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An integrated Best-Worst and interval type-2 fuzzy TOPSIS methodology for green supplier selection

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Abstract

Supplier selection is one of the most important multi criteria decision making (MCDM) problems for decision makers in competitive market. Organizations of today's world are seeking new ways to reduce negative effects of their organizations to the environment and to reach a greener system. At this point, green supplier selection concept has gained great importance with its ability on incorporating environmental or green criteria into the classical supplier selection practices. Therefore, in this study, it is aimed at proposing a multi-phase MCDM model based on Best-Worst Method (BWM) and interval type-2 fuzzy technique for order preference by similarity to ideal solution (TOPSIS). A case study in a plastic injection molding facility in Turkey is performed to show the applicability of the proposed integrated methodology. The paper ensures insights into the decision making, methodology, and managerial implications. Results of the case study are examined and suggestions for future research are provided.

Keyword: MCDM; BWM, interval type-2 fuzzy sets; TOPSIS; green supplier selection, plastic injection molding

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1. Introduction

Supply chain management (SCM) includes creation of information and material flows, production scheduling, and planning of distribution systems (Ketikidis et al 2008). Making value over supply chain management is crucial for today's businesses in improving organizational performance and providing competitive advantage. Because competition is no longer just between institutions, but in the area of SCM. SCM focuses not only on material resources but also on values such as knowledge. Information has become the most important source of SCM (Coulson-Thomas, 2004; Wang et. al. 2018). SCM builds an integrated approach by analyzing manufacturers, warehouses, production and suppliers. Thus, the enterprises produce and distributes the product at the appropriate time and appropriate quantities. SCM implements an entire system approach while managing materials and services. Decision makers attach importance to the management of internal operations in order to increase the productivity of the enterprises. SCM requires the integration of internal and external activities in enterprises. With the increasing global competition, the quality and price gap between the products is closing every day. Therefore, supplier selection is one of the most significant multi criteria decision making problems for enterprises (Yücenur et al. 2011; Kim et. al. 2018). Choosing an appropriate supplier is one of the most important processes in the responsibility of the purchasing department. On the other hand, the practices aimed at protecting the nature gain importance both in the private sector and in the public sector. As environmental awareness increases, an environmentally friendly approach is also inevitable in supply chain management applications. Hence, final consumers also consider environmentally sensitive products in their procurement processes nowadays.

The aim of green supply chain management (GSCM) is to minimize pollution and other factors affecting environment. it helps the suppliers to know significance of environmental resolving issues. In addition, GSCM is to assist enterprises for achieving a balance between environmental and economic performance, by this way reduce the impact of their products, foster an environmental image and services on the environment. GSCM is interested in increasing the use of green products and encouraging them to increase their market share. In addition to traditional goals, GSCM also aims to establish and develop an environmentally friendly supply chain system. Therefore, environmental criteria should be used together with traditional criteria in selecting green suppliers. However, most of the green supplier selection studies in the literature are based on environmental criteria. The main criteria for the development of suppliers are green information transfer, investment and resource transfer, management and organization practices. In the portfolio-based analysis, pollution prevention and avoidance of pollution are considered as major differences in the selection of green suppliers (Zhu et al., 2010). Some studies have also used criteria such as GSCM capabilities, strategic level of procurement department, environmental commitment level or degree of green supplier evaluation and cooperation. In the green purchasing process, regulation, customer pressure, social responsibility and commercial benefits are among the most commonly used criteria (ElTayeb et al., 2010).

This paper proposes an integrated best-worst and interval type-2 fuzzy TOPSIS methodology for green supplier selection in plastic injection molding industry. The methodology introduced in this paper has three phases in selection of green suppliers. First, the selection criteria under green concept is determined through literature review and interviews with decision makers. In the second phase, criteria weights are assigned using BWM. Finally, to prioritize suppliers with respect to the weighted criteria, an interval type-2 fuzzy TOPSIS method is utilized. This study is considered as the first attempt in the integration of BWM and interval type-2 fuzzy TOPSIS for supplier selection knowledge. Since BWM is more efficient and easier for pairwise comparisons versus AHP, it is used in weighting the selection criteria. Use of TOPSIS method extended with interval type-2 fuzzy sets enable reflecting more uncertainty and ambiguity in decision making process as well as including a concept of similarity to ideal solution.

The proposed approach was applied in plastic injection molding industry to select green supplier. The products of plastic injection have been broadly used in high-tech commodities and different household necessities. In this regard, pipe and fittings production technology and raw material usage is intensive. In addition, the competition conditions of this production area are very fierce. Hence, choosing the right supplier plays a vital role in the success of the enterprises. Rare methods and studies have done in the literature for this area. This paper proposes best-worst method to select which supplier suit a pipe manufacturing enterprise. A case design approach was adopted for the research – data being provided by Trabzon Turkey district -based small and medium-sized enterprise. In this regard, the main contributions of this paper are summarized as follows: *(i)* An integrated approach based on best-worst and interval type-2 fuzzy TOPSIS methodology was proposed. *(ii)* A case study was performed for plastic injection molding industry. This case study can highlight the implications of the methodology in the industry and the methodology followed can be easily adapted to another sector in this regard. *(iii)* In the literature, interval type-2 fuzzy sets are combined with BWM for the first

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time. By doing this, uncertainty in decision making process can be clearly reflected compared to type-1 fuzzy set theory.

The structure of the paper is given as follows: A literature review supply chain management and supplier selectin is presented in next section. The best worst method is described and analyzed in section 3. In Section 4, a case study is given for understand proposed method and performed green supplier selection in an injection molding facility in Turkey. Finally, conclusions and directions for future research are presented in section 5.

2. Literature review

Literature review section is divided as two-sub section. Firstly, green supplier selection literature is analyzed then literature related best worst method is addressed. There is a lot of studied related green supplier selection and evaluation in the literature. Supplier selection can be defined as one of most important phases in supply management function and purchasing (Banaeian et al. 2018). A variety of MCDM methods have been utilized by researchers for dealing with green supplier selection problem in recently. In the literature different supplier selection criteria are used like quality, delivery and cost for evaluating their supplier (Hlioui et al. 2017). There are a number of environmental factors to select green supplier (Yu et al. 2018). These criteria are considered by researcher such as pollution production Kannan et al. (2015); Rezaei et al. (2016), recycling utilization level of waste material Govindan and Sivakumar (2016), level of clean energy utilization Yazdani et al. (2017), noise level Hu et al. (2015), level of environmental protection input Shabanpour et al. (2017). On the other hand, individual and hybrid methods were proposed for determined supplier selection in the literature (Quan et al. 2018). A grey analytical network process-based (grey ANP-based) model to determine green supplier development programs for development the performance of suppliers was introduced by Dou et al. (2014). The proposed model was tested on real-world example to show model effectiveness. Tsui et al. (2015) proposed PROMETHEE method based on a hybrid multiple criteria decision making to develop green supplier performance in the TFT-LCD industry. Fuzzy Axiomatic Design approach was introduced to choose the best green supplier for plastic manufacturing company in Singapore by Kannan et al. (2015). The requirements of the manufacturer and the supplier were evaluated in proposed methodology with multi-objective optimization model and fuzzy nature. Hashemi et al. (2015) considered environmental and economic criteria and introduced a model, which is based on Improved Grey relational analysis and Analytic network process for comprehensive green supplier selection. Uygun and Dede

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(2016) proposed an integrated fuzzy MCDM methods, which is based on Fuzzy DEMATEL, Fuzzy ANP and Fuzzy TOPSIS, to evaluate and select green supplier by considering green purchasing, green design, green logistics and reverse logistics. Yazdani et al. (2017) designed a green supplier selection model. The proposed model focused the inter-relationships between requirement of customer with DEMATEL method when constructing a relationship structure. Moreover, Quality function deployment was used to determine degree of relationship for the criteria of supplier selection pair. Recently, three popular multi-criteria supplier selection application, which are TOPSIS, VIKOR and GRA, compared each other by Banaeian et al. (2018) under fuzzy environment. The method was applied actual company from the agri- food industry for a green supplier evaluation and selection. Yu et al. (2018) proposed a model based on carbon footprint including environmental and economic attributes to select green supplier with dynamic environment. Moreover, literature review related green supplier selection and estimation methods can be found in Govindan et al. (2015); Malyiya and Kant (2015).

On the other hand, the best worst method was first introduced by Rezaei, (2015) to solve multi-criteria decision-making problems. In this method, a lot of alternatives are considered according to among different criteria to choose the best alternative. According to the method, two of the criteria, which are the best or most important criteria and the worst or least important criteria, are determined by decision maker. This method is novel approach and has applied different research area due to flexibility and simplicity of BWM for solving the problems. Rezaei et al. (2015) applied Best Worst Method to supplier segmentation for finding the relative weight of the criteria. Then, the method was applied to different research area such as supplier selection Rezaei et al. (2016); Gupta and Barua, (2017), Multi criteria decision making Rezaei (2016), multi-criteria group decision making Mou et al. (2016), evaluating freight bundling configurations Rezaei et al. (2017), assessment of outer factors affecting sustainability in SCM Ahmad et al. (2017). Guo and Zhao (2017) proposed BWM technique with MCDM under fuzzy environment. van de Kaa et al. (2017) used BWM technique and expert opinions for calculating relative importance of factors to evaluate and rank technologies. The method was applied the technology battle for biomass conversion in the Netherlands. Omrani et al. (2018) proposed an integrated approach including Taguchi-neural network BWM and TOPSIS under fuzzy environment. The proposed integrated approach was applied on case study to find optimal combination different power plant.

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In the light of above, this paper aims to fill the gap in the literature for an integrated best-worst and interval type-2 fuzzy TOPSIS methodology for green supplier selection in plastic injection molding industry in Turkey.

3. Material and Method

3.1. The evaluation criteria for green supplier selection

Within the context of green supplier selection, the recent review of Govindan et al. (2015) identified Environmental Management Systems (EMS) as the most popular environmental criteria due to its flexibility. Nielsen et al. (2014) reviewed 57 related papers and, like Govindan et al. (2015), found EMS the most important and comprehensive environmental criteria amongst over 90 identified measures. Using these reviews and the identified criteria, a combination of conventional and green supplier selection criteria is used in our study for the purpose of supplier assessment. The criteria used in relevant literatures are listed in Table 1.

Table 1. The used criteria in literature for supplier selection

	Kahraman et al. 2009	Büyüközkan and Çiftçi 2010	Chun-hao et al. 2008	Demirtas and Ustun 2009	Lee 2009	Lin et al 2010	Lin et al. 2010	Liou and Chuang. 2010	Liu et al. 2009	Liu et al. 2018	Luthra et al. 2017	Malmir et al.2013	Razmi et al. 2009	Silva et al. 2009	Vinodh et al. 2011	Wadhwa and Ravindran 2007	Wang et al. 2009	Attari et al. 2012	Haq and Kannan 2006	Prahinsk and Benton 2004	Chiou et al. 2008	Freeman and chen 2015	Hsu et al. 2013	Kuo et al. 2010
C1-Environmental.																					X	X	X	X
C2-Social																					X	X	X	X
C3-Quality	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
C4-Service	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X									
C5-Risk			X		X				X	X		X	X		X	X						X	X	
C6-Cost/Price	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
C7-Capability				X	X				X		X	X	X	X										
C8-Business structure													X			X		X	X					X

3.2. Best and worst method

Best and worst method (BWM) is introduced for the choice phase (Rezaei, 2015). The BWM is characterized by some salient features such as *(i)* it provides a very structured pairwise

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comparison, which results in highly consistent and reliable results; *(ii)* it uses only two vectors instead of a full pairwise comparison matrix. This implies less data collection effort, taking less time from the analyst and the decision-maker. Interestingly as these two vectors are more structured than a full matrix, less data here leads to more reliability; *(iii)* the method uses only integer values, which makes it more practically understandable compared to methods utilizing fractions (Rezaei et al. 2016).

Step 1. Determine a set of decision criteria. In this step, we consider the criteria $(c_1, c_2 \dots, c_n)$ that should be used to arrive at a decision.

Step 2. Determine the best (e.g. most desirable, most important) and the worst (e.g. least desirable, least important) criteria. In this step, the decision-maker identifies the best and the worst criteria in general. No comparison is made at this stage.

Step 3. Determine the preference of the best criterion over all the other criteria using a number between 1 and 9. The resulting Best-to-Others vector would be:

$A_B = (a_{B1}, a_{B2}, \dots, a_{Bn}),$

Where a_{Bj} indicates the preference of the best criterion B over criterion j. It is clear that $a_{BB} = 1$

Step 4. Determine the preference of all the criteria over the worst criterion using a number between 1 and 9. The resulting Others-to-Worst vector would be

$A_B = (a_{1W}, a_{2W}, \dots, a_{nW})^T$

where a_{jW} indicates the preference of the criterion j over the worst criterion W. It is clear that $a_{WW} = 1$.

Step 5. Find the optimal weights $(w_1^*, w_2^*, \dots, w_n^*)$.

The optimal weight for the criteria is the one where, for each pair of w_B/w_j and w_j/w_w we have $w_B/w_j = a_{jw}$. To satisfy these for all j, we should find a solution where the maximum absolute differences $\left|\frac{w_B}{w_j} - a_{Bj}\right|$ and $\left|\frac{w_j}{w_W} - a_{jW}\right|$ for all j is minimized. Considering the non-negativity and sum condition for the weights, the following problem is resulted:

$$\min \max_j \left\{ \left|\frac{w_B}{w_j} - a_{Bj}\right|, \left|\frac{w_j}{w_W} - a_{jW}\right| \right\}$$

s.t

$\Sigma w_j = 1$

$w_j \geq 0$ for all j

Problem can be transferred to the following problem: ξ

min ξ

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$$\left|\frac{w_B}{w_j} - a_{Bj}\right| \leq \xi \text{ for all } j$$
$$\left|\frac{w_j}{w_W} - a_{jW}\right| \leq \xi \text{ for all } j$$
$$\Sigma w_j = 1$$
$$w_j \geq 0, \text{ for all } j$$

Solving problem, the optimal weights $(w_1^*, w_2^*, \ldots, w_n^*)$ and ξ^* are calculated. After that consistency ratio is calculated with consistency index (Table 2). It becomes clear that, the bigger the ξ^*, the higher the consistency ratio, and the less reliable the comparisons become.

Table 2. Consistency Index

a_{BW}	1	2	3	4	5	6	7	8	9
consistency index	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

3.3. Interval type-2 fuzzy TOPSIS

TOPSIS approach aims to choose alternatives that simultaneously have the shortest distance from the positive ideal solution and the farthest distance from the negative-ideal solution (Celik et al., 2012; Behzadian et al., 2012; Yoon and Hwang, 1995). Interval type-2 fuzzy TOPSIS, (Chen and Lee, 2010), Pythagorean fuzzy TOPSIS (Oz et al. 2018; Ak and Gul, 2018) are developed as different versions of TOPSIS based on fuzzy sets. TOPSIS based on IT2FSs reflects uncertainty, vagueness, and ambiguity (using advantages of IT2FSs (Celik et al., 2013; Celik et al., 2014a; 2014b; Chen and Lee, 2010; Celik and Gumus, 2018) better than ordinary fuzzy TOPSIS. The proposed TOPSIS based on IT2FSs can be applied via series of steps:

Step 1: Assume that there is a set S of alternatives, where $S = \{s_1, s_2, \ldots, s_n\}$, and assume that there is a set C of criteria, $C = \{c_1, c_2, \ldots, c_m\}$ and there are K decision makers $D = \{D_1, D_2, \ldots, D_K\}$

Each decision maker is a participant in our questionnaire and s/he has her/his own perception value regarding the performance of supplier with respect to each criterion. The aggregate performance value of supplier with respect to each criterion can be calculated using Eq. (1).

$$E_c = (\tilde{\tilde{c}}_{ij}^{p})_{m\times n} = \begin{array}{c} \\ c_1 \\ c_2 \\ \vdots \\ c_m \end{array} \begin{array}{c} \begin{array}{cccc} s_1 & s_2 & \cdots & s_n \end{array} \\ \begin{bmatrix} \tilde{\tilde{c}}_{11}^{p} & \tilde{\tilde{c}}_{12}^{p} & \cdots & \tilde{\tilde{c}}_{1n}^{p} \\ \tilde{\tilde{c}}_{21}^{p} & \tilde{\tilde{c}}_{22}^{p} & \cdots & \tilde{\tilde{c}}_{2n}^{p} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{\tilde{c}}_{m1}^{p} & \tilde{\tilde{c}}_{m2}^{p} & \cdots & \tilde{\tilde{c}}_{mn}^{p} \end{bmatrix} \end{array} \quad (1)$$

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where $\tilde{\tilde{c}}_{ij} = \left(\dfrac{\tilde{\tilde{c}}_{ij}^{1} \oplus \tilde{\tilde{c}}_{ij}^{2} \oplus \cdots \oplus \tilde{\tilde{c}}_{ij}^{k}}{k} \right)$, $\tilde{\tilde{s}}_{ij}$ is an interval type-2 fuzzy set $1 \le i \le m, 1 \le j \le n, 1 \le c \le k$ and k denotes the number of expert, $\tilde{\tilde{c}}_{ij} = \left(\left(a_{i1}^{U}, a_{i2}^{U}, a_{i3}^{U}, a_{i4}^{U}; H_1\left(\tilde{A}_i^{U}\right), H_2\left(\tilde{A}_i^{U}\right) \right), \left(a_{i1}^{L}, a_{i2}^{L}, a_{i3}^{L}, a_{i4}^{L}; H_1\left(\tilde{A}_i^{L}\right), H_2\left(\tilde{A}_i^{L}\right) \right) \right)$

Step 2: Obtain the weighting matrix W_s of the criteria using best-worst method,

$$W_s = \left(w_i^s\right)_{1\times m} = \begin{matrix} c_1 & c_2 & \cdots & c_m \\ \left[w_1^s, \right. & w_2^s, & \cdots, & \left. w_m^s \right] \end{matrix} \qquad (2)$$

Step 3: Calculate the weighted decision matrix by multiplying the importance weights of criteria and the values in the decision matrix. The weighted decision matrix $\tilde{\tilde{V}}$ for each criterion is defined as:

$$\tilde{\tilde{v}}_{ij} = \tilde{\tilde{c}}_{ij} \text{ x } w_i \qquad (3)$$

where $\tilde{\tilde{v}}_{ij}$ denotes the weighted trapezoidal interval type-2 fuzzy numbers.

Step 4: Calculate the ranking value $Rank\left(\tilde{\tilde{v}}_{ij}\right)$ of IT2FSs. The ranking weighted decision matrix E_w is constructed

$$E_w = (Rank\left(\tilde{\tilde{v}}_{ij}\right))_{m\times n}$$

Step 5: Determine the positive ideal solution $x^* = \left(v_1^*, v_2^*, ..., v_m^*\right)$ and the negative-ideal solution $x^- = \left(v_1^-, v_2^-, ..., v_m^-\right)$ where

$$v_i^* = \begin{cases} \max\limits_{i\le j\le n} \left\{ Rank\left(\tilde{\tilde{v}}_{ij}\right) \right\}, & if \ f_i \in B \\ \min\limits_{i\le j\le n} \left\{ Rank\left(\tilde{\tilde{v}}_{ij}\right) \right\}, & if \ f_i \in C \end{cases} \qquad (4)$$

$$v_i^- = \begin{cases} \min\limits_{i\le j\le n} \left\{ Rank\left(\tilde{\tilde{v}}_{ij}\right) \right\}, & if \ f_i \in B \\ \max\limits_{i\le j\le n} \left\{ Rank\left(\tilde{\tilde{v}}_{ij}\right) \right\}, & if \ f_i \in C \end{cases} \qquad (5)$$

Then positive $d^*(x_j)$ and negative $d^-(x_j)$ ideal solutions are determined for green supplier as follows:

$$d^*(x_j) = \sqrt{\sum_{i\in I} \left(Rank(\tilde{\tilde{v}}_{ij}) - v_i^* \right)^2} \qquad (6)$$

$$d^-(x_j) = \sqrt{\sum_{i\in I} \left(Rank(\tilde{\tilde{v}}_{ij}) - v_i^- \right)^2} \qquad (7)$$

The ranking value $Rank(\tilde{\tilde{A}}_i)$ of the trapezoidal interval type-2 fuzzy set $\tilde{\tilde{A}}_i$ is defined as follows:

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$$Rank(\tilde{\tilde{v}}_i) = M_1(\tilde{v}_i^U) + M_1(\tilde{v}_i^L) + M_2(\tilde{v}_i^U) + M_2(\tilde{v}_i^L) + M_3(\tilde{v}_i^U) + M_3(\tilde{v}_i^L)$$
$$-\frac{1}{4}\left(S_1(\tilde{v}_i^U) + S_1(\tilde{v}_i^L) + S_2(\tilde{v}_i^U) + S_2(\tilde{v}_i^L) + S_3(\tilde{v}_i^U) + S_3(\tilde{v}_i^L) + S_4(\tilde{v}_i^U) + S_4(\tilde{v}_i^L)\right)$$
$$+H_1(\tilde{v}_i^U) + H_1(\tilde{v}_i^L) + H_2(\tilde{v}_i^U) + H_2(\tilde{v}_i^L)$$

where $M_p(\tilde{v}_i^j)$ denotes the average of the elements v_{ip}^j and $v_{i(p+1)}^j$, $M_p(\tilde{v}_i^j) = \left(v_{ip}^j + v_{i(p+1)}^j\right)/2, 1 \le p \le 3$, denotes the standard deviation of the elements v_{iq}^j and $v_{i(q+1)}^j$, $S_q(\tilde{v}_i^j) = \sqrt{\frac{1}{2}\sum_{k=q}^{q+1}\left(v_{ik}^j - \frac{1}{2}\sum_{k=q}^{q+1} v_{ik}^j\right)^2}, 1 \le q \le 3$, $S_4(\tilde{v}_i^j)$ denotes the standard deviation of the elements $v_{i1}^j, v_{i2}^j, v_{i3}^j, v_{i4}^j$, $S_4(\tilde{v}_i^j) = \sqrt{\frac{1}{4}\sum_{k=1}^{4}\left(v_{ik}^j - \frac{1}{4}\sum_{k=1}^{4} v_{ik}^j\right)^2}$ $H_p(\tilde{v}_i^j)$ denotes the membership value of the element $v_{i(p+1)}^j$ in the trapezoidal membership function $\tilde{v}_i^j, 1 \le p \le 3, j \in \{U, L\}$, and $1 \le i \le n$.

Step 6: Then the closeness coefficient $CC(x_j)$ is calculated.

$$CC(x_j) = \frac{d^-(x_j)}{d^*(x_j) + d^-(x_j)} \tag{8}$$

Step 7: We can rank alternatives in decreasing order. The larger the value of $CC(x_j)$, the higher the preference of the green supplier.

4. Case Study

Injection molding is one of the most common methods used to produce plastic parts. With this method, complex geometric products can be produced easily. Molding machine, raw plastic material and mold of the product to be produced are necessary for the production by injection method. The raw material used in this production method is directly related to the quality of the product. In this respect, supplier choice plays an important role in the success of the operator. The injection method consists of 4 main stages as demonstrated in Figure 1. These stages drying, blending and dosing, injection molding and regrinding, respectively. In the drying stage, the material (plastic beads and the re-usable scrap) is fed into the dryer, to remove or reduce moisture to an acceptable level. In the second stage of blending and dosing, material is further mixed with the additives, like colors and other property enhancers. In the third stage, the injection molding process takes place, wherein the plastic mixture is melted and converted into a solid part. In the fourth stage of regrinding, runner, gates, and any other unwanted plastic, which is attached to the part, is removed and ground into granules appropriate for adding to virgin mix (Madan et al.,2015). In this study, we carried out a case study for green supplier selection in an injection molding facility in Turkey.

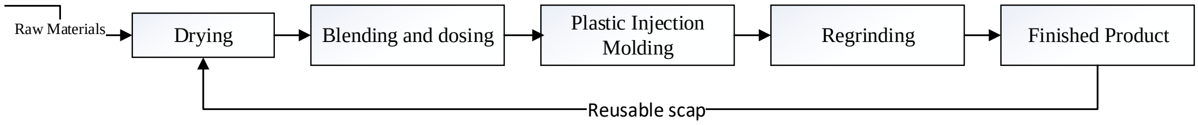

Figure 1. Stages of an injection molding process

4.1. The calculation process of Best-worst method

In this paper, we applied the best-worst method for obtaining the importance weights of the green criteria to evaluate supplier in plastic injection. This method is also based on comparison matrices as AHP (Rezaei, 2015). It also requires less pairwise comparison data against AHP. Then, we have applied BWM for obtaining the importance weights of the green criteria for all sub-criteria and main criteria. In this step, five experts evaluated the predefined green criteria. Five people are determined for the evaluations carried out to implement the proposed methodology in the enterprise. Expert 1 works as a manager in the enterprise and has 10 years of experience. The Expert 2, five years experienced chemical engineer. He is also responsible for the quality control of the enterprise. Expert 3 serves as a machine technician in the enterprise. The responsibility of the Expert 3 is to determine the raw material ratios and to connect the molds to the machines. Expert 4 is a machine technician and has the same duties and responsibilities as expert 3. Expert 5 works as a purchasing manager in the enterprise. He works coordinated with the company manager in the determination of the appropriate supplier. For example, the mathematical formulation of main criteria for BWM with respect to Expert1 evaluation is presented as follows:

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$$
\begin{aligned}
&\min \xi \\
&st. \\
&\left|\frac{w_6}{w_1}-4\right| \le \xi,\ \left|\frac{w_6}{w_2}-7\right| \le \xi,\ \left|\frac{w_6}{w_3}-1\right| \le \xi,\ \left|\frac{w_6}{w_4}-2\right| \le \xi, \\
&\left|\frac{w_6}{w_5}-3\right| \le \xi,\ \left|\frac{w_6}{w_7}-7\right| \le \xi,\ \left|\frac{w_6}{w_8}-7\right| \le \xi, \\
&\left|\frac{w_1}{w_8}-4\right| \le \xi,\ \left|\frac{w_2}{w_8}-1\right| \le \xi,\ \left|\frac{w_3}{w_8}-7\right| \le \xi,\ \left|\frac{w_4}{w_8}-6\right| \le \xi, \\
&\left|\frac{w_5}{w_8}-5\right| \le \xi,\ \xi, \left|\frac{w_7}{w_8}-1\right| \le \xi, \\
&w_1+w_2+w_3+w_4+w_5+w_6+w_7+w_8=1 \\
&w_1, w_2, w_3, w_4, w_5, w_6, w_7, w_8 \ge 0
\end{aligned}
$$

Then, all procedure is applied for sub-criteria according to the five experts. All calculations are presented in Table 3. These importance weights of green criteria are used for evaluating supplier in IT2FTOPSIS procedure. On the other hand, the all consistency ratio values are obtained that is presented in Table 4. w_1, w_2, w_3, w_4, w_5, w_6, w_7 and w_8 are found as 0.100, 0.035, 0.205, 0.170, 0.135, 0.285, 0.035 and 0.035 respectively. ζ is found 3.73 which used in CR calculation. Then we calculated the consistency ratio, using ξ and the corresponding consistency index by Eq. (9) (see Table 2), as follows: All the evaluations of risk parameters are provided in Table 5.

For example, the consistency ratio for main criteria with respect to Expert1 CR is $\xi / 3.73 = 0.307$ which implies a very good consistency. The all evaluations are made with good consistency.

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Table 3. The local and global weights

Criteria	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Local weights	Global weights	Ranking order
C1: Environmental.	0.1	0.159	0.086	0.197	0.2204		0.152	
C11: Environment management systems	0.073	0.091	0.09	0.107	0.0683	0.086	0.013	21
C12: Green design and purchasing	0.05	0.024	0.025	0.078	0.0249	0.041	0.006	35
C13: Green manufacturing	0.327	0.249	0.233	0.293	0.2306	0.267	0.041	12
C14: Green management	0.129	0.067	0.145	0.029	0.1467	0.103	0.016	18
C15: Green packing and labeling	0.123	0.225	0.209	0.136	0.1808	0.175	0.027	15
C16: Waste management and pollution prevention	0.224	0.201	0.233	0.164	0.0932	0.183	0.028	14
C17: Environmental competencies	0.073	0.143	0.065	0.193	0.2555	0.146	0.022	16
C2: Social	0.035	0.102	0.05	0.043	0.049		0.056	
C21: Occupational Health and Safety Systems	0.376	0.29	0.346	0.243	0.3302	0.317	0.018	17
C22: The interests and rights of employees	0.084	0.226	0.231	0.277	0.1967	0.203	0.011	25
C23: The rights of stakeholders	0.142	0.097	0.077	0.097	0.1157	0.106	0.006	36
C24: Information Disclosure	0.084	0.097	0.115	0.141	0.0796	0.103	0.006	37
C25: Labor relation records	0.057	0.032	0.038	0.034	0.0405	0.041	0.002	40
C26: training aids	0.257	0.258	0.192	0.209	0.2373	0.231	0.013	23
C3: Quality	0.205	0.196	0.191	0.14	0.1959		0.186	
C31: Low defect rate	0.455	0.388	0.419	0.383	0.5367	0.436	0.081	2
C32: Inspections methods and plans	0.35	0.184	0.15	0.213	0.2317	0.226	0.042	9
C33: Adherence to quality tools	0.123	0.326	0.349	0.319	0.1618	0.256	0.047	6
C34: Quality systems	0.072	0.102	0.083	0.085	0.0698	0.082	0.015	19
C4: Service	0.17	0.085	0.136	0.091	0.1224		0.121	
C41: Quick Responsivenes	0.1	0.1	0.1	0.125	0.1111	0.107	0.013	22
C42: Flexibility and Agility	0.416	0.3	0.254	0.399	0.3143	0.337	0.041	11
C43: After sales service	0.484	0.6	0.646	0.476	0.5746	0.556	0.067	3
C5: Risk	0.135	0.177	0.214	0.221	0.0816		0.166	
C51: Supply Constraint	0.225	0.247	0.281	0.269	0.1722	0.239	0.04	13
C52: Buyer Suplier Constraint	0.035	0.035	0.03	0.03	0.0353	0.033	0.005	38
C53: Bad Performance History and Reputation of	0.051	0.07	0.047	0.047	0.0662	0.056	0.009	29
C54: Variation in price	0.333	0.351	0.311	0.311	0.3226	0.326	0.054	5
C55: Supplier's production limitations	0.045	0.044	0.043	0.043	0.0397	0.043	0.007	31
C56: amount of past business	0.051	0.039	0.037	0.037	0.0413	0.041	0.007	32
C57: Uncompleted orders	0.26	0.212	0.251	0.253	0.3226	0.26	0.043	7
C6: Cost/Price	0.285	0.215	0.237	0.244	0.2449		0.245	
C61: Transportation Cost	0.196	0.176	0.123	0.178	0.1958	0.174	0.043	8
C62: Purchase Cost	0.251	0.242	0.205	0.232	0.2511	0.236	0.058	4
C63: Quantity discount	0.055	0.053	0.036	0.054	0.0553	0.051	0.012	24

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C64: Payment terms	0.141	0.123	0.086	0.124	0.3572	0.166	0.041	10
C65: Profit on Product	0.357	0.407	0.55	0.412	0.1405	0.373	0.092	1
C7: Capability of supplier	0.035	0.047	0.063	0.024	0.0612		0.046	
C71: Financial capability	0.128	0.203	0.141	0.125	0.0912	0.138	0.006	33
C72: Change order capability	0.182	0.17	0.287	0.178	0.1985	0.203	0.009	28
C73: Technical capability	0.278	0.286	0.12	0.27	0.2192	0.234	0.011	26
C74: Understanding of technology	0.128	0.107	0.141	0.151	0.156	0.137	0.006	34
C75: Engineering/technical support resources	0.027	0.028	0.031	0.099	0.0207	0.041	0.002	42
C76: Technical know how	0.101	0.078	0.11	0.026	0.1365	0.09	0.004	39
C77: Distribution capability	0.155	0.129	0.171	0.151	0.1779	0.157	0.007	30
C8: Business structure of supplier	0.035	0.019	0.028	0.043	0.0245		0.03	
C81: Knowledge of market	0.047	0.05124	0.0558	0.0387	0.0465	0.048	0.001	44
C82: Information systems	0.052	0.05855	0.0632	0.0453	0.041	0.052	0.002	43
C83: Communication system	0.041	0.04005	0.0632	0.0292	0.0525	0.045	0.001	45
C84: Desire for business	0.369	0.36957	0.3664	0.2661	0.3686	0.348	0.01	27
C85: Management and organizations	0.41	0.40962	0.4104	0.5661	0.4095	0.441	0.013	20
C86: Market share	0.082	0.07097	0.0409	0.0546	0.0819	0.066	0.002	41

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Table 4. The consistency for all experts

	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5
Main criteria	0.3070	0.4721	0.2406	0.2406	0.1912
C1	0.1786	0.2275	0.3120	0.2406	0.2406
C2	0.1786	0.2237	0.2237	0.3072	0.3072
C3	0.0995	0.1181	0.0870	0.2174	0.1832
C4	0.0706	0.0000	0.1529	0.1181	0.1716
C5	0.1030	0.1912	0.2710	0.1912	0.2521
C6	0.1529	0.1832	0.2092	0.1832	0.1529
C7	0.2406	0.2528	0.2666	0.2406	0.3049
C8	0.1912	0.2348	0.1009	0.2155	0.1912

The suppliers have been named as Supplier 1, Supplier 2 and Supplier 3 for the companies that it can supply in raw materials. Supplier 1 is a local company. Compared to the other two companies, the production volume and the transportation network is limited. Supplier 2 has a strong sales and transportation network throughout the country and does not sell internationally. This company is producing according to TSE and ISO quality standards. Supplier 3 is a global company. Technology levels are higher than the other two companies. The number of defective products is relatively low and production volume is high. However, raw material prices are higher than the other two firms.

In this step, the aggregated interval type-2 fuzzy evaluation matrix for green supplier evaluation is obtained and it is shown in Table 5. Then, the weighted evaluation matrix is calculated multiplying the importance weights of green criteria and the aggregated interval type-2 fuzzy evaluation matrix. The weighted evaluation matrix is presented in Table 6. In this process, the importance weights of green criteria are used as input that is obtained result of BWM approach. Then, the ranking values for each green criterion with respect to three supplier selection are calculated. The all calculations are presented in Table 7.

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Table 5. The aggregated evaluation matrix

	Supplier 1	Supplier 2	Supplier 3
C1			
C11	((0.05;0.2;0.2;0.4;1;1),(0.13;0.2;0.2;0.3;0.9;0.9))	((0.3;0.5;0.5;0.7;1;1),(0.4;0.5;0.5;0.6;0.9;0.9))	((0.5;0.7;0.7;0.85;1;1),(0.6;0.7;0.7;0.78;0.9;0.9))
C12	((0;0.1;0.1;0.3;1;1),(0.05;0.1;0.1;0.2;0.9;0.9))	((0.3;0.5;0.5;0.7;1;1),(0.4;0.5;0.5;0.6;0.9;0.9))	((0.3;0.5;0.5;0.7;1;1),(0.4;0.5;0.5;0.6;0.9;0.9))
C13	((0.05;0.2;0.2;0.4;1;1),(0.13;0.2;0.2;0.3;0.9;0.9))	((0.3;0.5;0.5;0.7;1;1),(0.4;0.5;0.5;0.6;0.9;0.9))	((0.4;0.6;0.6;0.75;1;1),(0.5;0.6;0.6;0.68;0.9;0.9))
C14	((0;0.1;0.1;0.3;1;1),(0.05;0.1;0.1;0.2;0.9;0.9))	((0.1;0.3;0.3;0.5;1;1),(0.2;0.3;0.3;0.4;0.9;0.9))	((0.1;0.3;0.3;0.5;1;1),(0.2;0.3;0.3;0.4;0.9;0.9))
C15	((0.05;0.2;0.2;0.4;1;1),(0.13;0.2;0.2;0.3;0.9;0.9))	((0.15;0.3;0.3;0.5;1;1),(0.23;0.3;0.3;0.4;0.9;0.9))	((0.15;0.3;0.3;0.5;1;1),(0.23;0.3;0.3;0.4;0.9;0.9))
C16	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))	((0.5;0.7;0.7;0.9;1;1),(0.6;0.7;0.7;0.8;0.9;0.9))	((0.6;0.8;0.8;0.95;1;1),(0.7;0.8;0.8;0.88;0.9;0.9))
C17	((0.1;0.3;0.3;0.5;1;1),(0.2;0.3;0.3;0.4;0.9;0.9))	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))	((0.3;0.5;0.5;0.7;1;1),(0.4;0.5;0.5;0.6;0.9;0.9))
C2	((0;0;0;0;0;0),(0;0;0;0;0;0))	((0;0;0;0;0;0),(0;0;0;0;0;0))	((0;0;0;0;0;0),(0;0;0;0;0;0))
C21	((0.3;0.5;0.5;0.7;1;1),(0.4;0.5;0.5;0.6;0.9;0.9))	((0.5;0.7;0.7;0.9;1;1),(0.6;0.7;0.7;0.8;0.9;0.9))	((0.9;1;1;1;1;1),(0.95;1;1;1;0.9;0.9))
C22	((0.05;0.2;0.2;0.4;1;1),(0.13;0.2;0.2;0.3;0.9;0.9))	((0.1;0.3;0.3;0.5;1;1),(0.2;0.3;0.3;0.4;0.9;0.9))	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))
C23	((0.7;0.85;0.85;0.95;1;1),(0.78;0.85;0.85;0.9;0.9;0.9))	((0.5;0.7;0.7;0.85;1;1),(0.6;0.7;0.7;0.78;0.9;0.9))	((0.5;0.7;0.7;0.9;1;1),(0.6;0.7;0.7;0.8;0.9;0.9))
C24	((0.05;0.2;0.2;0.4;1;1),(0.13;0.2;0.2;0.3;0.9;0.9))	((0;0.05;0.05;0.2;1;1),(0.03;0.05;0.05;0.13;0.9;0.9))	((0;0.05;0.05;0.2;1;1),(0.03;0.05;0.05;0.13;0.9;0.9))
C25	((0.15;0.3;0.3;0.5;1;1),(0.23;0.3;0.3;0.4;0.9;0.9))	((0.05;0.2;0.2;0.4;1;1),(0.13;0.2;0.2;0.3;0.9;0.9))	((0.05;0.2;0.2;0.4;1;1),(0.13;0.2;0.2;0.3;0.9;0.9))
C26	((0.15;0.3;0.3;0.5;1;1),(0.23;0.3;0.3;0.4;0.9;0.9))	((0.9;1;1;1;1;1),(0.95;1;1;1;0.9;0.9))	((0.8;0.95;0.95;1;1;1),(0.88;0.95;0.95;0.98;0.9;0.9))
C3	((0;0;0;0;0;0),(0;0;0;0;0;0))	((0;0;0;0;0;0),(0;0;0;0;0;0))	((0;0;0;0;0;0),(0;0;0;0;0;0))
C31	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))	((0.4;0.6;0.6;0.8;1;1),(0.5;0.6;0.6;0.7;0.9;0.9))	((0.7;0.85;0.85;0.95;1;1),(0.78;0.85;0.85;0.9;0.9;0.9))
C33	((0.1;0.3;0.3;0.5;1;1),(0.2;0.3;0.3;0.4;0.9;0.9))	((0.4;0.6;0.6;0.8;1;1),(0.5;0.6;0.6;0.7;0.9;0.9))	((0.7;0.85;0.85;0.95;1;1),(0.78;0.85;0.85;0.9;0.9;0.9))
C34	((0.3;0.5;0.5;0.7;1;1),(0.4;0.5;0.5;0.6;0.9;0.9))	((0.5;0.7;0.7;0.9;1;1),(0.6;0.7;0.7;0.8;0.9;0.9))	((0.6;0.8;0.8;0.95;1;1),(0.7;0.8;0.8;0.88;0.9;0.9))
C35	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))	((0.7;0.85;0.85;0.95;1;1),(0.78;0.85;0.85;0.9;0.9;0.9))	((0.7;0.85;0.85;0.95;1;1),(0.78;0.85;0.85;0.9;0.9;0.9))
C4	((0;0;0;0;0;0),(0;0;0;0;0;0))	((0;0;0;0;0;0),(0;0;0;0;0;0))	((0;0;0;0;0;0),(0;0;0;0;0;0))
C41	((0.4;0.6;0.6;0.8;1;1),(0.5;0.6;0.6;0.7;0.9;0.9))	((0.8;0.95;0.95;1;1;1),(0.88;0.95;0.95;0.98;0.9;0.9))	((0.7;0.9;0.9;1;1;1),(0.8;0.9;0.9;0.95;0.9;0.9))
C42	((0.3;0.5;0.5;0.7;1;1),(0.4;0.5;0.5;0.6;0.9;0.9))	((0.5;0.7;0.7;0.9;1;1),(0.6;0.7;0.7;0.8;0.9;0.9))	((0.6;0.8;0.8;0.95;1;1),(0.7;0.8;0.8;0.88;0.9;0.9))
C44	((0.3;0.5;0.5;0.7;1;1),(0.4;0.5;0.5;0.6;0.9;0.9))	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))	((0.5;0.7;0.7;0.9;1;1),(0.6;0.7;0.7;0.8;0.9;0.9))
C5	((0;0;0;0;0;0),(0;0;0;0;0;0))	((0;0;0;0;0;0),(0;0;0;0;0;0))	((0;0;0;0;0;0),(0;0;0;0;0;0))
C51	((0.4;0.6;0.6;0.8;1;1),(0.5;0.6;0.6;0.7;0.9;0.9))	((0.6;0.8;0.8;0.95;1;1),(0.7;0.8;0.8;0.88;0.9;0.9))	((0.25;0.4;0.4;0.6;1;1),(0.33;0.4;0.4;0.5;0.9;0.9))
C52	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))	((0;0.05;0.05;0.2;1;1),(0.03;0.05;0.05;0.13;0.9;0.9))	((0.15;0.3;0.3;0.5;1;1),(0.23;0.3;0.3;0.4;0.9;0.9))
C54	((0.3;0.5;0.5;0.7;1;1),(0.4;0.5;0.5;0.6;0.9;0.9))	((0.05;0.2;0.2;0.4;1;1),(0.13;0.2;0.2;0.3;0.9;0.9))	((0;0.05;0.05;0.2;1;1),(0.03;0.05;0.05;0.13;0.9;0.9))
C56	((0.3;0.5;0.5;0.7;1;1),(0.4;0.5;0.5;0.6;0.9;0.9))	((0.15;0.3;0.3;0.5;1;1),(0.23;0.3;0.3;0.4;0.9;0.9))	((0.05;0.2;0.2;0.4;1;1),(0.13;0.2;0.2;0.3;0.9;0.9))
C57	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))	((0.05;0.15;0.15;0.3;1;1),(0.1;0.15;0.15;0.23;0.9;0.9))	((0.15;0.3;0.3;0.5;1;1),(0.23;0.3;0.3;0.4;0.9;0.9))
C58	((0.4;0.6;0.6;0.8;1;1),(0.5;0.6;0.6;0.7;0.9;0.9))	((0.8;0.95;0.95;1;1;1),(0.88;0.95;0.95;0.98;0.9;0.9))	((0.8;0.95;0.95;1;1;1),(0.88;0.95;0.95;0.98;0.9;0.9))
C59	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))	((0;0.05;0.05;0.2;1;1),(0.03;0.05;0.05;0.13;0.9;0.9))	((0;0.05;0.05;0.2;1;1),(0.03;0.05;0.05;0.13;0.9;0.9))
C6	((0;0;0;0;0;0),(0;0;0;0;0;0))	((0;0;0;0;0;0),(0;0;0;0;0;0))	((0;0;0;0;0;0),(0;0;0;0;0;0))
C61	((0.05;0.2;0.2;0.4;1;1),(0.13;0.2;0.2;0.3;0.9;0.9))	((0.15;0.3;0.3;0.5;1;1),(0.23;0.3;0.3;0.4;0.9;0.9))	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))
C62	((0.3;0.5;0.5;0.7;1;1),(0.4;0.5;0.5;0.6;0.9;0.9))	((0.5;0.7;0.7;0.85;1;1),(0.6;0.7;0.7;0.78;0.9;0.9))	((0.6;0.8;0.8;0.95;1;1),(0.7;0.8;0.8;0.88;0.9;0.9))
C63	((0.15;0.3;0.3;0.5;1;1),(0.23;0.3;0.3;0.4;0.9;0.9))	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))	((0.3;0.5;0.5;0.7;1;1),(0.4;0.5;0.5;0.6;0.9;0.9))
C64	((0.6;0.8;0.8;0.95;1;1),(0.7;0.8;0.8;0.88;0.9;0.9))	((0.4;0.6;0.6;0.8;1;1),(0.5;0.6;0.6;0.7;0.9;0.9))	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))

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C65	((0.4;0.6;0.6;0.8;1;1),(0.5;0.6;0.6;0.7;0.9;0.9))	((0.1;0.3;0.3;0.5;1;1),(0.2;0.3;0.3;0.4;0.9;0.9))	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))
C7	((0;0;0;0;0;0),(0;0;0;0;0;0))	((0;0;0;0;0;0),(0;0;0;0;0;0))	((0;0;0;0;0;0),(0;0;0;0;0;0))
C71	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))	((0.4;0.6;0.6;0.8;1;1),(0.5;0.6;0.6;0.7;0.9;0.9))	((0.5;0.7;0.7;0.9;1;1),(0.6;0.7;0.7;0.8;0.9;0.9))
C72	((0.5;0.7;0.7;0.9;1;1),(0.6;0.7;0.7;0.8;0.9;0.9))	((0.4;0.6;0.6;0.8;1;1),(0.5;0.6;0.6;0.7;0.9;0.9))	((0.3;0.5;0.5;0.7;1;1),(0.4;0.5;0.5;0.6;0.9;0.9))
C73	((0.1;0.3;0.3;0.5;1;1),(0.2;0.3;0.3;0.4;0.9;0.9))	((0.4;0.6;0.6;0.8;1;1),(0.5;0.6;0.6;0.7;0.9;0.9))	((0.7;0.85;0.85;0.95;1;1),(0.78;0.85;0.85;0.9;0.9;0.9))
C74	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))	((0.5;0.7;0.7;0.9;1;1),(0.6;0.7;0.7;0.8;0.9;0.9))	((0.6;0.8;0.8;0.95;1;1),(0.7;0.8;0.8;0.88;0.9;0.9))
C75	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))	((0.7;0.85;0.85;0.95;1;1),(0.78;0.85;0.85;0.9;0.9;0.9))	((0.7;0.9;0.9;1;1;1),(0.8;0.9;0.9;0.95;0.9;0.9))
C76	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))	((0.9;1;1;1;1;1),(0.95;1;1;1;0.9;0.9))	((0.8;0.95;0.95;1;1;1),(0.88;0.95;0.95;0.98;0.9;0.9))
C77	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))	((0.5;0.7;0.7;0.9;1;1),(0.6;0.7;0.7;0.8;0.9;0.9))	((0.4;0.6;0.6;0.8;1;1),(0.5;0.6;0.6;0.7;0.9;0.9))
C8	((0;0;0;0;0;0),(0;0;0;0;0;0))	((0;0;0;0;0;0),(0;0;0;0;0;0))	((0;0;0;0;0;0),(0;0;0;0;0;0))
C81	((0.6;0.75;0.75;0.85;1;1),(0.68;0.75;0.75;0.8;0.9;0.9))	((0.6;0.8;0.8;0.95;1;1),(0.7;0.8;0.8;0.88;0.9;0.9))	((0.6;0.8;0.8;0.95;1;1),(0.7;0.8;0.8;0.88;0.9;0.9))
C82	((0;0.05;0.05;0.2;1;1),(0.03;0.05;0.05;0.13;0.9;0.9))	((0;0.1;0.1;0.3;1;1),(0.05;0.1;0.1;0.2;0.9;0.9))	((0.05;0.2;0.2;0.4;1;1),(0.13;0.2;0.2;0.3;0.9;0.9))
C83	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))	((0.1;0.3;0.3;0.5;1;1),(0.2;0.3;0.3;0.4;0.9;0.9))	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))
C84	((0.7;0.85;0.85;0.95;1;1),(0.78;0.85;0.85;0.9;0.9;0.9))	((0.4;0.6;0.6;0.8;1;1),(0.5;0.6;0.6;0.7;0.9;0.9))	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))
C85	((0.05;0.2;0.2;0.4;1;1),(0.13;0.2;0.2;0.3;0.9;0.9))	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))	((0.3;0.5;0.5;0.7;1;1),(0.4;0.5;0.5;0.6;0.9;0.9))
C86	((0.4;0.6;0.6;0.8;1;1),(0.5;0.6;0.6;0.7;0.9;0.9))	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))	((0.2;0.4;0.4;0.6;1;1),(0.3;0.4;0.4;0.5;0.9;0.9))

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Table 6. The weighted evaluation matrix

	Supplier 1	Supplier 2	Supplier 3
C1			
C11	((0;0;0;0.01;1;1),(0;0;0;0;0.9;0.9))	((0;0.01;0.01;0.01;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))	((0.01;0.01;0.01;0.01;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))
C12	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
C13	((0;0.01;0.01;0.02;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))	((0.01;0.02;0.02;0.03;1;1),(0.02;0.02;0.02;0.02;0.9;0.9))	((0.02;0.02;0.02;0.03;1;1),(0.02;0.02;0.02;0.03;0.9;0.9))
C14	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0.01;1;1),(0;0;0;0.01;0.9;0.9))	((0;0;0;0.01;1;1),(0;0;0;0.01;0.9;0.9))
C15	((0;0.01;0.01;0.01;1;1),(0;0.01;0.01;0.01;0.9;0.9))	((0;0.01;0.01;0.01;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))	((0;0.01;0.01;0.01;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))
C16	((0.01;0.01;0.01;0.02;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))	((0.01;0.02;0.02;0.03;1;1),(0.02;0.02;0.02;0.02;0.9;0.9))	((0.02;0.02;0.02;0.03;1;1),(0.02;0.02;0.02;0.02;0.9;0.9))
C17	((0;0.01;0.01;0.01;1;1),(0;0.01;0.01;0.01;0.9;0.9))	((0;0.01;0.01;0.01;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))	((0.01;0.01;0.01;0.02;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))
C2			
C21	((0.01;0.01;0.01;0.01;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))	((0.01;0.01;0.01;0.02;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))	((0.02;0.02;0.02;0.02;1;1),(0.02;0.02;0.02;0.02;0.9;0.9))
C22	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0.01;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0.01;1;1),(0;0;0;0.01;0.9;0.9))
C23	((0;0.01;0.01;0.01;1;1),(0;0.01;0.01;0.01;0.9;0.9))	((0;0;0;0.01;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0.01;1;1),(0;0;0;0;0.9;0.9))
C24	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
C25	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
C26	((0;0;0;0.01;1;1),(0;0;0;0.01;0.9;0.9))	((0.01;0.01;0.01;0.01;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))	((0.01;0.01;0.01;0.01;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))
C3			
C31	((0.02;0.03;0.03;0.05;1;1),(0.02;0.03;0.03;0.04;0.9;0.9))	((0.03;0.05;0.05;0.06;1;1),(0.04;0.05;0.05;0.06;0.9;0.9))	((0.06;0.07;0.07;0.08;1;1),(0.06;0.07;0.07;0.07;0.9;0.9))
C33	((0;0.01;0.01;0.02;1;1),(0.01;0.01;0.01;0.02;0.9;0.9))	((0.02;0.03;0.03;0.03;1;1),(0.02;0.03;0.03;0.03;0.9;0.9))	((0.03;0.04;0.04;0.04;1;1),(0.03;0.04;0.04;0.04;0.9;0.9))
C34	((0.01;0.02;0.02;0.03;1;1),(0.02;0.02;0.02;0.03;0.9;0.9))	((0.02;0.03;0.03;0.04;1;1),(0.03;0.03;0.03;0.04;0.9;0.9))	((0.03;0.04;0.04;0.05;1;1),(0.03;0.04;0.04;0.04;0.9;0.9))
C35	((0;0.01;0.01;0.01;1;1),(0;0.01;0.01;0.01;0.9;0.9))	((0.01;0.01;0.01;0.01;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))	((0.01;0.01;0.01;0.01;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))
C4			
C41	((0.01;0.01;0.01;0.01;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))	((0.01;0.01;0.01;0.01;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))	((0.01;0.01;0.01;0.01;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))
C42	((0.01;0.02;0.02;0.03;1;1),(0.02;0.02;0.02;0.02;0.9;0.9))	((0.02;0.03;0.03;0.04;1;1),(0.02;0.03;0.03;0.03;0.9;0.9))	((0.02;0.03;0.03;0.04;1;1),(0.03;0.03;0.03;0.04;0.9;0.9))
C44	((0.02;0.03;0.03;0.05;1;1),(0.03;0.03;0.03;0.04;0.9;0.9))	((0.01;0.03;0.03;0.04;1;1),(0.02;0.03;0.03;0.03;0.9;0.9))	((0.03;0.05;0.05;0.06;1;1),(0.04;0.05;0.05;0.05;0.9;0.9))
C5			
C51	((0.02;0.02;0.02;0.03;1;1),(0.02;0.02;0.02;0.03;0.9;0.9))	((0.02;0.03;0.03;0.04;1;1),(0.03;0.03;0.03;0.03;0.9;0.9))	((0.01;0.02;0.02;0.02;1;1),(0.01;0.02;0.02;0.02;0.9;0.9))
C52	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
C54	((0;0;0;0.01;1;1),(0;0;0;0.01;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
C56	((0.02;0.03;0.03;0.04;1;1),(0.02;0.03;0.03;0.03;0.9;0.9))	((0.01;0.02;0.02;0.03;1;1),(0.01;0.02;0.02;0.02;0.9;0.9))	((0;0.01;0.01;0.02;1;1),(0.01;0.01;0.01;0.02;0.9;0.9))
C57	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
C58	((0;0;0;0.01;1;1),(0;0;0;0;0.9;0.9))	((0.01;0.01;0.01;0.01;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))	((0.01;0.01;0.01;0.01;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))
C59	((0.01;0.02;0.02;0.03;1;1),(0.01;0.02;0.02;0.02;0.9;0.9))	((0;0;0;0.01;1;1),(0;0;0;0.01;0.9;0.9))	((0;0;0;0.01;1;1),(0;0;0;0.01;0.9;0.9))
C6			
C61	((0;0.01;0.01;0.02;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))	((0.01;0.01;0.01;0.02;1;1),(0.01;0.01;0.01;0.02;0.9;0.9))	((0.01;0.02;0.02;0.03;1;1),(0.01;0.02;0.02;0.02;0.9;0.9))
C62	((0.02;0.03;0.03;0.04;1;1),(0.02;0.03;0.03;0.03;0.9;0.9))	((0.03;0.04;0.04;0.05;1;1),(0.03;0.04;0.04;0.04;0.9;0.9))	((0.03;0.05;0.05;0.05;1;1),(0.04;0.05;0.05;0.05;0.9;0.9))
C63	((0;0;0;0.01;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0.01;1;1),(0;0;0;0.01;0.9;0.9))	((0;0.01;0.01;0.01;1;1),(0;0.01;0.01;0.01;0.9;0.9))
C64	((0.02;0.03;0.03;0.04;1;1),(0.03;0.03;0.03;0.04;0.9;0.9))	((0.02;0.02;0.02;0.03;1;1),(0.02;0.02;0.02;0.03;0.9;0.9))	((0.01;0.02;0.02;0.02;1;1),(0.01;0.02;0.02;0.02;0.9;0.9))

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C65	((0.04;0.05;0.05;0.07;1;1),(0.05;0.05;0.05;0.06;0.9;0.9))	((0.01;0.03;0.03;0.05;1;1),(0.02;0.03;0.03;0.04;0.9;0.9))	((0.02;0.04;0.04;0.05;1;1),(0.03;0.04;0.04;0.05;0.9;0.9))
C7			
C71	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0.01;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0.01;1;1),(0;0;0;0.01;0.9;0.9))
C72	((0;0.01;0.01;0.01;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))	((0;0.01;0.01;0.01;1;1),(0;0.01;0.01;0.01;0.9;0.9))	((0;0;0;0.01;1;1),(0;0;0;0.01;0.9;0.9))
C73	((0;0;0;0.01;1;1),(0;0;0;0;0.9;0.9))	((0;0.01;0.01;0.01;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))	((0.01;0.01;0.01;0.01;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))
C74	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0.01;1;1),(0;0;0;0.01;0.9;0.9))	((0;0.01;0.01;0.01;1;1),(0;0.01;0.01;0.01;0.9;0.9))
C75	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
C76	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
C77	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0.01;0.01;0.01;1;1),(0;0.01;0.01;0.01;0.9;0.9))	((0;0;0;0.01;1;1),(0;0;0;0.01;0.9;0.9))
C8			
C81	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
C82	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
C83	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))
C84	((0.01;0.01;0.01;0.01;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))	((0;0.01;0.01;0.01;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))	((0;0;0;0.01;1;1),(0;0;0;0.01;0.9;0.9))
C85	((0;0;0;0.01;1;1),(0;0;0;0;0.9;0.9))	((0;0.01;0.01;0.01;1;1),(0;0.01;0.01;0.01;0.9;0.9))	((0;0.01;0.01;0.01;1;1),(0.01;0.01;0.01;0.01;0.9;0.9))
C86	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))	((0;0;0;0;1;1),(0;0;0;0;0.9;0.9))

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Table 7. The rank values

	Supplier 1	**Supplier 2**	**Supplier 3**
C1			
C11	3.8147	3.8376	3.8530
C12	3.8036	3.8177	3.8177
C13	3.8458	3.9168	3.9403
C14	3.8091	3.8263	3.8263
C15	3.8300	3.8459	3.8459
C16	3.8634	3.9136	3.9297
C17	3.8372	3.8505	3.8639
C2			
C21	3.8508	3.8720	3.9042
C22	3.8127	3.8189	3.8257
C23	3.8293	3.8239	3.8240
C24	3.8065	3.8018	3.8018
C25	3.8039	3.8025	3.8025
C26	3.8222	3.8758	3.8715
C3			
C31	3.9839	4.0811	4.2033
C32	3.8700	3.9454	4.0087
C33	3.9362	3.9932	4.0206
C34	3.8348	3.8762	3.8762
C4			
C41	3.8450	3.8721	3.8678
C42	3.9169	3.9658	3.9893
C43	3.9931	3.9527	4.0737
C5			
C51	3.9373	3.9839	3.8920
C52	3.8124	3.8017	3.8094
C53	3.8268	3.8105	3.8029
C54	3.9548	3.8930	3.8607
C55	3.8162	3.8061	3.8123
C56	3.8237	3.8379	3.8379
C57	3.8977	3.8133	3.8133
C6			
C61	3.8479	3.8734	3.8967
C62	3.9663	4.0345	4.0692
C63	3.8215	3.8283	3.8357
C64	3.9895	3.9415	3.8926
C65	4.1179	3.9531	4.0080
C7			
C71	3.8144	3.8220	3.8258
C72	3.8382	3.8325	3.8269
C73	3.8181	3.8376	3.8539
C74	3.8143	3.8257	3.8293
C75	3.8043	3.8094	3.8099
C76	3.8095	3.8246	3.8232
C77	3.8165	3.8295	3.8252
C8			
C81	3.8062	3.8066	3.8066
C82	3.8005	3.8009	3.8017
C83	3.8031	3.8022	3.8031
C84	3.8516	3.8360	3.8235
C85	3.8148	3.8298	3.8377
C86	3.8068	3.8045	3.8045

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Table 8. The ranking of the supplier

	Supplier 1	Supplier 2	Supplier 3
d^+	0.3591	0.2839	0.2181
d^-	0.2408	0.2334	0.3705
CC	0.4014	0.4512	0.6295
Ranks	3	2	1

At the final steps, the positive ideal solutions and negative ideal solutions are calculated for green supplier. Then, the closeness coefficient for each green supplier is computed and the ranking of the green supplier is applied in decreasing order (Table 8). In TOPSIS approach, the larger the value of closeness coefficient, the higher the preference of the green supplier. We determined the greenest supplier is determined as Supplier 3 based on five experts evaluations using the proposed BWM and interval type- 2 fuzzy TOPSIS approach.

5. Conclusion

Selection of suppliers under green concept is significant milestone for organizations that are in the way towards a more environmental supply chain. In today's world, organizations are following new ways to reduce negative effects of their organizations to the environment and to reach a greener system. At this point, green supplier selection concept has gained great importance with its ability on incorporating environmental or green criteria into the classical supplier selection practices. In the literature, lots of approaches are proposed regarding supplier selection and green supplier selection. Integration of fuzzy set theory and its various versions with classical MCDM methods is the forefront in the modeling of green supplier selection.

Therefore, in this study, we propose a multi-phase approach for green supplier selection. First, the selection of criteria under green motivation through literature review and interviews with decision makers is performed. In the second phase, weights of green supplier selection criteria are determined using BWM. Finally, to obtain ranking order of suppliers with respect to previously weighted criteria an interval type-2 fuzzy TOPSIS method is used. This is the initial attempt that integrates BWM and interval type-2 fuzzy TOPSIS. BWM is preferred in weighting the selection criteria since it is more efficient and easier for pairwise comparisons versus Analytic Hierarchy Process. Use of TOPSIS method extended with interval type-2 fuzzy sets enable reflecting more uncertainty and ambiguity in decision making process as well as including a concept of similarity to ideal solution. The proposed multi-phase approach is applied to the green supplier selection process in a plastic injection molding facility in Turkey. The proposed approach with its case study has also some limitations. First concerns the integrated methodology.

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This study proposes an incorporation of BWM and interval type-2 fuzzy TOPSIS for green supplier selection. However, other MCDM methods like VIKOR, PROMETHEE and ELECTRE can also be used for this study. Moreover, different version of fuzzy set theory that has recently been popular such as Pythagorean fuzzy sets, hesitant fuzzy sets and intuitionistic fuzzy sets can be also applied to our case study. Secondly, in this study the case study in a single facility has been taken. So, the proposed approach can be adapted from one facility or industry to another. Future attempts can include the followings: (1) A comparative framework can be developed that can highlight the optimal method in selection of green suppliers. (2) A broader and multi-facility data can be used in the problem.

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