of sub-criteria. This procedure is presented in Table 9. The final score results of the mean scores for each supplier is demonstrated in Table 10. The final scores are calculated by the sum of multiplying the sub-criteria’s weight by the evaluation values. According to the experts’ opinions, suppliers with a minimum
Based on Table 10, alternatives 1, 2, 3, and 4 are the selected suppliers.

Second stage In this stage, the GAMS 24.1/CPLEX software is used to validate the model. The required information for supply, distribution, and recycling was extracted from the historical data of the factory and the data of other levels was simulated with the assistance of experts. The proposed model was run for three products, three distribution centres, four selected suppliers, six customers, three potential collection, recycling and disposal centres, four price levels, and six vehicles.

Due to the existence of uncertainty in cost and demand figures, the fuzzy approach proposed by Zimmermann (1978) and Lin (2012) is used to solve the model.

\[
\begin{align*}
\text{Max } & \alpha \\
\text{Subject to :} & \\
\alpha & \leq \mu_{z_{\text{max}}} (x) \\
\alpha & \leq \mu_{z_{\text{min}}} (x) \\
\alpha & \leq \mu_{z_{\text{gi}}} (x) \\
\end{align*}
\]

These membership functions are defined as follows (Zimmermann, 1978):

\[
\mu_{z_{\text{max}}} (x) = \begin{cases} 
1 & z_k > z_k^{\text{positive}} \\
0 & z_k^{\text{negative}} \leq z_k \leq z_k^{\text{positive}} \\
\end{cases}
\]

\[
\mu_{z_{\text{min}}} (x) = \begin{cases} 
1 & z_k < z_k^{\text{negative}} \\
0 & z_k^{\text{positive}} \leq z_k \leq z_k^{\text{negative}} \\
\end{cases}
\]

(60)
bound to the following constraints:

\[ \begin{align*}
\mu_{z_{x}}(x) = & \begin{cases} 
1 \text{ if } z_{i}(x) > z_{i}^{\text{positive}} \\
0 \text{ if } z_{i}(x) < z_{i}^{\text{negative}} \\
\frac{z_{i}(x) - z_{i}^{\text{negative}}}{z_{i}^{\text{positive}} - z_{i}^{\text{negative}}} \text{ if } z_{i}(x) \leq z_{i}^{\text{positive}}
\end{cases} \\
\mu_{g_{l}}(x) = & \begin{cases} 
1 \text{ if } g_{l}(x) > b_{l} \\
0 \text{ if } g_{l}(x) < b_{l} + d_{l} \\
\frac{1}{d_{l}} - \frac{\left| g_{l}(x) - b_{l} \right|}{d_{l}} \text{ if } b_{l} \leq g_{l}(x) \leq b_{l} + d_{l}
\end{cases}
\end{align*} \]

(61)

(62)

Where the objective function \( z_{k}(z_{i}) \) values change from lower bound \( z_{k}^{\text{negative}} \) (\( z_{k}^{\text{negative}} \)) to upper bound \( z_{k}^{\text{positive}} \) (\( z_{k}^{\text{positive}} \)). Also \( \mu_{z_{x}}(x), \mu_{z_{x1}}(x), \mu_{g_{l}}(x), \) and \( d_{l} \) represent the maximum membership function, minimum membership function, constraints, and tolerance values respectively. Thus, the objective functions are converted to the following constraints:

\[ \begin{align*}
\mu_{z_{x}} = & \frac{1464881000 - z_{x}^{\text{cos t}}}{1464881000} \geq \alpha \\
\mu_{z_{x1}} = & \frac{1130 - z_{x1}^{\text{shortage}}}{1130} \geq \alpha
\end{align*} \]

(63)

(64)

Since customers’ demands vary and are not fixed for all time periods, the average, maximum, and minimum values are determined. It was observed that the demand quantities do not violate more than 10 per cent. Thus, the demand satisfaction constraint (constraint (25)) considering 10 per cent of violations in the degree of demand is indicated as follows:

\[ \begin{align*}
\mu_{z_{x}}^{\text{dem t}} = & \sum_{v_{d}} X_{t_{v_{d}}} + INV_{t_{v_{d}}} + \frac{\sum_{v_{d}} W_{t_{v_{d}}} \times XCS_{CL_{v_{d}}}}{0.1 \times DMND_{t_{v_{d}}}} \geq \alpha \\
\mu_{z_{x}}^{\text{cen}} = & \sum_{v_{d}} X_{t_{v_{d}}} - INV - 0.9 \times DMND_{t_{v_{d}}} - \frac{\sum_{v_{d}} W_{t_{v_{d}}} \times XCS_{CL_{v_{d}}}}{0.1 \times DMND_{t_{v_{d}}}} \geq \alpha
\end{align*} \]

(65)

(66)

Based on these constraints, the model was run in the GAMS 24.1/CPLEX software for 1103.37 s to maximise \( \alpha \) and the following results were obtained in the relative gap of less than 5%. The objective function values are shown in Table 11:

| \( z_{x1}^{\text{dem t}} \) | \( z_{x1}^{\text{shortage}} \) |
|---|---|
| 1130 | 130 |

For instance, the route traveled by the vehicle 1 is from the distribution centre 1 to the customer 5 and then customers 4 and 3, respectively. It is finally returned to the distribution centre 1 after serving customer 2. As the results show, each vehicle returns to its centre after servicing the allocated customers.

- Arrival times to each customer point are calculated as follows:

\[ \begin{align*}
at_{1,5} = 26 & \quad at_{1,4} = 75 & \quad at_{1,3} = 118 & \quad at_{1,2} = 161 & \quad at_{1,1} = 190 \\
at_{2,3} = 34 & \quad at_{2,1} = 68 & \quad at_{3,6} = 24 & \quad at_{3,3} = 57 & \quad at_{3,2} = 96 & \quad at_{3,1} = 121
\end{align*} \]

\( at_{1,5} = 26 \) indicates the arrival time of vehicle 1 to customer 5. Hence, based on the results, it is possible to see the arrival time of each purchased vehicle to each allocated customer.

Based on the second objective function, the model shows shortages of 130 in total demand quantity. The total demand was 1130, out of which 1000 units is satisfied.

### 4.1. Managerial insights

As mentioned earlier, a portion of the data was extracted from the historical data and documents of the company under study, and the remaining datasets were simulated according to the experts’ opinions. In this section, the level of improvement in the chain is presented based on actual data that pertain to the levels of production (plant), distribution, and customers.

Before applying the proposed model, all products manufactured in production line 1 were transferred to three distribution centres in the vicinity of the factory. In other words, each product was allocated to one distribution centre and these products were delivered to customers by six vehicles. With the implementation of the model, it was determined that two distribution centres would suffice for distributing this product among the customers, and three vehicles would be required for transferring these products from distribution centres to customers. The management had allocated each product to one distribution centre to sort and separate products from each other, which had increased the costs of the chain. On the other hand, the non-use of proper routing in the distribution of products among customers had led to the selection of short routes and the increased frequency of vehicular returns to the centres. Thus, the number of vehicles for this task, increased fuel consumption, environmental pollution, and, eventually, the chain costs had experienced an increase. The analysis of the results of the proposed mode in the production, distribution, and customer...
levels led to the removal of one distribution centre and three vehicles, which had a significant impact on costs and environmental pollution.

5. Conclusions

Circular economy offers much potential to help firms and organisations achieve dramatic impact on sustainability of supply chains. However, it has not received enough attention so far. This paper sets out to integrate CE in supplier selection and supply chain network design. To do so, in this paper, a two-stage hybrid approach is developed to fill circular supplier selection and order allocation in a CLSC by means of MCDM methods and a MOMILP. This approach concurrently focuses on the minimisation of the network costs and shortages. In the first stage, the suppliers of the studied firm were evaluated using three criteria, namely circularity, quality, and on-time delivery through the integrated approach of FANP and FDEMATEL; then, four qualified suppliers were selected from them. In the second stage, a mathematical model was developed and all the four selected suppliers were chosen for collaboration after the model’s implementation in GAMS software. The proposed model led to the reduction of one distribution centre and three vehicles. Consequently, this brought about a reduction in costs and emissions.

The suppliers’ evaluations phase was conducted based on circular and traditional criteria; it is suggested that social research be taken into account in future research in order to select sustainable suppliers (Kannan, 2018). The design of a circular/sustainable supply chain network, considering the inventory-location-routing problem, is also an attractive problem that is suggested to be considered as a future research direction. Using new methods such as the fuzzy best-worst method, and its combination with other decision-making methods, can also be suggested for future research. As the last suggestion, due to the NP-hardness of the problem, employing meta-heuristic algorithms could ease the solvability of the considered models.

References

Aissouei, N., Hauouari, M., Hissini, E., 2007. Supplier selection and order lot sizing modeling: a review. Comput. Oper. Res. 34 (12), 3516–3540. https://doi.org/10.1016/j.cor.2006.01.012.

Akcali, E., Cetinkaya, S., 2011. Quantitative models for inventory and production planning in closed-loop supply chains. Int. J. Prod. Res. 49 (8), 2373–2407. https://doi.org/10.1080/00207540903692021.

Amin, S.H., Zhang, G., 2012. An integrated model for closed-loop supply chain network design problem with simultaneous pickups and deliveries under carbon cap-and-trade. Sustainability 9 (12), 2198.

Bafrooei, A.A., Mina, H., Ghaderi, S.F., 2014. A supplier selection problem in petrochemical industry using common weight data envelopment analysis with qualitative criteria. Int. J. Ind. Syst. Eng. 18 (3), 404–417. https://doi.org/10.1080/10286697.2014.605542.

Banerji, N., Mobhi, F., Fahimnia, B., Nielsen, E.E., Omid, M., 2018. Green supplier selection using fuzzy group decision making methods: a case study from the agri-food industry. Comput. Oper. Res. 89, 337–347.

Baraki, R.R., Kianifar, F., 2017. A fuzzy mathematical model for supplier selection and order allocation considering green vehicle routing problem. Int. J. Logist. Syst. Manag. 12 (2), 151–163. https://doi.org/10.1504/IJLSM.2017.083381.

Bozbura, F.T., Beskese, A., 2007. Prioritization of organizational capital measurement indicators using fuzzy AHP. Int. J. Approx. Reason. 44 (2), 124–147. https://doi.org/10.1016/j.ijar.2006.07.005.

Cardoso, S.R., Barbosa-Póvoa, A.P.F., Belvas, S., 2012, Design and planning of supply chains with consideration of reverse logistics activities under demand uncertainty. Eur. J. Oper. Res. 226 (3), 436–451. https://doi.org/10.1016/j.ejor.2012.11.035.

Chatterjee, K., Pamucar, D., Zavadskas, E.K., 2018. Evaluating the performance of suppliers based on using the R’AMATEL-MAIRCA method for green supply chain implementation in electronics industry. J. Clean. Prod. 184, 101–129. https://doi.org/10.1016/j.jclepro.2018.02.186.

Chen, Y.W., Wang, L.C., Wang, A., Chen, T.L., 2017. A particle swarm approach for optimizing a multi-stage closed loop supply chain for the solar cell industry. Robot. Comput. Integr. Manuf. 43, 111–123.

Chung, C.C., Chao, L.C., Lou, S.J., 2016. The establishment of a green supplier selection and guidance mechanism with the ANP and IPA. Sustainability 8 (3), 235.

Dagdeviren, M., Yüksel, I., 2010. A fuzzy analytic network process (ANP) model for measurement of the sectoral competition level (SCL). Expert Syst. Appl. 37 (2), 1005–1014. https://doi.org/10.1016/j.eswa.2009.05.074.

Darbari, J.D., Kannan, D., Agarwal, V., Jha, P.C., 2019. Fuzzy criteria programming approach for optimizing the TBL (triple bottom line) performance of closed loop supply chain network design problem. Ann. Oper. Res. 273 (1–2), 693–738.

Demirata, E.A., Ustun, D., 2008. An integrated multiobjective decision making process for supplier selection and order allocation. Omega 36 (1), 76–90. https://doi.org/10.1016/j.omega.2005.11.003.

Debs, L., Voïròsami, G., 2019. Inventory-related costs in green supplier selection problems with Data Envelopment Analysis (DEA). Int. J. Prod. Econ. 209, 374–380. https://doi.org/10.1016/j.ijpec.2018.09.017.

dos Santos, B.M., Godoy, L.P., Campos, L.M., 2019. Performance evaluation of green suppliers using entropy-TOPSIS-F. J. Clean. Prod. 207, 498–509. https://doi.org/10.1016/j.jclepro.2019.05.037.

EMF (Ellen MacArthur Foundation), 2017. What is a circular economy? https://www.ellenmacarthurfoundation.org/circular-economy. Accessed 14/03/2018.

European Commission, 2015. Closing the Loop – an EU Action Plan for the Circular Economy. COM(2015) 614 Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. European Commission, Brussels.

Fang, X., Du, Y., Qiu, Y., 2017. Reducing carbon emissions in a closed-loop production routing problem with simultaneous pickups and deliveries under carbon cap-and-trade. Sustainability 9 (12), 2198.

Fleischmann, M., Beullens, P., Bloemhof-Ruwaard, J.M., Wassenhove, L.N., 2001. The impact of product recovery on logistics network design. Prod. Oper. Manag. 10 (27), 221–237. https://doi.org/10.1002/1099-1401(200104)10:2<221::AID-POM77>3.0.CO;2-L.

Fleischmann, M., Bloemhof-Ruwaard, J.M., Dekker, R., Van der Laan, E., Van Nunen, J.A., Van Wassenhove, L.N., 1997. Quantitative models for reverse logistics: a review. Eur. J. Oper. Res. 103 (1), 1–17. https://doi.org/10.1016/S0377-2217(96)00037-9.

Geissdoerfer, M., Savaget, P., Bocken, N.M.P., Hultink, E.J., 2017. The circular economy – a new sustainability paradigm? J. Clean. Prod. 143, 757–768.

Genovese, A., Acquaye, A.A., Figueroa, A., Kob, S.C.L., 2017. Sustainable supply chain management and the transition towards a circular economy: evidence and some applications. Omega 66, 344–357.

Ghayebloo, S., Tarokh, M.J., Venkatadri, U., Diallo, C., 2015. Developing a bi-objective model of the closed-loop supply chain network with green supplier selection and disassembly of products: the impact of parts reliability and product greenness on the recovery network. J. Manuf. Syst. 36, 76–86. https://doi.org/10.1016/j.jmsy.2015.02.011.

Gönen, H.G., 2018. A decision framework for sustainable supplier selection and order allocation with lost sales. J. Clean. Prod. 183, 1156–1169.

Govindan, K., Sivakumar, R., 2016. Green supplier selection and order allocation in a low-carbon paper industry: integrated multi-criteria heterogeneous decision-making and multi-objective linear programming approaches. Ann. Oper. Res. 238 (1–2), 243–276. https://doi.org/10.1007/s10479-015-1904-4.

Govindan, K., Bouzon, M., 2018. From a literature review to a multi-perspective framework for reverse logistics barriers and drivers. J. Clean. Prod. 187, 318–337. Govindan, K., Noorul Haq, A., Devika, M., 2009, A review of reverse logistics and closed-loop supply chains: a Journal of Cleaner Production focus. J. Clean. Prod. 142, 371–384.

Govindan, K., Noorul Haq, A., Devika, M., 2009. Analysis of closed loop supply chain using genetic algorithm and particle swarm optimization. Int. J. Prod. Res. 47 (5), 1175–1200. https://doi.org/10.1080/00207540701543585.

Govindan, K., Khodaverdi, R., Jafari, A., 2013. A fuzzy multi-criteria approach for measuring sustainability performance of a supplier based on triple bottom line approach. J. Clean. Prod. 47, 343–354.
Govindan, K., Rajendran, S., Sarkis, J., Murugesan, P., 2015a. Multi criteria decision making approaches for green supplier evaluation and selection: a literature review. J. Clean. Prod. 98, 66–83.

Govindan, K., Sasikumar, P., Devika, K., 2010. A genetic algorithm approach for solving a closed loop supply chain model: a case of battery recycling. Appl. Math. Model. 34 (3), 655–670. https://doi.org/10.1016/j.apm.2009.06.021.

Govindan, K., Soleimani-Damghani, K., Kannan, D., 2015b. Reverse logistics and closed-loop supply chain: a comprehensive review to explore the future. Eur. J. Oper. Res. 240 (3), 603–626. https://doi.org/10.1016/j.ejor.2014.07.012.

Govindan, K., Shankar, M., Kannan, D., 2018. Supplier selection based on corporate social responsibility practices. Int. J. Prod. Econ. 200, 353–375.

Grisi, R.M., Guerra, L., Naviglio, G., 2010. Supplier performance evaluation for GreenSupply chain management. In: Business Performance Measurement and Management Part4, pp. 149–163. https://doi.org/10.1087/978-3-642-048000-5_14.

Guamier, P., Trojan, F., 2019. Decision making on supplier selection based on social, ethical, and environmental criteria: a study in the textile industry. Resour. Conserv. Recycl. 140, 36–48. https://doi.org/10.1016/j.resconrec.2019.01.026.

Guide Jr, V.D.R., Van Wassenhove, L.N., 2009. ORFORM-The evolution of closed-loop supply chain research. Oper. Res. 57 (1), 10–18. https://doi.org/10.1287/opre.1080.0628.

Guneri, A.F., Yucel, A., Ayyildiz, G., 2009. An integrated fuzzy-Ip approach for a supplier selection problem in supply chain management. Expert Syst. Appl. 36 (5), 9223–9228. https://doi.org/10.1016/j.eswa.2009.05.008.

Guo, H., Li, C., Zhang, Y., Zhang, C., Wang, Y., 2018. A Nonlinear Integer Programming Model for Integrated Location, Inventory, and Routing Decisions in a Closed-Loop Supply Chain: a case study. J. Clean. Prod. 175, 258–282. https://doi.org/10.1016/j.jclepro.2018.04.105.

Gunther, J., Kannan, D., 2018. Risk analysis in green supply chain using fuzzy AHP approach: a case study. Resour. Conserv. Recycl. 134, 375–390. https://doi.org/10.1016/j.resconrec.2018.01.001.

Mardian, E., Govindan, K., Mina, H., Gholamzangi, S.M., 2019. An accelerated benders decomposition algorithm to solve a biobjective green closed loop supply chain network design problem. J. Clean. Prod. 235, 1499–1514.

Mav, R.K., 2015. Green supplier selection: a fuzzy AHP and fuzzy ARAS approach. Int. J. Sustain. Manag. 36, 152–166. https://doi.org/10.1504/IJMCP.2016.079837.

N, H., Mirabedini, S.P., Pakzad-Moghadam, S.H., 2014a. An integrated fuzzy analytic network process approach for green supplier selection: a case study of Petrochemical industry. Management Science and Practice 2 (2), 31–47.

Mirzae, H., Naderi, B., Pashadideh, S.H.R., 2018. A preemptive fuzzy goal programming model for generalized supplier selection and order allocation with incremental discount. Comput. Ind. Eng. 122, 292–302.

Mohammed, A., Seth, R., Filip, M., Harris, L., Li, X., 2018. An integrated methodology for a sustainable two-stage supplier selection and order allocation problem. J. Clean. Prod. 192, 99–114.

Motshoile, X., Tyetse, D., Wehrmeyer, W., Wagner, M., 2001. Environmental indicators for business: a review of the literature and standardisation methods. Int. J. Prod. Res. 9 (5), 1035–1050. https://doi.org/10.1080/00207540500357476.

Park, K., Kremer, G.E.O., Ma, J., 2018. A regional information-based multi-attribute and multi-objective decision-making approach for sustainable supplier selection and order allocation. J. Clean. Prod. 187, 590–604. https://doi.org/10.1016/j.jclepro.2018.08.052.

Parkhouri, S.V., Ghadiokolaei, A.S., Lajimi, H.F., 2019. Resilient supplier selection and segmentation in grey environment. J. Clean. Prod. 207, 1123–1137. https://doi.org/10.1016/j.jclepro.2018.10.007.

Patil, R.K., Vrat, P., Kumar, P., 2008. A goal programming model for paper recycling system. J. Clean. Prod. 16 (3), 285–296. https://doi.org/10.1016/j.jclepro.2006.04.014.

Pishvaee, M.S., Torabi, S.A., 2010. A possibilistic programming approach for closed-loop supply chain network design under uncertainty. Fuzzy Sets Syst. 160, 2688–2693. https://doi.org/10.1016/j.fss.2009.04.005.

Popa, V.N., Popa, L.I., 2016. Green product lifecycle management of industrial products. In: The Circular Economy, IOP Conference Series: Materials Science and Engineering, IOP Publishing, p. 012112.

Qazvini, Z.E., Amalnick, M.S., Mina, H., 2016. A green multi-depot location routing problem with split delivery. IEEE. In: Industrial Products. In: The Circular Economy, IOP Conference Series: Materials Science and Engineering. IOP Publishing, p. 012112.

Rashidi, K., Saen, R.F., 2018. Incorporating dynamic concept into gradual efficiency: improving suppliers in sustainable supplier development. J. Clean. Prod. 202, 226–243. https://doi.org/10.1016/j.jclepro.2018.08.052.

Rubio, S., Chamorro, A., Miranda, F.J., 2008. “Characteristics of the research on reverse logistics (1995–2005).” Int. J. Prod. Res. 46 (4), 1099–1120. https://doi.org/10.1080/00207540600943977.

Sadeghi, A., Mina, H., Bahrami, N., 2019. A mixed integer linear programming model for designing a green closed-loop supply chain network considering location-routing problem. Int. J. Logist. Syst. Manag. in Press.

Sahiner, O., Nurdin, N., Neldor, N.A., 2018. Sustainable tire closed-loop supply chain network design: hybrid metaheuristic algorithms for large-scale networks. J. Clean. Prod. 196, 273–296.

Sari, T., Timor, M., 2016. Integrated supplier selection model using ANP, Taguchi loss function and PROMETHEE methods. Journal of Applied Quantitative Methods 11 (1), 19–34. https://doi.org/10.1080/15501477.2016.1204060-y.

Scur, C., Barbosa, M.E., 2017. Green supply chain management practices: multiple case studies in the Brazilian home appliance industry. J. Clean. Prod. 141, 1137–1148. https://doi.org/10.1016/j.jclepro.2016.11.005.

Shankar, K.M., Kannan, D., Kumar, P.U., 2017. Analyzing sustainable manufacturing systems and decision-making: A review. Int. J. Prod. Econ. 186, 1123–1130. https://doi.org/10.1016/j.ijpe.2016.11.005.

Shir, J., Zhang, G., Sha, J., 2011. Optimal production planning for a multi-product closed loop system with uncertain demand and return. Comput. Oper. Res. 38 (3), 641–650. https://doi.org/10.1016/j.cor.2010.08.008.
Soleimani, H., Chaharlang, Y., Ghaderi, H., 2018. Collection and distribution of returned-remanufactured products in a vehicle routing problem with pickup and delivery considering sustainable and green criteria. J. Clean. Prod. 172, 960–970. https://doi.org/10.1016/j.jclepro.2017.10.124.

Soleimani, H., Govindan, K., Saghaifi, H., Jafari, H., 2017. Fuzzy multi-objective sustainable and green closed-loop supply chain network design. Comput. Ind. Eng. 109, 191–203.

Taleizadeh, A.A., Haghighi, F., Niaki, S.T.A., 2019. Modeling and solving a sustainable closed loop supply chain problem with pricing decisions and discounts on returned products. J. Clean. Prod. 207, 163–181. https://doi.org/10.1016/j.jclepro.2018.09.198.

Tate, W.L., Ellram, L.M., Kirchoff, J.F., 2010. Corporate social responsibility reports: a thematic analysis related to supply chain management. J. Supply Chain Manag. 46 (1), 19–44. https://doi.org/10.1111/j.1745-493X.2009.03184.x.

Tavana, M., Yazdani, M., Di Caprio, D., 2017. An application of an integrated ANP–QFD framework for sustainable supplier selection. International Journal of Logistics Research and Applications 20 (3), 254–275.

Thongchattu, C., Siripokapirom, S., 2010. Notice of retraction green supplier selection consensus by neural network. Mechanical and Electronics Engineering 2010 2nd International Conference on 2, 313. https://doi.org/10.1109/ICMEE.2010.5558417.

Üster, H., Easwaran, G., Akçali, E., Çetinkaya, S., 2007. “Benders decomposition with alternative multiple cuts for a multi-product closed-loop supply chain network design model. Nav. Res. Logist. 54 (8), 890–907. https://doi.org/10.1002/nav.20262.

Vahidi, F., Torabi, S.A., Ramezankhani, M.J., 2018. Sustainable supplier selection and order allocation under operational and disruption risks. J. Clean. Prod. 174, 1351–1365.

Vieira, K.R.O., Battistelle, R.A.G., Bezerra, B.S., de Castro, R., Jabbour, C.J.C., Deus, R.M., 2018. An exploratory study of environmental practices in two Brazilian higher education institutions. J. Clean. Prod. 187, 940–949. https://doi.org/10.1016/j.jclepro.2018.03.260.

Wang, T.Y., Yang, Y.H., 2009. A fuzzy model for supplier selection in quantity discount environments. Expert Syst. Appl. 36 (10), 12179–12187. https://doi.org/10.1016/j.eswa.2009.03.018.

Wijes, S., Lozano, R., 2016. Towards a more Circular Economy: proposing a framework linking sustainable public procurement and sustainable business models. Resour. Conserv. Recycl. 112, 37–44.

Yadav, V., Sharma, M.K., 2015. An application of hybrid data envelopment analytical hierarchy process approach for supplier selection. J. Enterp. Inf. Manag. 28 (2), 218–242. https://doi.org/10.1108/JEIM-04-2014-0041.

Yücel, A., Güneri, A.F., 2011. A weighted additive fuzzy programming approach for multi-criteria supplier selection. Expert Syst. Appl. 38 (5), 6281–6286. https://doi.org/10.1016/j.eswa.2010.11.086.

Zhang, X., Deng, Y., Chan, F.T., Mahadevan, S., 2015. A fuzzy extended analytic network process-based approach for global supplier selection. Appl. Intell. 43 (4), 760–772. https://doi.org/10.1007/s10489-015-0664-z.

Zimmermann, H.J., 1978. Fuzzy programming and linear programming with several objective functions. Fuzzy Sets Syst. 1 (1), 45–55. https://doi.org/10.1016/0165-0114(78)90031-3.