RAIRO-Oper. Res. 51 (2017) 875–902
DOI: 10.1051/ro/2016070

RAIRO Operations Research
www.rairo-ro.org

A MULTI-PRODUCT MODEL FOR EVALUATING AND SELECTING TWO LAYERS OF SUPPLIERS CONSIDERING ENVIRONMENTAL FACTORS

Alireza Eydi[1] and Mahnaz Bakhtiari[2]

Abstract. New requirements and developments in the world of business and commerce era provide a background to the emergence of new attitudes which are essential for those involved in the field of production and trade. In this regard, there are new approaches and attitudes toward the subject matter of supply chain which is following an approach to a green chain *via* environmental requirements. In this study, not only the suppliers directly associated with the company, but also those providing raw materials for manufacturers were also considered in a second layer of supply chain, so as to select optimal suppliers from the both layers. Considering the first and second layers of suppliers as well as the green factor, a criteria called "second layer" was developed, with its associated fuzzy numbers been calculated using a proposed method, so as to rank suppliers on the first layer in hierarchical fuzzy TOPSIS method based on different levels of alpha. Finally, in order to assign orders to suppliers from the first and second layer, multi-objective linear programming was used to formulate various constraints such as size of each supplier on either the first or second layers as well as the capacity of the communication paths between suppliers on the first layer and the buyer, with respect to extenuating circumstances. In this paper, a multi-product model is proposed to solve multiple sourcing supplier problem in green supply chains considering environmental issues. The proposed model aims to maximize value of the suppliers while minimizing the costs associated with environmental pollutions, purchasing expenses, fixed ordering cost, transportation costs and penalties for returned goods. The solution method succeed to improve epsilon constraint in GAMS Software. The efficiency and applicability of the proposed approach is further illustrated with a case study in a washing machine manufacturing company.

Mathematics Subject Classification. 90B50.

Received July 13, 2016. Accepted October 20, 2016.

1. Introduction

In a competitive environment, supplier selection represents one of the most critical issues faced by manufacturing firms. Cost of parts and raw materials in such industries comprises a major portion of product's final cost, so that the selection of appropriate suppliers can significantly reduce purchasing costs. Saving on production costs contributes, significantly, to survival in the today's competitive environment (Ghodsypour and O'Brien [25], Ghodsypour and O'Brien [24], Kannan *et al.* [37], Amid, *et al.* [8]). Due to increased public

Keywords. Supply chain management, multi-objective optimization, two layers of suppliers, hierarchical fuzzy TOPSIS, the augmented e-constraint method.

[1] Department of Industrial Engineering, University of Kurdistan, Sanandaj. Iran, alireza.eydi@uok.ac.ir

[2] Masters student of Industrial Engineering, University of Kurdistan, Sanandaj, Iran, baxtiarim70@yahoo.com

Article published by EDP Sciences

awareness regarding the necessity of protecting the environment and associated governmental legislations, firms may not ignore environmental issues given their tendency to maintain their competitive advantages in current globalization trend. Growth of environmental concerns means that it is necessary to consider environmental pollution issues including industrial development in supply chain management activities, leading to the emerging concept of green supply chain management (GSCM) Hsu and Hu [31], Diabat and Govindan [20]. In recent years, companies have implemented several regulatory checks and programs to ensure that suppliers can provide materials and services both with high quality and respecting environmental standards Ku *et al.* [42]. GSCM is generally recognized as the activity of having suppliers monitored based on their environmental performance, so as to collaborate only with green suppliers who respect environmental standards Hsu and Hu [31]. Hence, to the best of our knowledge, a study that propose supplier selection based on the adoption of GSCM practices, which is a modern environmental sustainability concept, by suppliers, is yet to be done. GSCM offers an extended perspective on environmental management where practices adopted both inside and outside the company are considered Ageron *et al.* [1]; this approach can generate more business opportunities for firms Wang and Chan [74]. This new legislation requires firms and municipalities to adopt proactive green management values and practices, and companies are feeling pressured to enact these environmentally sensitive practices in a timely manner de Sousa Jabbour *et al.* [70].

Most authors have addressed supplier selection issues in green supply chain from an environmental point of view *e.g.* Rao [59], Kannan and Vinay [39], Hsu and Hu [31], Bai and Sarkis [11], Yeh and Chuang [82], Hsu *et al.* [32], Govindan, Khodaverdi, and Jafarian [26], Tseng and Chiu [72], Kuo *et al.* [45], Büyüközkan and Çifçi [14]); further, many researchers have applied different mathematical programming methods and hybrid techniques to solve supplier selection and order allocation problem (*e.g.* Amid *et al.* [7], Yigin *et al.* 2007, Kokangul and Susuz [41], Wu *et al.* [78], Chen [18], Zeydan *et al.* [86], Amin *et al.* [9]). As mentioned before, many studies have discussed traditional supply chain management and green supplier selection, but limited work has been donning on developing practical order allocation methods to solve multiple sourcing supplier problem in green supply chains. So, the process of supplier selection is introduced by a new research area known as green supplier selection; this new research area suffers from many research gaps which are to be explored Kumar *et al.* [43]. Green supplier selection should be considered important when companies are looking for greener supply chain management including, for example, remanufacturing targets Xiong *et al.* [80].

Various approaches and models have been used to solve the problem; however, in all of the solutions, suppliers were always selected from the first layer, leaving the suppliers on the second layer paid no attention. In many academic studies, no emphasis has been put on the fact that raw materials have an important influence on quality and price of final components, and that, as elements of supply chain, suppliers of suppliers can affect effectiveness and competitiveness of the supply chain Nobar and Setak [55]. Indeed, buyers can determine the best suppliers on the second layer by evaluating them using various criteria, and suggest them to their direct suppliers when contracting, or they can refer to this as one of the clauses in the contract.

Essentially, two types of supplier selection are prominent:

- In the first type (single sourcing), one supplier can satisfy entire buyer's needs, so that the buyer needs to make only one decision: which supplier is the best?
- In the second and more common type (multiple sourcing), more than one supplier must be selected as no single supplier can provide all buyer's orders.

Thus, companies need to not only select the best suppliers, but also to determine how much quantity should be allocated to each of the best suppliers, so as to create a stable environment of competitiveness Alyanak and Armaneri [6]. Accordingly, multiple sourcing provides significant assurance of timely delivery and order flexibility due to the diversity of the firm's total orders Ghodsypour and O'Brien [25], Kumar *et al.* [44], Aissaoui *et al.* [3], Jolai *et al.* [36]. With supplier selection problem being a multi-criteria decision making problem which needs to be solved by appropriate approaches, different individual and integrated approaches have been proposed for this problem Ho *et al.* [30]. As an instance, Liao and Kao [49] applied a combination of Taguchi loss function, AHP, and goal programming approaches to select the best supplier. YüCel and GüNeri [84] solved the multi-criteria decision making problem of supplier selection using multi-objective fuzzy programming. Their method begins with determining weights of criteria using trapezoidal fuzzy numbers. Then, the supplier selection problem and order assignment to suppliers were solved according to the weights as well as suppliers' objectives and limitations using a multi-criteria fuzzy programming model. Mafakheri *et al.* [51] applied a two-phase method based on multi-criteria dynamic programming to solve supplier selection and order assignment problems. In the first phase, suppliers were ranked following an AHP approach. Then, the ranked suppliers were incorporated into an order assignment model seeking to maximize the utility function while minimizing total costs of the supply chain respecting demand, capacity, and inventory constraints. Chai [15] provided a systematic literature review on 123 journal articles published from 2008 to 2012 on the application of decision making (DM) techniques for supplier selection; they indicated that the most frequently used technique has been AHP followed by linear programming (LP) and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). Wu and Barnes [77] reviewed the literature on supply partner decision-making published between 2001 and 2011 and concluded that the most popular hybrid approaches to supplier selection problem have been the models that include mathematical programming, AHP/ANP, or fuzzy set approaches.

Hence, the present paper introduces a multi-objective programming approach to solve so-called multiple sourcing supplier problem in green supply chains. The model's objectives are to maximize the value of suppliers while minimizing the costs due to environmental pollutions, purchasing expenses, fixed ordering cost, transportation costs and penalties for returned goods. Used for this purpose was hierarchical Fuzzy TOPSIS method based on different levels of alpha, using which suppliers were ranked and weighted. Taking into account the characteristics of the second-layer suppliers, weights of the first-layer suppliers were obtained to be used in presented green supply chain model. Then a two-objective mixed integer linear programming model (MILP) was presented for supply chain network design, wherein carbon emission, as one of the most important environmental pollutants, was taken into consideration. The most important feature of this model is its multi-product nature which allows suppliers to order different products simultaneously. The rest of paper is organized as follows. Section 2 provides a comprehensive survey on literature discussing green supply chain management, supplier selection criteria, green supplier selection, and selection of two layers of suppliers. Section 3 introduces an integrated approach to the evaluation and selection of green suppliers; the section includes discussions on fuzzy set theory, first and second-layer suppliers' evaluation criteria, assessment criteria for the "second layer", hierarchical fuzzy TOPSIS method, the proposed MILP green model and its solution (*via* augmented epsilon-constraint method). In Sections 4 and 5, the proposed method is illustrated with a case study in a washing machine manufacturing company, with the results being subjected to sensitivity analysis. Finally, Sections 6 and 7 present managerial implications, concluding remarks, research limitations, and future works.

2. Literature review

2.1. Green supply chain management

Green supply chain management is not a concept agreed by all researchers Ahi and Searcy [2]. However, the majority of authors believe that it emerges from the ideas that companies must become greener Alfred and Adam [5], must try to reach a win-win perspective (Hart and Dowell [29]) and must establish a link between their supply chains and sustainable development Seuring [66]. The concepts of GSCM emerged from the realization that isolated implementations of environmental practices by companies are not as effective as collective actions that make the entire supply chain greener Ageron *et al.* [1]. This broader systematic perspective of environmental management dispersed among all players in a supply chain has been called GSCM Linton *et al.* [50]. This concept is a part of the broad effort to align operations management with the goal of improving the quality of life in society and it is a theme that requires more attention and emphasis in future studies Sarkis [63]. GSCM is, therefore, a part of the environmental dimension of the Sustainable Supply Chain Management (SSCM) concept Seuring and Müller [67]. SSCM can be defined as the management of materials, the distribution of information, the flow of capital, and the cooperation among companies in a supply chain as they strive to improve their economic, environmental, and social performances while simultaneously considering the expectations of other stakeholders Seuring and Müller [67]. The interest of the scientific community in this subject is increasing quickly Seuring [66].

From this literature review, several definitions of GSCM deserve attention:

- GSCM encompasses a set of environmental practices that encourage improvements to the environmental practices of two or more organizations within the same supply chain Vachon, *et al.* [73].
- GSCM is the process of incorporating environmental concerns into supply chain management including product design, material sourcing and selection, manufacturing, delivery of final products, and the management of product's end-of-life Srivastava [71].
- GSCM can be achieved by considering environmental issues at the purchasing, product design and development, production, transportation, packaging, storage, disposal, and end of product's life cycle management stages Min and Kim [54].
- GSCM is the integration of environmental concerns in the inter-organizational practices of supply chain management Sarkis *et al.* [64].

Some recent findings confirm the relevance of GSCM to success for many companies. For example, investigating automotive industry in a developing country, Diabat *et al.* [21] found design for environment, collaboration with clients, and reverse logistics as the three most relevant GSCM practices. Based on a survey on163 container shipping firms in Taiwan, Yang *et al.* [81] determined that internal green practices and external green collaboration imposed positive impacts on green performance, so that firms could enhance their competitiveness *via* GSCM practices. GSCM is particularly relevant in contemporary organizational management because it can create synergy with other managerial principles such as lean manufacturing Dües *et al.* [23]. However, not all companies adopt GSCM practices equally Lai and Wong [46]. For example, Ageron *et al.* [1] studied more than 170 French companies to analyze the degree to which environmental sustainability was incorporated into supply chain management. They discovered that: (a) strategic plans and actions serve as a foundation for the adoption of green supply chain management; (b) size of company and its international activities may influence its participation in a green supply chain; and (c) waste management comprised central theme of the companies. In developing countries, GSCM may not be seen as a realistic option for most firms Diabat *et al.* [21].

2.2. Green supplier selection

The increased inclusion of environmental considerations in the fields of operations management and supply chains has become a strong trend Gunasekaran and Ngai [27]. One of the most important GSCM practices is to set environmental considerations in supplier selection, maintenance, and development Dekker *et al.* [19].

There are many studies wherein green supplier selection has been discussed. For example, Large and Thomsen [47] utilized data from more than 100 German companies and discovered that the degree of green supplier assessment and the level of green collaboration may impose direct influences on a company's environmental performance. These two practices are driven at strategic level by the firm's purchasing department and through its level of environmental commitment. Other researchers have consistently indicated that including environmental considerations in supplier selection has been a fundamental practice among organizations that strive for sustainability Sarkis [61]. However, although there is a consensus about the importance of supplier selection using environmental criteria, some challenges exist in developing robust selection methods Humphreys *et al.*[34]. Accordingly, several studies have proposed a variety of approaches to overcome these challenges. Govindan *et al.* [26] explored sustainable supply chain initiatives and presented a fuzzy multi-criteria approach to identify an effective model for supplier selection in supply chains based on the triple bottom line (TBL) approach (*i.e.*, economic, environmental, and social considerations). Hsu and Hu [31] presented an Analytic Network Process (ANP) approach to incorporate the issue of Hazardous Material Management (HSM) into the supplier selection. An illustrative example in an electronics company was presented to demonstrate how to select the most appropriate supplier in accordance with environmental regulatory requirements on hazardous materials. However, environmental evaluation of the GSCM practices that suppliers could adopt is lacking. Suppliers who adopt

GSCM practices may encourage improved environmental performance throughout the entire supply chain. Advances in the development of novel GSCM approaches for selecting suppliers may help those companies which are still struggling with green supplier selection Handfield *et al.* [28].

2.3. Selection of two layers of suppliers

Different approaches and models have been used to solve the selection problem; however, they have always considered the suppliers on the first layer, *i.e.* the ones connected directly to the customer, with no attention paid to those on the second layer. This is despite the fact that most firms see the second layer's suppliers as especially important and although the proposed models and academic studies have not paid much attention to these suppliers, materials and components used can have a significant impact on the quality and price of the final parts.

Osman and Demirli [57] introduced a strategic supply chain reconfiguration and supplier selection model. The configuration of this chain included two stages of multiple suppliers. The initial stage was the layer 2 (T2 supplier), while the intermediate stage was the layer 1 (T1-supplier). The most downstream stage, however, was an assembly facility. The model was developed to improve on time delivery performance of the supply chain and reallocate the capacity available to each supply chain member in order to face an expected demand increase. Results of the proposed model specified the selected suppliers and provided the amounts that should be delivered to each supply chain member on a yearly basis. Osman and Demirli [58] developed a bilinear goal programming model to find compromising solutions where the company's requirements were distributed among reliable suppliers while the distribution cost was minimized. The first two objectives were the sources of bi-linearity in the model through the multiplication of binary variables representing the selected suppliers and established links among them by continuous variables representing the material distribution through the network. The model could be applied to configure new supply chains by distributing materials among the best candidate suppliers.

Nobar and Setak [55] proposed an article including a novel approach to supplier selection with an overview on top suppliers in the previous layer. Then, using a combined method, the concepts of fuzzy set theory and linear programming were utilized to propose the model which was subsequently examined in terms of accuracy using actual data derived from an engineering design company and component suppliers. This article was the first to consider more than one layer of suppliers, indicating that other layers could affect the quality of the entire supply chain and overall cost. In their paper, Setak and Sharifi [65] proposed an integrated model to select suppliers from the two layers in supply chain; indeed, the integrated multi-objective linear and integer programming model provided served as a tool to reduce supply chain costs, where not only the suppliers directly connected to the organization, but also the characteristics of the participants on the second layer were examined and the flow of goods between buyer and suppliers in both layers was determined. Finally, a numerical example was presented to verify the model.

2.4. Supplier selection criteria

Establishing the criteria for supplier selection and evaluation has been a popular area of research since the 1960s. Looking into the history of popular criteria identified in the literature, one can conclude three primary categories of emphasis: in the late 1970s and early 1980s, cost was the main focus; then in early 1990s, cycle time and customer responsiveness were considered as the main category of emphasis, and, finally, in late 1990s, the focus shifted to flexibility. However, as of now, environmental factors are the key factors giving rise to the new paradigm of focusing on green supply chains Huang and Keskar [33]. The GSCM literature has focused on encouraging existing suppliers to improve their environmental performance by requiring these suppliers to acquire certifications or to introduce green practices. Supplier selection in GSCM has been identified as significant in making purchasing decisions Seuring and Müller [67]. In order to meet the environmental regulations, many scholars have studied what was referred to as indicators of green supplier evaluation. A number of literature surveys have been made to summarize the criteria and decision methods involved in papers starting from the mid-1960s (*e.g.* Weber, Current, and Benton [76], Ghodsypour and O'Brien [25], De Boer et al. [13], Aissaoui *et al.* [3], Wu and Olson [79], Lee *et al.* [48], Liao and Kao [49], Chen *et al.* [17], Ho *et al.* [30]). Various researchers have done thorough studies to identify important criteria for the vendor selection problem, with their findings summarized here. According to Dickson [22], the important criteria were quality, delivery, and performance history; Weber *et al.* [76] identified the most important criteria as price, delivery, quality, facilities and capacity, geographic location, and technological capabilities; and, based on the literature review by Ho *et al.* [30], the most popular criterion is quality, followed by delivery, price/cost, manufacturing capabilities, service, management, and technology. In addition to the above literature, Chang [16] and Liao and Kao [49] further summarized economic criteria presented in previous articles and came to the conclusion that the most important criteria were quality, price, and delivery performance.

Noci [56] applied an AHP model to design a green supplier rating system. Sarkis [61] categorized environmentally conscious business practices into five major components: design for environment (Green design), life cycle analysis, total quality environmental management, green supply chain and environment-related certificates such as ISO 14 000. Handfield *et al.* [28] utilized the Delphi method to collect environmental experts' opinions from different companies and proposed an environmentally conscious purchasing decision model based on AHP. Sarkis [62]) utilized ANP to develop a six-dimensional strategic decision framework for GSCM. Hsu and Hu [31] presented new criteria for supplier selection in the field of hazardous material management including green purchasing, green materials coding and recording, green design capability, inventory of hazardous materials, management for hazardous materials, legal-compliance competency, and environmental management systems. Lee *et al.* [48] proposed quality, technological capabilities, pollution control, environment management, green products and green competencies for green supplier selection in high-tech industry. Bai and Sarkis [11] used grey system and rough set methodologies to integrate sustainability into supplier selection and summarized environmental metrics as pollution controls, pollution prevention, environmental management system, resource consumption, and pollution production. Yeh and Chuang [82] developed two multi-objective genetic algorithms for green partner selection; the algorithms sought four objectives including cost, time, product quality, and a green appraisal score. They offered green image, product recycling, green design, green supply chain management, pollution treatment cost, and environment performance assessment criteria for green supplier selection. Govindan *et al.* [26] proposed a multi-criteria fuzzy approach for measuring sustainability of a supplier and considered pollution production, resource consumption, eco-design and environmental management system as environmental criteria.

3. Evaluation and selection of green supplier

According to Kumar *et al.* [43], supplier selection process involves a set of activities such as identifying, analyzing, and choosing suppliers to form a layer of the supply chain. Suppliers who adopt GSCM practices can strengthen the environmental performances of companies throughout the supply chain. Addressing environmental criteria during supplier selection process is even more important in developing countries because of the difficulties and barriers companies in these countries face Akamp and Müller [4].

In this section, considering the concepts of the first and second-layer suppliers and also the green factor, a proposed method called "the second layer" is used to calculate the second layer and its associated criteria (fuzzy numbers) to be used to rank vendors on the first layer using hierarchy fuzzy TOPSIS based on different levels of alpha. The ranking and weighting of the providers on the first layer are used to solve the original model presented in the next section where fuzzy set theory has been used to transform the human mind's perception into numerical values. With the development of the fuzzy TOPSIS technique, these numerical values (preferences) can be used to produce an overall performance score for the behavior by each supplier.

3.1. Fuzzy set theory

In several situations, crisp numbered data is insufficient to model real world systems due to the vagueness, imprecision, and subjective nature of human thinking, judgment, and preferences Shen *et al.* [68]. Also, since performance ratings and weights cannot be given precisely in various situations, fuzzy set theory is introduced to model the uncertainty of human judgments; the process is called fuzzy multi-criteria decision making (FMCDM). Singh and Benyoucef [69] and Zadeh [85] introduced the fuzzy set theory in multi-criteria decision making (MCDM) to resolve the uncertainty and vagueness of human cognitive and judgment by providing mathematical strengths to work out such uncertainties of human thinking and reasoning. Use of fuzzy sets to analysis the decision-making problem was first introduced by Bellman and Zadeh [12] and Shen *et al.* [68]. As an extension of the crisp set theory, fuzzy set theory uses linguistic terms to represent the decision maker's selections. In FMCDM problems, the ratings and weights of the attributes estimated from vagueness, imprecision, and subjectivity are expressed in linguistic terms and then converted to fuzzy numbers Kannan *et al* [40].

Definition 3.1. The fuzzy set A is defined as a pre-defined set U with the membership function $A(x)$that assigns each x member to a real number in U ranging within [0, 1]. The numerical value of $A(x)$ shows the membership degree in the fuzzy set A Kannan *et al* [38].

Definition 3.2. The Fuzzy number m is shown as $m = (m_1, m_2, m_3)$. The corresponding membership function is defined by equation (3.1) Kannan *et al.* [38]:

$$m(x) = \begin{cases} 0 & x < m_1 \\ \dfrac{x - m_1}{m_2 - m_1} & m_1 \leq x \leq m_2 \\ \dfrac{m_3 - x}{m_3 - m_2} & m_2 \leq x \leq m_3 \\ 0 & x > m_3 \end{cases} \tag{3.1}$$

Due to their conceptual and computational simplicity, triangular fuzzy numbers are more commonly used in practical applications.

Consider two triangular fuzzy numbers of $m = (m_1, m_2, m_3)$ and $n = (n_1, n_2, n_3)$, then operations with fuzzy numbers are defined by equations (3.2)−(3.6) Kannan *et al.* [38]:

$$n(+)m = (n_1, n_2, n_3)(+)(m_1, m_2, m_3) = (n_1 + m_1, n_2 + m_2, n_3 + m_3) \tag{3.2}$$

$$n(-)m = (n_1, n_2, n_3)(-)(m_1, m_2, m_3) = (n_1 - m_3, n_2 - m_2, n_3 - m_1) \tag{3.3}$$

$$n(\times)m = (n_1, n_2, n_3)(\times)(m_1, m_2, m_3) = (n_1 m_1, n_2 m_2, n_3 m_3) \tag{3.4}$$

$$n(\div)m = (n_1, n_2, n_3)(\div)(m_1, m_2, m_3) = \left(\frac{n_1}{m_3}, \frac{n_2}{m_2}, \frac{n_3}{m_1}\right) \tag{3.5}$$

$$kn = k(n_1, n_2, n_3) = (kn_1, kn_2, kn_3) \tag{3.6}$$

Definition 3.3. The ($\alpha \in [0, 1]$) cut of fuzzy number is defined by equation (3.7):

$$A_\alpha = \{x \in U | A(x) \geq \alpha\} \tag{3.7}$$

where A_α refers to a limited non-empty subset of Uthat is shown as $A_\alpha = [a_\alpha^l, a_\alpha^u]$. The lower and upper bounds of α cut are a_α^l a_α^l and a_α^u, respectively. If $a_\alpha^l \geq 0$ and $a_\alpha^u \leq 1$ for $\alpha \in [0, 1]$, A is a normalized positive fuzzy number Wang and Elhag [75].

TABLE 1. Evaluation criteria for first-layer suppliers.

Criterion	Symbol	Sub-criterion	symbol
Quality	C_1	Having qualitative characteristics of products	L_{11}
		Having a proper method of tracking and identification of defective goods	L_{12}
Financial status	C_2	Payment method	L_{21}
		Collected profit during the financial year	L_{22}
Delivery	C_3	Precision in delivery	L_{31}
		Quality of packaging	L_{32}
Pollution	C_4	Average amount of greenhouse gases released during the day of the measurement	L_{41}
		Average amounts of water and wastewater released during the measurement	L_{42}
Echo design	C_5	Reduction in the use of hazardous materials	L_{51}
		Designing products to consume less material / energy	L_{52}
		Designing products for reuse	L_{53}
Environmental management system	C_6	Having ISO 14 000 certification	L_{61}
		Planning environmental objectives	L_{62}
Second layer	C_7	Effectiveness of supplier performance in the second layer on the selection of first-layer suppliers	L_{71}
		Work experience of supplier in improving performance	L_{72}

TABLE 2. Evaluation criteria for the second-layer suppliers.

Criterion	Symbol	Details
Quality	L_1	Quality of raw materials delivered from the second-layer suppliers
Good Price	L_2	Cheap raw materials provided by second-layer suppliers
Green factor	L_3	Importance of environmental issues to the second-layer suppliers

TABLE 3. Linguistic expression of relative importance (weight) of the criteria (GSCM practices).

Linguistic expression	Fuzzy numbers
Very Low (VL)	(0,0,0.1)
Low (L)	(0,0.1,0.3)
Rather Low (RL)	(0.1,0.3,0.5)
Average (M)	(0.3,0.5,0.7)
Rather much (RH)	(0.5,0.7,0.9)
High (H)	(0.7,0.9,1)
Very High (VH)	(0.9,1,1)

3.2. Evaluation criteria of first and second-layer suppliers

As Dickson [22] has mentioned, many criteria can be used to select the best supplier. In this study, in order to evaluate the first-layer suppliers, in addition to the criteria for the second-layer suppliers, quality, financial status and delivery time (*i.e.* a series of green criteria) are used, as presented by Shen *et al.* [68]. All criteria and sub-criteria used in the assessment of the first-layer suppliers are listed in Table 1.

The evaluation criteria for the second-layer suppliers are tabulated in Table 2.

To solve this problem, we must be familiar with linguistic variables and associated triangular fuzzy numbers, so as to undertake pairwise comparisons based on the above criteria in order to simplify the process for both the first- and second-layer suppliers. Tables 3 and 4 give linguistic variables used for ranking purpose and the relative importance (weights) of the criteria.

Table 4. Linguistic expression of rating alternatives (green suppliers).

Linguistic expression	Fuzzy numbers
Very Poor (VP)	(0,0,1)
Poor (P)	(0,1,3)
Medium Poor (MP)	(1,3,5)
Fair (F)	(3,5,7)
Medium Good (MG)	(5,7,9)
Good (G)	(7,9,10)
Very Good (VG)	(9,10,10)

3.3. The assessment method of "second layer" criteria

Here, in fact, two layers of suppliers are considered as a supply chain. The suppliers on the first layer are measured by two groups of criteria, with the first group addressing the properties of the suppliers in the first layer and the second group including the criteria belonging to the properties of the suppliers in the second layer. Traditionally, when companies want to evaluate supplier performance, they consider criteria such as price, quality and delivery time, and do not consider environmental standards as a mean to evaluate suppliers. Today, however, many companies have started to implement green supply chain management, *i.e.* to consider environmental issues.

Step 1. second-layer supplier evaluation against three criteria: quality, cost and green factor:
In this step, decision-maker evaluates the second-layer supplier in terms of the corresponding criteria to each material used. This assessment is carried out using linguistic variables.

Step 2. Changing linguistic variables to fuzzy numbers and evaluation of second-layer suppliers against the three mentioned criteria:
$\alpha_{lu}^{L_n}, \beta_{lu}^{L_n}, \gamma_{lu}^{L_n}$ Performance of lth supplier of uth material_ based on nth criterion (L_n)

Step 3. Calculation of the value of criteria called "second layer" for the first-layer suppliers, with integration of performance of the second-layer supplier against the quality, affordability and green factors:
n_i: Number of consumable materials required by the ith supplier of first-layer suppliers.
w_{iu}: The importance of the ith consumable material for the ith supplier from the first layer of supplier. $\sum_{u=1}^{n_i} w_{iu} = 1$.
$(\lambda_i^{L_n}, \theta_i^{L_n}, \phi_i^{L_n})$: Consolidated performance of second-layer suppliers for the ith supplier from the first layer of suppliers against nth criterion.
Because each supplier in the first layer is connected to a supplier in the second layer, in order to calculate the equations of each criterion, performance of each supplier in each material based on that criterion is multiplied by the weight of that material for the first-layer supplier; sum of the multiplication results is referred to as the score of the supplier based on the "the second layer" criterion. Equations for the three criteria (namely quality, affordability and the green factor) are shown by equations (3.8)–(3.10):

$$\lambda_i^{L_n} = \sum_{u=1}^{n_i} w_{iu} \alpha_{iu}^{L_n} \tag{3.8}$$

$$\theta_i^{L_n} = \sum_{u=1}^{n_i} w_{iu} \beta_{iu}^{L_n} \tag{3.9}$$

$$\phi_i^{L_n} = \sum_{u=1}^{n_i} w_{iu} \gamma_{iu}^{L_n} \tag{3.10}$$

Step 4. Calculating the scores of the first-layer suppliers considering the "second layer" criterion $(\lambda_i, \theta_i, \phi_i)$: the score of the ith supplier based on the "the second layer" criterion is shown by equations (3.11)–(3.13):
$w^{L_3}, w^{L_2}, w^{L_1}$: The importance of three criteria for the set of first-layer suppliers.

$$\lambda_i = w^{L_1}\lambda_i^{L_1} + w^{L_2}\lambda_i^{L_2} + w^{L_3}\lambda_i^{L_3} \tag{3.11}$$

$$\theta_i = w^{L_1}\theta_i^{L_1} + w^{L_2}\theta_i^{L_2} + w^{L_3}\lambda\theta_i^{L_3} \tag{3.12}$$

$$\phi_i = w^{L_1}\phi_i^{L_1} + w^{L_2}\phi_i^{L_2} + w^{L_3}\phi_i^{L_3} \tag{3.13}$$

In order to calculate final score of the first-layer suppliers, the "second layer" criterion is used as an indicator for the first layer criterion. In fact, the main part of the methodology for green supplier evaluation starts from this stage. Subsequently, a description of the fuzzy TOPSIS technique and hierarchy fuzzy TOPSIS and TOPSIS based on alpha levels (necessary steps to rank the green supplier) is provided.

3.4. Hierarchical fuzzy TOPSIS method

In the present paper, hierarchical fuzzy TOPSIS (HFTOPSIS) is used for the supplier selection problem. As an extension to fuzzy TOPSIS method from the three levels (objectives, criterion, and alternatives) to four and more levels (*e.g.* objectives, criterion, sub criterion, and alternatives), HFTOPSIS can be used to solve hierarchical decision making problems. This method was initially introduced by Ateş *et al.* [10] to evaluate university professors' performance. The followings explain the HFTOPSIS approach.

Suppose a problem with m main criteria, n sub-criteria, s alternatives, and k decision makers. Each main criterion i has r_i sub-criteria where the total number of sub-criteria is $(n = \sum_{i=1}^{m} r_i)$. The hierarchical structure has four levels, namely objectives, main criteria, sub-criteria, and alternatives. Three weight matrixes should exist as follows:

- ✓ Matrix (vector) of weights of main criteria of the problem from the objectives (I_{MA}).
- ✓ Matrix of weights of sub-criteria from the corresponding criteria (I_{KA}).
- ✓ Matrix of scores of alternatives from sub-criteria (I_A).

3.4.1. HFTOPSIS algorithm

Steps of HFTOPSIS algorithm are as follows:

Step 1. Obtaining the decision matrix

At first, three matrixes are formed. The first matrix (I_{MA}) is shown by equation (3.14):

$$I_{MA} = \begin{matrix} MA_1 \\ \vdots \\ MA_m \end{matrix} \begin{bmatrix} W_1 \\ \vdots \\ W_m \end{bmatrix} \tag{3.14}$$

where w_c is the average of the weights assigned to the main criterion c by the decision makers and is calculated by equation (3.15):

$$w_c = \frac{\sum_{i=1}^{k} q_{ci}}{k} \qquad c = 1, \ldots, m \tag{3.15}$$

q_{ci} represents the fuzzy number corresponding to the ith decision maker's judgment about weight of the criterion c from the objective.

The second matrix, I_{KA}, is shown by equation (3.16):

$$I_{KA} = \begin{array}{c} \\ KA_{11} \\ \vdots \\ KA_{1r_1} \\ KA_{21} \\ \vdots \\ KA_{2r_2} \\ \vdots \\ KA_{m1} \\ \vdots \\ KA_{mr_m} \end{array} \begin{array}{c} \begin{array}{cccc} MA_1 & MA_2 & \cdots & MA_m \end{array} \\ \begin{bmatrix} w_{11} & 0 & & 0 \\ \vdots & \vdots & \cdots & \vdots \\ w_{1r_1} & 0 & \cdots & 0 \\ 0 & w_{21} & \cdots & 0 \\ \vdots & \vdots & \cdots & \vdots \\ 0 & w_{2r_2} & \cdots & 0 \\ \vdots & \vdots & \cdots & \vdots \\ 0 & 0 & \cdots & w_{m1} \\ \vdots & \vdots & \cdots & \vdots \\ 0 & 0 & & w_{mr_m} \end{bmatrix} \end{array} \tag{3.16}$$

where w_{cl} stands for the average of weights by decision makers and is calculated by equation (3.17):

$$w_{cl} = \frac{\sum_{i=1}^{k} q_{cl}}{k} c = 1, \ldots, m \tag{3.17}$$

qcl_i represents the fuzzy number corresponding to the ith decision maker's judgment about the weight of lth sub-criterion from the criterion c. The third matrix I_A is shown by equation (3.18):

$$I_A = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_s \end{array} \begin{array}{c} \begin{array}{cccc} KA_{11} & KA_{12} & \cdots & KA_{mr_m} \end{array} \\ \begin{bmatrix} c_{111} & c_{112} & \ldots & \vdots \\ c_{211} & c_{212} & \ldots & \vdots \\ \vdots & \vdots & \cdots & \vdots \\ c_{n11} & c_{n12} & \cdots & \vdots \\ & & & c_{smr_m} \end{bmatrix} \end{array} \tag{3.18}$$

where $W_{cl} = \sum_{j=1}^{m} w_c w_{cj}$.

In this matrix, fuzzy numbers c_{qcl} s are average of scores given by decision makers and calculated by equation (3.19):

$$C_{qcl} = \frac{\sum_{i=1}^{k} q_{qcl_i} k}{c} = 1, 2, \ldots, m \tag{3.19}$$

where q_{qcl_i} stands for the fuzzy numbers corresponding to the opinion of the ith decision maker about the score of the qth alternative from the lth sub-criterion of criterion c.

The weight matrix of sub-criteria is obtained by multiplying I_{MA} and I_{SA} matrixes calculated by equation (3.20):

$$L = I_{MA} \times I_{kA} \tag{3.20}$$

I_A denotes the decision making matrix that should be normalized in order to unify the unit of elements of matrixes Roshandel *et al.* [60]. After calculating the decision matrix, other steps such as fuzzy TOPSIS will be carried out as follows.

After normalizing, normalized fuzzy decision matrix of $R = [r_{ij}]_{n\times m}$ is obtained. However, due to the difference in importance coefficients of different criteria, the weighted normalized fuzzy matrix $V = [v_{ij}]_{n\times m}$ is calculated, where $v_{ij} = r_{ij}(.)w_j$. Using the matrix $V = [v_{ij}]_{n\times m}$, the fuzzy positive ideal answer $(FPIS, A^+)$and the fuzzy negative ideal answer $(FNIS, A^-)$can be calculated by equations (3.21) and (3.22):

$$A^+ = (v_1^+, v_2^+, \ldots, v_n^+) \tag{3.21}$$

$$A^- = (v_1^-, v_2^-, \ldots, v_n^-) \tag{3.22}$$

where $v_j^+ = (1, 1, 1)$, $v_j^- = (0, 0, 0)$ and $j = 1, 2, \ldots, n$.

Then the distance of each option from $(FPIS, A^{+})$ and $(FNIS, A^{-})$is determined *via* equations (3.23) and (3.24):

$$d_i^+ = \sum_{j=1}^{m} d(v_{ij}, v_j^+), \quad i = 1, \ldots, n \tag{3.23}$$

$$d_i^- = \sum_{j=1}^{m} d(v_{ij}, v_j^-), \quad i = 1, \ldots, n \tag{3.24}$$

Finally, the corresponding relative proximity index to each option is obtained *via* equation (3.25):

$$RC_i = \frac{d_i^-}{d_i^+ + d_i^-}, \quad i = 1, \ldots, n \tag{3.25}$$

It is clear that, the closer option A_i is to $(FPIS, A^{+})$ and the further it is from $(FNIS, A^{-})$, the closer will be the relative index to 1 Jafarnezhad *et al.* [35].

3.4.2. Fuzzy TOPSIS method based on different alpha levels

In this section a TOPSIS method is proposed for ranking and selecting the suppliers in supply chain based on alpha levels. In the previously presented method, although the elements of the decision matrix were fuzzy values (w_j, x_{ij}), with calculating the difference from the ideal positive or negative answer, relative closeness index, RC_i, was obtained in certain values. This is while it is better for RC_i to be in fuzzy values to represent its uncertain nature.

Using alpha cut with the help of extension principle, the relative closeness index, RC_i, can be calculated as distance values. Considering the extension principle, any fuzzy number A can be shown by equation (3.26) Wang and Elhag [75]:

$$A = {}_{\alpha}^{U} \alpha A_{\alpha}, \qquad 0 \leq \alpha \leq 1 \tag{3.26}$$

Using alpha cut , $r_{ij_\alpha} = \{r_{ij}^l, r_{ij}^u\}$ and $w_{j_\alpha} = \{w_j^l, w_j^u\}$can be obtained.

So equation (3.25) can be rewritten as in equation (3.27):

$$RC_i = \frac{\sqrt{\sum_{j=1}^{m} (w_j r_{ij})^2}}{\sqrt{\sum_{j=1}^{m} (w_j r_{ij})^2} + \sqrt{\sum_{j=1}^{m} (w_j (1 - r_{ij}))^2}}$$

$$i = 1, 2, \ldots, n \tag{3.27}$$

$$st:$$

$$(w_j)_\alpha^l \leq w_j \leq (w_j)_\alpha^u j = 1, \ldots, m$$

$$(r_{ij})_\alpha^l \leq r_{ij} \leq (r_{ij})_\alpha^u j = 1, \ldots,$$

Considering the fact that $\frac{\partial RC_i}{\partial r_{ij}} \geq 0$, then RC_i is an increasing function of $r_{\ ij}$that is shown in equation (3.28):

$$\frac{\partial RC_i}{\partial r_{ij}} = \frac{r_{ij}\sqrt{\frac{\sum_{j=1}^{m}(w_j(r_{ij}-1))^2}{\sum_{j=1}^{m}(w_j r_{ij})^2}} + w_j^2(1 - r_{ij})\sqrt{\frac{\sum_{j=1}^{m}(w_j r_{ij})^2}{\sum_{j=1}^{m}(w_j(r_{ij}-1))^2}}}{\left(\sqrt{\sum_{j=1}^{m}(w_j r_{ij})^2} + \sqrt{\sum_{j=1}^{m}(w_j(r_{ij}-1))^2}\right)^2} > 0 \tag{3.28}$$

$$j = 1, \ldots, m$$

Therefore, RC_i is minimum for $r_{ij} = (r_{ij})^l_\alpha$ and maximum for $r_{ij} = (r_{ij})^u_\alpha$. So the above-mentioned fractional linear programming problems can be converted into simpler forms shown by equations (3.29) and (3.30) Wang and Elhag [75]:

$$(RC_i)^L_\alpha = \min \frac{\sqrt{\sum_{j=1}^m (w_j(r_{ij})^l_\alpha)^2}}{\sqrt{\sum_{j=1}^m (w_j(r_{ij})^l_\alpha)^2} + \sqrt{\sum_{j=1}^m (w_j(1-(r_{ij})^l_\alpha))^2}}$$

$$i = 1, 2, \ldots, n \tag{3.29}$$

$$st:$$

$$(w_j)^l_\alpha \le w_j \le (w_j)^u_\alpha j = 1, \ldots, m$$

$$(RC_i)^u_\alpha = \max \frac{\sqrt{\sum_{j=1}^m (w_j(r_{ij})^u_\alpha)^2}}{\sqrt{\sum_{j=1}^m (w_j(r_{ij})^u_\alpha)^2} + \sqrt{\sum_{j=1}^m (w_j(1-(r_{ij})^u_\alpha))^2}}$$

$$i = 1, 2, \ldots, n \tag{3.30}$$

$$st:$$

$$(w_j)^l_\alpha \le w_j \le (w_j)^u_\alpha j = 1, \ldots, m$$

For n options, relative closeness index, RC_i, is obtained for each alpha level.

To choose the best option and rank the options, the relative closeness index should be turned into non-fuzzy values. The average cutting level is used for this purpose. For $\alpha_1, \alpha_2, \ldots, \alpha_N$ given $0 = \alpha_1 < \alpha_2 < \ldots < \alpha_N = 1$, the corresponding certain value of RC_i is obtained as shown by equation (3.31) Wang and Elhag [75]:

$$(RC_i)^+_{ALC} = \frac{1}{N} \sum_{j=1}^N \left[\frac{(RC_i)^L_{\alpha_j} + (RC_i)^U_{\alpha_j}}{2} \right] i = 1, \ldots, n \tag{3.31}$$

3.5. Proposed MILP green model

In this section, a bi-objective mathematical model for selecting suppliers of two layers of green supply chain is provided. In addition to the features of direct suppliers, the features of the second-layer suppliers are considered in this model. And the possibility of ordering a combination of different products simultaneously and discounts are provided for the first-layer suppliers. In this paper, the objective is to select the optimum suppliers of each layer. So, two layers of suppliers are considered as a supply chain. Designing a supply network, the flow of products between buyer and selected supplier in both layers is determined.

The purpose of this research is to design a supply network for goods. According to Figure 1, communications between all suppliers in the first layer and buyer as well as the second-layer suppliers are established. In fact, there is an industrial unit where the final product is produced and marketed directly and delivered to the customer. Solving the model, the best communicational routes and the volume of transformed goods along these routes are obtained in an optimum way. In other words, the best suppliers in both layers are selected, with the allocated amount of order to each one being determined. First-layer suppliers propose different prices for different amounts of goods and these discounts are taken into accounted in the model. The most important feature of this model is its multi-product nature and the possibility for suppliers to be ordered a combination of different products simultaneously. In this study, supplier evaluation criteria are taken from the Section 3 and multi-objective programming is used. The first objective is to minimize the environmental costs, transportation costs, the cost of returned goods, purchase cost and the fixed ordering cost and the second objective is to maximize the value of suppliers score.

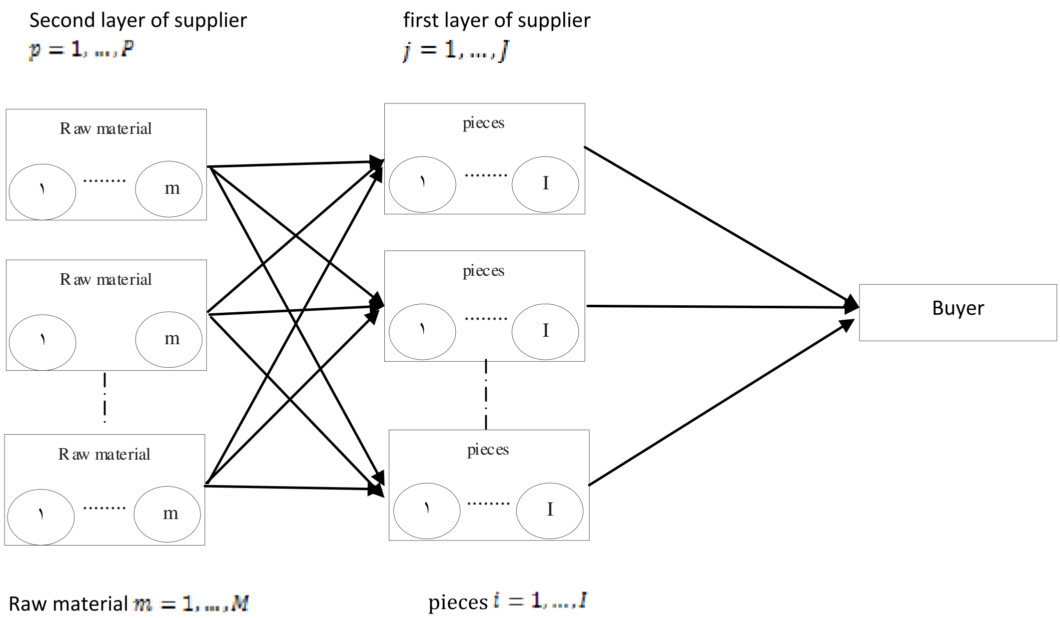

FIGURE 1. Supply chain network examined in this study.

Assumptions:

✓ The problem is a single period one.
✓ The objectives of the model include the minimization of costs (transportation cost, the cost of returned goods, purchase good, shortage cost, and environmental costs) and maximization of suppliers' scores.
✓ Supply chain includes the suppliers of the second layer (suppliers of suppliers), the first-layer suppliers and the customer.
✓ The criteria for selecting the suppliers are independent.
✓ Decisions are made by one decision-maker.
✓ Suppliers are independent and each supplier can provide all or a part of buyers' demand.
✓ Each supplier has a limited production capacity.
✓ The problem is considered as a multi-product one and it is possible to order a combination of different products simultaneously.
✓ Discount circumstances are considered for the suppliers of the first layer.
✓ The buyer's demand for each product (good) is determined and predefined.
✓ Greenhouse gases emissions are considered as an environmental problem due to the economic aspects in the chain.

Parameters (Nomenclatures)

O_{ij} The cost of greenhouse gases produced by jth supplier to produce ith part.
f_{ij} Pollution cost incurred by transportation facilities for transporting ith part from the jth supplier in the first layer to the buyer.
O'_{mp} The cost of pollutants produced by pth supplier for producing mth consuming substance.
f'_{mpj} The cost of pollutants caused by transportation facilities for transporting mth consuming material from the pth supplier in the second layer to the jth supplier in the first layer.
Q_{ijkt} The transportation cost of ith part from the jth supplier in the first layer with kth price level through the tth route to the buyer.

Q'_{mpjv} The transportation cost of mth consuming part from the pth supplier in the second layer to the jth supplier in the first layer through the vth route.

w_j The weight of first-layer supplier (obtained from the hierarchical fuzzy TOPSIS model).

$n_{ijk}k$ kth price level from the jth supplier in the first layer for ith product.

R_{ijk} The penalty cost of each part of ith returned product from the jth supplier of the first layer at kth price level which is paid to the buyer.

$B^{\sim}_{ijk}$ A percent of sold product i by jth supplier of the first layer at kth price level to the buyer that is returned by the buyer for reasons such as defective products.

R'_{mpj} The penalty cost that is paid for each mth returned consuming material from the pth second-layer supplier to the jth supplier of the first layer.

$B^{\sim'}_{mpj}$ A percent of mth consuming material by the pth supplier of the second layer to the jth supplier of the first layer that is returned for the reasons such as defective consuming material.

C_{ijk} The purchasing cost of ith product from the jth supplier in the first layer at kth price level.

C'_{mpj} The purchasing cost of mth consuming material from the pth second-layer supplier to the jth first-layer supplier.

f_j The constant ordering cost to the jth supplier in the first layer.

A_{mi} The demand for ith product D_i. The ratio of mth consuming material in ith product.

S_{ij} The capacity of jth supplier in the first layer to manufacture ith product.

S'_{pm} The capacity of pth supplier in the second layer to supply mth consuming material.

a_t The capacity of tth route between the first-layer supplier and the buyer.

M large enough arbitrary number.

Decision variables

D_{ijt} The amount of product i transported (equal to the demand for the product) from the jth supplier in the first layer *via* tth route to the buyer.

D_{ijpmv} The amount of mth consuming material transported (equal to the demand for the product) from the pth supplier in the second layer to the jth supplier in the first layer for ith product through the vth route.

x_{ijkt} The amount of ith product assigned to the jth supplier in the first layer at the kth price level along tth route.

y_{ijpm} The amount of mth consuming material from the pth supplier in the second layer to the jth supplier in the first layer for the ith product.

z_{ijk} 1 if the jth supplier in the first layer in the kth price level to manufacture ith product is selected, otherwise 0.

Objective functions

The main objective is to determine optimum suppliers in both layers. In this research, the objectives are to minimize the cost of carbon emission, transportation cost, the penalty of returned products, prices and the constant ordering cost across entire set of suppliers and in both layers, while increasing the suppliers' score.

$$\min F_1 = \left[\sum_i \sum_j \sum_t (O_{ij} + f_{ij}) D_{ijt} + \sum_i \sum_j \sum_m \sum_p \sum_v (O'_{mp} + f'_{mpj}) D_{ijmpv}\right] \tag{3.32}$$

$$+ \left[\sum_i \sum_j \sum_k \sum_t Q_{ijkt} w_j x_{ijkt} + \sum_i \sum_j \sum_m \sum_p \sum_v Q'_{mpjv} y_{ijmp}\right] \tag{3.33}$$

$$+ \left[\sum_i \sum_j \sum_k \sum_t R_{ijk} (B^{\sim}_{ijk} w_j x_{ijkt}) + \sum_i \sum_j \sum_m \sum_p R_{mpj} (B^{\sim'}_{mpj} y_{ijmp})\right] \tag{3.34}$$

$$+ \left[\sum_i \sum_j \sum_k \sum_t C_{ijk} w_j x_{ijkt} + \sum_i \sum_j \sum_m \sum_p C'_{mpj} y_{ijmp}\right] + \left[\sum_i \sum_j \sum_k f_j \times z_{ijk}\right] \tag{3.35}$$

$$\max F_2 = \sum_i \sum_j \sum_k \sum_t w_j x_{ijkt} \tag{3.36}$$

$s.t$

$$\sum_j \sum_k \sum_t w_j x_{ijkt} \geq D_i \forall i \tag{3.37}$$

$$\sum_p y_{ijmp} \geq A_{mi} \times \sum_k \sum_t w_j x_{ijkt} \forall i, j, m \tag{3.38}$$

$$\sum_k \sum_t w_j x_{ijkt} \leq S_{ij} \forall i, j \tag{3.39}$$

$$\sum_i \sum_j y_{ijmp} \leq S'_{mp} \forall m, p \tag{3.40}$$

$$\sum_i \sum_j \sum_k w_j x_{ijkt} \leq a_t \forall t \tag{3.41}$$

$$\sum_m \sum_p y_{ijpm} \leq M \times \sum_k z_{ijk} \forall i, j \tag{3.42}$$

$$D_{ijt} \geq \sum_k w_j x_{ijkt} \forall i, j, t \tag{3.43}$$

$$\sum_v D_{ijmpv} \geq y_{ijmp} \forall i, j, p, m \tag{3.44}$$

$$\sum_k z_{ijk} \leq 1 \forall i, j \tag{3.45}$$

$$n_{ijk-1} \times z_{ijk} \leq \sum_t x_{ijkt} \leq n_{ijk} \times z_{ijk} \forall i, j, k \tag{3.46}$$

$$D_{ijt}, D_{ijmpv}, x_{ijkt}, y_{ijmp} \geq 0 \quad \text{and} \quad z_{ijk} = \{0, 1\} \tag{3.47}$$

In this model, the cost function can be divided into two groups of functions addressing environmental costs and supply chain costs, respectively. The first group is composed of four functions. In the first objective function (Eq. (3.32)), the environmental costs are considered as the pollutant costs caused by each manufacturer and the cost of greenhouse gases emission generated by means of transportation. The second objective function (Eq. (3.33)) seeks to minimize transportation costs. The third and fourth objective functions (Eqs. (3.34) and (3.35), respectively minimize returned goods costs and purchasing and constant ordering cost, respectively. In the second group of objective functions (Eq. (3.36)) the value of suppliers' score is maximized.

Constraint (3.37) shows that the sum of products provided by the suppliers of the first layer should meet the buyer's demand for each product. Constraint (3.38) is equal to the demand of the first-layer suppliers for the consuming materials from the second-layer suppliers. Constraint (3.39) shows the manufacturing capacity of the suppliers in the first layer. Constraint (3.40) sets the manufacturing capacity of consuming materials for the second-layer suppliers. Constraint (3.41) limits the capacity of each outgoing route between the suppliers of the first layer and the buyer, so that products cannot be transported in any amount along these routes. In fact, it shows the capacity of routes and states that the amounts of goods going through any route must not exceed the route capacity. Constraint (3.42) ensures that if a supplier in the first layer is not selected, the associated suppliers in the second layer are not selected neither. This means that if z_{ijk} is zero, the relevant supplier y_{ijpmt} should be zero as well. Constraint (3.43) covers the amount of product transported by vehicles and the allocated amounts to be delivered to first-layer suppliers. Constraint (3.44) ensures that the amount of consuming materials transported by vehicles is equal to allocated amounts to be delivered to second-layer supplier. Constraint (3.45) ensures that only one level of price is selected from each supplier. Indeed, in case where more than one levels are selected, the constraint exceeds 1 and does not satisfy the equation. Constraint (3.46) shows that the amount of good purchased from each supplier at any price level satisfies the pre-defined price interval, and finally, Constraint (3.47) is the indication constraint of this model.

3.6. Solution (augmented epsilon-constraint method)

In order to use the e-constraint method in an appropriate way, the range of objective functions used in constraints should be determined. It is not easy to calculate these values, because unlike the single-objective optimization where optimum value of objective function is easy to calculate, the worst values in the effective set cannot be obtained as easily. The most common method for doing this is the balance table (a table obtained by optimizing a set of single objective functions). If there are multiple optimal solutions, there will be no guarantee that all solutions produced are from the effective set. To overcome this ambiguity, Mavrotas [52] suggested the use of hierarchical optimization for each objective table in order to produce balance table. The solution he suggested to get rid of this problem when estimating the worst values of the objective function was to define reserve values for the objective function as a lower bound (or upper bound) and minimize the objective function subsequently.

If multiple optimal solutions exist for at least one of the objective functions, the solution obtained using usual e-constraint method may not represent the effective solution; it is rather called a poor effective solution. Mavrotas [52] suggested converting the constraints of the objective functions into equations in order to avoid the production of poor values in effective solutions. But at the same time, the sum of these covariates as the latter term will be in the objective function with less weight.

Consider the following problem:

$$\max(f_1(x), f_2(x), \ldots, f_p(x))$$

$$s.t \tag{3.48}$$

$$x \varepsilon S$$

where x is the vector of decision variables, $f_1(x), f_2(x), \ldots, f_p(x)$are objective functions and S denotes the feasible space. One of the objective functions are selected for optimization by e-constraint method and the other objective functions are converted into constraints with an upper bound of ε. As an instance:

$$\max f_1(x)$$

$$s.t$$

$$
\begin{aligned}
&f_2(x) \geq e_2 \\
&f_3(x) \geq e_3 \\
&\ldots \\
&f_p(x) \geq e_p \\
&x \varepsilon S
\end{aligned} \tag{3.49}
$$

In fact, e-constraint approach is obtained by equation (3.50) in reinforced status:

$$
\begin{aligned}
&\max\left(f_1(x) + \text{eps} \times \left(\frac{s_2}{r_2} + \frac{s_3}{r_3} + \ldots + \frac{s_p}{r_p}\right)\right) \\
&s.t \\
&f_2(x) - s_2 = e_2 \\
&f_3(x) - s_3 = e_3 \\
&\ldots \\
&f_p(x) - s_p = e_p \\
&x \varepsilon S \\
&s_i \varepsilon R
\end{aligned} \tag{3.50}
$$

where $e_2, e_3, \ldots, e_p$ are the right hand side parameters and $r_2, r_3, \ldots, r_p$are the regions of the objective functions.$s_2, s_3, \ldots, s_p$ are the covariates of the constraints and epsilon ranges within 10^{-6} , 10^{-3}.

With an improvement in enforced e-constraint method, the objective function changes into equation (3.51):

$$
\max\left(f_1(x) + eps \times \left(\frac{s_2}{r_2} + 10^{-1} \times \frac{s_3}{r_3} + \ldots + 10^{-(p-2)} \times \frac{s_p}{r_p}\right)\right) \tag{3.51}
$$

These changes are applied to make a lexicographic optimization on other objective functions because that might exist other optimum solutions. For example, with this formulization, the solver finds the optimum solution for f_1 and then tries to optimize f_2, f_3, *etc.* respectively. But using the previous formulization, the order of optimization of f_2 ,. . . , f_3 was different. While using this method the restricted objective functions are forced to give sequential optimal solutions.

The region of the objective function is calculated for each objective function $2, \ldots, p$. Then the region of kth objective function is divided into q_k equal intervals. r_k is equal to the number of regions of the kth objective function ($k = 2, \ldots, p$). Then the discretization step for the objective function is defined as equation (3.52):

$$
step_k = \frac{r_k}{q_k} \tag{3.52}
$$

And the right hand side values for the corresponding limits in the tth iteration in the specified objective function are expressed as in equation (3.53):

$$
e_{kt} = f\min_k + t \times step_k \tag{3.53}
$$

here $f\min_k$ is the minimum of the objective function and t is the counter of the specific objective function. The aim of this method is to present and evaluate an improvement on the main e-constraint method, so as to make it suitable for solving multi-objective integer programming problems. This method has proven to be more effective in providing accurate Pareto solution sets in integer programming problems, as compared to the previous version and some other common methods. It has the ability to produce accurate Pareto sets by parameter adjustment. In the augmented e-constraint method, the conversion of the constraints into equations overcomes the deficient or dysfunctional solution combining shortage or additional variables. These variables are used, as the second term (with lower priority in lexicographic method), in the objective function simultaneously and make the model able to produce more effective solutions Mavrotas and Florios [53]. Mavrotas and Florios [53] proved that with this method, one can prevent the generation of poor solutions, so that only robust and effective solutions would be generated; they named their method "completed constraint epsilon". Another novelty of this approach was that if a combination of e_i is unjustified, it stops and gets out of the loop. Accordingly, the restricting strategy of each objective function started from the fully released value (lower bound for maximization and upper bound for minimization) and moves forward to the optimum value in a step-by-step fashion. When the method arrived at an unjustified point, there was no need to go through the rest of loop, so that it gets out of the loop leading to sometime saving. Especially when there were lots of objective functions, it was a quite tangible saving.

4. Case study

Techno Wash Co. owns a factory located in Khavaran Industrial Town (Tehran, Iran). The company manufactures electrical appliances including washing machines. In order to manufacture their products, the factory is provided with some of the required parts by different suppliers before the components are assembled into the final product which is subsequently sent to market. In this case study, the first-layer suppliers are actually those companies whose products (washing machine components) are directly purchased by Techno Wash. In this respect, there are four products (Products 1−4) supplied by four suppliers who can provide either some or all of them. These suppliers are designated as First-layer Suppliers 1−4. Each of the suppliers of the first layer is provided with its consuming material by suppliers in the second layer. To solve this numerical example, the suppliers of the first layer are weighted using the "second layer" approach and hierarchical fuzzy TOPSIS with different alpha levels, and then, using augmented e-constraint method, the corresponding green supply chain model is solved.

The criteria for selecting different alternatives are those discussed in Section 2.3. The steps of the proposed method are as follows.

4.1. Second layer criteria

In this section, the second-layer suppliers (manufacturing companies producing raw materials needed for the washing machine) are studied. There is a single decision-maker together with four suppliers that should be ranked considering the three criteria mentioned in Section 3.2. These suppliers are included in the evaluations as they attained the green qualification. This survey is done using questionnaire and the decision-maker's opinion. The decision-maker is the procurement manager of the company. Suppliers are independently ranked based on various criteria. The seven-point Likert scale was used to provide the decision-maker's opinion in the questionnaire. The linguistic variable for ranking was classified from 1 (very poor) to 7 (very good), with importance weight of criteria set from 1 (very low) to 7 (very much), see Table 3.

Step 1: Evaluation of the second-layer suppliers in terms of criterion 1 (quality), criterion 2 (good price), and criterion 3 (green factor) using the results of the questionnaire - the results are shown in Table 5.

Then, using a Likert scale, the linguistic variables are converted into fuzzy numbers and the value of "the second layer" criterion is calculated for the first-layer suppliers by combining performances of the second-layer suppliers in terms of quality, affordability and the green factor.

In order to calculate the score of the first-layer suppliers considering the "second layer" criterion, there is a need for measuring the importance of the mentioned criteria for the set of suppliers in the first layer, as shown in Table 6.

In order to calculate the final score of the first-layer suppliers, information related to the "second layer" criterion is used as an indicator for the first-layer suppliers, as shown in Table 7.

TABLE 5. Evaluation criteria and the results for the second-layer suppliers (*via* questionnaire).

Supplier 4	Supplier 3	Supplier 2	Supplier 1		
Very low	Rather much	Very low	Very much	Consuming material 1	Criterion 1
Low	low	Rather low	Much	Consuming material 2	
Average	Rather much	Rather low	Much	Consuming material 3	
Average	Average	Average	Average	Consuming material 4	
Rather much	Low	Average	Average	Consuming material 1	Criterion 2
Rather much	Low	Rather much	Rather much	Consuming material 2	
Very much	Low	Low	Much	Consuming material 3	
Much	Rather much	Low	Rather much	Consuming material 4	
Rather much	Average	Very much	Rather low	Consuming material 1	Criterion 3
Rather much	Average	Much	Low	Consuming material 2	
Very much	low	Low	Very low	Consuming material 3	
Average	Average	Rather much	Average	Consuming material 4	

TABLE 6. Importance of quality, price and green factor for the first layer of suppliers.

Criterion	Importance
(W^Q) quality	0.4
(W^P) affordability	0.3
(W^G) Green factor	0.3

TABLE 7. Final scores of the first-layer suppliers based on "second layer" criterion.

The second layer criterion			Supplier
U	M	L	
0.448	0.498	0.452	Supplier 1
0.486	0.326	0.2	Supplier 2
0.596	0.399	0.208	Supplier 3
0.4	0.284	0.576	Supplier 4

4.2. Hierarchical fuzzy TOPSIS based on different alpha levels

In this section, the first-layer suppliers (companies producing different parts of the washing machines) are surveyed regardless of the decision-maker, with the four suppliers ranked in terms of the 7 criteria mentioned in Section 3.2. The suppliers are then green qualified and evaluated. This survey is done considering the questionnaire results as well as the decision-maker's opinion. Suppliers are independently ranked based on various criteria. Hierarchical structure of the decision-making is shown in Figure 2.

By distributing a questionnaire, the decision-maker's opinion about the main criteria is measured and in fact the weight matrix of the main criteria of the problem is defined considering the objectives as follows:

$$I_{MA} = \begin{bmatrix} (0.9, 1, 1) \\ (0.5, 0.7, 0.9) \\ (0.7, 0.9, 1) \\ (0.5, 0.7, 0.9) \\ (0.3, 0.5, 0.7) \\ (0.3, 0.5, 0.7) \\ (0.3, 0.5, 0.7) \end{bmatrix}$$

Then, in order to obtain the corresponding fuzzy numbers to the weight of sub-criteria, another questionnaire is used to attain the decision-maker's judgment about the weight of each sub-criterion in terms of the main

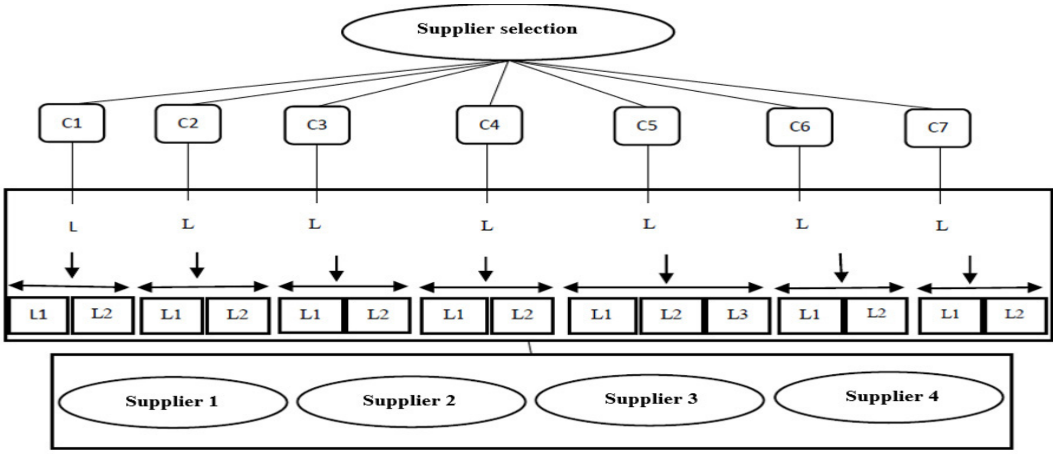

FIGURE 2. Hierarchical structure of the decision-making.

criterion. The weight matrix of sub-criteria corresponding to the main criteria is as follows:

$$I_{KA} = \begin{bmatrix} (0.9,1,1)(0)(0)(0)(0)(0)(0) \\ (0.5,0.7,0.9)(0)(0)(0)(0)(0)(0) \\ (0)(0.7,0.9,1)(0)(0)(0)(0)(0) \\ (0)(0.5,0.7,0.9)(0)(0)(0)(0)(0) \\ (0)(0)(0.3,0.5,0.7)(0)(0)(0)(0) \\ (0)(0)(0.3,0.5,0.7)(0)(0)(0)(0) \\ (0)(0)(0)(0.7,0.9,1)(0)(0)(0) \\ (0)(0)(0)(0.1,0.3,0.5)(0)(0)(0) \\ (0)(0)(0)(0)(0.3,0.5,0.7)(0)(0) \\ (0)(0)(0)(0)(0.9,1,1)(0)(0) \\ (0)(0)(0)(0)(0.3,0.5,0.7)(0)(0) \\ (0)(0)(0)(0)(0)(0.7,0.9,1)(0) \\ (0)(0)(0)(0)(0)(0.3,0.5,0.7)(0) \\ (0)(0)(0)(0)(0)(0)(0.1,0.3,0.5) \\ (0)(0)(0)(0)(0)(0)(0.1,0.3,0.5) \end{bmatrix}$$

So the weights of sub-criteria are obtained by multiplying I_{MA} into I_{KA}, then the matrix of alternatives' score considering the sub-criteria (I_A matrix) is calculated by linguistic evaluation of the suppliers done by the decision-maker. Finally, the normalized decision matrix is developed.

For different levels of alpha, the obtained results in terms of relative closeness are shown in Tables 8 and 9.

Regarding the values of Table 8, one can find certain values of relative closeness as in equation (4.1):

$$(CC_i)^*_{ALC} = \frac{1}{N}\sum_{p=1}^{N}\left(\frac{(CC_i)^L_{\alpha p} + (CC_i)^U_{\alpha p}}{2}\right) \qquad i = 1,2,\ldots,m \tag{4.1}$$

Sorting the closeness coefficients in descending order, the suppliers are ranked as 3−1−4−2. This deficit planning problem is solved using GAMS 24.3 software with BARON solver used to solve the model because of the problem's nonlinear nature.

Figure 3 shows relative proximity to different suppliers.

Table 8. Relative closeness results for different levels of alpha to suppliers.

Alpha	Supplier 1		2		3		4	
	$(CC_1)^L_\alpha$	$(CC_1)^U_\alpha$	$(CC_2)^L_\alpha$	$(CC_2)^U_\alpha$	$(CC_3)^L_\alpha$	$(CC_3)^U_\alpha$	$(CC_4)^L_\alpha$	$(CC_4)^U_\alpha$
0	0.2993	0.8414	0.5257	0.9642	0.2387	0.7242	0.3821	0.8959
0.1	0.3257	0.8184	0.5537	0.9542	0.2627	0.7012	0.4114	0.8773
0.2	0.3526	0.7944	0.5820	0.9420	0.2870	0.6775	0.4409	0.8578
0.3	0.3802	0.7697	0.6106	0.9284	0.3114	0.6534	0.4706	0.8374
0.4	0.4083	0.7444	0.6392	0.9137	0.3357	0.6287	0.5003	0.8161
0.5	0.4369	0.7184	0.6678	0.8978	0.3600	0.6037	0.5298	0.7940
0.6	0.4657	0.6919	0.6962	0.8811	0.3840	0.5786	0.5592	0.7711
0.7	0.4948	0.6649	0.7243	0.8634	0.4077	0.5537	0.5881	0.7474
0.8	0.5240	0.6376	0.7521	0.8449	0.4311	0.5284	0.6167	0.7230
0.9	0.5532	0.6100	0.7792	0.8256	0.4541	0.5026	0.6447	0.6979
1	0.5822	0.5822	0.8055	0.8055	0.4766	0.4766	0.6721	0.6721

Table 9. Calculated certain values of relative closeness.

$(CC_i)^*_{ALC}$	Supplier 1	2	3	4
	0.659359	0.4808	0.779868	0.5771

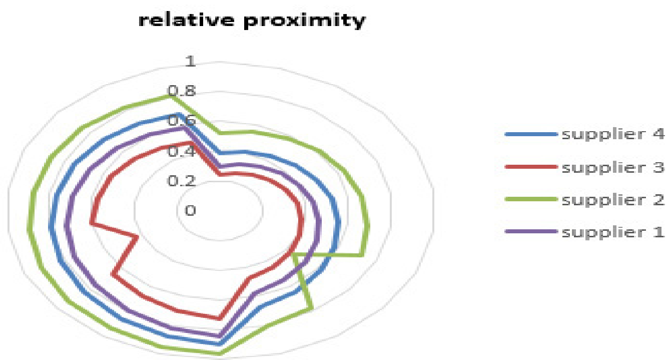

Figure 3. Relative proximity to different suppliers.

4.3. The main model

For outsourcing the four parts demanded by Techno Wash, this manufacturing unit should rank the four suppliers and determine the amount to be allocated to each of them. Each of the products needs several kinds of consuming materials to be produced; the materials are produced by four suppliers in the second layer. Table 10 gives sufficient information on consuming materials used in the production of the parts and the related consumption coefficients. In this model, three different routes with different capacities are considered to transform the products. The routes are different is in cost, carbon emissions, transition time and capacity.

The model is solved using GAMS 24.3 and CPLEX solver. Once the model is solved, Pareto front can be plotted as in Figure 4:

The results of the model for the last point of the Pareto front are reported in Table 11.

TABLE 10. Raw material consumption coefficient per product.

Product 4	Product 3	Product 2	Product 1	
0.44	0	0.26	0.3	Consuming material 1
0.6	0.2	0	0.2	Consuming material 2
0	0.5	0.5	0	Consuming material 3
0.15	0.63	0	0.22	Consuming material 4

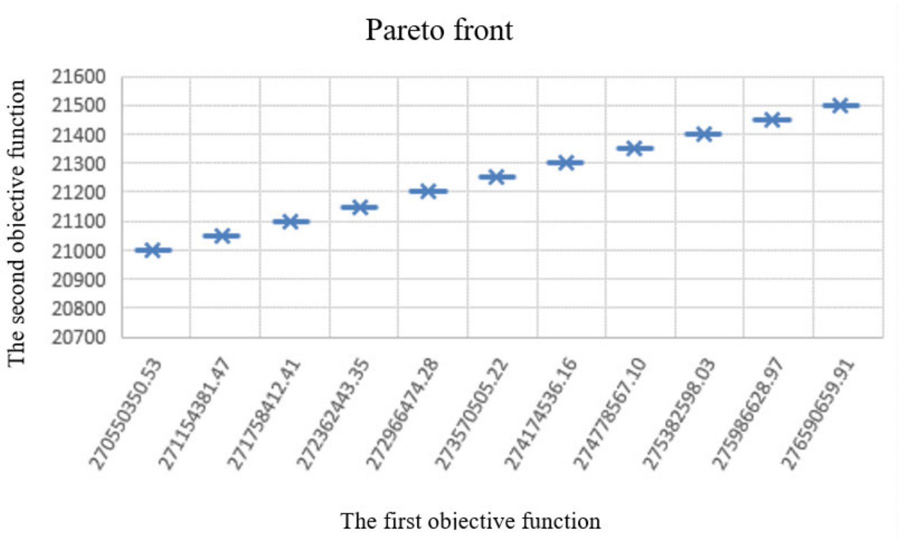

FIGURE 4. Pareto front.

TABLE 11. Last Pareto solution and the objective values.

F_2^*	F_1^*	Optimum objective values
21 500	276590659.9	Last Pareto solution

TABLE 12. The objective function changes with change in demand for products.

The second objective function	The first objective function	Demand for products				Different values
		4	3	2	1	
21 500	276590659.9	4800	6200	5700	4300	Scenario 1
21 801	286682424.8	5000	6400	5900	4500	Scenario 2
22 602	300499649.8	5200	6600	6100	4700	Scenario 3
23 700	318176659.5	5400	6800	6300	4900	Scenario 4

5. RESULTS AND SENSITIVITY ANALYSIS

In order to verify and validate the model, sensitivity analysis is done on the supply chain model. For this purpose, the buyer's demand parameters for the product are defined in four scenarios and the behavior of this model is checked applying either of the scenarios. According to the obtained results, the scenarios are shown on the graph and their process can be easily followed.

Changes in the objective function values under the four scenarios are shown in Table 12.

The following charts show the trend in changes related to two objective functions.

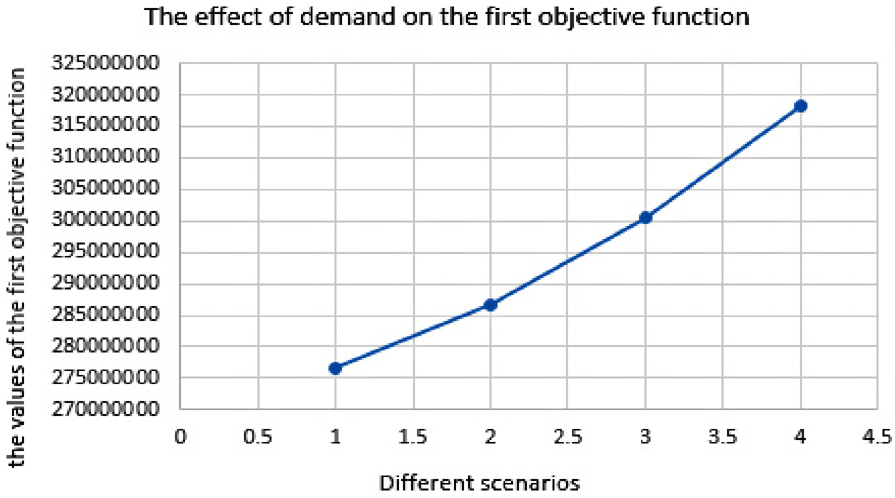

FIGURE 5. Analysis of the effect of buyer's demand for the product on the objective functions.

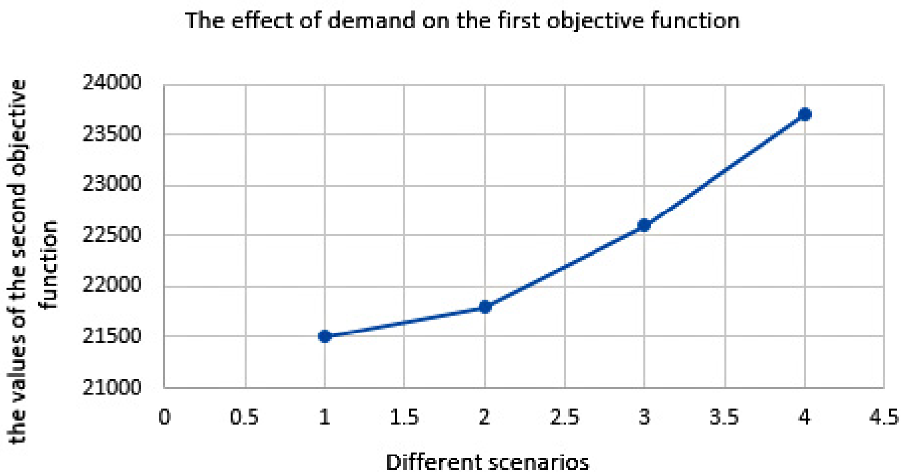

FIGURE 6. Analysis of the effect of buyer's demand for the product on the objective functions.

An increase in demand leads to a rise of costs, so that, as is shown in Figure 5, the first objective function values follow an increasing trend.

Increased demand causes an increase in score value of the suppliers from whom larger amounts will be purchased; as shown in Figure 6, the second objective function values increase with increasing the demand.

6. Summary and conclusion

How to determine the most suitable supplier(s) in supply chains has been considered as a strategic factor in the supply chain management in recent years. The nature of these types of decisions is usually complex and has no specific structure, so that many qualitative and quantitative performance criteria such as quality, price, flexibility, delivery time and the green factor should be taken into consideration when determining the most appropriate supplier(s). To create an efficient and competitive supply chain, close and long-term relationships between suppliers and buyers seem necessary. The aim of this study was to examine and analyze the ability of first-layer suppliers considering second level providers based on different criteria. Furthermore, a supply network was designed where the flow of goods was obtained on each arc and optimal suppliers in both layers were selected simultaneously. It was also possible to order multiple products at the same time, *i.e.* to use a multiple-product single-period model.

In this study, supplier selection in green supply chain was investigated by considering cost-related objectives coupled with reduced environmental impacts. Environmental impacts were evaluated from two perspectives including the reduction of gases produced by transportation facilities which depended on track condition. The multiple-objective mathematical model for supplier selection at both layers in green supply chain was developed to determine the first-layer suppliers to provide the buyer with required parts and also the second-layer supplier to provide the first-layer suppliers with raw materials, so as to achieve both environmental and cost-related objectives. Also it is highly important to consider the weight of sub-criteria compared to the criteria and that of criteria compared to the sub-criteria when ranking the suppliers. Indeed, the proposed model turned into a comprehensive one considering the features of the suppliers in the second layer.

In order to show applicability of the model, a numerical example using data from Techno Wash Company was presented, solved and analyzed. Considering the bi-objective nature of the model, it was tried to select a solving method that best fits the model and provides better and more accurate results. Thus, the augmented e-constraint method was applied wherein the shortcomings of e-constraint method has been overcome, offering better solutions.

7. Recommendation for future research

As explained in the text, there are different methods for solving multi-objective problems. To further validate this model it can be solved using other methods, with the results compared. Another techniques that may be suitable for future research on supplier evaluation and ranking are VIKOR and PROMETHEE techniques; one can compare their results with those of the proposed method. Of the factors causing the model to be closer to reality is taking into account the inventory costs as well as parameters such as demand (with associated uncertainties) which can be expressed by fuzzy numbers; these may represent further research topics. For further validation, the proposed model can be tested using other read industrial data, especially those from automotive industry.

One of the main recommendations regarding model development and the present research is the introduction of sustainability topics into the model. Recently introduced into supply chain concept, sustainability topics not only account for economic and environmental issues, but also introduce social issues such as social justice and human rights into equations. Adding the social aspects to the supply chain decisions allows the supply chain decisions to better assess the effects of supply chain on stakeholders and shareholders (including employees, customers and local communities).

References

[1] B. Ageron, Angappa Gunasekaran and A. Spalanzani, Sustainable Supply Management: An Empirical Study. *Int. J. Prod. Econ.* **140** (2012) 168–82.

[2] P. Ahi and C. Searcy, A Comparative Literature Analysis of Definitions for Green and Sustainable Supply Chain Management. *J. Clean. Prod.* **52** (2013) 329–41.

[3] N. Aissaoui, M. Haouari and E. Hassini, Supplier Selection and Order Lot Sizing Modeling: A Review. *Comput. Oper. Res.* **34** (2007) 3516–40.

[4] A. Marion and M. Müller. Supplier Management in Developing Countries. *J. Clean. Prod.* **56** (2013) 54–62.

[5] A. Marcus Alfred and R. Fremeth Adam, Green Management Matters Regardless. *Acad. Manage. Perspect.* **23** (2009) 17–26.

[6] G. Alyanak and O. Armaneri. An Integrated Supplier Selection and Order Allocation Approach in a Battery Company. *Makine Mühendisleri Odasi* **19** (2009) 2–19.

[7] A. Amid, S.H. Ghodsypour and Ch. O'Brien. Fuzzy Multiobjective Linear Model for Supplier Selection in a Supply Chain. *Int. J. Prod. Econ.* **104** (2006) 394–407.

[8] A. Amid, S.H. Ghodsypour and Ch. O'Brien. A Weighted Max-min Model for Fuzzy Multi-Objective Supplier Selection in a Supply Chain. *Int. J. Prod. Econ.* **131** (2011) 139–45.

[9] A. Amin, S. Hassanzadeh, J. Razmi and G. Zhang, Supplier Selection and Order Allocation Based on Fuzzy SWOT Analysis and Fuzzy Linear Programming. *Exp. Syst. Appl.* **38** (2011) 334–42.

[10] A.N. Yasin, S. Cevik, C. Kahraman, M. Gülbay and S. Ayça Erdogan. Multi Attribute Performance Evaluation Using a Hierarchical Fuzzy TOPSIS Method. In *Fuzzy Applications in Industrial Engineering*. Springer (2006) 537–72.

[11] Bai, Chunguang and J. Sarkis, Integrating Sustainability into Supplier Selection with Grey System and Rough Set Methodologies. *Int. J. Prod. Econ.* **124** (2010) 252–64.

[12] R.E. Bellman and L.A. Zadeh, Decision-Making in a Fuzzy Environment. *Manage. Sci.* **17** (1970) B–141.

[13] L. De Boer, E. Labro and P. Morlacchi, A Review of Methods Supporting Supplier Selection. *Eur. J. Purch. Suppl. Manage.* **7** (2001) 75–89.

[14] G. Büyüközkan and G. Çifçi, A Novel Hybrid MCDM Approach Based on Fuzzy DEMATEL, Fuzzy ANP and Fuzzy TOPSIS to Evaluate Green Suppliers. *Exp. Syst. Appl.* **39** (2012) 3000–3011.

[15] Chai, Junyi, J.N.K. Liu and E.W.T. Ngai, Application of Decision-Making Techniques in Supplier Selection: A Systematic Review of Literature. *Exp. Syst. Appl.* **40** (2013) 3872–85.

[16] Chang, Ching-Ter, Multi-Choice Goal Programming with Utility Functions. *Eur. J. Oper. Res.* **215** (2011) 439–45.

[17] Chen, Vivien Y. C. et al. Fuzzy MCDM Approach for Selecting the Best Environment-Watershed Plan. *Appl. Soft Comput.* **11** (2011) 265–75.

[18] Chen, Yuh-Jen, Structured Methodology for Supplier Selection and Evaluation in a Supply Chain. *Inform. Sci.* **181** (2011) 1651–70.

[19] R. Dekker, J. Bloemhof and I. Mallidis, Operations Research for Green logistics-An Overview of Aspects, Issues, Contributions and Challenges. *Eur. J. Oper. Res.* **219** (2012) 671–79.

[20] A. Diabat and K. Govindan, An Analysis of the Drivers Affecting the Implementation of Green Supply Chain Management. *Resources, Conserv. Recycl.* **55** (2011) 659–67.

[21] A. Diabat, Roohollah Khodaverdi and Laya Olfat, An Exploration of Green Supply Chain Practices and Performances in an Automotive Industry. *Int. J. Adv. Manufact. Technol.* **68** (2013) 949–61.

[22] G.W. Dickson, An Analysis of Vendor Selection and the Buying Process. *J. Purch.* **2** (1966) 5–17.

[23] Ch.M. Dües, K. Hua Tan and M. Lim, Green as the New Lean: How to Use Lean Practices as a Catalyst to Greening Your Supply Chain. *J. Clean. Prod.* **40** (2013) 93–100.

[24] S.H. Ghodsypour and C. O'brien, The Total Cost of Logistics in Supplier Selection, under Conditions of Multiple Sourcing, Multiple Criteria and Capacity Constraint. *Int. J. Prod. Econ.* **73** (2001) 15–27.

[25] Ghodsypour, S. Hassan and Ch. O'Brien, A Decision Support System for Supplier Selection Using an Integrated Analytic Hierarchy Process and Linear Programming. *Int. J. Prod. Econ.* **56** (1998) 199–212.

[26] K. Govindan, R.H Khodaverdi and A. Jafarian, A Fuzzy Multi Criteria Approach for Measuring Sustainability Performance of a Supplier Based on Triple Bottom Line Approach. *J. Clean. Prod.* **47** (2013) 345–54.

[27] Gunasekaran, Angappa and E.W.T. Ngai, The Future of Operations Management: An Outlook and Analysis. *Int. J. Prod. Econ.* **135** (2012) 687–701.

[28] R. Handfield, S.V. Walton, R. Sroufe and S.A. Melnyk. . Applying Environmental Criteria to Supplier Assessment: A Study in the Application of the Analytical Hierarchy Process. *Eur. J. Oper. Res.* **141** (2002) 70–87.

[29] S.L. Hart and G. Dowell, A Natural-Resource-Based View of the Firm: Fifteen Years after. *J. Manag.* **37** (2010) 1464–1479.

[30] W. Ho, X. Xu and P.K. Dey, Multi-Criteria Decision Making Approaches for Supplier Evaluation and Selection: A Literature Review. *Eur. J. Oper. Res.* **202** (2010) 16–24.

[31] Hsu, Chia-Wei and A.H. Hu, Applying Hazardous Substance Management to Supplier Selection Using Analytic Network Process. *J. Clean. Prod.* **17** (2009) 255–64.

[32] Hsu, Chia-Wei, T.-Ch. Kuo, Sh.-H. Chen and A.H. Hu, Using DEMATEL to Develop a Carbon Management Model of Supplier Selection in Green Supply Chain Management. *J. Clean. Prod.* **56** (2013) 164–72.

[33] S.H. Huang and H. Keskar, Comprehensive and Configurable Metrics for Supplier Selection. *Int. J. Prod. Econ.* **105** (2007) 510–23.

[34] P.K. Humphreys, Y.K. Wong and F.T.S. Chan, Integrating Environmental Criteria into the Supplier Selection Process. *J. Mater. Process. Technol.* **138** (2003) 349–56.

[35] A. Jafarnezhad, M. Esmaelian and M. Rabie, Evaluation and Selection of Suppliers in Supply Chain Single Sourcing with Fuzzy Approach. *J. Humanities Teacher* **12** (2007) 127–53.

[36] F. Jolai, S.A. Yazdian, K. Shahanaghi and M. Azari Khojasteh, Integrating Fuzzy TOPSIS and Multi-Period Goal Programming for Purchasing Multiple Products from Multiple Suppliers. *J. Purch. Supply Manag.* **17** (2011) 42–53.

[37] D. Kannan, R. Khodaverdi, L. Olfat, A. Jafarian and A. Diabat, Integrated Fuzzy Multi Criteria Decision Making Method and Multiobjective Programming Approach for Supplier Selection and Order Allocation in a Green Supply Chain. *J. Clean. Prod.* **47** (2013) 355–67.

[38] D. Kannan Ana Beatriz Lopes de Sousa Jabbour and Charbel José Chiappetta Jabbour, Selecting Green Suppliers Based on GSCM Practices: Using Fuzzy TOPSIS Applied to a Brazilian Electronics Company. *Eur. J. Oper. Res.* **233** (2014) 432–47.

[39] G. Kannan and V.P. Vinay, Multi-Criteria Decision Making for the Selection of CAD/CAM System. *Int. J. Interactive Design Manufact. (IJIDeM)* **2** (2008) 151–59.

[40] G. Kannan, Sh. Pokharel and P.S. Kumar, A Hybrid Approach Using ISM and Fuzzy TOPSIS for the Selection of Reverse Logistics Provider. *Res., Conserv. Recycl.* **54** (2009) 28–36.

[41] A. Kokangul and Z. Susuz, Integrated Analytical Hierarch Process and Mathematical Programming to Supplier Selection Problem with Quantity Discount. *Appl. Math. Model.* **33** (2009) 1417–29.

[42] Ku, Cheng-Yuan, Ch.-T. Chang and H.-P. Ho, Global Supplier Selection Using Fuzzy Analytic Hierarchy Process and Fuzzy Goal Programming. *Qual. Quant.* **44** (2010) 623-40.

[43] A. Kumar, V. Jain and S. Kumar. A Comprehensive Environment Friendly Approach for Supplier Selection. *Omega* **42** (2014) 109–23.

[44] M. Kumar, P. Vrat and R. Shankar, A Fuzzy Goal Programming Approach for Vendor Selection Problem in a Supply Chain. *Comput. Ind. Eng.* **46** (2004) 69–85.

[45] R.J. Kuo, Y.C. Wang and F.C. Tien, Integration of Artificial Neural Network and MADA Methods for Green Supplier Selection. *J. Clean. Prod.* **18** (2010) 1161–70.

[46] Lai, Kee-hung and Christina W.Y. Wong, Green Logistics Management and Performance: Some Empirical Evidence from Chinese Manufacturing Exporters. *Omega* **40** (2012) 267–82.

[47] R.O. Large and C.G. Thomsen, Drivers of Green Supply Management Performance: Evidence from Germany. *J. Purch. Supply Manag.* **17** (2011) 176–84.

[48] Lee, Amy H. I., He-Yau Kang, Chang-Fu Hsu and Hsiao-Chu Hung, A Green Supplier Selection Model for High-Tech Industry. *Expert Systems Appl.* **36** (2009) 7917–27.

[49] Liao, Chin-Nung and H.-P. Kao, An Integrated Fuzzy TOPSIS and MCGP Approach to Supplier Selection in Supply Chain Management. *Exp. Syst. Appl.* **38** (2011) 10803–11.

[50] J.D. Linton, R. Klassen and V. Jayaraman, Sustainable Supply Chains: An Introduction. *J. Oper. Manag.* **25** (2007) 1075–82.

[51] F. Mafakheri, M. Breton and A. Ghoniem, Supplier Selection-Order Allocation: A Two-Stage Multiple Criteria Dynamic Programming Approach. *Int. J. Prod. Econ.* **132** (2011) 52–57.

[52] G. Mavrotas, Effective Implementation of the ε-Constraint Method in Multi-Objective Mathematical Programming Problems. *Appl. Math. Comput.* **213** (2009) 455–65.

[53] G. Mavrotas and K. Florios, An Improved Version of the Augmented ε-Constraint Method (AUGMECON2) for Finding the Exact Pareto Set in Multi-Objective Integer Programming Problems. *Appl. Math. Comput.* **219** (2013) 9652–69.

[54] H. Min and I. Kim, Green Supply Chain Research: Past, Present, and Future. *Logis. Res.* **4** (2012) 39–47.

[55] M.N. Nobar and M. Setak, A New Approach for Supplier Selection Process from the Features of Second Layer Suppliers Point of View. *Int. J. Ind. Eng.* **21** (2010).

[56] G. Noci, Designing 'green' vendor Rating Systems for the Assessment of a Supplier's Environmental Performance. *Eur. J. Purch. Supply Manag.* **3** (1997) 103–14.

[57] H. Osman and K. Demirli, A Bilinear Goal Programming Model and a Modified Benders Decomposition Algorithm for Supply Chain Reconfiguration and Supplier Selection. *Int. J. Prod. Econ.* **124** (2010) 97–105.

[58] H. Osman and K. Demirli, Economic Lot and Delivery Scheduling Problem for Multi-Stage Supply Chains. *Int. J. Prod. Econ.* **136** (2012) 275–86.

[59] P. Rao, The Greening of Suppliers-in the South East Asian Context. *J. Clean. Prod.* **13** (2005) 935–45.

[60] J. Roshandel, S.S. Miri-Nargesi and Loghman Hatami-Shirkouhi, Evaluating and Selecting the Supplier in Detergent Prod. Industry Using Hierarchical Fuzzy TOPSIS. *Appl. Math. Model.* **37** (2013) 10170–81.

[61] J. Sarkis, Evaluating Environmentally Conscious Business Practices. *Eur. J. Oper. Res.* **107** (1998) 159–74.

[62] J. Sarkis, A Strategic Decision Framework for Green Supply Chain Management. *J. Clean. Prod.* **11** (2003) 397–409.

[63] J. Sarkis, Models for Compassionate Operations. *Int. J. Prod. Econ.* **139** (2012) 359–65.

[64] J. Sarkis, Q. Zhu and K.-h. Lai, An Organizational Theoretic Review of Green Supply Chain Management Literature. *Int. J. Prod. Econ.* **130** (2011) 1–15.

[65] M. Setak and S. Sharifi, An Integrated Mathematical Model for Two Layers of Supplier Selection in the Supply Chain. *Int. J. Ind. Eng. Prod. Res.* (2011) 92–98

[66] S. Seuring, A Review of Modeling Approaches for Sustainable Supply Chain Management. *Decis. Supp.* **54** (2013) 1513–20.

[67] S. Seuring and M. Müller, From a Literature Review to a Conceptual Framework for Sustainable Supply Chain Management. *J. Clean. Prod.* **16** (2008) 1699–1710.

[68] Shen, Lixin and L. Olfat, Kannan Govindan, Roohollah Khodaverdi and Ali Diabat, A Fuzzy Multi Criteria Approach for Evaluating Green Supplier's Performance in Green Supply Chain with Linguistic Preferences. *Res. Conserv. Recycl.* **74** (2013) 170–79.

[69] Singh, Ritesh Kumar and Lyes Benyoucef., A Fuzzy TOPSIS Based Approach for E-Sourcing. *Eng. Appl. Artif. Intell.* **24** (2011) 437–48.

[70] J. de Sousa, A.B. Lopes, Ch.J.Ch. Jabbour, J. Sarkis and K. Govindan, Brazil's New National Policy on Solid Waste: Challenges and Opportunities. *Clean Technol. Environ. Policy* **16** (2014) 7–9.

[71] S. Srivastava, K, Green Supply Chain Management: A State of the Art Literature Review. *Int. J. Manag. Rev.* **9** (2007) 53–80.

[72] Tseng, Ming-Lang and Anthony S. F. Chiu, Evaluating Firm's Green Supply Chain Management in Linguistic Preferences. *J. Clean. Prod.* **40** (2013) 22–31.

[73] S. Vachon and R.D. Klassen, Extending Green Practices across the Supply Chain: The Impact of Upstream and Downstream Integration. *Int. J. Operat. Prod. Manag.* **26** (2006) 795–821.

[74] Wang, Xiaojun and Hing Kai Chan, A Hierarchical Fuzzy TOPSIS Approach to Assess Improvement Areas When Implementing Green Supply Chain Initiatives. *Int. J. Prod. Res.* **51** (2013) 3117–30.

[75] Wang, Ying-Ming and T.M.S. Elhag, Fuzzy TOPSIS Method Based on Alpha Level Sets with an Application to Bridge Risk Assessment. *Expert Syst. Appl.* **31** (2006) 309–19.

[76] Ch. Weber, A., John R. Current and W. C. Benton, Vendor Selection Criteria and Methods. *Eur. J. Oper. Res.* **50** (1991) 2–18.

[77] Wu, Chong and D. Barnes, A Literature Review of Decision-Making Models and Approaches for Partner Selection in Agile Supply Chains. *J. Purch. Supply Manage.* **17** (2011) 256–74.

[78] Wu, Desheng Dash, Y. Zhang, Dexiang Wu and David L. Olson, Fuzzy Multi-Objective Programming for Supplier Selection and Risk Modeling: A Possibility Approach. *Eur. J. Oper. Res.* **200** (2010) 774–87.

[79] Wu, Desheng and D.L. Olson, Supply Chain Risk, Simulation, and Vendor Selection. *Int. J. Prod. Econ.* **114** (2008) 646–55.

[80] Xiong, Yu, Yu Zhou, Gendao Li, Hing-Kai Chan and Zhongkai Xiong, Don't Forget Your Supplier When Remanufacturing. *Eur. J. Oper. Res.* **230** (2013) 15–25.

[81] Yang, Chung-Shan, Ch.-Sh. Lu, Jane Jing Haider and Peter Bernard Marlow, The Effect of Green Supply Chain Management on Green Performance and Firm Competitiveness in the Context of Container Shipping in Taiwan. *Trans. Res. Part E: Logist. Trans. Rev.* **55** (2013) 55–73.

[82] Yeh, Wei-Chang and M.-Ch. Chuang, Using Multi-Objective Genetic Algorithm for Partner Selection in Green Supply Chain Problems. *Exp. Syst. Appl.* **38** (2011) 4244–53.

[83] Yigin, I. H., H. Taşkin, I.H. Cedimoglu and B. Topal, Supplier Selection: An Expert System Approach. *Prod. Plann. Control* **18** (2007) 16–24.

[84] YüCel, Atakan and A. Fuat GüNeri, A Weighted Additive Fuzzy Programming Approach for Multi-Criteria Supplier Selection. *Exp. Syst. Appl.* **38** (2011) 6281–86.

[85] L.A. Zadeh, A Fuzzy-Algorithmic Approach to the Definition of Complex or Imprecise Concepts. *Int. J. Man-machine Studies* **8** (1976) 249–91.

[86] M. Zeydan, Cüneyt Çolpan and Cemal Çobanoglu, A Combined Methodology for Supplier Selection and Performance Evaluation. *Exp. Syst. Appl.* **38** (2011) 2741–51.