Global Journal of Flexible Systems Management (December 2020) 21(4):309–322
https://doi.org/10.1007/s40171-020-00250-w

ORIGINAL RESEARCH

An Integrated Sustainable and Flexible Supplier Evaluation Model under Uncertainty by Game Theory and Subjective/Objective Data: Iranian Casting Industry

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Received: 22 February 2020 / Accepted: 21 July 2020 / Published online: 9 August 2020
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Abstract *According to the rapid growth of sustainability in supply chain management in recent years, experts are encouraged to consider more detailed social and environmental factors in their assessment models. In our proposed model for investigating the mentioned factors in more real condition and to obtain superior indices, the best–worst method and stepwise weight assessment ratio analysis method have been suggested for subjective and objective data which have been prepared based on specialist opinion and real registered data, respectively. Game theory has been applied to explore more appropriate combinations of subjective and objective weights and decreasing the conflicts, while DEMATEL was employed to define the internal relationship of the criteria. For tackling the inhomogeneous information and input data's uncertainty, Dempster–Shafer theory has been applied. Finally for assessment of the proposed model, real data from an Iranian Casting Factory would have been considered for sustainable/flexible supplier selection.*

Keywords BWM · DEMATEL · Dempster–Shafer · Flexibility · Game theory · Subjective/objective · Sustainable supplier selection · SWARA

Introduction and Literature Review

In the scope of supply chain management, supplier selection is of vital importance. The sustainability of the supply chain is significant which made the choice of suppliers a challenging issue. In addition, more harvesting of natural resources is as a result of competition and increased economic growth of countries, which leads to problems such as climate pollution or environmental dangers. Therefore, the choice of green suppliers these days has been increasingly taken into consideration and is a significant factor. Experts have included sustainable supply chain management in the mentioned topic too, which includes social, economic and environmental key factors which are the main criteria for selecting a sustainable supplier (Azadnia et al. 2015; Kaur et al. 2016; Zahraee et al. 2018). Supply chain management have to find innovative ways to overcome disruption risks through being more sustainable, and one of the main factors which plays an important role in this issue is flexibility of suppliers. This flexibility and sustainability even though have some conflict at a glance, but can have some consistency to make sustainable and flexible SCM at the same time. Being more flexible causes better functionality in the SCM and also affords market advantage (Chirra and Kumar 2018; Pérez-Pérez et al. 2019). This rise in market share would bring enough profit, and by accompaniment of the enterprises through their social responsibilities, social concerns will be decreased and the world would be a better place to live (Siddiqui et al. 2009; Shukla et al. 2010). In their essay, they illustrated in

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a descriptive chart in four segments based on the two statuses for flexibility and sustainability (low/high). As they depicted, there are traditional and benevolent status in low flexibility and high sustainability, and in the contrast with that, we will have self-centric and trend setter states in which trendsetter would be in the position of high flexibility and sustainability and brings proactive involvement, striking a good balance to achieve sustainability.

Multi-criteria decision-making (MCDM) tool has been used extensively for supplier evaluation and prioritization which in the following, a number of MCDM methods have been proposed (Chithambaranathan et al. 2015; Banaeian et al. 2018). These MCDM techniques have several applications, and some are utilized for criteria weighting such as AHP and BMW methods, while a part of them are used for alternative ranking as TOPSIS. Apart from these techniques, some of MCDM methods are suitable for finding the main criteria which have the greatest effects on the others. In this case, we can mention DEMATEL and ANP. DANP is a technique extracted from previous methods which is appropriate for cases with related criteria and feedback (Khan et al. 2020). The best–worst method (BWM) and stepwise weight assessment ratio analysis method (SWARA) generally used in combination with other MCDM methods as TOPSIS, ARAS, VIKOR and ELECTRE (Kia et al. 2014; Gupta and Barua 2017; Shojaie et al. 2018; Khan et al. 2019; Khanmohammadi et al. 2019; Ghenai et al. 2020; Yadav et al. 2020).

ANP is able to overcome the limitations of the AHP method, but by increasing the criteria and indices, more comparative data need to be explored for solving a specific problem. To overcome this issue and to achieve a lower computationally acceptable solution, taking advantage of the BWM method leads to more robust comparisons.

In the beginign of any project lack of accurate information encounter the investors take risks and trust the data which is provided by organizations or companies. This problem in supplier selection in an uncertain environment has made researchers to think about the solution of the uncertainty for incoming data. Experts have proposed methods such as fuzzy sets theory (Kannan et al. 2013; Salehi 2015; Alimohammadlou and Bonyani 2019), an approach for supplier evaluation according to type II fuzzy set (You et al. 2015; He et al. 2018) and grey theory approach (Wu 2009; Su et al. 2016). Dempster–Shafer's theory is a powerful tool according to the suggestions of investigators among the methods for obtaining uncertain information. This method is well functioning, and measuring and quantifying the uncertainty of input data derived from knowledge is one of the advantages (Binaghi et al. 2000; Beynon 2002). This is known as a tool for knowledge uncertainty problem solving which creates rules for the combination of information from different sources. By using mentioned method, random and intrinsic uncertainties could be merged in a simpler, non-default way. We can see these drawbacks in the previous studies:

- Creation of a decision-making method considers simultaneously both subjective and objective data (Sushil 1994). As we know, subjective data come from the expert opinion and are related to the expert's experiences when the objective data come from the previous events and statistical data.
- As there are several interconnections and dependencies between several criteria, finding the most significant one which would be noteworthy is a must.

Game theory and Dempster–Shafer theory have been found to overcome these problems and reduce errors in existing methods (Liu et al. 2018). In particular, the conflict and collaboration between players in game theory are similar to that of pairing and the interrelationship between criteria in MCDM problems. In other words, if a vector of criteria (weights obtained for the criteria) is considered to be similar to that of a player in game theory, then the principles of mathematical theory and mathematics governing game theory can also be applied to MCDM problems. Each of the weighting methods is considered as a player in game theory (Sevastjanov and Dymova 2015).

Here, two methods of BWM and SWARA as players of game theory and comprehensive weight which is based on the Nash equilibrium and makes the weights more reasonable and closer to reality have been utilized. DEMATEL has been used to examine the relationship between criteria, the impact of criteria on the system and confronting MCDM problems. In this study, we use DEMATEL approach to examine the relationships and impacts between criteria and identify the most effective criterion as a result of combining it with game theory to apply the more prominent criterion effect on the overall weight. In the next step, we use Dempster–Shafer's theory to deal with uncertainty of input data and to find the sustainable supplier and prioritization. Some of the main appropriate papers related to our MCDM methods are summarized in Table 1.

Preliminaries

In this section, some preliminaries are briefly introduced.

We collected all the criteria related to our study based on studies on several papers and literature review and expert opinions and illustrate them in Table 3. As a challenge, we must identify movement based on the expert's opinion or on documented data. After that, in our case we encounter two types of opinions: One of them is based on the subjective data which are gathered based on the

Table 1 Literature review on related supplier selection models

References	Methodology
Alimohammadlou and Bonyani (2019)	Fuzzy BWANP
Azadnia et al. (2015)	Fuzzy AHP
Banaeian et al. (2018)	Fuzzy TOPSIS, fuzzy VIKOR and fuzzy GRA
Beynon (2002)	DS/AHP
Binaghi et al. (2000)	Fuzzy Dempster–Shafer
Chithambaranathan et al. (2015)	Grey theory, ELECTR and VIKOR
Ghenai et al. (2020)	SWARA/ARAS method
Greiner et al. (2019)	Nash–evolutionary algorithms
Gupta and Barua (2017)	BWM and fuzzy TOPSIS
He et al. (2018)	Fuzzy set theory and Dempster–Shafer evidence theory
Kannan et al. (2013)	Fuzzy AHP, fuzzy TOPSIS and fuzzy MOLP
Khan et al. (2019)	BWM
Khan and Haleem (2020)	Fuzzy DEMATEL
Khan et al. (2020)	DANP
Karabasevic et al. (2016)	SWARA and ARAS methods
Kaur et al. (2016)	AHP, fuzzy AHP, TOPSIS, fuzzy TOPSIS, ILP and IRP
Keršuliene et al. (2010)	SWARA
Kia et al. (2014)	Fuzzy TOPSIS
Lee (2018)	Nash equilibrium and data envelopment analysis
Liu (2016)	FMEA, fuzzy evidential reasoning and GRA method
Liu et al. (2018)	DEMATEL and game theory
Orji and Wei (2014)	Fuzzy DEMATEL and TOPSIS
Qin et al. (2019)	DEMATEL
Rezaei (2015)	BWM
Rezaei et al. (2016)	BWM
Sadjadi and Karimi (2018)	BWM
Salehi (2015)	Fuzzy AHP and fuzzy VIKOR
Sevastjanov and Dymova (2015)	Hesitant fuzzy sets theory and Dempster–Shafer
Shafer (1976)	Evidence theory
Su et al. (2016)	Grey theory and DEMATEL
Sun et al. (2016)	Game theory, fuzzy AHP and *D* numbers
Ware et al. (2014)	AHP, MINLP and IRP
Wu (2009)	Grey related analysis and Dempster–Shafer
Xiao et al. (2015).	Game theory
Yadav et al. (2020)	BWM and ELECTRE
You et al. (2015)	VIKOR and interval 2-tuple

expert's opinion and are used for the BMW method. These data have been collected through questionnaires distributed among experts (subjective weight). The other type of weight is objective type which is collected by questionnaire collected from old data and experiences (objective weight) and would been utilized for SWARA method.

BWM Method

The best–worst method was first introduced in 2015 by Mr. Jafar Rezai. The BWM technique is one of the newest and most effective multi-criteria decision-making techniques used to weight decision-making factors and criteria. To analyze this method, like other decision-making methods, a decision matrix or BWM questionnaire should be designed. This questionnaire is actually a pairwise comparison of the best criteria with other criteria and the other criteria with the worst criteria. The best criterion is the criterion with the highest priority in the system, and the worst criterion has the least importance through criteria. In pairwise comparisons, the best–worst method uses the 9-standard spectrum, the same as the AHP method. The steps are as follows:

Step 1 Define a set of decision criteria.

Step 2 Determine the best and the worst criteria. The best can be the most desirable or the most important criterion.

Step 3 Do pair comparisons between the best criterion and other criteria (set priorities). The best benchmark results over the other benchmarks may be as follows:

$$A_B = (a_{B1}.a_{B2}...a_{Bn})$$

where a_{Bj} determines the best performance of B against the criterion j. It is obvious that $a_{BB} = 1$.

Step 4 Do pair comparisons between the other criteria against the worst one. The results of benchmark comparisons against the worst benchmark are as follows:

$$A_W = (a_{1w}.a_{2w}...a_{nw})^{\mathrm{T}}$$

where a_{jw} represents the performance of criterion j against the worst criterion of W. It is obvious that $a_{ww} = 1$.

Step 5 Find the most optimal weights. In this step, we form the nonlinear optimization model of BWM method using the following equation:

$$\begin{aligned} &\textbf{MinMax}\left\{\left|\frac{W_B}{W_j} - a_{Bj}\right| . \left|\frac{W_j}{W_W} - a_{jw}\right|\right\} \\ &\text{s.t.} \quad \sum_j W_j = 1 \\ &\qquad W_j \geq 0 \quad \forall j \in J \end{aligned} \tag{1}$$

The above relationship is a nonlinear model that Rezai et al. (2016) converted it to a linear model as follows:

$$
\begin{aligned}
&\mathbf{Min}\,\zeta \\
&\text{s.t.} \quad \left|\frac{W_B}{W_j} - a_{Bj}\right| \le \zeta \quad \forall j \in J \\
&\left|\frac{W_j}{W_w} - a_{wj}\right| \le \zeta \quad \forall j \in J \\
&\sum_j W_j = 1 \\
&W_j \ge 0 \quad \forall j \in J
\end{aligned} \tag{2}
$$

A comparison is perfectly consistent when $a_{Bj} \times a_{Jw} = a_{BW}$ for all j, where a_{Bj}, a_{Jw} and a_{BW} represent the best performance against the j criterion, the performance of the j criterion against the worst criterion and the best performance against the worst criterion, respectively. Then, the compatibility rate is calculated by using ζ, which is the incompatibility rate, and is obtained from Eq. (3). The corresponding consistent index, which is given by the highest score that the best criteria have against the worst, is as follows:

$$\text{Consistency Rate} = \frac{\zeta}{\text{consistency index}} \tag{3}$$

SWARA Method

SWARA, or gradual weighting ratio analysis, is one of the multi-criteria decision-making methods used to calculate the weight of criteria and sub-criteria. The SWARA method was introduced by Keršuliene et al. (2010). In this method, the criteria are ranked by value in which the most important criterion would have the first priority and the least important criterion would be the last one. In this way, experts (respondents) play an important role in determining the weight of the criteria. The main characteristic of this method is the ability of experts to estimate the relative importance of criteria in their weight determination process. This method is useful for gathering and coordinating information obtained from experts. In this way, each expert prioritizes the criteria. The most important criterion receives the first rank, and the least important criterion receives the last rank. The overall rating is determined by a group of experts, determined by the average value of the ratings (Karabasevic et al. 2016).

Step 1 Sort the criteria
At first, the criteria are written according to their importance in descending manner.
Step 2 Determine the relative importance of each criterion (S_j)
In this step, the relative importance of each criterion is compared with the previous ones. In the process of the SWARA method, this value is denoted by S_j.

Step 3 Calculate the coefficient K_j
The coefficient K_j, which is a function of the relative importance value of each criterion, is calculated using Eq. (4):

$$K_j = S_j + 1 \tag{4}$$

Step 4 Calculate the initial weight of each criterion
The initial weight of the criteria is calculated by Eq. 2. In this regard, it should be noted that the weight of the first criterion, which is the most important criterion, is equal to (5):

$$q_j = \frac{q_{j-1}}{K_j} \tag{5}$$

Step 5 Calculate the final normal weight
In the last step of the SWARA method, the final weight of the indices, which is also the normalized weight, is calculated by Eq. (6). Normalization is done by a simple linear method:

$$W_j = \frac{q_j}{\sum q_j} \tag{6}$$

DEMATEL Method

The DEMATEL technique was introduced by Fonetla and Gabus. The purpose of the DEMATEL technique is to identify the pattern of causal relationships among a set of criteria. This technique evaluates the severity of communications as scoring, observes its important feedback and accepts non-transferable relationships (Qin et al. 2019). The advantages of this method used to apply benchmark weights are as follows:

1. Considering the interconnections: The advantage of this method over similar methods is its clarity and transparency in reflecting the interconnections between a wide range of components in which experts are more able to express their views on the effects (direction and severity of effects) among the factors.
2. Structuring complex factors into causal groups: By dividing a broad set of complex factors into causal groups, it puts the decision maker in a better position to understand the relationship. This leads to a greater understanding of the status of the factors and their role in the interaction.
   For example, in our essay we want to investigate the effectiveness of flexibility on the other criteria such as cost and green activities by our proposed model.

Steps

Step 1 Direct matrix formation (X)
To identify N criterion relationships, first form an $N \times N$ matrix. This matrix is called a direct relation matrix and is represented by X. The effect of each

criterion on the other criteria is denoted by a number from 0 to 4 as shown in Table 2.

Step 2 Normalize the direct relation matrix

The normalized direct relations of factors are a mapping from d_{ij} to [0, 1]. For the framework of n influential characteristics $\{F_1; F_2,\ldots, F_{ng}\}$, normalized matrix N of direct relation matrix $D = [d_{ij}]$ $(i,j = 1, 2, 3\ldots)$ is obtained by:

$$N = \frac{D}{\max\left(\sum_{j=1}^{n} d_{ij}.\sum_{i=1}^{n} d_{ij}\right)} \quad (7)$$

Step 3 Calculate the complete correlation matrix T

Due to the characteristic of normalized direct relation matrix N, total relation matrix which contains direct and indirect relations among factors can be derived from Eq. (8). We assume $N = \left[n_{ij}\right]_{n\times n}$ $(i,j = 1, 2,\ldots,n)$ is the normalized direct relation matrix, and total relation matrix T is defined as:

$$T = \lim_{K\to\infty}\left(N + N^2 + \cdots + N^K\right) = N(I - N)^{-1} \quad (8)$$

where I is the identity matrix.

Step 4 Determine the effectiveness and impact factors

- The sum of the elements of each row C_i $(i = 1,2,\ldots n)$ for each factor indicates the extent of influence of the specific factor on the other factors.
- The sum of the elements of the column R_i $(i = 1,2,\ldots n)$ for each agent indicates the influence of other factors on a specific one.
- Therefore, the horizontal vector $\beta = C_i + R_i$ is the magnitude of the factors affecting each other and the effect of the desired factor on the system. In other words, the higher the β-factor, the more it interacts with other system factors.

Table 2 Five-degree spectrum of DEMATEL technique and definite equivalent for verbal expressions

Score	Degree of influence
0	No impact
1	Little impact
2	Low impact
3	High impact
4	Very high impact

Game Theory

The Nash equilibrium (Lee 2018; Greiner et al. 2019) is the most widely used concept in game theory. In a non-cooperative or Nash game model, each actor attempts to minimize the objective function in a single and non-cooperative approach with a set of strategies (design variables). The final solution to the game is the so-called Nash equilibrium, in which none of the actors can gain more fame by changing their strategies, while the other players are not changing theirs. The important aspect of the Nash equilibrium is that each player's profits depend not only on their preferred strategy but also on the preferred strategy of the other players.

Let (A, E) be a game with n players, where A_i is the strategy set for player i, $A = a_1 \times a_2 \times \cdots \times a_n$ is the set of strategy profiles and $E(x) = (E1(x)\ldots En(x))$ is its payoff function evaluated at $a \in \{1\ldots n\}$. Let σ_i be a strategy profile of player i and σ_{-i} be a strategy profile of all players except for player i. When each player $i \in \{1\ldots n\}$ chooses strategy $\sigma_i = a_1\ldots a_n$, then player i obtains payoff $E_i(\sigma_i)$. A strategy profile $\sigma^* \in A$ is a Nash equilibrium (Nash 1950, 1951), if no unilateral deviation in strategy by any single is profitable for that player, that is:

$$\forall i.\sigma_i \in A : E_i\left(\sigma_i^*.\sigma_{-i}^*\right) \geq E_i\left(\sigma_i.\sigma_{-i}^*\right) \quad (9)$$

Dempster–Shafer Theory

The mathematical theory of evidence was introduced by Dempster (1967) and extended by Shafer (1976). This theory is important by discussing beliefs about a situation or a system of situations. Beliefs about events are not the same, but this theory can be used to assess and combine existing evidence in a similar approach. Dempster–Shafer's theory is based on the belief that results from evidence, so that the structure of belief theory of evidence is related to the classical probability (Liu 2016). The following are the basic concepts of evidence:

Suppose Θ is a finite set of elements, an element can be a hypothesis, an objective or a case of the status of a system. Θ is called a framework of diagnosis. The set of power Θ is determined by 2^{Θ}. Consider following example:

$$\Theta = \{a, b, c\}$$

The power set Θ is as follows:

$$2^{\Theta} = \{\Phi, \{a\}, \{b\}, \{c\}, \{a, b\}, \{a, c\}, \{b, c\}, \{a, b, c\}\}$$

Θ is a null set that indicates the status of a perfect system. The mass function is determined by m, which is as follows:

$$m : 2^{\Theta} \rightarrow [0, 1] \quad m(\Phi) = 0 \quad \sum_{A \subset 2\square} m(A) = 1 \tag{10}$$

A belief function is also called a basic probability assignment (BPA) to all subsets of Θ. The subsets together with the respective exact mass values of a BPA make up a body of evidence. If $A \in 2^{\Theta}$, A is called a proposition.

Suppose m_1 and m_2 are two mass functions derived from different information, based on the available data. The detection framework Θ is the same for both sources of information. According to the orthogonal Dempster law, we have:

$$m(A) = \frac{1}{1-k} \sum_{A_1 \cap A_2 \cap A_3 \ldots = A} m_1(A_1) m_2(A_2) \ldots \tag{11}$$

where

$$k = \sum_{A_1 A_2 A_3 = \Phi} m_1(A_1) m_2(A_2) \ldots \tag{12}$$

k represents the base probability mass of incompatibility between sources of evidence. A larger value of k indicates more incompatibility of resources.

The Combination of DEMATEL and Game Theory

In this paper, we use two multi-criteria decision-making methods: SWARA and BWM, each of which gains criteria's weight from a specific point of view, one of them, based on the experience and knowledge of the experts (subjective) and the other on the basis of existing data (objective). We use DEMATEL to examine the intrinsic relationships of the criteria and their direct and indirect effects on each other, and the game theory to optimize and combine the results obtained by the SWARA and BWM methods. Finally, to overcome the uncertainty of the input data, we use multi-criteria decision-making methods and Dempster–Shafer theory to make the final decision on choosing a sustainable and flexible supplier.

Game theory can be defined as the science of modeling and investigating the behavior of the decision maker and can be used to create an optimal solution between two or more factors.

Game theory is a research of strategic interaction and specifically is adopted to obtain the optimum equilibrium solution among two or more conflicts. In game theory, a decision is made either individually or collectively. Additionally, the decision can maximize the utility payoffs out of participants expectations (Xiao et al. 2015; Sun et al. 2016). We consider different weighting methods as different players, and the comprehensive weight based on Nash equilibrium will be obtained according to Eq. (9).

In addition, the relationships between the criteria, which are not specified by the two weighting methods and the power of the prominent factors, are determined by the combined DEMATEL and game theory approach. Therefore, the comprehensive weight is obtained from the evolutionary processes of trial and error of players and the equilibrium and combination of DEMATEL results which are as follows:

Step 1 Obtain β, which is the sum of the rows and columns of the complete relation matrix T.

Step 2 According to the weighting methods, two sets of weights are obtained for the criteria. Each of these sets is considered a weight vector. The new weight vector by applying β is as follows, and the operator ''×'' means that the corresponding positions of two vectors are multiplied to obtain a new vector of the same dimension, ($w = w_1.w_2 \ldots w_m$):

$$v_i = \frac{w_i \times \beta}{sum(w_i \times \beta)} \tag{13}$$

Step 3 In accordance with the n weighting method and their v weighted vector, the sum of the possible weights is obtained as arbitrary linear combination:

$$W = \sum_{j=1}^{m} \alpha_j v_j^T \quad (\alpha_j > 0) \tag{14}$$

where W is a possible weight vector and α_j is the weight coefficient which needs to be determined.

Step 4 Calculate α_j based on game theory.

According to game theory, when a consensus is reached among m weights, we will get the optimum equilibrium weight vector W^*. Such a consensus can be taken as the optimization of the weight coefficient α_j, which is a linear combination. The purpose of the optimization is to minimize the deviation between W and w_j using the following formula:

$$\mathbf{min} \sum_{k=1}^{m} \alpha_k \times v_k^T - w_i^{T2}. \quad (i = 1.2.3 \ldots m) \tag{15}$$

Based on the differentiation property of the matrix, the condition of the optimal first-order derivative in Eq. (15) is determined as:

$$\sum_{k=1}^{m} \alpha_k \times w_i \times v_K^T = w_i \times w_i^T. \quad (i = 1.2.3 \ldots m) \tag{16}$$

Then, we have:

$$\begin{bmatrix} w_1 \cdot v_1^T & w_1 \cdot v_2^T & \cdots & w_1 \cdot v_m^T \\ w_2 \cdot v_1^T & w_2 \cdot v_2^T & \cdots & w_2 \cdot v_m^T \\ \vdots \quad \vdots & \vdots & \vdots \quad \vdots & \vdots \\ w_m \cdot v_1^T & w_m \cdot v_2^T & \cdots & w_m \cdot v_m^T \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \vdots \\ \alpha_m \end{bmatrix} = \begin{bmatrix} w_1 \times w_1^T \\ w_2 \times w_2^T \\ \vdots \\ w_m \times w_m^T \end{bmatrix} \quad (17)$$

. Equation (17) consists of m linear equations corresponding to m variables [(a_1, a_2,…,a_n)] which can be easily solved by mathematical techniques. After computing the weight coefficient (a_1, a_2,…,a_n) by using Eq. (17), the normalized form can be obtained using the following equation:

$$\alpha_j^* = \frac{\alpha_j}{\sum_{j=1}^m \alpha_j} \quad (18)$$

Step 5 Calculate the optimum equilibrium weight vector W^*.
Obtain the final comprehensive weight with the following formula:

$$W^* = \sum_{j=1}^m \alpha_j^* \cdot w_j^T \quad (19)$$

. Comprehensive weights obtained from different weights according to game theory are obtained through the interpolation and integration of SWARA and BWM methods.

Dempster–Shafer Theory for Ranking

In this step, we construct the probability function of the initial allocation of BPA for each criterion and form the knowledge matrix according to the expert's opinion (Anderson et al. 1998). For each criterion, according to the characteristics and criterion's condition, we assign a set of selection options which are the suppliers. Next, according to the obtained weights from game theory by applying it to the previous BPA, we obtain new BPA for each criterion:

$$m_j^d(A_j) = \begin{cases} W_j^* m_j(A_j) & A_j \neq \Theta \\ 1 - W_j^* + W_j^* m_j(\Theta) & A_j = \Theta \end{cases} \quad (20)$$

Θ is the framework of discernment, the $m_j^d(A_j)$ is the new BPA after discounting and the W_j^* is the discounting coefficient, which we have obtained in game theory. By using Dempster–Shafer combination ruler [Eqs. (11) and (12)], we will get the performance for each alternative decision. By ranking the performance, we can select the best supplier(s).

Suggested Method Steps

The supplier selection process can be summarized as follows:

Step 1 Weigh the stable criteria according to Eqs. (1) and (2).
Step 2 Obtain the weight of the stable criteria according to the implicit method of SWARA and BWM: Eqs. (4)–(6).
Step 3 Determine the internal interface and level of the criteria's impact by the DEMATEL method by using Eqs. (8) and (9).
Step 4 Obtain the new weight vector by applying the results obtained from the DEMATEL method and two elementary weighting methods of Eqs. (13) and (14).
Step 5 In order to deviate the two weighting methods and obtain the weighting coefficient for each method, we obtain the coefficients Eqs. (15)–(18).
Step 6 Obtain the comprehensive weight with the acquired coefficients from Eq. (19).
Step 7 Get initial BPA by using the evidence theory.
Step 8 Get the new BPA from Eq. (20).
Step 9 Prioritize each supplier and choose the best one by using Dempster–Shafer combination rules.

Case Study

In order to evaluate the performance of the proposed model, here we surveyed a real case in a casting plant (for confidential reasons, the company's name has not been represented). The factory is engaged in the casting of all kinds of cast iron parts and includes the lines for grinding, finishing, molding and melting. Some examples of raw materials needed by the plant are as follows: sand, furnace soil, concrete furnace, ferrosilicon and ferromanganese. The factory has more than 200 employees, and the production capacity of the casting plant is 6000 tons annually with the ability of casting parts from 500 grams up to 5000 kg. Currently, most of the manufactured parts in this factory would be utilized in the automotive, pumping industries, industrial valves, fittings and home lifts. Four suppliers (A, B, C, D) work with the plant to supply the raw materials.

As previously mentioned, the criteria have been applied to evaluate the performance and finalize the selected suppliers. The criteria for selecting a supplier are determined in Table 3 (Orji and Wei 2014; Zimmer et al. 2016).

Table 3 Sustainable supplier selection criteria

S. No	Criteria	Brief description
C_1	Product quality	Offering a remarkable quality level
C_2	Environmental competencies	Supplier ability to use environmentally compatible materials, implement clean technologies and reduce pollution impacts
C_3	Contamination and hazardous substances diffusion rate	The amount of contamination that the supplier produces in order to manufacture the product and meet the desired need
C_4	Product price	Ability to provide products with reasonable price
C_5	Flexibility	The supplier must be flexible enough to withstand market changes
C_6	Product delivery and service	Ensures proper delivery and service of the product
C_7	Transportation cost	Willingness to transport products with minimum transportation cost
C_8	Green research and development	Suppliers' ability to strive for research and development activities to innovate new technologies, processes, clean technology approaches
C_9	Green production	Suppliers' ability to consider environmental considerations for production, packaging and labeling
C_{10}	Environmental management systems	Structure, plan and enforce environmental protection policies
C_{11}	Occupational safety and health systems	This concerns the safety, health and welfare of those who work in the supplier's workplace
C_{12}	Product profit	Produce a reasonable profit from the product
C_{13}	Environmental costs	Raw materials and products must minimize environmental damages
C_{14}	Green management	Product capability to maximize performance and environmental management
C_{15}	Waste management and pollution prevention	Raw materials are produced in such a way as to minimize waste and contamination during production
C_{16}	Disclosure of information	Provide information to our customers and stakeholders on used materials, carbon emissions and toxins released during production, etc.

Table 4 The result of BWM

Criteria	W_i
C_1	0.007
C_2	0.25
C_3	0.168
C_4	0.068
C_5	0.012
C_6	0.01
C_7	0.024
C_8	0.029
C_9	0.033
C_{10}	0.057
C_{11}	0.06
C_{12}	0.046
C_{13}	0.079
C_{14}	0.035
C_{15}	0.043
C_{16}	0.031

BWM Method

As explained in "Dempster–Shafer Theory" section, BWM is one of our weighting methods in this study, which has been filled and noticed by experts in questionnaires. Here, a comparison is made between the best criterion and the other criteria, as well as the comparison between the worst criterion and the other main criteria. The importance of the best criterion in comparison t the other criteria and the status of the criteria to the worst criterion will be clarified.

The best and the worst criteria, according to the expert, are considered C_2 or environmental competence and C_7 or transportation costs, respectively.

The optimal weights obtained according to Eqs. (1) and (2) are shown in Table 4.

SWARA Method

Prioritization of the criteria through SWARA method has been done and is depicted in Table 5.

DEMATEL

In this step, before entering the weights obtained from the best–worst methods and the SWARA method in game theory formulas, we examine the direct and indirect relationships between the criteria using the DEMATEL method to evaluate the importance and relationship between the components of the system.

Table 5 The result of SWARA

Criteria	S_j	K_j	Q_j	W_j
C_{11}		1.0000	1.0000	0.153
C_9	0.124	1.1240	0.8897	0.116
C_{12}	0.116	1.1160	0.7972	0.114
C_{10}	0.142	1.1420	0.6981	0.09
C_5	0.156	1.1560	0.6039	0.086
C_2	0.129	1.1290	0.5349	0.076
C_8	0.182	1.1820	0.4525	0.067
C_6	0.146	1.1460	0.3949	0.063
C_1	0.140	1.1400	0.3464	0.056
C_4	0.137	1.1370	0.3046	0.044
C_{15}	0.192	1.1920	0.2556	0.036
C_{14}	0.260	1.2600	0.2028	0.024
C_7	0.183	1.1830	0.1715	0.023
C_3	0.302	1.3020	0.1317	0.019
C_{16}	0.128	1.1280	0.1167	0.017
C_{13}	0.146	1.1460	0.1019	0.015

We extract and normalize the relation matrix for DEMATEL, which is shown in Table 6.

The direct relation matrix is a $n \times n$ matrix (number of criteria). Each of the numbers in the table represents the effect of that criterion on the other criterion. The numbers on the original diameter must be 0, which is the relation of each criterion to itself.

After normalizing the direct relation matrix of relation and obtaining the complete relations matrix T of Eq. (8), the β value from the sum of C_i and R_i in the complete relation matrix T will be calculated. The final results for β are shown in Table 7.

It can be concluded from the results of DEMATEL that the criteria C_2, C_3, C_{10} are of the utmost importance, which should play a remarkable role in computing the comprehensive weight.

According to Eq. (13), the weights obtained by BWM and SWARA methods can be normalized with β and are shown in Table 8.

After entering the game theory results into Eq. (17), the coefficients of weight after normalization by Eq. (18) would be acquired for two weighting methods:

$$\alpha = \{0.796, 0.204\}$$

We obtain the optimum weight according to the weighting coefficients obtained from Eq. (19). The final results of the proposed model are shown in Table 9.

According to the results obtained from the proposed method and by applying internal relationships, direct and indirect relationship and covering the inconsistencies of the two weighting methods, the conclusion is clearly shown in Fig. 1.

Furthermore, we use DEMATEL here to analyze the relation of sub-criterion. The prominence calculated by DEMATEL is employed to modify game theory. The different results of comprehensive weight calculated by game theory and game theory optimized by DEMATEL are

Table 6 Direct relation matrix for criterion

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}
C_1		0	0	4	1	0	0	0	2	1	0	1	0	0	0	0
C_2	0		3	0	0	0	1	2	4	1	0	0	1	2	2	0
C_3	0	2		1	1	0	0	1	2	1	3	1	1	2	3	1
C_4	3	0	0		2	2	1	0	0	0	0	2	1	0	0	2
C_5	0	0	0	1		2	0	1	1	2	1	0	1	1	0	0
C_6	0	0	0	0	2		2	0	0	1	0	1	0	0	0	0
C_7	0	1	0	3	0	0		0	0	0	0	2	3	0	0	1
C_8	0	2	1	0	1	0	0		3	2	0	1	0	3	0	2
C_9	2	4	2	0	1	0	0	2		1	1	1	2	3	2	1
C_{10}	1	1	1	0	2	1	0	2	1		3	2	1	1	2	2
C_{11}	0	0	3	0	1	0	0	0	1	2		0	0	0	0	1
C_{12}	1	0	1	1	0	0	1	1	0	1	0		3	1	1	3
C_{13}	0	2	1	0	1	0	2	0	1	0	0	2		0	1	0
C_{14}	0	1	1	0	2	0	0	2	2	0	0	0	0		3	0
C_{15}	0	1	2	0	0	0	0	0	1	1	0	2	0	2		1
C_{16}	0	0	0	1	0	0	0	1	0	1	0	2	0	0	1	

Table 7 β values for each criterion

Criteria	β
C_1	2.396
C_2	5.006
C_3	5.139
C_4	2.812
C_5	3.359
C_6	1.478
C_7	2.142
C_8	4.44
C_9	4.766
C_{10}	6.027
C_{11}	2.662
C_{12}	4.188
C_{13}	3.44
C_{14}	4.269
C_{15}	4.114
C_{16}	2.96

Table 8 The result of Eq. (13)

Criteria	V_1	V_2
C_1	0.064	0.048
C_2	0.19	0.237
C_3	0.174	0.136
C_4	0.057	0.050
C_5	0.026	0.036
C_6	0.022	0.02
C_7	0.009	0.007
C_8	0.058	0.056
C_9	0.03	0.052
C_{10}	0.082	0.07
C_{11}	0.081	0.062
C_{12}	0.049	0.049
C_{13}	0.079	0.07
C_{14}	0.027	0.039
C_{15}	0.039	0.046
C_{16}	0.013	0.023

shown in Fig. 2. It is obvious that the significant criterion plays an important role in supplier selection.

Supplier Selection

At this stage, the evidence theory and proposed method are used to construct BPA associated with each alternative option. The technique was developed by Beynon (2002) by combining the process of network analysis and evidence theory. Here, for Dempster–Shafer theory/suggested method, a 5-point scale is adopted as the basis for knowledge-level separation. We make basic probability assignment (BPA) for each criterion. Here, Table 10 relates to C_1, which, according to the decision makers, supplier D has different values and suppliers A and B have the same value regarding C_1. The values in the end column are the groups of decision options measurement per row related to $\boldsymbol{\Theta}$. It can be noted that A, B seem very desirable compared to $\boldsymbol{\Theta}$. Initial knowledge matrix for C_1 is found in Table 10.

The results of the BPA's benchmark are presented in Table 11.

To obtain the new BPA according to Eq. (20), we apply the weight of each criterion to the probabilities. Here, the new BPA for criterion C_1 is calculated as follows:

$$m\{D\} = 0.3419 \times 0.06 = 0.020514$$
$$m\{A, B\} = 0.2849 \times 0.06 = 0.017094$$
$$m\{\Theta\} = (1 - 0.06) + 0.06 \times 0.3732 = 0.96234$$

In the next step, we have to combine each of the obtained probabilities using the rules of evidence theory composition from Eqs. (11) and (12).

Based on the Dempster's combination ruler, we obtain the performance for each decision alternative in Table 12. To determine the performance of the proposed method, we compare the results with the BWM method. In both methods, supplier B has the highest value and is the best known, but supplier A, which could not find good rank in the BWM method, has advanced in the proposed method and, owing to that, could be chosen as an alternative, according to voters.

Conclusion and Future Studies

In this study, in order to achieve sustainability and related flexibility in the supply chain, all components of the supply chain, including the processes of supply, flexibility, provisions, production, logistics, distribution, as well as the collection of defective products and their recycling, must be designed in a consistent format by considering sustainability concept. One of these processes, which is the starting point of the supply chain, is the supply of raw materials or initial products from suppliers. This paper focuses on sustainable, economic, environmental and social aspects regarding the flexibility concept. Owing to the fact that criteria's evaluation is mostly vague, qualitative and verbal, here a model is presented that can address the weaknesses of past methods such as inconsistency of results, not distinguishing the criteria's internal communication, ambiguities and uncertainties of input data and

Table 9 The final weight for each criterion

Criteria	Proposed method	BWM	SWARA
C_1	0.06	0.077	0.056
C_2	0.2	0.25	0.076
C_3	0.166	0.168	0.019
C_4	0.055	0.068	0.044
C_5	0.028	0.012	0.086
C_6	0.021	0.01	0.063
C_7	0.008	0.002	0.024
C_8	0.058	0.029	0.067
C_9	0.035	0.033	0.116
C_{10}	0.08	0.057	0.09
C_{11}	0.077	0.06	0.153
C_{12}	0.049	0.046	0.114
C_{13}	0.077	0.079	0.015
C_{14}	0.03	0.035	0.024
C_{15}	0.041	0.043	0.036
C_{16}	0.015	0.031	0.017

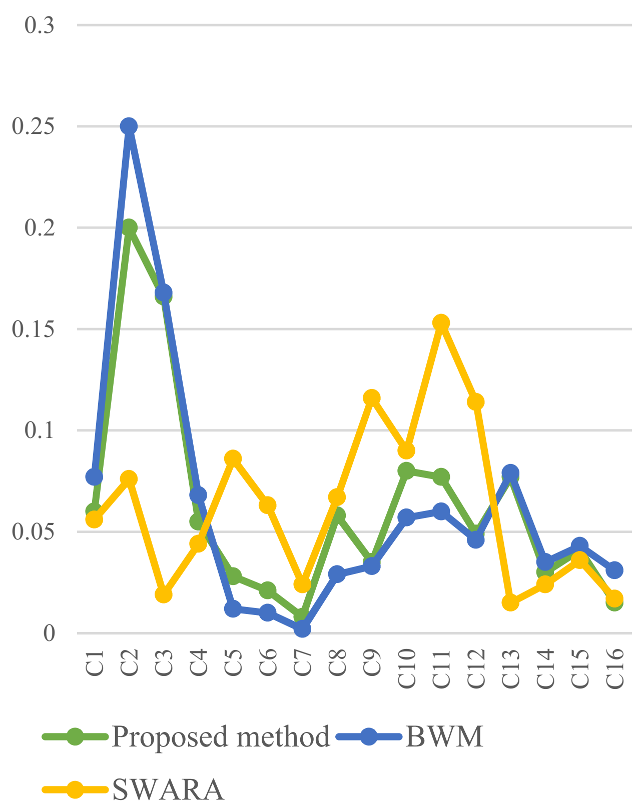

Fig. 1 The final result comparison for criteria

simultaneously considers qualitative and quantitative input data and finally selects the sustainable supplier. The case study of our proposed model is the casting industry which

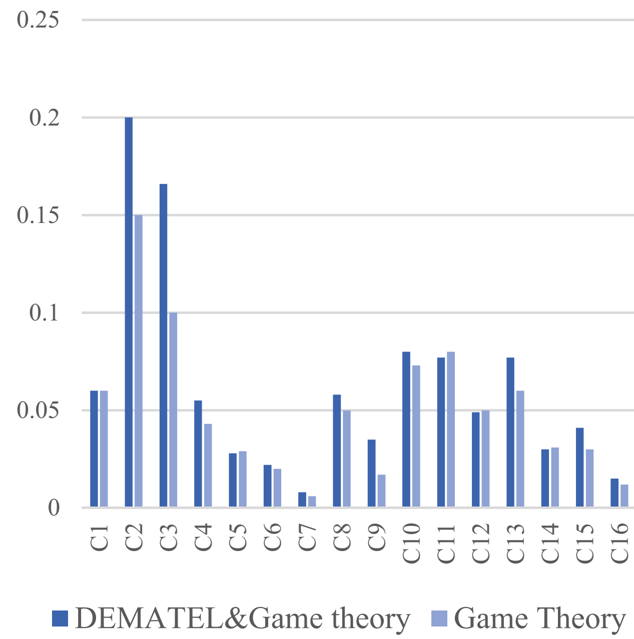

Fig. 2 The comparison between normal and improved game theory by DEMATEL

Table 10 Initial knowledge matrix for C_1 criterion

C_1	$\{D\}$	$\{A, B\}$	$\{\Theta\}$
$\{D\}$	1	0	6P
$\{A, B\}$	0	1	5P
$\{\Theta\}$	1/6P	1/5P	1

Table 11 The initial BPA associated with each criterion

Criterions		Initial probabilities of suppliers	
C_1	$m\{D\} = .3419$	$m\{A, B\} = .2849$	$m\{\Theta\} = .373$
C_2	$m\{B\} = .344$	$m\{A\} = .206$	$m\{\Theta\} = .450$
C_3	$m\{B\}.412$	$m\{A, D\} = .138$	$m\{\Theta\} = .450$
C_4	$m\{D\}.322$	$m\{B, C\} = .257$	$m\{\Theta\} = .421$
C_5	$m\{B, D\} = .344$	$m\{A\} = .206$	$m\{\Theta\} = .450$
C_6	$m\{B\} = .412$	$m\{D\} = .138$	$m\{\Theta\} = .450$
C_7	$m\{A, D\} = .3625$	$m\{C\} = .2417$	$m\{\Theta\} = .395$
C_8	$m\{D\} = .412$	$m\{A\} = .138$	$m\{\Theta\} = .450$
C_9	$m\{D\} = .295$	$m\{B\} = .221$	$m\{\Theta\} = .483$
C_{10}	$m\{A, C\} = .412$	$m\{B\} = .138$	$m\{\Theta\} = .450$
C_{11}	$m\{A\} = .260$	$m\{D\} = .173$	$m\{\Theta\} = .567$
C_{12}	$m\{B\} = .322$	$m\{C, D\} = .257$	$m\{\Theta\} = .421$
C_{13}	$m\{C\} = .319$	$m\{D\} = .159$	$m\{\Theta\} = .522$
C_{14}	$m\{C\} = .319$	$m\{A\} = .159$	$m\{\Theta\} = .522$
C_{15}	$m\{D\} = .386$	$m\{A\} = .193$	$m\{\Theta\} = .421$
C_{16}	$m\{A, C\} = .322$	$m\{D\} = .257$	$m\{\Theta\} = .421$

Table 12 The results of BWM and proposed method

Decision alternatives	BWM	Proposed method
{*A*}	0.1816	0.2116
{*B*}	0.3826	0.2261
{C}	0.0291	0.0437
{*D*}	0.1209	0.1315
{*A*, *C*}	0.0144	0.034
{*A*, *D*}	0.0173	0.0351
{*C*, *D*}	0.0082	0.0197
{*B*, *D*}	0.0051	0.0114
{*B*, *D*}	0.0113	0.0167
{Θ}	0.2311	0.3215

Table 13 Comparison of integrated model with BWM and SWARA in our problem

	BWM	SWARA	Proposed method
Subjective opinions	✔	✘	✔
Objective opinions	✘	✔	✔
Consistency in comparisons	✔	✘	✔
Consistency/inconsistency in decision	✘	✘	✔
Uncertainty in data	✘	✘	✔

is heavily involved in the three economic, environmental and social aspects and simultaneously flexible content in customer services. To implement this method, we first obtained the weight of the criteria using objective and subjective data obtained from the experts with SWARA and BWM methods. Thereafter, DEMATEL method was applied to identify the internal relationships of the criteria. Facing with qualitative indices brings several MCDM methods which may bring different prioritization. To overcome the mentioned issue in our study, by taking the advantage of the game theory, decreasing in deviations, homogenization for integrated solution, inconsistency reduction and comprehensive weight for criteria would be achieved in solution. Finally, to reduce the uncertainties and ambiguity, Dempster–Shafer theory has been utilized. At the end of the essay, our proposed model is applied to show the advantages in a real case study in casting factories to reduce the uncertainty and rational prioritization of sustainable suppliers according to the available criteria. We summarize advantages of our proposed model in comparison with BWM and SWARA in our model, separately in Table 13.

For future studies, we propose several applications of our proposed model for other supplier selection problems in SCM because of the advantage of utilization of both subjective and objective opinions in our model under uncertainty; also, we propose development of BWM with fuzzy set theory. Also, utilization of D-type model of Dempster–Shafer for its characteristics and ability for incomplete data would be reasonable.

Acknowledgements We would like to thank the esteemed reviewers for their valuable and unique contribution by providing critical feedback and comments to improve the manuscript. We would like to thank the editors and editor-in-chief for their encouragement and framework for keeping the paper in shape.

Compliance with Ethical Standards

Conflict of interest The authors hereby declare that there are no potential conflicts of interest in terms of authorship, research and/or publication of this article.

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Key Questions

1. How would be flexible suppliers determined regarding decreasing uncertainty and taking advantage of applied mathematical models?
2. Does sustainability and flexibility as a pack raise the customer satisfaction level?

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