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ORIGINAL RESEARCH

A novel fuzzy general best–worst method for considering diversity and inclusion in supplier selection programs

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Abstract

Socially responsible procurement includes diversity and inclusion, and many companies have found diverse sourcing plays a substantial role in their success. Supplier diversity and inclusion initiatives can significantly impact innovation, reputation, employee engagement, and organizational retention. This paper presents a novel fuzzy general best–worst method for considering diversity and inclusion in supplier selection programs. The proposed approach considers the causal relationships between the criteria in the evaluation process within a network with complex intertwined components and a hierarchical structure. The uncertainty consideration method integrated into the proposed approach allows experts to consider ambiguous and imprecise judgments in the assessment process. We present a supplier selection case study with scenario analysis for a clean energy public–private partnership in the wind farm industry to demonstrate the applicability and efficacy of the proposed approach.

Keywords Supplier selection · Diversity and inclusion · General best–worst method · Fuzzy set theory · Clean energy · Wind farm

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1 Introduction

Many organizations have recognized demographic shifts in the workforce by launching various diversity and inclusion initiatives. Minority business owners create jobs, improve the economy, and build stronger communities. They have the potential to initiate positive change and boost the economy and standard of living. Despite that, many face diversity and inclusion barriers (Fujimoto & Uddin, 2021; Rahman et al., 2018). Diversity programs are needed to eliminate these barriers in many business opportunities, including procurement and supplier selection (Klocek et al., 2014; Versavel et al., 2023). In light of this, supplier diversity programs encourage the participation of underrepresented groups in the production supply networks (Mani et al., 2018; Miguel & Tonelli, 2023). However, supplier diversity programs are often expensive and challenging (Miguel & Tonelli, 2023; Sordi et al., 2022). On the positive side, these programs boost organizational performance and improve stakeholder relationships (Silva et al., 2023). There is a correlation between supplier diversity and a reduction in minority unemployment since minority-owned businesses are more likely to employ employees of the same group (Blount & Li, 2021; Park et al., 2024). Supplier diversity can also reduce economic disparity between minority groups and large corporations (van Hoek et al., 2023); it can be required due to stakeholder pressure and regulatory requirements (Miguel & Tonelli, 2023). Thus, many businesses use supplier diversity as a public statement of their commitment to addressing economic inequality and social unrest in underserved communities (Modgil et al., 2023).

Supplier diversity programs can potentially benefit the entire society and industrial system. Still, choosing the right business partners and suppliers is a strategic decision that will have long-term consequences for the success of any company (Mukherjee, 2016). Yang et al. (2024) explain enterprises encounter substantial limitations when attempting to increase supplier diversity or create inclusive models. Without a well-thought plan and a standard procedure for best-fit supplier selections, any decision could severely impact the corporation and other sectors of the economy (Lajimi et al., 2021). Our primary research objective is to propose a decision-support framework with diversity and inclusion since the current literature is still evolving (Blount & Li, 2021; Liern & Pérez-Gladish, 2022; Sordi et al., 2022). Although supplier diversity has been known for years, most organizations and government agencies demand more research in the field because of its importance due to racial unrest and social polarization worldwide (Sordi et al., 2022). This is a complex task since choosing suitable suppliers from among a broad pool of candidates, each with their own unique set of potentials and capabilities, is a difficult task that necessitates complex models with intertwined relationships. The supplier selection process aims to find the companies with the best strategic fit for supplying a business with the goods and services they require (Guarnieri & Trojan, 2019; Pamucar et al., 2023). Supplier selection is a critical process in organizations because it significantly impacts the company's overall performance and success (Alavi et al., 2021; Mina et al., 2021).

The supplier selection problem has been the subject of numerous studies on the company's financial, environmental, and sustainability needs (Kannan et al., 2020; Li et al., 2020). A recent literature review on supplier selection methods shows several methods are used in supplier selection problems, including the analytic hierarchy process (AHP), analytic network process (ANP), activity-based costing, multi-objective programming, mixed integer programming, goal programming, the technique for order preference by similarity to ideal solution, genetic algorithm, case-based reasoning, data mining, data envelopment analysis, cluster analysis, rough sets theory, and quality function deployment (Mukherjee, 2016).

A supplier selection problem is complex, and a multi-criteria decision-making (MCDM) model is often needed to consider relevant tangible or intangible criteria and weights (Koc et al., 2023; Nasr et al., 2021; Rasmussen et al., 2023). It is argued that the decision criteria and attributes (sub-criteria) are necessary to facilitate best-fit supplier selection (Alikhani et al., 2019; Govindan et al., 2020). MCDM can ensure that the supplier selection process is systematic, objective, and unbiased (Awasthi et al., 2018).

Although many methods for MCDM exist, the AHP and ANP are the most popular MCDM methods for supplier selection (Ebrahim Qazvini et al., 2021; Nasri et al., 2023). While the AHP helps organize the complexities of a problem into a hierarchy, the ANP provides a more comprehensive way of depicting the interplay between them (Janeš et al., 2018). However, AHP and ANP have shortcomings. With the recent emergence of the best–worst method (BWM), attention has shifted from AHP to BWM since BWM has fewer pairwise comparisons and higher consistency than AHP and ANP (Pamučar et al., 2020; Rezaei, 2015; Tavana et al., 2023a). In this regard, Tavana et al. (2023b) presented an approach to evaluate circular suppliers in the renewable energy sector by integrating the fuzzy BWM and a fuzzy inference system. They calculated the weight of the criteria using the fuzzy BWM method and determined the final score of the suppliers. Ghamari et al. (2022) combined BWM and TOPSIS methods and proposed a practical framework for ranking suppliers in the steel industry. Amiri et al. (2021) developed a new approach based on BWM to evaluate sustainable suppliers in the automotive manufacturing industry. Literature review shows that BWM has been widely used in supplier selection problems in various sectors such as the healthcare industry (Rostami et al., 2023), garment industry (Nasr et al., 2021), agriculture industry (Zhu & Wang, 2023), oil industry (Hailiang et al., 2023), and appliance industry (Govindan et al., 2023), among others.

Both AHP and BWM were intended to function with simplified versions of connections between criteria/alternatives. While there is limited research that would allow us to list selection criteria for supplier diversity programs, studies that focus on areas other than supplier diversity do provide evidence of a possible interdependency among supplier selection criteria (Nasrollahi et al., 2021). Yet, the hybridization of the BWM with other methods was an approach to address intertwined relations (Govindan et al., 2022; Kumar et al., 2023; Yazdani et al., 2020). Although the number of applications of BWM for supplier selection is on the rise, the method also has drawbacks (Liang et al., 2020; Pamučar et al., 2020). The general best–worst method (GBWM) proposed by Tavana et al. (2023a) has addressed those drawbacks by generalizing the classic BWM with the added ability to factor in dependencies and the value of those dependencies among the selection criteria through their proposed relative influence-intensity weights. The GBWM has been well-tested and demonstrated applicability and efficacy in dealing with complex problems involving several interdependent decision criteria and sub-criteria (Tavana et al., 2023a).

Although GBWM has the potential to aid practicing managers in the supplier selection process for diversity programs, it frequently needs to be modified to address uncertainty inherent in real-world problems. In many real-world contexts, decision-makers often struggle to provide precise numeric judgments on confusing and partial decision inputs (Chai et al., 2023). Fuzzy set theory is a natural fit for addressing this uncertainty in supplier selection (Mahmoudi et al., 2022; Masoomi et al., 2022). Therefore, we will reformulate the GBWM with a fuzzy approach and put it to the test in a case study to see if it helps us achieve our primary research objectives. Thus, along with the practical contributions, this study also consists of methodological contributions with the introduction and application of fuzzy GBWM. This study aims to answer the following questions: (1) Which criteria are appropriate for evaluating suppliers from the diversity and inclusion perspective? (2) What approach is suitable for evaluating diverse suppliers in complex and intertwined networks? (3) How is the effectiveness of the proposed approach evaluated? Accordingly, the contributions of this study are as follows: (1) Identifying a set of diversity and inclusion criteria and sub-criteria to evaluate supplier diversity programs; (2) Developing a novel approach based on fuzzy GBWM for evaluation of diverse suppliers in networks with hierarchical structure and intertwined components; and (3) Validating the applicability and efficacy of the proposed approach through a case study.

The remainder of this article is organized as follows. In Sect. 2, we present the proposed approach. A case study to demonstrate the applicability of the proposed framework is implemented in Sect. 3. Sections 4 and 5 present our comparative study and sensitivity analysis. Finally, Sect. 5 concludes with our conclusions.

2 Methodology

This section briefly introduces BWM and GBWM before presenting the fuzzy arithmetics and the approach proposed in this study.

2.1 BWM

BWM is a recent MCDM method introduced by Rezaei (2015). This method is based on paired comparisons, has fewer paired comparisons, and has higher consistency than conventional AHP. For further clarification, the number of pairwise comparisons in AHP is $\frac{n(n-1)}{2}$, where n represents the number of factors. In contrast, the number of pairwise comparisons in BWM is $2n$-3. Unlike AHP, where all factors are compared in pairs, only the best and worst factors are compared with other factors in BWM. It should be noted that BWM is based on a mathematical model that aims to minimize the maximum absolute difference among the weight ratios and their corresponding comparisons. The mathematical model of the BWM proposed by Rezaei (2015) was non-linear. The results of this model may have multiple optimal solutions. To solve this problem, Rezaei (2016) presented the linear version of BWM, which always has a unique optimal solution.

2.2 GBWM

In addition to its advantages, BWM ignores the interdependencies between factors in the weighting process. To overcome this challenge, researchers often combine this method with other methods such as DEMATEL and weighted influence non-linear gauge system (WINGS). A literature review reveals that until Tavana et al. (2023a), there was no integrated method based on BWM for weighting the intertwined factors. Tavana et al. (2023a) showed that in some problems, the factors are intertwined and should not be assumed to be independent. In this vein, they introduced the GBWM by proposing the influence intensity of the factors on each other, structuring the influence intensity matrix using the BWM provided by Rezaei (2016), and applying it to independent weights of the factors in multiple criteria decision-making problems with intertwined factors.

2.3 Triangular fuzzy number

Fuzzy set theory was first introduced in 1965 by Zadeh (1965). This theory provides the possibility of solving problems under uncertainty. Triangular fuzzy numbers are the most widely used numbers in fuzzy set theory. In this paper, we use triangular fuzzy numbers to fuzzify GBWM. To structure the fuzzy GBWM, we use the following fuzzy arithmetics:

(1) Addition of two triangular fuzzy numbers:

$$\tilde{a} + \tilde{b} = (a^l + b^l, a^m + b^m, a^u + b^u) \tag{1}$$

(2) Subtraction of two triangular fuzzy numbers:

$$\tilde{a} - \tilde{b} = (a^l - b^u, a^m - b^m, a^u - b^l) \tag{2}$$

(3) Multiplication of two triangular fuzzy numbers:

$$\tilde{a} \times \tilde{b} = (a^l \times b^l, a^m \times b^m, a^u \times b^u) \tag{3}$$

(4) Division of two triangular fuzzy numbers:

$$\frac{\tilde{a}}{\tilde{b}} = (\frac{a^l}{b^u}, \frac{a^m}{b^m}, \frac{a^u}{b^l}) \tag{4}$$

(5) Defuzzification using graded mean integration representation (GMIR) (Guo & Zhao, 2017):

$$a^{Def} = \frac{a^l + 4 \times a^m + a^u}{6} \tag{5}$$

where $\tilde{a} = (a^l, a^m, a^u)$ and $\tilde{b} = (a, b, c)$ represent triangular fuzzy numbers, and a^{Def} is the defuzzified value of $\tilde{a}$.

2.4 Proposed approach

The invitation of more and more minority- and women-owned business enterprises to compete in such a business can lead to an increased degree of resilience, innovation, and sound competition using the value chain. Moreover, this can unlock additional values. A more desirable workplace can be created by utilizing diversity, where great performance and social advancement can result. For this reason, governments and enterprises have concentrated on improving their suppliers' diversity for many years. Governments oblige companies to cooperate with diverse suppliers, even in some public and private projects. Companies need a scoring system to evaluate diverse suppliers and select the best available suppliers in such a situation. This article aims to develop a practical approach for assessing diverse suppliers under uncertainty. The general structure of the proposed approach is depicted in Fig. 1.

The presented approach includes the following 14 steps:

Step 1: In this paper, diversity, equity, and inclusion criteria, including diversity leadership, diversity analytics, diversity equity, diversity climate, and diversity training, are considered supplier evaluation criteria. The sub-criteria of these criteria are identified by reviewing the literature and applying the experts' knowledge.
Step 2: The experts determine the most important (the best) and the least important (the worst) criteria and sub-criteria.

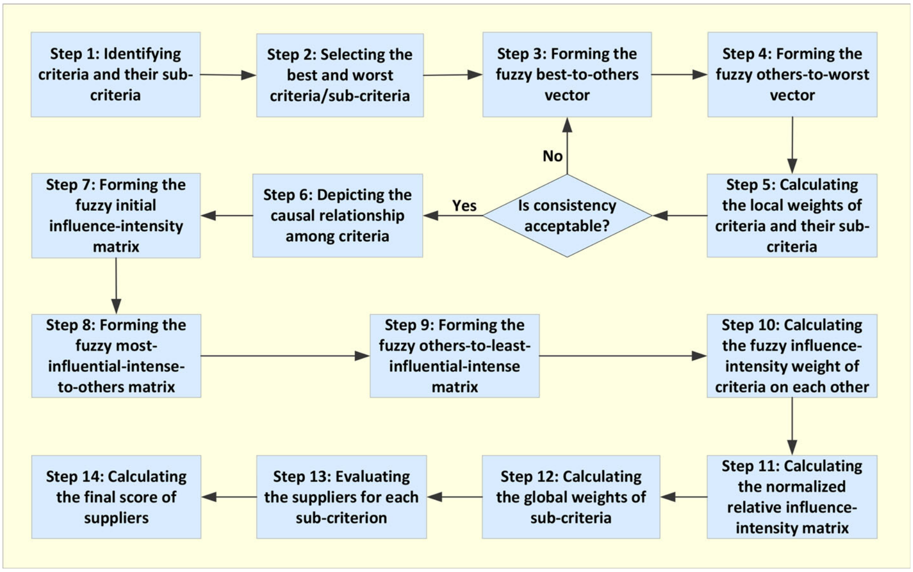


Fig. 1 The proposed approach for evaluating diverse suppliers

Step 3: This step compares the most important criterion/sub-criterion to other criteria/sub-criteria in pairs using the linguistic terms shown in Table 1 to extract the fuzzy best-to-others (BO) vector.
Step 4: This step compares the least important criterion/sub-criterion to other criteria/sub-criteria in pairs using the same linguistic to extract the fuzzy others-to-worst (OW) vector.
Step 5: In this step, the fuzzy linear programming model presented by Govindan et al. (2022) is structured using fuzzy BO and fuzzy OW vectors.

Notations

$i, j \in \{1, 2, ..., n\}$	Criterion/Sub-criterion
$\tilde{\beta}_i = (\beta_i^a, \beta_i^b, \beta_i^c)$	The fuzzy BO vector
$\tilde{\omega}_i = (\omega_i^a, \omega_i^b, \omega_i^c)$	The fuzzy OW vector
$\tilde{x}_B = (x_B^a, x_B^b, x_B^c)$	Fuzzy weight of the best criterion/sub-criterion
$\tilde{x}_W = (x_W^a, x_W^b, x_W^c)$	Fuzzy weight of the worst criterion/sub-criterion
$\tilde{x}_i = (x_i^a, x_i^b, x_i^c)$	Fuzzy weight of the criterion/sub-criterion i

Table 1 The fuzzy linguistic terms for pairwise comparison (Govindan et al., 2022)

Linguistic terms	Triangular fuzzy numbers
Equally significant	(1, 1, 1)
Slightly significant	(2/3, 1, 3/2)
Significant	(3/2, 2, 5/2)
Very significant	(5/2, 3, 7/2)
Absolutely significant	(7/2, 4, 9/2)

$\tilde{\gamma} = (\gamma^a, \gamma^b, \gamma^c)$	$Max\left\{\left\|\tilde{x}_B - \tilde{x}_i \times \tilde{\beta}_i\right\|, \|\tilde{x}_i - \tilde{x}_W \times \tilde{\omega}_i\|\right\}$
x_i^{Def}	Defuzzified weight of the criterion/sub-criterion *i*.

Mathematical model

$$\begin{aligned}
&Min\ \tilde{\gamma}\\
&s.t.\\
&\left|\tilde{x}_B - \tilde{x}_i \times \tilde{\beta}_i\right| \le \tilde{\gamma}\ \forall i\\
&\left|\tilde{x}_B - \tilde{x}_i \times \tilde{\beta}_i\right| \le \tilde{\gamma}\ \forall i\\
&\sum_{i=1}^{n} \frac{x_i^a + 4 \times x_i^b + x_i^c}{6} = 1\\
&x_i^a \le x_i^b \le x_i^c\\
&x_i^a \ge 0
\end{aligned} \tag{6}$$

If we consider γ^* as the optimal value of the objective function ($\gamma^* \le \gamma^a$), the proposed model can be developed as follows.

$$\begin{aligned}
&Min\ \gamma^*\\
&s.t.\\
&\left|(x_B^a, x_B^b, x_B^c) - (x_i^a, x_i^b, x_i^c) \times (\beta_i^a, \beta_i^b, \beta_i^c)\right| \le (\gamma^*, \gamma^*, \gamma^*)\ \forall i\\
&\left|(x_i^a, x_i^b, x_i^c) - (x_W^a, x_W^b, x_W^c) \times (\omega_i^a, \omega_i^b, \omega_i^c)\right| \le (\gamma^*, \gamma^*, \gamma^*)\ \forall i\\
&\sum_{i=1}^{n} \frac{x_i^a + 4 \times x_i^b + x_i^c}{6} = 1\\
&x_i^a \le x_i^b \le x_i^c\\
&x_i^a \ge 0
\end{aligned} \tag{7}$$

The optimal fuzzy independent criteria/sub-criteria weights can be calculated by running the proposed model in commercial optimization software such as GAMS. If the calculated optimal value for γ^* is less than 0.1, the consistency in pairwise comparisons is acceptable. Otherwise, the pairwise comparisons should be revised. Note that the threshold value of 0.1 to accept consistency has been widely used in pairwise comparisons since the inception of AHP (Saaty, 1980) and has been confirmed by Rezaei (2016). After confirming consistency in pairwise comparisons, defuzzified weights of criteria/sub-criteria are calculated using Eq. (8).

$$x_i^{Def} = \frac{x_i^a + 4 \times x_i^b + x_i^c}{6} \tag{8}$$

Step 6: Experts determine the causal relationship between criteria and sub-criteria. It should be noted that considering the causal relationship between sub-criteria has a higher computational complexity than the causal relationship between criteria. Therefore, practicing managers often only consider the causal relationship between criteria to reduce and manage the necessary computational complexities.
Step 7: Based on the causal diagram obtained from the previous step, we form the fuzzy initial influence-intensity matrix. In this regard, the experts are asked to determine the influence intensity of the criteria on each other using the linguistic terms presented in Table 2.

Table 2 The fuzzy influence-intensity scale (Govindan et al., 2022)

Linguistic terms	Triangular fuzzy numbers
Equally influence	(1, 1, 1)
Slightly influence	(2/3, 1, 3/2)
Strongly influence	(3/2, 2, 5/2)
Very strongly influence	(5/2, 3, 7/2)
Absolutely influence	(7/2, 4, 9/2)

Step 8: The fuzzy most-influential-intense-to-others (MIITO) vectors are extracted in this step. For this purpose, we identify the most influential criterion for each column of the fuzzy initial influence-intensity matrix and divide it by the numbers in that column. Note that these operations are done separately for each column.
Step 9: The fuzzy others-to-least-influential-intense (OTLII) vectors are extracted in this step. For this purpose, we identify the least influential criterion for each column of the fuzzy initial influence-intensity matrix and divide the numbers by that column. Note that these operations are done separately for each column.
Step 10: In this step, same as step 5, the following fuzzy linear programming model is structured using fuzzy MIITO and fuzzy OTLII vectors.

Notations

$\tilde{\alpha}_{C_j^B} = (\alpha^a_{C_j^B}, \alpha^b_{C_j^B}, \alpha^c_{C_j^B})$	The fuzzy MIITO vector.
$\tilde{\delta}_{C_j^W} = (\delta^a_{C_j^W}, \delta^b_{C_j^W}, \delta^c_{C_j^W})$	The fuzzy OTLII vector.
$\tilde{x}_{C_j^B} = (x^a_{C_j^B}, x^b_{C_j^B}, x^c_{C_j^B})$	Fuzz influence intensity weight of the best criterion on sub-criterion *j*.
$\tilde{x}_{C_j^W} = (x^a_{C_j^W}, x^b_{C_j^W}, x^c_{C_j^W})$	Fuzzy influence intensity weight of the criterion *j* on the worst criterion.
$\tilde{x}_{C_j^i} = (x^a_{C_j^i}, x^b_{C_j^i}, x^c_{C_j^i})$	Fuzzy influence intensity weight of criterion *i* on Criterion *j*
$\tilde{\gamma}_j = (\gamma^a_j, \gamma^b_j, \gamma^c_j)$	$Max\left\{\left|\tilde{x}_{C_j^B} - \tilde{x}_{C_j^i} \times \tilde{\alpha}_{C_j^B}\right|, \left|\tilde{x}_{C_j^i} - \tilde{x}_{C_W^i} \times \tilde{\delta}_{C_W^i}\right|\right\}$
$x^{Def}_{C_j^i}$	Defuzzified influence intensity weight of criterion i on Criterion j.

Mathematical model

$$
\begin{aligned}
& Min\ \tilde{\gamma}_j \\
& s.t. \\
& \left| \tilde{x}_{C_j^B} - \tilde{x}_{C_j^i} \times \tilde{\alpha}_{C_j^B} \right| \le \tilde{\gamma}_j\ \forall i, j \\
& \left| \tilde{x}_{C_j^i} - \tilde{x}_{C_j^W} \times \tilde{\alpha}_{C_j^W} \right| \le \tilde{\gamma}_j\ \forall i, j \\
& \sum_{i=1}^{n} \frac{x^a_{C_j^i} + 4 \times x^b_{C_j^i} + x^c_{C_j^i}}{6} = 1\ \forall j \\
& x^a_{C_j^i} \le x^b_{C_j^i} \le x^c_{C_j^i} \\
& x^a_{C_j^i} \ge 0
\end{aligned}
\tag{9}
$$

If we consider γ_j^* as the optimal value of the objective function for column j ($\gamma_j^* \le \gamma_j^a$), the proposed model can be developed as follows.

$$
\begin{aligned}
& Min\ \gamma_j^* \\
& s.t. \\
& \left| (x^a_{C_j^B}, x^b_{C_j^B}, x^c_{C_j^B}) - (x^a_{C_j^i}, x^b_{C_j^i}, x^c_{C_j^i}) \times (\alpha^a_{C_j^B}, \alpha^b_{C_j^B}, \alpha^c_{C_j^B}) \right| \le (\gamma_j^*, \gamma_j^*, \gamma_j^*)\ \ \forall i, j \\
& \left| (x^a_{C_j^i}, x^b_{C_j^i}, x^c_{C_j^i}) - (x^a_{C_j^W}, x^b_{C_j^W}, x^c_{C_j^W}) \times (\delta^a_{C_j^W}, \delta^b_{C_j^W}, \delta^c_{C_j^W}) \right| \le (\gamma_j^*, \gamma_j^*, \gamma_j^*) \\
& \sum_{i=1}^{n} \frac{x^a_{C_j^i} + 4 \times x^b_{C_j^i} + x^c_{C_j^i}}{6} = 1\ \ \forall j \\
& x^a_{C_j^i} \le x^b_{C_j^i} \le x^c_{C_j^i} \\
& x^a_{C_j^i} \ge 0
\end{aligned}
\tag{10}
$$

By running the developed model in GAMS software using CPLEX solver, the optimal value of the objective function and the fuzzy influence-intensity weight of criterion i on criterion j are calculated. Based on the obtained results, we form the fuzzy initial influence-intensity matrix. It should be noted that in this matrix, the symbol "-" is placed on the main diameter, and the symbol "N" indicates no effect.

Step 11: The fuzzy relative influence-intensity matrix is first calculated in this step. For this purpose, we should put fuzzy numbers (1, 1, 1) and (0, 0, 0) instead of the symbols "-" and "N" in the matrix obtained from the previous step, respectively. Then, the obtained matrix is defuzzified by Eq. (11). The defuzzified matrix is called the relative influence-intensity matrix.

$$
x^{Def}_{C_j^i} = \frac{x^a_{C_j^i} + 4 \times x^b_{C_j^i} + x^c_{C_j^i}}{6} \tag{11}
$$

Step 12: The normalized relative influence-intensity matrix is calculated in this step. For this end, we should divide the numbers in each column of the relative influence-intensity matrix by the sum of the numbers in that column.

Table 3 The fuzzy score for supplier evaluation (Tavana et al., 2023b)

Linguistic terms	Fuzzy score	Defuzzified score
Absolutely weak	(0, 0, 0)	0
Very weak	(0, 0.1, 0.2)	0.1
Weak	(0.1, 0.2, 0.3)	0.2
Slightly weak	(0.2, 0.3, 0.4)	0.3
Mid-weak	(0.3, 0.4, 0.5)	0.4
Mid	(0.4, 0.5, 0.6)	0.5
Mid-strong	(0.5, 0.6, 0.7)	0.6
Slightly strong	(0.6, 0.7, 0.8)	0.7
Strong	(0.7, 0.8, 0.9)	0.8
Very strong	(0.8, 0.9, 1)	0.9
Absolutely strong	(1, 1, 1)	1

Step 13: In this step, the final dependent weights of criteria are calculated by multiplying the normalized relative influence intensity matrix into the independent weights of criteria obtained from step 1.5. Finally, to calculate the global weights of sub-criteria, we should multiply the dependent criteria weights by the independent weights of sub-criteria.
Step 14: The experts evaluate the suppliers for each sub-criterion using the linguistic terms presented in Table 3. Finally, we use average or median values obtained from expert opinions as the supplier scores for each sub-criterion. We will further explain when to use the mean or median in Step 14 of the case study. Note that there are different scoring scales in the literature for evaluating suppliers. In this study, we apply the scales provided by Tavana et al. (2023b), which provides a wide range of scoring for the experts. Note that the paired comparison questionnaires are completed by consensus, while the supplier evaluation questionnaires are completed separately by each expert for each sub-criteria.
Step 15: In this step, the final score of suppliers is calculated. For this purpose, we should calculate the sum of the product of the sub-criteria weight in their evaluated scores.

3 Case study

The Virginia state government plans to add a new wind farm to the existing wind farms in West Virginia to increase the use of wind energy for electricity production. This is a state-sponsored public–private partnership, and Coastal Virginia Wind Power Company,[1] an engineering, construction, and project management company, has won the bid to implement this project. One of the conditions of partnership with this company is that the company should consider supplier diversity, equity, and inclusion factors in their supplier selection for project implementation. Coastal Virginia Wind Power Company applied the proposed approach to include diversity, equity, and inclusion factors in evaluating 23 suppliers to comply with this requirement. Coastal Virginia Wind Power Company has appointed five experts, including the project manager, quality control manager, HSE manager, project technical manager, and design and construction manager, to manage the evaluation process consistent with the state mandate. Demographic information of these experts is given in Table 4.

[1] The name is changed to protect the company anonomity.

Table 4 The demographic information of experts

Demographic attributes		No. of experts	
		Male	Female
Age	30–40 years	1	–
	40–50 years	3	–
	50–60 years	1	–
Experience	5–10 years	1	–
	10–15 years	2	–
	15–20 years	2	–
Expertise	Project manager	1	–
	Quality control manager	1	–
	HSE manager	1	–
	Project technical manager	1	–
	Design and construction manager	1	–

In the following, the evaluation process of these suppliers is presented step by step.

Step 1: Literature review shows that although the supplier selection problem is popular and widely used, there is a research gap in the field of diverse supplier evaluation, and so far, no research has provided standard and well-known criteria for this issue. For this purpose, using the knowledge of experts and literature review, a set of criteria and sub-criteria was extracted for evaluating diverse suppliers, presented in Table 5.

Step 2: In this step, the experts determine the best and worst criteria and sub-criteria. According to expert opinions, Diversity Leadership and Diversity Analytics are the best and worst criteria. The best and worst sub-criteria for each criterion are given in Table 6.

Step 3: In this step, experts compare the best criterion (sub-criterion) with other criteria (sub-criteria) using linguistic terms shown in Table 1. The BO vectors obtained from pairwise comparisons are presented in Tables 15.

Step 4: Similarly, in this step, experts compare the worst criterion (sub-criterion) with other criteria (sub-criteria) via linguistic terms represented in Table 1. The OW vectors obtained from pairwise comparisons are shown in Table 16.

Step 5: In this step, the model presented in Eq. (7) is developed using obtained BO and OW vectors. For example, the proposed model for criteria is formulated as follows.

$$Min\ \gamma^* \tag{12}$$

$$s.t.$$

$$\left|(x_{DL}^a, x_{DL}^b, x_{DL}^c) - (\frac{7}{2}, 4, \frac{9}{2}) \times (x_{DA}^a, x_{DA}^b, x_{DA}^c)\right| \leq (\gamma^*, \gamma^*, \gamma^*) \tag{12.1}$$

$$\left|(x_{DL}^a, x_{DL}^b, x_{DL}^c) - (\frac{2}{3}, 1, \frac{3}{2}) \times (x_{DE}^a, x_{DE}^b, x_{DE}^c)\right| \leq (\gamma^*, \gamma^*, \gamma^*) \tag{12.2}$$

$$\left|(x_{DL}^a, x_{DL}^b, x_{DL}^c) - (\frac{5}{2}, 3, \frac{7}{2}) \times (x_{DC}^a, x_{DC}^b, x_{DC}^c)\right| \leq (\gamma^*, \gamma^*, \gamma^*) \tag{12.3}$$

$$\left|(x_{DL}^a, x_{DL}^b, x_{DL}^c) - (\frac{3}{2}, 2, \frac{5}{2}) \times (x_{DT}^a, x_{DT}^b, x_{DT}^c)\right| \leq (\gamma^*, \gamma^*, \gamma^*) \tag{12.4}$$

Table 5 Criteria and sub-criteria for diverse supplier evaluation

Criteria	Sub-criteria	Description	References
Diversity leadership (DL)	Parity success (DL1)	The parity of women and men, and the equality of white males and underrepresented minorities	Berenguer et al. (2024)
	Disparity plans (DL2)	Short-term and long-term plans to address disparities	Miguel and Tonelli (2023)
	Hierarchical Plans (DL3)	Relevance of diversity to every leader, or only the responsibility of a Chief Diversity Officer or similar	Miguel and Tonelli (2023)
	Parity spending (dl4)	Investment in diversity expertise and hiring a well-resourced team of diversity experts	Berenguer et al. (2024)
	Leadership review (DL5)	Leadership frequency review of diversity policies	Sordi et al. (2022)
Diversity analytics (DA)	Diversity program review (DA1)	Diversity program goals and data frequency	van Hoek et al. (2023)
	Diversity benchmarking (DA2)	Benchmark diversity data	Holton (2005)
	Diversity gap analysis (DA3)	Frequency of diversity gap analysis with underrepresented communities	Wang (2023)
	Diversity scale (DA4)	Recording and considering small, intersectional groups in diversity data rather than rolling everyone up into broad groups	Steiger et al. (2020)
Diversity equity (DE)	Internal pay transparency (DE1)	Sharing pay transparency information with all employees	Blount and Li (2021); Miguel and Tonelli (2023)
	External pay transparency (DE2)	Sharing pay transparency information publicly	Blount and Li (2021); Miguel and Tonelli (2023)
	Competition pay transparency (DE3)	Incorporating competitors' pay transparency data into salary plans	Blount and Li (2021); Miguel and Tonelli (2023)

Table 5 (continued)

Criteria	Sub-criteria	Description	References
Diversity climate (DC)	Diversity scope (DC1)	Diversity programs incorporate all aspects of identity individually as well as holistically	Steiger et al. (2020)
	Diversity data reporting (DC2)	Robust diversity data capture and reporting tools	Berenguer et al. (2024)
	Diversity management training (DC3)	Managers' ability to gain appropriate diversity knowledge and skills	Madera et al. (2018)
Diversity training (DT)	Training scope (DT1)	Diversity training covers all aspects of diversity, equity, inclusion, and respect	Madera et al. (2018)
	practical training (dt2)	Diversity training includes real-world examples to help ground the diversity principles	Richard et al. (2015)
	Training availability (DT3)	Diversity training is available to all employees	Richard et al. (2015)

Table 6 The best and worst sub-criteria of each criterion

Criterion	Best sub-criterion	Worst sub-criterion
DL	Parity success	Hierarchical plans
DA	Diversity benchmarking	Diversity gap analysis
DE	Internal pay transparency	External pay transparency
DC	Diversity management training	Diversity scope
DT	Training availability	Training scope

$$\left|(x_{DE}^a, x_{DE}^b, x_{DE}^c) - (\frac{5}{2}, 3, \frac{7}{2}) \times (x_{DA}^a, x_{DA}^b, x_{DA}^c)\right| \le (\gamma^*, \gamma^*, \gamma^*) \tag{12.5}$$

$$\left|(x_{DC}^a, x_{DC}^b, x_{DC}^c) - (\frac{2}{3}, 1, \frac{3}{2}) \times (x_{DA}^a, x_{DA}^b, x_{DA}^c)\right| \le (\gamma^*, \gamma^*, \gamma^*) \tag{12.6}$$

$$\left|(x_{DT}^a, x_{DT}^b, x_{DT}^c) - (\frac{3}{2}, 2, \frac{5}{2}) \times (x_{DA}^a, x_{DA}^b, x_{DA}^c)\right| \le (\gamma^*, \gamma^*, \gamma^*) \tag{12.7}$$

$$\begin{aligned} &\frac{x_{DL}^a + 4 \times x_{DL}^b + x_{DL}^c}{6} + \frac{x_{DA}^a + 4 \times x_{DA}^b + x_{DA}^c}{6} + \frac{x_{DE}^a + 4 \times x_{DE}^b + x_{DE}^c}{6} \\ &+ \frac{x_{DC}^a + 4 \times x_{DC}^b + x_{DC}^c}{6} + \frac{x_{DT}^a + 4 \times x_{DT}^b + x_{DT}^c}{6} = 1 \end{aligned} \tag{12.8}$$

$$x^a_{DL} \le x^b_{DL} \le x^c_{DL};\ x^a_{DA} \le x^b_{DA} \le x^c_{DA};\ x^a_{DE} \le x^b_{DE} \le x^c_{DE};$$
$$x^a_{DC} \le x^b_{DC} \le x^c_{DC};\ x^a_{DT} \le x^b_{DT} \le x^c_{DT} \tag{12.9}$$

$$x^a_{DL} \ge 0;\ x^a_{DA} \ge 0;\ x^a_{DE} \ge 0;\ x^a_{DC} \ge 0;\ x^a_{DT} \ge 0 \tag{12.10}$$

Constraints (12.1) to (12.4) indicate the relationship between the best criterion and other criteria in pairs. Also, the relationship between the worst criterion and other criteria is shown in constraints (12.5) to (12.7). Constraint (12.8) guarantees that the sum of the defuzzified weights of the criteria is equal to 1. The relationship between triangular fuzzy numbers' lower, middle, and upper bounds is given in constraint (12.9). Constraint (12.10) guarantees that the calculated weights take values greater than or equal to zero.

We expand Eq. (12) in Appendix B as Eq. (12B). By running the model presented in Eq. (12B) in GAMS software via CPLEX solver, the optimal fuzzy independent weights of criteria are calculated. Similarly, we can calculate the fuzzy independent weights of sub-criteria. Finally, the fuzzy weights are defuzzified using Eq. (8). Table 7 shows the optimal value of γ^* the fuzzy and defuzzified independent criteria weights and their sub-criteria.

Step 6: Experts depict the causal relationship between the criteria in this step. Figure 2 shows the causal relationships between the criteria. Also, the general structure of the investigated hierarchical network is presented in Fig. 3. Figure 3a depicts the hierarchical relationship between criteria, sub-criteria, and alternatives (suppliers). Note that the sub-criteria are not drawn completely to reduce the visual complexity of the presented figure. For example, the criterion DL includes five sub-criteria. Instead of drawing each, DL1:DL5 denotes DL1, DL2, DL3, DL4, and DL5. Additionally, for greater clarity, Fig. 3b zooms in on the relationship between the DA criterion, its subcriteria, and suppliers.

Step 7: In this step, the experts determine the influence intensity of criteria on each other with the help of linguistic terms shown in Table 2, and the fuzzy initial influence-intensity matrix is formed. This matrix is given in Table 17.

Step 8: In this step, in each column, we divide the most-influenced criterion by other criteria to obtain the MIITO vector. The most-influenced criteria are shown in Table 17. Table 18 represents the fuzzy MIITO vectors.

Step 9: Similarly, in this step, in each column, we divide the other criteria by the least-influenced criterion to obtain the OTLII vector. The least-influenced criteria are shown in Table 17. Table 19 represents the fuzzy OTLII vectors.

Step 10: In this step, the fuzzy linear programming model presented in Eq. (10) is developed using MIITO and OTLII vectors. For example, this model for the column related to the criterion DL is formulated as follows.

$$Min\ \gamma^*_{DL} \tag{13}$$

$$s.t.$$

$$\left|(x^a_{C^{DA}_{DL}},\ x^b_{C^{DA}_{DL}},\ x^c_{C^{DA}_{DL}}) - (1, \frac{3}{2}, \frac{7}{3}) \times (x^a_{C^{DE}_{DL}},\ x^b_{C^{DE}_{DL}},\ x^c_{C^{DE}_{DL}})\right| \le (\gamma^*_{DL},\ \gamma^*_{DL},\ \gamma^*_{DL}) \tag{13.1}$$

$$\left|(x^a_{C^{DA}_{DL}},\ x^b_{C^{DA}_{DL}},\ x^c_{C^{DA}_{DL}}) - (1, \frac{3}{2}, \frac{7}{3}) \times (x^a_{C^{DC}_{DL}},\ x^b_{C^{DC}_{DL}},\ x^c_{C^{DC}_{DL}})\right| \le (\gamma^*_{DL},\ \gamma^*_{DL},\ \gamma^*_{DL}) \tag{13.2}$$

$$\left|(x^a_{C^{DA}_{DL}},\ x^b_{C^{DA}_{DL}},\ x^c_{C^{DA}_{DL}}) - (\frac{5}{3}, 3, \frac{21}{4}) \times (x^a_{C^{DT}_{DL}},\ x^b_{C^{DT}_{DL}},\ x^c_{C^{DT}_{DL}})\right| \le (\gamma^*_{DL},\ \gamma^*_{DL},\ \gamma^*_{DL}) \tag{13.3}$$

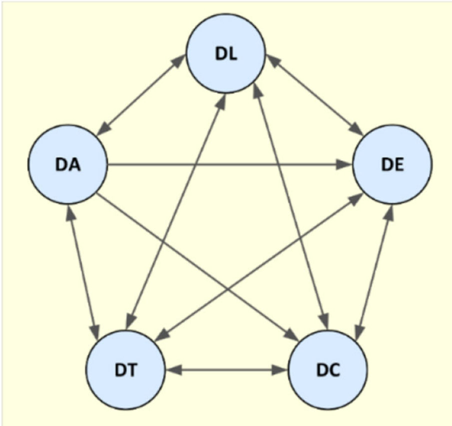
Table 7 The independent weights of criteria and sub-criteria

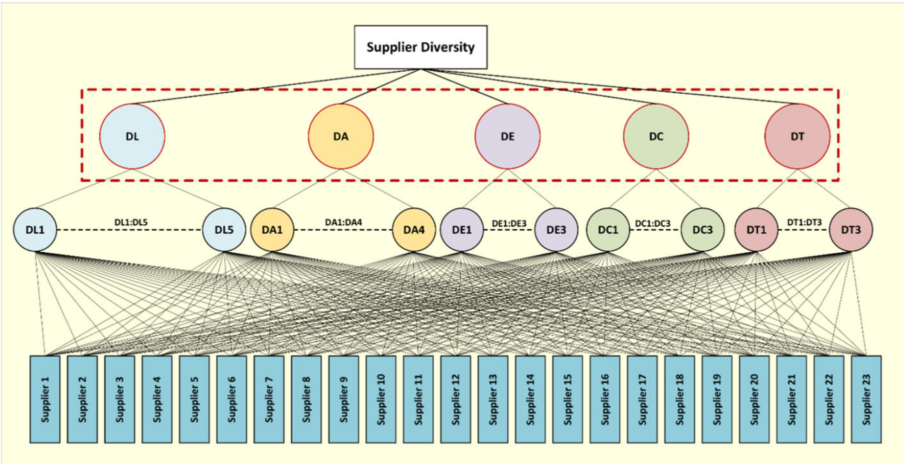
Criteria	Fuzzy independent weight ($\gamma^* = 0.036$)	Defuzzified independent weight	Sub-criteria	Fuzzy independent weight	Defuzzified independent weight
DL ($\gamma^* = 0.044$)	(0.146, 0.346, 0.448)	0.3297	DL1	(0.12, 0.219, 0.878)	0.3123
			DL2	(0.114, 0.176, 0.556)	0.229
			DL3	(0.047, 0.066, 0.205)	0.086
			DL4	(0.114, 0.176, 0.556)	0.229
			DL5	(0.075, 0.11, 0.351)	0.1443
DA ($\gamma^* = 0.035$)	(0.052,0.092,0.092)	0.0853	DA1	(0.161, 0.347, 0.533)	0.347
			DA2	(0.142, 0.382, 0.764)	0.4057
			DA3	(0.051, 0.104, 0.162)	0.1048
			DA4	(0.068, 0.139, 0.228)	0.142
DE ($\gamma^* = 0.048$)	(0.165, 0.31, 0.322)	0.2878	DE1	(0.133, 0.238, 1.619)	0.4507
			DE2	(0.12, 0.143, 0.667)	0.2265
			DE3	(0.128, 0.19, 1.048)	0.3227
DC ($\gamma^* = 0.03$)	(0.07, 0.127, 0.138)	0.1193	DC1	(0.071, 0.121, 0.546)	0.1835
			DC2	(0.078, 0.152, 0.789)	0.2458
			DC3	(0.147, 0.334, 1.942)	0.5708
DT ($\gamma^* = 0.048$)	(0.113, 0.191, 0.193)	0.1783	DT1	(0.12, 0.143, 0.667)	0.2265
			DT2	(0.128, 0.19, 1.048)	0.3227
			DT3	(0.133, 0.238,1.619)	0.4507

$$\left|(x^a_{C^{DE}_{DL}},\ x^b_{C^{DE}_{DL}},\ x^c_{C^{DE}_{DL}}) - (1, 2, \frac{15}{4}) \times (x^a_{C^{DT}_{DL}},\ x^b_{C^{DT}_{DL}},\ x^c_{C^{DT}_{DL}})\right| \le (\gamma^*_{DL},\ \gamma^*_{DL},\ \gamma^*_{DL}) \tag{13.4}$$

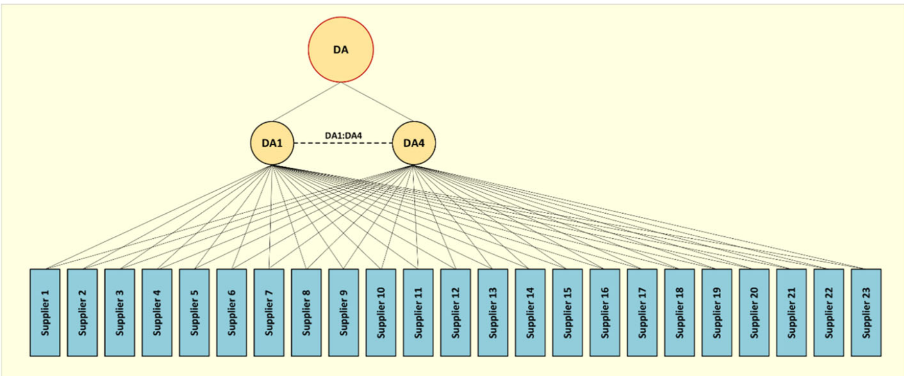
$$\left|(x^a_{C^{DC}_{DL}},\ x^b_{C^{DC}_{DL}},\ x^c_{C^{DC}_{DL}}) - (1, 2, \frac{15}{4}) \times (x^a_{C^{DT}_{DL}},\ x^b_{C^{DT}_{DL}},\ x^c_{C^{DT}_{DL}})\right| \le (\gamma^*_{DL},\ \gamma^*_{DL},\ \gamma^*_{DL}) \tag{13.5}$$

Fig. 2 Causal relationship among criteria





(a) Overall structure



(b) Zoomed view of the DA criterion

Fig. 3 The general structure of investigated diverse supplier selection problem

$$\frac{x^a_{C^{DA}_{DL}} + 4 \times x^b_{C^{DA}_{DL}} + x^c_{C^{DA}_{DL}}}{6} + \frac{x^a_{C^{DE}_{DL}} + 4 \times x^b_{C^{DE}_{DL}} + x^c_{C^{DE}_{DL}}}{6} + \frac{x^a_{C^{DC}_{DL}} + 4 \times x^b_{C^{DC}_{DL}} + x^c_{C^{DC}_{DL}}}{6} + \frac{x^a_{C^{DT}_{DL}} + 4 \times x^b_{C^{DT}_{DL}} + x^c_{C^{DT}_{DL}}}{6} = 1 \tag{13.6}$$

$$\begin{aligned} &x^a_{C^{DA}_{DL}} \le x^b_{C^{DA}_{DL}} \le x^c_{C^{DA}_{DL}}; \quad x^a_{C^{DE}_{DL}} \le x^b_{C^{DE}_{DL}} \le x^c_{C^{DE}_{DL}}; \\ &x^a_{C^{DC}_{DL}} \le x^b_{C^{DC}_{DL}} \le x^c_{C^{DC}_{DL}}; \quad x^a_{C^{DT}_{DL}} \le x^b_{C^{DT}_{DL}} \le x^c_{C^{DT}_{DL}} \end{aligned} \tag{13.7}$$

$$x^a_{C^{DA}_{DL}},\ x^a_{C^{DE}_{DL}},\ x^a_{C^{DC}_{DL}},\ x^a_{C^{DT}_{DL}} \ge 0 \tag{13.8}$$

Constraints (13.1) to (13.3) indicate the relationship between the most influential criterion and other criteria in pairs. Also, the relationship between the least influential criterion and other criteria is shown in constraints (13.4) and (13.5). Constraint (13.6) guarantees that the sum of the defuzzified relative influence-intensity weights of the criteria is equal to 1. The relationship between triangular fuzzy numbers' lower, middle, and upper bounds is given in constraint (13.7). Constraint (13.8) guarantees that the calculated relative influence-intensity weights take values greater than or equal to zero.

We expand Eq. (13) in Appendix C as Eq. (13C). By running the model provided in Eq. (13B) in GAMS software by CPLEX solver, fuzzy relative influence-intensity weights for columns related to criterion DL are calculated. This operation is performed similarly for other columns. The fuzzy initial influence-intensity matrix obtained from this operation is presented in Table 20.

Step 11: The fuzzy relative influence-intensity matrix is first structured in this step. For this purpose, in Table 20, instead of symbols "-" and "N", it is enough to place the values (1, 1, 1) and (0, 0, 0), respectively. Table 21 represents the fuzzy relative influence-intensity matrix. Then, the fuzzy relative influence-intensity matrix is defuzzified using Eq. (11), which is shown in Table 8.

Step 12: We should normalize the defuzzified relative influence-intensity matrix in this step. For this purpose, we divide the numbers of each column of the matrix by the sum of the numbers of that column. The normalized relative influence-intensity matrix is shown in Table 9.

Step 13: In this step, the dependent weight of criteria is calculated by multiplying the normalized matrix obtained from the previous step with the independent weight of criteria, which

Table 8 Defuzzified relative influence-intensity matrix

	DL	DA	DE	DC	DT
DL	1	0.7012	0.3435	0.3435	0.3435
DA	0.385	1	0.2558	0.2558	0.2558
DE	0.259	0	1	0.2558	0.145
DC	0.259	0	0.145	1	0.2558
DT	0.097	0.2983	0.2558	0.145	1

Table 9 Normalized relative influence-intensity matrix

	DL	DA	DE	DC	DT
DL	0.5	0.3507	0.1717	0.1717	0.1717
DA	0.1925	0.5	0.1279	0.1279	0.1279
DE	0.1295	0	0.5	0.1279	0.0725
DC	0.1295	0	0.0725	0.5	0.1279
DT	0.0485	0.1493	0.1279	0.0725	0.5

is shown as follows:

$$\begin{bmatrix} 0.5 & 0.3507 & 0.1717 & 0.1717 & 0.1717 \\ 0.1925 & 0.5 & 0.1279 & 0.1279 & 0.1279 \\ 0.1295 & 0 & 0.5 & 0.1279 & 0.0725 \\ 0.1295 & 0 & 0.0725 & 0.5 & 0.1279 \\ 0.0485 & 0.1493 & 0.1279 & 0.0725 & 0.5 \end{bmatrix} \times \begin{bmatrix} 0.3297 \\ 0.0853 \\ 0.2878 \\ 0.1193 \\ 0.1783 \end{bmatrix} = \begin{bmatrix} 0.2951 \\ 0.1809 \\ 0.2147 \\ 0.146 \\ 0.1633 \end{bmatrix}$$

Then, to calculate the global weight of sub-criteria, we should multiply the dependent weights of criteria by the independent weights of sub-criteria, which is represented in Fig. 4.
Step 14: The experts evaluated the suppliers' performance for each sub-criterion using the linguistic terms shown in Table 3. A normality test (Shapiro–Wilk test) is used to determine whether sample data is drawn from a normally distributed population. We considered the performance of each supplier for each sub-criterion as a variable and ran 414 variables, each containing five observations, using the Shapiro–Wilk test in SPSS software. An abbreviated output of the software is provided in Fig. 5.
As shown in Fig. 5, the Sig. (p-value) is greater than 0.05 for all variables, indicating data normality. Of course, the Shapiro–Wilk test alone is insufficient when the number of samples for each variable is small. Therefore, we identified the variables that included outlier data

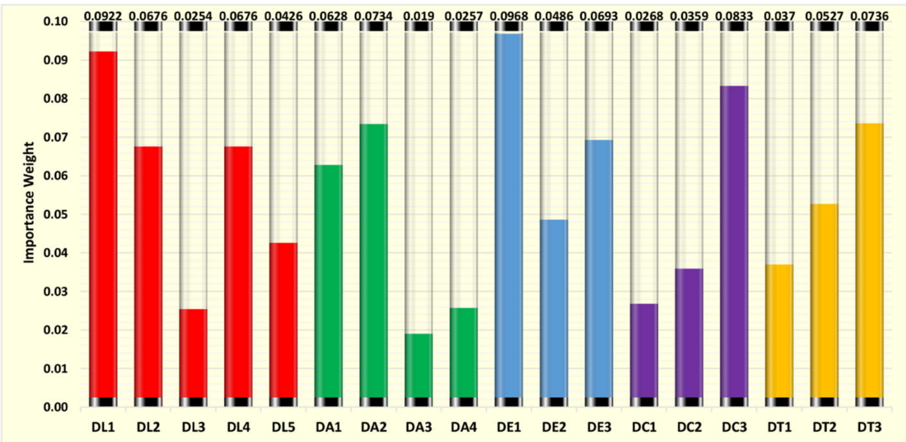


Fig. 4 Defuzzified global weights of sub-criteria

Variable	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
VAR00001	.304	5	.149	.817	5	.111
VAR00002	.286	5	.200*	.813	5	.103
VAR00003	.254	5	.200*	.914	5	.492
VAR00004	.243	5	.200*	.894	5	.377
VAR00005	.300	5	.161	.921	5	.537
VAR00006	.237	5	.200*	.961	5	.814
VAR00007	.237	5	.200*	.961	5	.814
VAR00008	.258	5	.200*	.925	5	.563
VAR00009	.220	5	.200*	.956	5	.777
VAR00010	.250	5	.200*	.885	5	.332
VAR00011	.292	5	.190	.845	5	.180
VAR00012	.252	5	.200*	.845	5	.179
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
VAR00409	.254	5	.200*	.803	5	.086
VAR00410	.261	5	.200*	.823	5	.124
VAR00411	.243	5	.200*	.922	5	.544
VAR00412	.300	5	.161	.833	5	.146
VAR00413	.287	5	.200*	.914	5	.490
VAR00414	.273	5	.200*	.931	5	.603

Fig. 5 The output of SPSS software

and used the median instead of the average. This led to the calculation of the final score of each supplier in each sub-criterion, which is given in Table 22.

Step 15: In this step, the final score of the suppliers is calculated. For this end, we must calculate the sum of the product of global weights of sub-criteria in the scores evaluated for suppliers. The final score and rank of diverse suppliers are presented in Table 10.

The results shown in Table 10 show that suppliers 23, 2, and 20 are the suppliers that have the highest score, and suppliers 17, 16, and 11 are the suppliers that have poor performance compared to other suppliers. These results can help decision-makers make decisions related to cooperation with diverse suppliers. The results of the proposed approach are compared with the results of a method presented in the literature in the next section.

4 Comparative analysis

In this section, we examine the reliability of the results obtained from the proposed approach by comparing them with those from two commonly used fuzzy approaches in the literature. We show the performance of fuzzy GBWM is significantly different from that of fuzzy BWM and similar to fuzzy ANP. Note that a fair comparison requires the results obtained from the proposed approach to (1) be based on pairwise comparisons, (2) use the linguistic terms used in the proposed approach for comparisons, and (3) consider the interdependencies between criteria. The literature review shows that the fuzzy ANP method presented by Dağdeviren and Yüksel (2010) has all the comparative features. In addition, we use the fuzzy BWM provided by Govindan et al. (2022) method to show the effect of interdependency on the final weight of sub-criteria. This method is the same as Steps 1 through 5 of the proposed approach, with one exception in Step 5, where the independent weight of criteria is multiplied

Table 10 Final score and rank of diverse suppliers

Supplier	Final score	Rank
Supplier 1	0.4926	18
Supplier 2	0.5609	2
Supplier 3	0.5273	9
Supplier 4	0.5103	15
Supplier 5	0.5294	8
Supplier 6	0.5068	16
Supplier 7	0.5044	17
Supplier 8	0.5302	7
Supplier 9	0.5135	14
Supplier 10	0.5407	6
Supplier 11	0.4861	20
Supplier 12	0.5257	10
Supplier 13	0.5414	5
Supplier 14	0.5188	13
Supplier 15	0.5248	11
Supplier 16	0.4826	21
Supplier 17	0.4711	22
Supplier 18	0.5294	8
Supplier 19	0.5208	12
Supplier 20	0.5437	3
Supplier 21	0.5416	4
Supplier 22	0.4894	19
Supplier 23	0.5731	1

by the independent weight of sub-criteria to calculate the global independent weights. In the following, we first evaluate the suppliers and then check the accuracy of the results obtained from the proposed approach by applying the fuzzy ANP method provided by Dağdeviren and Yüksel (2010). We then calculate the global independent weights of sub-criteria using the fuzzy BWM method and report the resulting weights. The following is the evaluation process using fuzzy ANP provided by Dağdeviren and Yüksel (2010).

Step 1: In this step, criteria and sub-criteria are identified. Table 5 shows the criteria and sub-criteria.
Step 2: The pairwise comparison matrices are structured using the linguistic terms shown in Table 1. The paired comparisons matrix for the criteria is given in Table 11. Also, pairwise comparison matrices for the sub-criteria are represented in the Appendix.
Step 3: In this step, the following non-linear programming model is developed using the pairwise comparisons matrix presented in Table 11, and by running it in GAMS software via CONOPT solver, the independent weights of criteria are calculated. Similarly, the independent weights of sub-criteria can also be calculated. Table 12 shows the independent weights of criteria and their sub-criteria. Also, the consistency check index for the criteria and their sub-criteria is reported in this table. Based on the fuzzy ANP method presented by Dağdeviren and Yüksel (2010), if λ^* is greater than zero, consistency in pairwise comparisons is acceptable. Pairwise comparisons should be revisited if the value of this variable is less than zero.

Table 11 Pairwise comparisons matrix for criteria

	DL	DA	DE	DC	DT
DL	(1, 1, 1)	(7/2, 4, 9/2)	(2/3,1,3/2)	(5/2, 3, 7/2)	(3/2, 2, 5/2)
DA	(2/9, 1/4, 2/7)	(1, 1, 1)	(2/7, 1/3, 2/5)	(2/3, 1, 3/2)	(2/5,1/2,2/3)
DE	(2/3, 1, 3/2)	(5/2, 3, 7/2)	(1, 1, 1)	(3/2, 2, 5/2)	(2/3,1,3/2)
DC	(2/7, 1/3, 2/5)	(2/3, 1, 3/2)	(2/5, 1/2, 2/3)	(1,1,1)	(2/3, 1, 3/2)
DT	(2/5, ½ ,2/3)	(3/2, 2, 5/2)	(2/3, 1, 3/2)	(2/3,1,3/2)	(1, 1, 1)

Table 12 Independent weights of criteria and their sub-criteria obtained from fuzzy ANP

Criteria	Independent weight ($\lambda^* = 0.205$)	Sub-criteria	Independent weight
DL ($\lambda^* = 0.394$)	0.346	DL1	0.296
		DL2	0.227
		DL3	0.077
		DL4	0.227
		DL5	0.174
DA ($\lambda^* = 0.376$)	0.096	DA1	0.329
		DA2	0.416
		DA3	0.113
		DA4	0.142
DE ($\gamma^* = 0.359$)	0.249	DE1	0.425
		DE2	0.253
		DE3	0.322
DC ($\lambda^* = 0.472$)	0.131	DC1	0.203
		DC2	0.246
		DC3	0.551
DT ($\lambda^* = 0.342$)	0.178	DT1	0.255
		DT2	0.327
		DT3	0.418

As seen in Table 12, the value λ^* is positive for the criteria and their sub-criteria. Therefore, all pairwise comparisons are consistent and acceptable.

Step 4: In this step, the interdependence matrix is constructed. The causal relationship in Fig. 2 and Tables 28, 29, 30, 31, 32 is used to build this matrix. The dependent weight of criteria is obtained by multiplying the interdependence matrix with the independent criteria weights. The results of this operation are given below.

$$\begin{bmatrix} 0.5 & 0.3335 & 0.161 & 0.16 & 0.161 \\ 0.16 & 0.5 & 0.1215 & 0.123 & 0.1215 \\ 0.123 & 0 & 0.5 & 0.123 & 0.0955 \\ 0.123 & 0 & 0.0955 & 0.5 & 0.1215 \\ 0.0945 & 0.1665 & 0.1215 & 0.0945 & 0.5 \end{bmatrix} \times \begin{bmatrix} 0.346 \\ 0.096 \\ 0.249 \\ 0.131 \\ 0.178 \end{bmatrix} = \begin{bmatrix} 0.2947 \\ 0.1714 \\ 0.2002 \\ 0.1535 \\ 0.1803 \end{bmatrix}$$

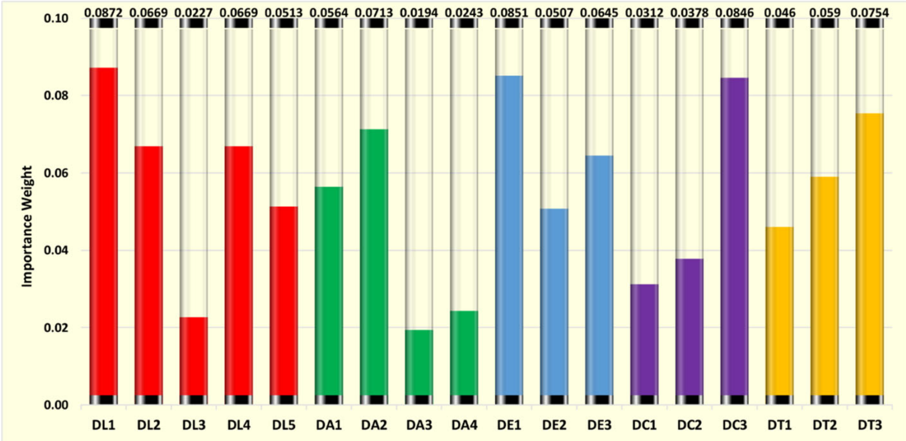


Fig. 6 The global weight of sub-criteria obtained from fuzzy ANP

The global weight of sub-criteria is calculated by multiplying the dependent weight of criteria by the independent weights. Figure 6 shows the global weight of sub-criteria.
Step 5: In this step, the final score of suppliers is calculated. For this purpose, the sum of the product of global weights of sub-criteria in the scores shown in Table 22 is calculated. The final score and rank of diverse suppliers are presented in Table 13.

Comparing the results obtained from fuzzy ANP and our proposed approach shows that the difference between the results of these two methods in calculating the score of 23 suppliers is very small, and in no case does this difference exceed 0.9%. These two methods differ by 0.35%, which is insignificant. Therefore, the correctness of the results obtained from the proposed approach is confirmed. Compared to fuzzy ANP, the proposed approach uses fewer pairwise comparisons and is more consistent.

After examining the validity of the results obtained from the proposed approach, we investigate the effect of interdependency on the weights of the criteria and their sub-criteria. Table 7 shows the independent weights of the criteria and their sub-criteria. To calculate the global independent weights of sub-criteria, we must multiply the independent weights of the criteria by the independent weights of their sub-criteria. Table 14 shows the global independent weights of sub-criteria. Also, the difference between the weights calculated by fuzzy BWM and our proposed approach is presented in this table.

Comparing the results obtained from fuzzy BWM and our proposed approach reveals significant differences in four cases where the difference is 112% or more. These two methods differ by 37.3% in weight, which is noticeable. We conclude that considering interdependency can significantly affect the weights of criteria and sub-criteria and the final score of suppliers.

5 Sensitivity analysis

In this section, we analyze the sensitivity of the proposed approach to the changes in interdependencies between criteria. In other words, we will investigate how the results change when the interdependency between two or more criteria is ignored. We define the sensitivity analysis process by applying changes in the interdependency between the DL criterion and

Table 13 The final score of diverse suppliers obtained from fuzzy ANP and our approach

Supplier	Final score		$\left\| \frac{Fuzzy\ ANP - Our\ approach}{Fuzzy\ ANP} \right\| \times 100\ (\%)$
	Fuzzy ANP	Our approach	
Supplier 1	0.4907	0.4926	0.387
Supplier 2	0.5599	0.5609	0.179
Supplier 3	0.5301	0.5273	0.528
Supplier 4	0.5089	0.5103	0.275
Supplier 5	0.5294	0.5294	0
Supplier 6	0.5039	0.5068	0.576
Supplier 7	0.5020	0.5044	0.478
Supplier 8	0.5317	0.5302	0.282
Supplier 9	0.5179	0.5135	0.850
Supplier 10	0.5449	0.5407	0.771
Supplier 11	0.4861	0.4861	0
Supplier 12	0.5291	0.5257	0.643
Supplier 13	0.5432	0.5414	0.331
Supplier 14	0.5195	0.5188	0.135
Supplier 15	0.5235	0.5248	0.248
Supplier 16	0.4815	0.4826	0.228
Supplier 17	0.4707	0.4711	0.085
Supplier 18	0.5311	0.5294	0.320
Supplier 19	0.5197	0.5208	0.212
Supplier 20	0.5444	0.5437	0.129
Supplier 21	0.5441	0.5416	0.459
Supplier 22	0.4937	0.4894	0.871
Supplier 23	0.5719	0.5731	0.210
Mean	–	–	0.356

other criteria. A total of six scenarios are presented. Scenario 1 is the base case. In scenario 2, it is assumed that the DL and DA criteria are independent. Scenario 3 assumes that DL and DE criteria do not influence each other and are independent of each other. Scenario 4 assumes that the DL and DC criteria are independent and not intertwined. In scenario 5, DL and DT criteria are considered independent. Finally, scenario 6 assumes that the network is not intertwined and all criteria are independent. The proposed what-if analysis is implemented for each scenario, and the final score and ranking of the suppliers are calculated for all scenarios. It should be noted that steps 1 to 5 are constant in all scenarios and steps 6 to 14 will change with the abovementioned scenarios. Table 33 and Fig. 7 present the sub-criteria weights for different scenarios. The suppliers' final score and rank for various scenarios are presented in Table 34. In addition, the suppliers' rankings in other scenarios are depicted in Fig. 8.

The results presented in Table 33 and Fig. 7 show the significant changes in the sub-criteria weights in different scenarios. This considerable weight variation shows the interdependencies between the criteria can substantially impact the final weight of the sub-criteria. In this

Table 14 The global weights obtained from fuzzy BWM and our approach

Sub-criteria	Global weight		$\left\lvert \frac{Fuzzy\ BWM - Our\ approach}{Fuzzy\ BWM} \right\rvert \times 100\ (\%)$
	Fuzzy BWM	Our approach	
DL1	0.103	0.0922	10.49
DL2	0.0755	0.0676	10.46
DL3	0.0284	0.0254	10.56
DL4	0.0755	0.0676	10.46
DL5	0.0476	0.0426	10.5
DA1	0.0296	0.0628	112.16
DA2	0.0346	0.0734	112.14
DA3	0.0089	0.019	113.48
DA4	0.0121	0.0257	112.4
DE1	0.1297	0.0968	25.37
DE2	0.0652	0.0486	25.46
DE3	0.0929	0.0693	25.4
DC1	0.0219	0.0268	22.37
DC2	0.0293	0.0359	22.53
DC3	0.0681	0.0833	22.32
DT1	0.0404	0.037	8.42
DT2	0.0575	0.0527	8.35
DT3	0.0804	0.0736	8.46
Mean	–	–	37.30

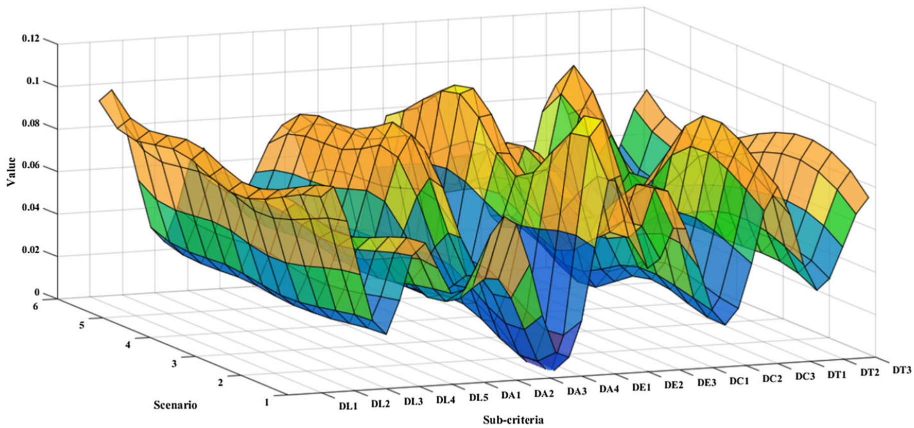


Fig. 7 Sub-criteria weights in different scenarios

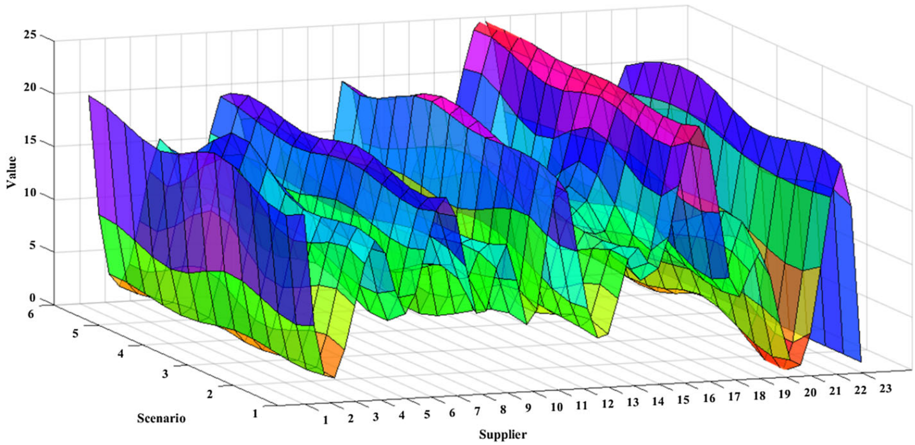


Fig. 8 Suppliers' rankings in different scenarios

regard, a change in the weight of sub-criteria leads to a change in suppliers' final scores and rankings, as shown in Table 34 and Fig. 8.

6 Managerial implications

Diversity and inclusion are central to creating a more just and sustainable business, and cooperation with diverse suppliers is a competitive advantage that can play an essential role in a company's success. Strengthening relationships with diverse suppliers also leads to the development of local communities and brings vibrant social effects. Despite these advantages, the diverse supplier selection problem is a new and complex problem with multiple and often conflicting criteria. While supplier selection criteria are well-researched, the diversity and inclusion criteria are new and less explored in the supplier selection literature. This study highlights the importance of diversity and inclusion in supplier selection within a complex multi-criteria environment with hierarchical and interdependent factors. Practicing managers can use the method proposed in this study to determine the criteria weights by considering their interdependency under uncertainty. The fuzzy GBWM method analyzes the interwoven relationships between the diversity selection criteria in a network with a hierarchical structure and calculates their weights under uncertainty.

While cooperation with diverse suppliers is considered a competitive advantage, it does not mean organizations must do business with every diverse supplier. A systematic approach is needed to efficiently and effectively evaluate all potential suppliers and select those suppliers who add the most value to the company's profitability and sustainability goals. The proposed approach as a decision support system can help organizations achieve this goal and strengthen their competitiveness while improving their profitability. Cooperation with diverse suppliers can also help enhance the reputation and branding of organizations. This forward-looking research has presented a structured and novel evaluation approach with new diversity selection criteria for sustainable suppliers.

7 Conclusion

Selecting suitable diverse suppliers reduces risk, increases efficiency, and brings constructive social effects in supply chain management. Over the past decade, many organizations have included diversity and inclusion in their policies and operating practices. Despite the importance of supplier diversity, diversity and inclusion have not yet received adequate attention in manufacturing and supply chain research. This study identified critical diversity criteria for supplier selection through a literature review and proposed a practical and novel approach to evaluate and select the most suitable suppliers systematically. A novel fuzzy GBWM was developed to assess 23 suppliers under uncertainty at Coastal Virginia Wind Power Company through a public–private partnership project with a state government agency. Finally, the performance of the proposed approach was evaluated by comparing it with the benchmark fuzzy ANP method and fuzzy BWM. The comparative analysis results confirmed the applicability and effectiveness of the approach proposed in this study. A sensitivity analysis was performed to investigate the effect of interdependencies between criteria on the weight of sub-criteria and the final score and rankings of the suppliers.

In this study, suppliers are evaluated from a diversity perspective. A comprehensive set of mature diversity criteria is needed for sustainable supplier selection. It is suggested that future researchers focus on the supplier diversity problem and help develop an extensive set of evaluation criteria, including economic, environmental, and social factors. It is suggested that a more inclusive, diverse supplier selection and order allocation model be developed in future research by integrating mathematical programming techniques in complex, multi-faceted, and multi-criteria models.

Declaration

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A

See Tables 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34.

Table 15 The fuzzy BO vector

Criteria	Fuzzy BO vector	Sub-criteria	Fuzzy BO vector
Diversity leadership	(1, 1, 1)	DL1	(1, 1, 1)
		DL2	(2/3, 1, 3/2)
		DL3	(7/2, 4, 9/2)
		DL4	(2/3, 1, 3/2)
		DL5	(3/2, 2, 5/2)
Diversity analytics	(7/2, 4, 9/2)	DA1	(2/3, 1, 3/2)
		DA2	(1, 1, 1)
		DA3	(7/2, 4, 9/2)
		DA4	(5/2, 3, 7/2)
Diversity equity	(2/3, 1, 3/2)	DE1	(1, 1, 1)
		DE2	(3/2, 2, 5/2)
		DE3	(2/3, 1, 3/2)
Diversity climate	(5/2, 3, 7/2)	DC1	(5/2, 3, 7/2)
		DC2	(3/2, 2, 5/2)
		DC3	(1, 1, 1)
Diversity training	(3/2, 2, 5/2)	DT1	(3/2, 2, 5/2)
		DT2	(2/3, 1, 3/2)
		DT3	(1, 1, 1)

Table 16 The fuzzy OW vector

Criteria	Fuzzy OW vector	Sub-criteria	Fuzzy OW vector
Diversity leadership	(7/2, 4, 9/2)	DL1	(7/2, 4, 9/2)
		DL2	(3/2, 2, 5/2)
		DL3	(1, 1, 1)
		DL4	(3/2, 2, 5/2)
		DL5	(2/3, 1, 3/2)
Diversity analytics	(1, 1, 1)	DA1	(5/2, 3, 7/2)
		DA2	(7/2, 4, 9/2)
		DA3	(1, 1, 1)
		DA4	(2/3, 1, 3/2)
Diversity equity	(5/2, 3, 7/2)	DE1	(3/2, 2, 5/2)
		DE2	(1, 1, 1)
		DE3	(2/3, 1, 3/2)
Diversity climate	(2/3, 1, 3/2)	DC1	(1, 1, 1)
		DC2	(2/3, 1, 3/2)
		DC3	(5/2, 3, 7/2)
Diversity training	(3/2, 2, 5/2)	DT1	(1, 1, 1)
		DT2	(2/3, 1, 3/2)
		DT3	(3/2, 2, 5/2)

Table 17 Fuzzy influence-intensity matrix

	DL	DA	DE	DC	DT
DL	–	(3/2, 2, 5/2)**	(7/2, 4, 9/2)**	(7/2, 4, 9/2)**	(7/2, 4, 9/2)**
DA	(5/2, 3, 7/2)**	–	(5/2, 3, 7/2)	(5/2, 3, 7/2)	(5/2, 3, 7/2)
DE	(3/2, 2, 5/2)	N	–	(5/2, 3, 7/2)	(3/2, 2, 5/2)*
DC	(3/2, 2, 5/2)	N	(3/2, 2, 5/2)*	–	(5/2, 3, 7/2)
DT	(2/3, 1, 3/2)*	(2/3, 1, 3/2)*	(5/2, 3, 7/2)	(3/2, 2, 5/2)*	–

**Most-influenced and * Least-influenced

Appendix B

$$Min\ \gamma^*$$
$$s.t.$$
$$x_{DL}^a \le \frac{7}{2} \times x_{DA}^a + \gamma^*; \quad x_{DL}^b \le 4 \times x_{DA}^b + \gamma^*; \quad x_{DL}^c \le \gamma^* + \frac{9}{2} \times x_{DA}^c$$
$$x_{DL}^a \ge \frac{7}{2} \times x_{DA}^a - \gamma^*; \quad x_{DL}^b \ge 4 \times x_{DA}^b - \gamma^*; \quad x_{DL}^c \ge \frac{9}{2} \times x_{DA}^c - \gamma^*$$
$$x_{DL}^a \le \frac{2}{3} \times x_{DE}^a + \gamma^*; \quad x_{DL}^b \le x_{DE}^b + \gamma^*; \quad x_{DL}^c \le \frac{3}{2} \times x_{DE}^c + \gamma^*$$
$$x_{DL}^a \ge \frac{2}{3} \times x_{DE}^a - \gamma^*; \quad x_{DL}^b \ge x_{DE}^b - \gamma^*; \quad x_{DL}^c \ge \frac{3}{2} \times x_{DE}^c - \gamma^*$$
$$x_{DL}^a \le \frac{5}{2} \times x_{DC}^a + \gamma^*; \quad x_{DL}^b \le 3 \times x_{DC}^b + \gamma^*; \quad x_{DL}^c \le \frac{7}{2} \times x_{DC}^c + \gamma^*$$
$$x_{DL}^a \ge \frac{5}{2} \times x_{DC}^a - \gamma^*; \quad x_{DL}^b \ge 3 \times x_{DC}^b - \gamma^*; \quad x_{DL}^c \ge \frac{7}{2} \times x_{DC}^c - \gamma^*$$
$$x_{DL}^a \le \frac{3}{2} \times x_{DT}^a + \gamma^*; \quad x_{DL}^b \le 2 \times x_{DT}^b + \gamma^*; \quad x_{DL}^c \le \frac{5}{2} \times x_{DT}^c + \gamma^*$$
$$x_{DL}^a \ge \frac{3}{2} \times x_{DT}^a - \gamma^*; \quad x_{DL}^b \ge 2 \times x_{DT}^b - \gamma^*; \quad x_{DL}^c \ge \frac{5}{2} \times x_{DT}^c - \gamma^*$$
$$x_{DE}^a \le \frac{5}{2} x_{DA}^a + \gamma^*; \quad x_{DE}^b \le 3 \times x_{DA}^b + \gamma^*; \quad x_{DE}^c \le \frac{7}{2} \times x_{DA}^c + \gamma^*$$
$$x_{DE}^a \ge \frac{5}{2} x_{DA}^a - \gamma^*; \quad x_{DE}^b \ge 3 \times x_{DA}^b - \gamma^*; \quad x_{DE}^c \ge \frac{7}{2} \times x_{DA}^c - \gamma^*$$
$$x_{DC}^a \le \frac{2}{3} \times x_{DA}^a + \gamma^*; \quad x_{DC}^b \le x_{DA}^b + \gamma^*; \quad x_{DC}^c \le \frac{3}{2} \times x_{DA}^c + \gamma^*$$
$$x_{DC}^a \ge \frac{2}{3} \times x_{DA}^a - \gamma^*; \quad x_{DC}^b \ge x_{DA}^b - \gamma^*; \quad x_{DC}^c \ge \frac{3}{2} \times x_{DA}^c - \gamma^*$$
$$x_{DT}^a \le \frac{3}{2} x_{DA}^a + \gamma^*; \quad x_{DT}^b \le 2 \times x_{DA}^b + \gamma^*; \quad x_{DT}^c \le \frac{5}{2} \times x_{DA}^c + \gamma^*$$
$$x_{DT}^a \ge \frac{3}{2} x_{DA}^a - \gamma^*; \quad x_{DT}^b \ge 2 \times x_{DA}^b - \gamma^*; \quad x_{DT}^c \ge \frac{5}{2} \times x_{DA}^c - \gamma^*$$
$$\frac{x_{DL}^a + 4 \times x_{DL}^b + x_{DL}^c}{6} + \frac{x_{DA}^a + 4 \times x_{DA}^b + x_{DA}^c}{6} + \frac{x_{DE}^a + 4 \times x_{DE}^b + x_{DE}^c}{6}$$

Table 18 Fuzzy MIITO vectors

	DL	DA	DE	DC	DT
DL	–	$\frac{\left(\frac{3}{2},\ 2,\ \frac{5}{2}\right)}{\left(\frac{3}{2},\ 2,\ \frac{5}{2}\right)} = \left(\frac{3}{5},\ 1,\ \frac{5}{3}\right)$	$\frac{\left(\frac{7}{2},\ 4,\ \frac{9}{2}\right)}{\left(\frac{7}{2},\ 4,\ \frac{9}{2}\right)} = \left(\frac{7}{9},\ 1,\ \frac{9}{7}\right)$	$\frac{\left(\frac{7}{2},\ 4,\ \frac{9}{2}\right)}{\left(\frac{7}{2},\ 4,\ \frac{9}{2}\right)} = \left(\frac{7}{9},\ 1,\ \frac{9}{7}\right)$	$\frac{\left(\frac{7}{2},\ 4,\ \frac{9}{2}\right)}{\left(\frac{7}{2},\ 4,\ \frac{9}{2}\right)} = \left(\frac{7}{9},\ 1,\ \frac{9}{7}\right)$
DA	$\frac{\left(\frac{5}{2},\ 3,\ \frac{7}{2}\right)}{\left(\frac{5}{2},\ 3,\ \frac{7}{2}\right)} = \left(\frac{5}{7},\ 1,\ \frac{7}{5}\right)$	–	$\frac{\left(\frac{7}{2},\ 4,\ \frac{9}{2}\right)}{\left(\frac{5}{2},\ 3,\ \frac{7}{2}\right)} = \left(1,\ \frac{4}{3},\ \frac{9}{5}\right)$	$\frac{\left(\frac{7}{2},\ 4,\ \frac{9}{2}\right)}{\left(\frac{5}{2},\ 3,\ \frac{7}{2}\right)} = \left(1,\ \frac{4}{3},\ \frac{9}{5}\right)$	$\frac{\left(\frac{7}{2},\ 4,\ \frac{9}{2}\right)}{\left(\frac{5}{2},\ 3,\ \frac{7}{2}\right)} = \left(1,\ \frac{4}{3},\ \frac{9}{5}\right)$
DE	$\frac{\left(\frac{5}{2},\ 3,\ \frac{7}{2}\right)}{\left(\frac{3}{2},\ 2,\ \frac{5}{2}\right)} = \left(1,\ \frac{3}{2},\ \frac{7}{3}\right)$	N	–	$\frac{\left(\frac{7}{2},\ 4,\ \frac{9}{2}\right)}{\left(\frac{5}{2},\ 3,\ \frac{7}{2}\right)} = \left(1,\ \frac{4}{3},\ \frac{9}{5}\right)$	$\frac{\left(\frac{7}{2},\ 4,\ \frac{9}{2}\right)}{\left(\frac{3}{2},\ 2,\ \frac{5}{2}\right)} = \left(\frac{7}{5},\ 2,\ 3\right)$
DC	$\frac{\left(\frac{5}{2},\ 3,\ \frac{7}{2}\right)}{\left(\frac{3}{2},\ 2,\ \frac{5}{2}\right)} = \left(1,\ \frac{3}{2},\ \frac{7}{3}\right)$	N	$\frac{\left(\frac{7}{2},\ 4,\ \frac{9}{2}\right)}{\left(\frac{3}{2},\ 2,\ \frac{5}{2}\right)} = \left(\frac{7}{5},\ 2,\ 3\right)$	–	$\frac{\left(\frac{7}{2},\ 4,\ \frac{9}{2}\right)}{\left(\frac{5}{2},\ 3,\ \frac{7}{2}\right)} = \left(1,\ \frac{4}{3},\ \frac{9}{5}\right)$
DT	$\frac{\left(\frac{5}{2},3,\frac{7}{2}\right)}{\left(\frac{2}{3},1,\frac{3}{2}\right)} = \left(\frac{5}{3},3,\frac{21}{4}\right)$	$\frac{\left(\frac{3}{2},2,\frac{5}{2}\right)}{\left(\frac{2}{3},1,\frac{3}{2}\right)} = \left(1,2,\frac{15}{4}\right)$	$\frac{\left(\frac{7}{2},4,\frac{9}{2}\right)}{\left(\frac{5}{2},3,\frac{7}{2}\right)} = \left(1,\frac{4}{3},\frac{9}{5}\right)$	$\frac{\left(\frac{7}{2},4,\frac{9}{2}\right)}{\left(\frac{3}{2},2,\frac{5}{2}\right)} = \left(\frac{7}{5},2,3\right)$	–

Table 19 Fuzzy OTLII vectors

	DL	DA	DE	DC	DT
DL	–	$\frac{\left(\frac{3}{2}, 2, \frac{5}{2}\right)}{\left(\frac{2}{3}, 1, \frac{3}{2}\right)} = \left(1, 2, \frac{15}{4}\right)$	$\frac{\left(\frac{7}{2}, 4, \frac{9}{2}\right)}{\left(\frac{3}{2}, 2, \frac{5}{2}\right)} = \left(\frac{7}{5}, 2, 3\right)$	$\frac{\left(\frac{7}{2}, 4, \frac{9}{2}\right)}{\left(\frac{3}{2}, 2, \frac{5}{2}\right)} = \left(\frac{7}{5}, 2, 3\right)$	$\frac{\left(\frac{7}{2}, 4, \frac{9}{2}\right)}{\left(\frac{3}{2}, 2, \frac{5}{2}\right)} = \left(\frac{7}{5}, 2, 3\right)$
DA	$\frac{\left(\frac{5}{2}, 3, \frac{7}{2}\right)}{\left(\frac{2}{3}, 1, \frac{3}{2}\right)} = \left(\frac{5}{3}, 3, \frac{21}{4}\right)$	–	$\frac{\left(\frac{5}{2}, 3, \frac{7}{2}\right)}{\left(\frac{3}{2}, 2, \frac{5}{2}\right)} = \left(1, \frac{3}{2}, \frac{7}{3}\right)$	$\frac{\left(\frac{5}{2}, 3, \frac{7}{2}\right)}{\left(\frac{3}{2}, 2, \frac{5}{2}\right)} = \left(1, \frac{3}{2}, \frac{7}{3}\right)$	$\frac{\left(\frac{5}{2}, 3, \frac{7}{2}\right)}{\left(\frac{3}{2}, 2, \frac{5}{2}\right)} = \left(1, \frac{3}{2}, \frac{7}{3}\right)$
DE	$\frac{\left(\frac{3}{2}, 2, \frac{5}{2}\right)}{\left(\frac{2}{3}, 1, \frac{3}{2}\right)} = \left(1, 2, \frac{15}{4}\right)$	N	–	$\frac{\left(\frac{5}{2}, 3, \frac{7}{2}\right)}{\left(\frac{3}{2}, 2, \frac{5}{2}\right)} = \left(1, \frac{3}{2}, \frac{7}{3}\right)$	$\frac{\left(\frac{3}{2}, 2, \frac{5}{2}\right)}{\left(\frac{3}{2}, 2, \frac{5}{2}\right)} = \left(\frac{3}{5}, 1, \frac{5}{3}\right)$
DC	$\frac{\left(\frac{3}{2}, 2, \frac{5}{2}\right)}{\left(\frac{2}{3}, 1, \frac{3}{2}\right)} = \left(1, 2, \frac{15}{4}\right)$	N	$\frac{\left(\frac{3}{2}, 2, \frac{5}{2}\right)}{\left(\frac{3}{2}, 2, \frac{5}{2}\right)} = \left(\frac{3}{5}, 1, \frac{5}{3}\right)$	–	$\frac{\left(\frac{5}{2}, 3, \frac{7}{2}\right)}{\left(\frac{3}{2}, 2, \frac{5}{2}\right)} = \left(1, \frac{3}{2}, \frac{7}{3}\right)$
DT	$\frac{\left(\frac{2}{3}, 1, \frac{3}{2}\right)}{\left(\frac{2}{3}, 1, \frac{3}{2}\right)} = \left(\frac{4}{9}, 1, \frac{9}{4}\right)$	$\frac{\left(\frac{2}{3}, 1, \frac{3}{2}\right)}{\left(\frac{2}{3}, 1, \frac{3}{2}\right)} = \left(\frac{4}{9}, 1, \frac{9}{4}\right)$	$\frac{\left(\frac{5}{2}, 3, \frac{7}{2}\right)}{\left(\frac{3}{2}, 2, \frac{5}{2}\right)} = \left(1, \frac{3}{2}, \frac{7}{3}\right)$	$\frac{\left(\frac{3}{2}, 2, \frac{5}{2}\right)}{\left(\frac{3}{2}, 2, \frac{5}{2}\right)} = \left(\frac{3}{5}, 1, \frac{5}{3}\right)$	–

Table 20 Fuzzy initial influence-intensity matrix

	DL ($\gamma^* = 0.079$)	DA ($\gamma^* = 0$)	DE ($\gamma^* = 0.046$)	DC ($\gamma^* = 0.046$)	DT ($\gamma^* = 0.046$)
DL	–	(0, 0.716, 1.343)	(0.236, 0.336, 0.481)	(0.236, 0.336, 0.481)	(0.236, 0.336, 0.481)
DA	(0.241, 0.37, 0.589)	–	(0.191, 0.263, 0.292)	(0.191, 0.263, 0.292)	(0.191, 0.263, 0.292)
DE	(0.176, 0.273, 0.286)	N	–	(0.191, 0.263, 0.292)	(0.145, 0.145, 0.145)
DC	(0.176, 0.273, 0.286)	N	(0.145, 0.145, 0.145)	–	(0.191, 0.263, 0.292)
DT	(0.097, 0.097, 0.097)	(0, 0.358, 0.358)	(0.191, 0.263, 0.292)	(0.145, 0.145, 0.145)	–

N means non-influence and is equal to (0,0,0)

Table 21 Fuzzy relative influence-intensity matrix

	DL	DA	DE	DC	DT
DL	(1, 1, 1)	(0, 0.716, 1.343)	(0.236, 0.336, 0.481)	(0.236, 0.336, 0.481)	(0.236, 0.336, 0.481)
DA	(0.241, 0.37, 0.589)	(1, 1, 1)	(0.191, 0.263, 0.292)	(0.191, 0.263,0.292)	(0.191, 0.263, 0.292)
DE	(0.176, 0.273, 0.286)	(0, 0, 0)	(1, 1, 1)	(0.191, 0.263, 0.292)	(0.145, 0.145, 0.145)
DC	(0.176, 0.273, 0.286)	(0,0,0)	(0.145, 0.145, 0.145)	(1, 1, 1)	(0.191, 0.263, 0.292)
DT	(0.097, 0.097,0.097)	(0, 0.358, 0.358)	(0.191, 0.263, 0.292)	(0.145, 0.145, 0.145)	(1, 1, 1)

$$
\begin{aligned}
&+\frac{x_{DC}^{a} + 4 \times x_{DC}^{b} + x_{DC}^{c}}{6} + \frac{x_{DT}^{a} + 4 \times x_{DT}^{b} + x_{DT}^{c}}{6} = 1 \\
&x_{DL}^{a} \leq x_{DL}^{b} \leq x_{DL}^{c}; \quad x_{DA}^{a} \leq x_{DA}^{b} \leq x_{DA}^{c}; \quad x_{DE}^{a} \leq x_{DE}^{b} \leq x_{DE}^{c}; \\
&x_{DC}^{a} \leq x_{DC}^{b} \leq x_{DC}^{c}; \quad x_{DT}^{a} \leq x_{DT}^{b} \leq x_{DT}^{c} \\
&x_{DL}^{a}, \quad x_{DA}^{a}, \quad x_{DE}^{a}, \quad x_{DC}^{a}, \quad x_{DT}^{a} > 0
\end{aligned}
\tag{12B}
$$

Table 22 The final score of suppliers for each sub-criterion

Supplier	DL1	DL2	DL3	DL4	DL5	DA1	DA2	DA3	DA4	DE1	DE2	DE3	DC1	DC2	DC3	DT1	DT2	DT3
Supplier 1	0.4	0.34	0.56	0.38	0.6	0.44	0.66	0.5	0.44	0.58	0.66	0.64	0.36	0.4	0.4	0.32	0.52	0.56
Supplier 2	0.72	0.72	0.38	0.54	0.42	0.62	0.44	0.48	0.46	0.46	0.56	0.68	0.62	0.32	0.54	0.54	0.58	0.64
Supplier 3	0.54	0.58	0.6	0.42	0.6	0.54	0.4	0.4	0.66	0.48	0.5	0.38	0.6	0.62	0.7	0.58	0.5	0.54
Supplier 4	0.42	0.7	0.6	0.52	0.22	0.46	0.32	0.74	0.72	0.44	0.46	0.54	0.64	0.78	0.64	0.46	0.36	0.58
Supplier 5	0.48	0.52	0.58	0.48	0.46	0.42	0.5	0.6	0.42	0.58	0.5	0.68	0.4	0.66	0.44	0.54	0.64	0.62
Supplier 6	0.46	0.58	0.5	0.58	0.46	0.56	0.52	0.48	0.64	0.58	0.44	0.46	0.52	0.3	0.62	0.34	0.54	0.38
Supplier 7	0.74	0.42	0.6	0.5	0.36	0.46	0.56	0.42	0.48	0.6	0.3	0.48	0.54	0.42	0.44	0.6	0.64	0.34
Supplier 8	0.26	0.58	0.58	0.56	0.44	0.66	0.5	0.58	0.6	0.5	0.66	0.6	0.5	0.72	0.46	0.64	0.56	0.52
Supplier 9	0.38	0.4	0.48	0.3	0.66	0.62	0.52	0.46	0.42	0.46	0.58	0.66	0.6	0.6	0.52	0.6	0.68	0.5
Supplier 10	0.38	0.72	0.76	0.34	0.42	0.66	0.62	0.7	0.46	0.36	0.62	0.5	0.6	0.6	0.38	0.74	0.7	0.7
Supplier 11	0.56	0.7	0.42	0.3	0.42	0.7	0.42	0.52	0.6	0.32	0.7	0.42	0.46	0.6	0.52	0.42	0.5	0.34
Supplier 12	0.58	0.44	0.76	0.66	0.82	0.32	0.48	0.54	0.5	0.44	0.64	0.36	0.46	0.7	0.68	0.4	0.34	0.54
Supplier 13	0.38	0.66	0.62	0.46	0.54	0.62	0.58	0.4	0.46	0.54	0.48	0.42	0.68	0.52	0.6	0.48	0.6	0.68
Supplier 14	0.42	0.64	0.62	0.58	0.34	0.58	0.32	0.5	0.74	0.44	0.56	0.46	0.64	0.58	0.62	0.48	0.6	0.52
Supplier 15	0.68	0.58	0.72	0.3	0.58	0.46	0.38	0.66	0.54	0.56	0.56	0.58	0.5	0.4	0.52	0.54	0.4	0.58
Supplier 16	0.4	0.46	0.46	0.32	0.58	0.62	0.5	0.4	0.48	0.72	0.54	0.36	0.56	0.56	0.38	0.48	0.44	0.44
Supplier 17	0.52	0.42	0.48	0.26	0.36	0.46	0.34	0.76	0.5	0.46	0.66	0.62	0.5	0.52	0.56	0.46	0.48	0.38
Supplier 18	0.7	0.44	0.44	0.36	0.72	0.42	0.52	0.44	0.58	0.54	0.54	0.6	0.34	0.52	0.62	0.72	0.4	0.46
Supplier 19	0.38	0.58	0.48	0.5	0.48	0.62	0.54	0.48	0.6	0.6	0.52	0.48	0.64	0.36	0.64	0.5	0.44	0.48
Supplier 20	0.56	0.68	0.42	0.42	0.5	0.54	0.48	0.52	0.5	0.54	0.42	0.62	0.44	0.56	0.54	0.64	0.58	0.64
Supplier 21	0.44	0.58	0.44	0.56	0.5	0.5	0.52	0.58	0.36	0.62	0.4	0.56	0.7	0.72	0.48	0.6	0.7	0.54
Supplier 22	0.48	0.34	0.58	0.6	0.5	0.54	0.52	0.38	0.4	0.36	0.56	0.4	0.54	0.5	0.52	0.68	0.54	0.5
Supplier 23	0.46	0.66	0.3	0.62	0.42	0.68	0.74	0.48	0.56	0.58	0.6	0.66	0.66	0.54	0.52	0.5	0.68	0.44

Table 23 Pairwise comparisons matrix for DL's sub-criteria

	DL1	DL2	DL3	DL4	DL5
DL1	(1, 1, 1)	(2/3, 1, 3/2)	(7/2, 4, 9/2)	(2/3, 1, 3/2)	(3/2, 2, 5/2)
DL2	(2/3, 1, 3/2)	(1, 1, 1)	(5/2, 3, 7/2)	(1, 1, 1)	(2/3, 1, 3/2)
DL3	(2/9, 1/4, 2/7)	(2/7, 1/3, 2/5)	(1, 1, 1)	(2/7, 1/3, 2/5)	(2/5, 1/2, 2/3)
DL4	(2/3, 1, 3/2)	(1, 1, 1)	(5/2, 3, 7/2)	(1, 1, 1)	(2/3, 1, 3/2)
DL5	(2/5, 1/2, 2/3)	(2/3, 1, 3/2)	(3/2, 2, 5/2)	(2/3, 1, 3/2)	(1, 1, 1)

Table 24 Pairwise comparisons matrix for DA's sub-criteria

	DA1	DA2	DA3	DA4
DA1	(1, 1, 1)	(2/3, 1, 3/2)	(5/2, 3, 7/2)	(3/2, 2, 5/2)
DA2	(2/3, 1, 3/2)	(1, 1, 1)	(7/2, 4, 9/2)	(5/2, 3, 7/2)
DA3	(2/7, 1/3, 2/5)	(2/9, 1/4, 2/7)	(1, 1, 1)	(2/3, 1, 3/2)
DA4	(2/5, 1/2, 2/3)	(2/7, 1/3 2/5)	(2/3, 1, 3/2)	(1, 1, 1)

Table 25 Pairwise comparisons matrix for DE's sub-criteria

	DE1	DE2	DE3
DE1	(1, 1, 1)	(3/2, 2, 5/2)	(2/3, 1, 3/2)
DE2	(2/5, 1/2, 2/3)	(1, 1, 1)	(2/3, 1, 3/2)
DE3	(2/3, 1, 3/2)	(2/3, 1, 3/2)	(1, 1, 1)

Table 26 Pairwise comparisons matrix for DC's sub-criteria

	DC1	DC2	DC3
DC1	(1, 1, 1)	(2/3, 1, 3/2)	(2/7, 1/3, 2/5)
DC2	(2/3, 1, 3/2)	(1, 1, 1)	(2/5, 1/2, 2/3)
DC3	(5/2, 3, 7/2)	(3/2, 2, 5/2)	(1, 1, 1)

Table 27 Pairwise comparisons matrix for DT's sub-criteria

	DT1	DT2	DT3
DT1	(1, 1, 1)	(2/3, 1, 3/2)	(2/5, 1/2, 2/3)
DT2	(2/3, 1, 3/2)	(1, 1, 1)	(2/3, 1, 3/2)
DT3	(3/2, 2, 5/2)	(2/3, 1, 3/2)	(1, 1, 1)

Table 28 Inner dependence matrix of the criteria for DL

	DA	DE	DC	DT
DA	(1, 1, 1)	(2/3, 1, 3/2)	(2/3, 1, 3/2)	(3/2, 2, 5/2)
DE	(2/3, 1, 3/2)	(1, 1, 1)	(1, 1, 1)	(2/3, 1, 3/2)
DC	(2/3, 1, 3/2)	(1, 1, 1)	(1, 1, 1)	(2/3, 1, 3/2)
DT	(2/5, 1/2 , 2/3)	(2/3, 1, 3/2)	(2/3, 1, 3/2)	(1, 1, 1)

Table 29 Inner dependence matrix of the criteria for DA

	DL	DT
DL	(1, 1, 1)	(3/2, 2, 5/2)
DT	(2/5, 1/2, 2/3)	(1, 1, 1)

Table 30 Inner dependence matrix of the criteria for DE

	DL	DA	DC	DT
DL	(1, 1, 1)	(2/3, 1, 3/2)	(3/2, 2, 5/2)	(2/3, 1, 3/2)
DA	(2/3, 1, 3/2)	(1, 1, 1)	(2/3, 1, 3/2)	(1, 1, 1)
DC	(2/5, 1/2, 2/3)	(2/3, 1, 3/2)	(1, 1, 1)	(2/3, 1, 3/2)
DT	(2/3, 1, 3/2)	(1, 1, 1)	(2/3, 1, 3/2)	(1, 1, 1)

Table 31 Inner dependence matrix of the criteria for DC

	DL	DA	DE	DT
DL	(1, 1, 1)	(2/3, 1, 3/2)	(2/3, 1, 3/2)	(3/2, 2, 5/2)
DA	(2/3, 1, 3/2)	(1, 1, 1)	(1, 1, 1)	(2/3, 1, 3/2)
DE	(2/3, 1, 3/2)	(1, 1, 1)	(1, 1, 1)	(2/3, 1, 3/2)
DT	(2/5,1/2,2/3)	(2/3, 1, 3/2)	(2/3, 1, 3/2)	(1, 1, 1)

Table 32 Inner dependence matrix of the criteria for DT

	DL	DA	DE	DC
DL	(1, 1, 1)	(2/3, 1, 3/2)	(3/2, 2, 5/2)	(2/3, 1, 3/2)
DA	(2/3, 1, 3/2)	(1, 1, 1)	(2/3, 1, 3/2)	(1, 1, 1)
DE	(2/5, 1/2, 2/3)	(2/3, 1, 3/2)	(1, 1, 1)	(2/3, 1, 3/2)
DC	(2/3, 1, 3/2)	(1, 1, 1)	(2/3, 1, 3/2)	(1, 1, 1)

Table 33 Weights of the sub-criteria in different scenarios

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
DL1	0.0922	0.0828	0.0767	0.0858	0.0826	0.1029
DL2	0.0676	0.0607	0.0563	0.0629	0.0606	0.0754
DL3	0.0254	0.0228	0.0211	0.0236	0.0227	0.0283
DL4	0.0676	0.0607	0.0563	0.0629	0.0606	0.0754
DL5	0.0426	0.0383	0.0355	0.0396	0.0382	0.0475
DA1	0.0628	0.0408	0.0782	0.0737	0.0716	0.0566
DA2	0.0734	0.0477	0.0915	0.0861	0.0837	0.0662
DA3	0.019	0.0123	0.0236	0.0222	0.0216	0.0171
DA4	0.0257	0.0167	0.032	0.0301	0.0293	0.0232
DE1	0.0968	0.1103	0.0776	0.1071	0.099	0.083
DE2	0.0486	0.0554	0.039	0.0538	0.0497	0.0417
DE3	0.0693	0.079	0.0555	0.0767	0.0709	0.0594
DC1	0.0268	0.0323	0.0301	0.019	0.0297	0.0223
DC2	0.0359	0.0433	0.0403	0.0254	0.0398	0.0299
DC3	0.0833	0.1005	0.0937	0.059	0.0925	0.0695
DT1	0.037	0.0446	0.0434	0.0387	0.0334	0.0457
DT2	0.0527	0.0635	0.0618	0.0551	0.0475	0.0651
DT3	0.0736	0.0887	0.0863	0.077	0.0664	0.0909

Table 34 Final score and rank of the suppliers in different scenarios

Suppliers	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6	
	Final score	Rank	Final score	Rank	Final score	Rank	Final score	Rank	Final score	Rank	Final score	Rank
Supplier 1	0.4926	18	0.4927	18	0.4901	20	0.5017	18	0.4945	19	0.488	20
Supplier 2	0.5609	2	0.562	2	0.5558	2	0.5602	2	0.5563	2	0.5664	2
Supplier 3	0.5273	9	0.5319	9	0.5302	8	0.5176	12	0.5274	9	0.5276	9
Supplier 4	0.5103	15	0.5164	15	0.5121	16	0.5005	19	0.5124	16	0.5062	17
Supplier 5	0.5294	8	0.5375	7	0.5265	9	0.5314	8	0.5271	10	0.5312	7
Supplier 6	0.5068	16	0.5017	16	0.5051	17	0.5057	16	0.5088	17	0.5027	18
Supplier 7	0.5044	17	0.5014	17	0.5007	18	0.5044	17	0.502	18	0.507	16
Supplier 8	0.5302	7	0.5316	10	0.5345	7	0.5334	7	0.5332	7	0.5266	10
Supplier 9	0.5135	14	0.5199	13	0.5196	13	0.515	13	0.5166	15	0.5101	15
Supplier 10	0.5407	6	0.5387	6	0.5529	3	0.5457	3	0.5399	6	0.5477	3
Supplier 11	0.4861	20	0.4787	21	0.4883	21	0.4836	22	0.4888	20	0.4828	21
Supplier 12	0.5257	10	0.5277	11	0.5191	14	0.5129	14	0.5232	12	0.5263	11
Supplier 13	0.5414	5	0.5438	5	0.5483	4	0.5388	6	0.5422	3	0.5428	5
Supplier 14	0.5188	13	0.523	12	0.5212	12	0.5122	15	0.519	14	0.5188	13
Supplier 15	0.5248	11	0.5277	11	0.5167	15	0.5237	10	0.5216	13	0.5262	12
Supplier 16	0.4826	21	0.4819	20	0.4819	22	0.487	20	0.4857	22	0.4766	22
Supplier 17	0.4711	22	0.4777	22	0.4688	23	0.4697	23	0.4743	23	0.4636	23
Supplier 18	0.5294	8	0.5322	8	0.5242	10	0.5267	9	0.5285	8	0.5281	8
Supplier 19	0.5208	12	0.5196	14	0.5231	11	0.5204	11	0.5249	11	0.5145	14
Supplier 20	0.5437	3	0.5482	4	0.5439	5	0.5431	4	0.5413	4	0.5475	4

Table 34 (continued)

Suppliers	Scenario 1		Scenario 2		Scenario 3		Scenario 4		Scenario 5		Scenario 6	
	Final score	Rank	Final score	Rank	Final score	Rank	Final score	Rank	Final score	Rank	Final score	Rank
Supplier 21	0.5416	4	0.5491	3	0.5426	6	0.5391	5	0.5409	5	0.5424	6
Supplier 22	0.4894	19	0.49	19	0.4944	19	0.4864	21	0.4884	21	0.493	19
Supplier 23	0.5731	1	0.5678	1	0.5758	1	0.5777	1	0.5773	1	0.5674	1

Appendix C

$$
\begin{aligned}
& Min\ \gamma^*_{DL} \\
& s.t. \\
& x^a_{C^{DA}_{DL}} \le x^a_{C^{DE}_{DL}} + \gamma^*_{DL}; \quad x^b_{C^{DA}_{DL}} \le \frac{3}{2} \times x^b_{C^{DE}_{DL}} + \gamma^*_{DL}; \quad x^b_{C^{DA}_{DL}} \le \frac{7}{3} \times x^c_{C^{DE}_{DL}} + \gamma^*_{DL} \\
& x^a_{C^{DA}_{DL}} \ge x^a_{C^{DE}_{DL}} - \gamma^*_{DL}; \quad x^b_{C^{DA}_{DL}} \ge \frac{3}{2} \times x^b_{C^{DE}_{DL}} - \gamma^*_{DL}; \quad x^b_{C^{DA}_{DL}} \ge \frac{7}{3} \times x^c_{C^{DE}_{DL}} - \gamma^*_{DL} \\
& x^a_{C^{DA}_{DL}} \le x^a_{C^{DC}_{DL}} + \gamma^*_{DL}; \quad x^b_{C^{DA}_{DL}} \le \frac{3}{2} \times x^b_{C^{DC}_{DL}} + \gamma^*_{DL}; \quad x^c_{C^{DA}_{DL}} \le \frac{7}{3} \times x^c_{C^{DC}_{DL}} + \gamma^*_{DL} \\
& x^a_{C^{DA}_{DL}} \ge x^a_{C^{DC}_{DL}} - \gamma^*_{DL}; \quad x^b_{C^{DA}_{DL}} \ge \frac{3}{2} \times x^b_{C^{DC}_{DL}} - \gamma^*_{DL}; \quad x^c_{C^{DA}_{DL}} \ge \frac{7}{3} \times x^c_{C^{DC}_{DL}} - \gamma^*_{DL} \\
& x^a_{C^{DA}_{DL}} \le \frac{5}{3} \times x^a_{C^{DT}_{DL}} + \gamma^*_{DL}; \quad x^b_{C^{DA}_{DL}} \le 3 \times x^b_{C^{DT}_{DL}} + \gamma^*_{DL} \quad ; x^c_{C^{DA}_{DL}} \le \frac{21}{4} \times x^c_{C^{DT}_{DL}} + \gamma^*_{DL} \\
& x^a_{C^{DA}_{DL}} \ge \frac{5}{3} \times x^a_{C^{DT}_{DL}} - \gamma^*_{DL}; \quad x^b_{C^{DA}_{DL}} \ge 3 \times x^b_{C^{DT}_{DL}} - \gamma^*_{DL} \quad ; x^c_{C^{DA}_{DL}} \ge \frac{21}{4} \times x^c_{C^{DT}_{DL}} - \gamma^*_{DL} \\
& x^a_{C^{DE}_{DL}} \le x^a_{C^{DT}_{DL}} + \gamma^*_{DL}; \quad x^b_{C^{DE}_{DL}} \le 2 \times x^b_{C^{DT}_{DL}} + \gamma^*_{DL}; \quad x^c_{C^{DE}_{DL}} \le \frac{15}{4} \times x^c_{C^{DT}_{DL}} + \gamma^*_{DL} \\
& x^a_{C^{DE}_{DL}} \ge x^a_{C^{DT}_{DL}} - \gamma^*_{DL}; \quad x^b_{C^{DE}_{DL}} \ge 2 \times x^b_{C^{DT}_{DL}} - \gamma^*_{DL}; \quad x^c_{C^{DE}_{DL}} \ge \frac{15}{4} \times x^c_{C^{DT}_{DL}} - \gamma^*_{DL} \\
& x^a_{C^{DC}_{DL}} \le x^a_{C^{DT}_{DL}} + \gamma^*_{DL}; \quad x^b_{C^{DC}_{DL}} \le 2 \times x^b_{C^{DT}_{DL}} + \gamma^*_{DL}; \quad x^c_{C^{DC}_{DL}} \le \frac{15}{4} \times x^c_{C^{DT}_{DL}} + \gamma^*_{DL} \\
& x^a_{C^{DC}_{DL}} \ge x^a_{C^{DT}_{DL}} - \gamma^*_{DL}; \quad x^b_{C^{DC}_{DL}} \ge 2 \times x^b_{C^{DT}_{DL}} - \gamma^*_{DL}; \quad x^c_{C^{DC}_{DL}} \ge \frac{15}{4} \times x^c_{C^{DT}_{DL}} - \gamma^*_{DL} \\
& \frac{x^a_{C^{DA}_{DL}} + 4 \times x^b_{C^{DA}_{DL}} + x^c_{C^{DA}_{DL}}}{6} + \frac{x^a_{C^{DE}_{DL}} + 4 \times x^b_{C^{DE}_{DL}} + x^c_{C^{DE}_{DL}}}{6} + \frac{x^a_{C^{DC}_{DL}} + 4 \times x^b_{C^{DC}_{DL}} + x^c_{C^{DC}_{DL}}}{6} + \\
& \frac{x^a_{C^{DT}_{DL}} + 4 \times x^b_{C^{DT}_{DL}} + x^c_{C^{DT}_{DL}}}{6} = 1 \\
& x^a_{C^{DA}_{DL}} \le x^b_{C^{DA}_{DL}} \le x^c_{C^{DA}_{DL}}; \quad x^a_{C^{DE}_{DL}} \le x^b_{C^{DE}_{DL}} \le x^c_{C^{DE}_{DL}}; \\
& x^a_{C^{DC}_{DL}} \le x^b_{C^{DC}_{DL}} \le x^c_{C^{DC}_{DL}}; \quad x^a_{C^{DT}_{DL}} \le x^b_{C^{DT}_{DL}} \le x^c_{C^{DT}_{DL}} \\
& x^a_{C^{DA}_{DL}}, \quad x^a_{C^{DE}_{DL}}, \quad x^a_{C^{DC}_{DL}}, \quad x^a_{C^{DT}_{DL}} > 0
\end{aligned} \tag{13C}
$$

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