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ASSESSING SME CREDIT RATING IN SUPPLY CHAIN FINANCE WITH MULTI-PHASE QFD-BASED MULTIMOORA UNDER UNCERTAINTY

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Abstract. Presently, financial institutions have tentatively utilized supply chain finance as a means of assessing small and medium-sized enterprise (SME) credit rating. However, traditional techniques cannot satisfy the requirements of such assessments because financial institutions need to assess SME credit rating from the perspective of the supply chain and core enterprise rather than only from the perspective of SME. In this study, a hybrid technique with quantitative and qualitative criteria called multi-phase quality function deployment (QFD)-based MULTIMOORA under interval type-2 fuzzy set (IT2FS) is proposed to overcome the defects of traditional techniques. First, the quantitative values were converted into IT2FSs using the developed formulas. Second, a multi-phase QFD model is proposed to obtain the SME credit rating matrix by integrating the core enterprise credit rating matrix and the criterion relationship matrices among SME, core enterprises and supply chains. Third, IT2FS-MULTIMOORA is enhanced by considering the improved Borda Rule and extended reference point simultaneously to derive the final rankings; therefore, a weight-determining technique is presented based on the correlation coefficients. Finally, the proposed technique was applied to the SME credit rating assessment problem. Comparisons with other techniques and the sensitivity analysis results provide suggestions for financial institutions to provide loans to SMEs.

Keywords: multi-phase QFD, MULTIMOORA, SME credit rating, supply chain finance.

JEL Classification: C43, C61, D81.

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1. Introduction

Small and medium-sized enterprises (SMEs), known as the "new economic turning point," have generally played the most significant role in a country's economic development, especially in China. Promoting and improving the positive development of SMEs has also become a new economic trend in many countries. However, because credit ratings are difficult to measure, it is difficult for SMEs to gain support from financial institutions. The major cause of this situation is information asymmetry between SMEs and financial institutions (Liu et al., 2023; Pang et al., 2024). Consequently, financial institutions would prefer to make loans to large enterprises (that is, core enterprises) for lower credit risk rather than to SMEs. However, in terms of their potential to unlock market resources, the SME market niche cannot be overlooked.

Supply chain finance is an innovative financing method that solves the problem of information asymmetry among the note-enterprises. And it is based on supply chains centered on core enterprises, guaranteed by business contracts between core enterprises and upstream and downstream SMEs, and relies on core enterprises to conduct financing business (Lin & Dong, 2024). In other words, core enterprises play critical role in the credit enhancement of supply chain finance. Financial institutions take the credit standing level of core enterprises as credit review certificates, and SMEs take the credit granting of core enterprises as credit application guarantees. Therefore, Financial institutions force SME credit rating (SMECR) to mitigate the risk of default. The purpose of the SMECR is to ascertain how an SME is capable of carrying out contract obligations, particularly based on supply chains. Most importantly, financial institutions rely on SMECR to make lending decisions (Goldmann et al., 2024). The accuracy and reasonability of SMECR have a crucial impact on lending decision. Even a 1% improvement in the SMECR decreases the risk and loss of financial institutions (Xu et al., 2024). Therefore, developing an accurate and reasonable SMECR model based on the credit rating of the corresponding core enterprises and supply chains is a significant task. In this regard, multi-criteria decision-making (MCDM) techniques enable financial institutions to easily solve this problem. This is because SMECR assessment involves quantitative and qualitative criteria. With the assistance of experts, MCDM techniques can select the most suitable SME among the candidate SMEs. Some MCDM techniques have been applied to credit ratings owing to their simplicity and flexibility (Goldmann et al., 2024; Zhang et al., 2023b). However, they cannot be directly applied to SMECR problems that contain the credit rating information of the corresponding core enterprises and supply chains.

To assess the SMECR accurately and reasonably, it is vital to consider how the credit rating information of the corresponding core enterprises and supply chains can be incorporated into the SMECR model. Quality function deployment (QFD) (Akao & Mazur, 2003) is a powerful technique that can translate the credit rating information of core enterprises and supply chains into SMECR and can help financial institutions tackle the problems of whether to lend to SMEs and how much to allocate to SMEs. QFD is a quality management technique that aims to translate customer needs into technical criteria and allow enterprises to efficiently design products and services. According to this idea, in supply chain finance, QFD can be applied to translate the credit rating information of core enterprises into one of the supply chains and then translate the credit rating information of supply chains into one of the SMEs, thus becoming a multi-phase QFD (Yang et al., 2021). Some integrated models of MCDM and QFD have also been used for real MCDM problems (Chen et al., 2021, 2024; Wu et al., 2024). However, only a few studies have shown that a multi-phase QFD-based MCDM technique in an environment of uncertainty can be applied to assess the SMECR.

Note that in an actual SMECR assessment, owing to the environmental conditions of the arising ambiguity and uncertainty, the assessment values of most criteria proposed by experts, such as credit condition, financial situation, market competitiveness, cannot be adequately represented by type-1 fuzzy sets. This is because the member functions are uncertain (Shang et al., 2022; Yucesan et al., 2024). In this case, type-2 fuzzy sets, can be regarded as applicable tools for handling high-order ambiguity and uncertainty precisely. Most importantly, compared with other fuzzy sets (such as the trapezoidal fuzzy set, intuitionistic fuzzy set, neutrosophic fuzzy set, hesitant fuzzy set, and Pythagorean fuzzy set), the membership functions of the type-2 fuzzy set are three-dimensional and involve an uncertainty footprint. However, type-2 fuzzy sets are not easy to use for real MCDM techniques because of the large number of calculations (Li et al., 2024). In practice, as a particular type of type-2 fuzzy set, the interval type-2 fuzzy set (IT2FS) can generally be regarded as the simplest and most efficient tool, offering greater flexibility and freedom for experts to better express their uncertain judgments (Hernandez et al., 2022; Li et al., 2024). Consequently, this study takes advantage of IT2FSs to represent the assessment of candidate SMEs based on these criteria.

Furthermore, the ranking technique is vital for assessing SMECR. In general, many MCDM techniques are used to deal with this ranking, such as WASPAS (Weighted Aggregated Sum Product Assessment), TOPSIS (Technique for Order Preference by Similarity to Ideal Solution), and VIKOR (Vlse Kriterijumska Optimizacija I Kompromisno Resenje). However, their wide application in SMECR is restricted by their low computational efficiency and poor stability. The multi-objective optimization by ratio analysis (MOORA) technique was first developed by Brauers and Zavadaskas (2006) and was further supplemented and refined by coupling with the full multiplicative form to develop the multiplicative MOORA (MULTIMOORA) technique. The MULTIMOORA technique, which includes a ration system, reference point and full multiplicative form, has become one of the most commonly used MCDM techniques. Compared with WASPAS (Ghorabaee et al., 2016), TOPSIS (Yiilmaz & Polat, 2023), and VIKOR (Meniz & Özkan, 2023), MULTIMOORA has certain advantages such as higher stability, more conciseness, less computation time and stronger robustness (Wang et al., 2024). MULTIMOORA has also been extended to various forms of uncertain information, such as IT2FS (Qin & Ma, 2022; Shang et al., 2022; Yucesan et al., 2024; Nemati, 2024). Although the interval type-2 fuzzy MULTIMOORA (IT2F-MULTIMOORA) technique gets ample attention, both the initial technique and its extension exhibit a less active aspect of aggregating the ranking outcome from three techniques. These studies have some limitations:

- In reality, SMECR assessments generally involve both quantitative and qualitative criteria, and under most circumstances, quantitative criteria assessment values are easy to acquire. However, the existing IT2F-MULTIMOORA techniques can only solve decision-making problems in which the assessment values are represented as IT2FSs and cannot solve real problems in which an unspecified number of assessment values are crisp numbers.
- More specifically, subordinate rankings based on these techniques are acquired using dominance theory, and the corresponding utility values are not considered. Beside this, the dominance theory fails in many alternatives because of a complicated pairwise comparison.
- In addition, the existing reference point technique merely considers the distance between the alternatives and the positive ideal point, neglecting that the alternative should be far from the negative ideal point. Consequently, the rationality and effectiveness of this technique cannot fully realize its potential because the positive and negative ideal points are not involved simultaneously. Another drawback of this technique is that the calculated maximum-minimum measurements are the same for some alternatives. Therefore, it is impossible to discriminate between these alternatives and effectively determine a unique ranking.

In reality, the limitations described above may lead to inaccurate and irrational rankings. Consequently, to ensure the accuracy and rationality of the rankings, the IT2F-MULTIMOORA technique should be improved further based on the above limitations. Therefore, it is necessary to combine the MULTIMOORA technique with multi-phase QFD for SMECR in an IT2FS context. The contributions of this study are as follows:

- A new multi-phase QFD model was developed to obtain the SMECR matrix by integrating the core enterprise credit rating (CECR) matrix, the relationship matrix between the CECR and supply chain credit rating (SCCR) criteria, and the relationship matrix between the SCCR and SMECR criteria. This model ensure that the credit rating information of the corresponding core enterprises and supply chains can be incorporated into SMECR model.
- IT2FSs are used to express the assessment values of the SMECR criteria to address SMECR problems involving a high degree of uncertainty efficiently and rationally. The IT2F-MULTIMOORA technique was further improved by introducing the improved Borda Rule and the extended reference point technique to derive the final rankings. Therefore, the improved Borda Rule was developed as an aggregation function that does not have the defects of the dominance theory, and the extended reference point technique can resolve the inherent limitations of the existing reference point technique by considering the positive and negative ideal points simultaneously. In addition, formulas have been developed to convert quantitative assessment values to IT2FSs to combine the quantitative and qualitative criteria. These improvements ensure that the rankings based on the IT2F-MULTIMOORA technique are more efficient and rational.
- A multi-phase QFD-based IT2F-MULTIMOORA technique was developed for assessing the SMECR in supply chain finance. Therefore, a weight-determining technique is presented based on the correlation coefficients. This hybrid technique ensures that the SMECR in supply chain finance is accurately and reasonably assessed.
- Some proposed helpful references obtained from a case study concerning the assessment of SMECR in supply chain finance ensure that financial institutions can choose the most suitable SME among candidate SMEs more effectively.

The remainder of this paper is organized as follows. Section 2 reviews the QFD model, IT2FS, and the classical MULTIMOORA techniques. Section 3 describes the proposed technique, and Section 4 presents a case study on the application of the SMECR. Section 5 presents concluding remarks

2. Literature review

2.1. Integration of MCDM techniques and QFD

Currently, multi-phase QFD has been successfully carried over into many areas to improve decision-making process. Shaker et al. (2019) developed a two-phase QFD for improving failure modes and effects analysis. Yang et al. (2021) suggested a three-phase QFD-based framework for identifying key passenger needs to improve satisfaction. Now, some integrated models of MCDM and QFD have also been used for real problems. Chen et al. (2021) developed an integrated MCDM approach for improving QFD based on DEMATEL and extended MULTIMOORA. Liu et al. (2022) proposed an integrated behavior MCDM approach for large group QFD. Zhang et al. (2023a) proposed a hybrid QFD-based human-centric MCDM method of disassembly schemes. Chen et al. (2024) proposed an online reviews-driven Kano-QFD method for service design. Wu et al. (2024) presented an integrated QFD and FMEA method under the co-opetitional relationship for product upgrading. The existing researches proved that the integrated techniques are effective tools for dealing with the MCDM problems. However, only few studies give real attention to the issue of applying a multi-phase QFD-based MCDM technique under the environment of uncertainty for dealing with the problem of SMECR in supply chain finance.

2.2. IT2F-MULTIMOORA

Among the well-established MCDM techniques, MULTIMOORA is mostly applied in MCDM and proved as a reliable process. Garg and Rani (2022) proposed a MCDM method based on MULTIMOORA to assess solid waste management techniques. Gai et al. (2023) used the MULTIMOORA method based on linguistic Z-numbers for green supply chain management. Vaezi et al. (2024) proposed a modified MUTIMOORA method to evaluate suppliers. Now, the IT2F-MULTIMOORA technique has also become one of the commonly used MCDM technique. Wang et al. (2019) proposed a risk evaluation technique for failure mode and effect analysis with extended IT2F-MULTIMOORA technique. Qin and Ma (2022) presented an IT2F-MULTIMOORA technique to evaluate emergency response plan. Shang et al. (2022) used the IT2F-MULTIMOORA technique to select supplier in sustainable supply chains. Yucesan et al. (2024) proposed an integrated IT2F-MULTIMOORA and best-worst technique for evaluating sustainability of urban mobility of Asian cities. Nemati (2024) developed a new version of the IT2F-MULTIMOORA model to evaluate suppliers through the resiliency and sustainability paradigms.

Although this technique has been covered in various fields, it has never been originally integrated into QFD model, especially multi-phase QFD model. Therefore, by integration of the benefits of each of these techniques, a multi-phase QFD-based IT2F-MULTIMOORA technique is formed in this study, which proposes a responsible framework for assessing SMECR in supply chain finance. And it should be noted that this is the first study that address SMECR problems in supply chain finance by multi-phase QFD to fill the gap in practical lending decision.

3. Preliminaries

3.1. QFD model

The basic concept of QFD (Akao & Mazur, 2003) is to identify customer needs and transforms them into technical criteria for products and services. In general, QFD can produce more accurate decision-making by concentrating on an adequate number of criteria based on customer needs. In reality, to meet the goal of credit enhancement, it is not sufficient to assess SMECR information directly in supply chain finance; however, this goal can be met based on the credit rating information of the corresponding core enterprises and supply chains. Therefore, translating the credit rating assessment of the corresponding core enterprises and supply chains into one of SMEs is a key task for this model. House of quality is the fundamental planning tool for QFD and includes the following six items, as shown in Figure 1.

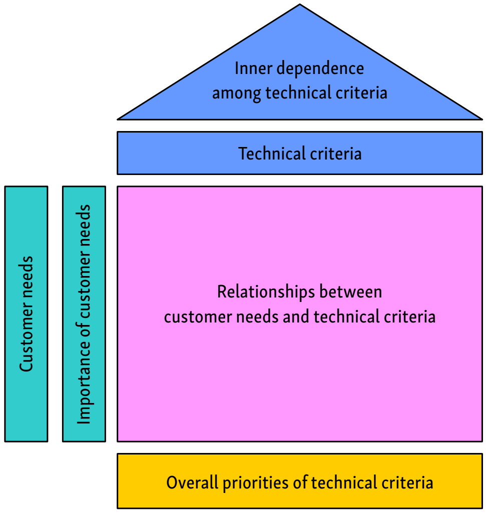

Figure 1. Structure of house of quality (Akao & Mazur, 2003)

3.2. IT2FS

Type-2 fuzzy sets, initially proposed by Zadeh (1975), are known as an extension of type-1 fuzzy sets. The key difference between the two is that, while the memberships of type-1 fuzzy sets are crisp values, the memberships of type-2 fuzzy sets are type-1 fuzzy sets, so type-2 fuzzy sets can more easily denote vagueness and imprecision than type-1 fuzzy sets. Thus far, IT2FSs have been the most actively implemented type-2 fuzzy sets.

Definition 1 (Liu & Gao, 2021). Let E be the universe of the discourse. A T2FS $\tilde{A}$ in E is defined as follows:

$$\tilde{A} = \left\{\left((\varepsilon,\sigma),\mu_{\tilde{A}}(\varepsilon,\sigma)\right)\middle|\forall\varepsilon\in E,\forall\sigma\in J_{\varepsilon}\right\}, \tag{1}$$

where $J_{\varepsilon} \in [0,1]$ denotes the main membership at ε and $\mu_{\tilde{A}}(\varepsilon,\sigma) \in [0,1]$ represents the secondary grade of $(\varepsilon,\ \sigma)$. Moreover, the type-2 fuzzy set $\tilde{A}$ can be denoted as follows:

$$\tilde{A} = \int_{\varepsilon\in E}\int_{\sigma\in J_{\varepsilon}} \mu_{\tilde{A}}(\varepsilon,\sigma)/(\varepsilon,\sigma) = \int_{\varepsilon\in E}\left(\int_{\sigma\in J_{\varepsilon}} \mu_{\tilde{A}}(\varepsilon,\sigma)/\sigma\right)/\varepsilon, \tag{2}$$

where $J_{\varepsilon} \in [0,1]$ is the primary membership at ε.

Definition 2 (Liu & Gao, 2021). Le $\tilde{A}$ be a type-2 fuzzy set in E, if $\mu(\varepsilon,\sigma) = 1$, then $\tilde{A}$ is called an IT2FS, and is expressed as follows:

$$\tilde{A} = \int_{\varepsilon\in E}\int_{\sigma\in J_{\varepsilon}} 1/(\varepsilon,\sigma) = \int_{\varepsilon\in E}\left(\int_{\sigma\in J_{\varepsilon}} 1/\sigma\right)/\varepsilon. \tag{3}$$

In general, some simplified forms can be applied to denote IT2FS because of its high computational complexity. In this study, we applied trapezoidal IT2FS to address SMECR problems.

Definition 3 (Liu & Gao, 2021). Let $\tilde{A}^L$ and $\tilde{A}^U$ be two generalized trapezoidal fuzzy numbers, where the height is positioned in the $\left[0,1\right]$. Let $h_{\tilde{A}}^L$ and $h_{\tilde{A}}^U$ be the lower and upper heights of $\tilde{A}$, respectively. An IT2FS can be defined as follows:

$$\tilde{A} = \left(\tilde{A}^L, \tilde{A}^U\right) = \left[\left(\alpha_1^L, \alpha_2^L, \alpha_3^L, \alpha_4^L; h_{\tilde{A}}^L\right), \left(\alpha_1^U, \alpha_2^U, \alpha_3^U, \alpha_4^U; h_{\tilde{A}}^U\right)\right], \quad (4)$$

where $\tilde{A}^L$ and $\tilde{A}^U$ are type-1 fuzzy sets, $\alpha_1^L \le \alpha_2^L \le \alpha_3^L \le \alpha_4^L$, $\alpha_1^U \le \alpha_2^U \le \alpha_3^U \le \alpha_4^U$, $\alpha_1^U \le \alpha_1^L$, $\alpha_4^L \le \alpha_4^U$ and $0 \le h_{\tilde{A}}^L \le h_{\tilde{A}}^U \le 1$.

In addition, the arithmetic operations and distance measures of any two IT2FSs, as well as the expected value of the IT2FS, are shown in Appendix A.

3.3. The classical MULTIMOORA

The classical MULTIMOORA (Brauers & Zavadaskas, 2006) includes three subordinate techniques: the ration system, reference point and full multiplicative form. It also applies the dominance theory to calculate the rankings. Suppose $E = \left(e_{ij}\right)_{t\kappa}$ is a decision matrix , where e_{ij} is the assessment value of alternative $\Re_i \left(i = 1, 2, \cdots, t\right)$ on the criterion $\mathbb{C}_j \left(j = 1, 2, \cdots, \kappa\right)$, and γ and $\kappa - \gamma$ represent the number of benefit and cost criteria, respectively. The detailed procedures are presented in Appendix B.

4. The proposed technique

Suppose that $\Re = \left\{\Re_i \middle| i = 1, 2, \cdots, t\right\}$ is a set of SMEs, $\mathbb{C}_1 = \left\{\mathbb{C}_{1j} \middle| j = 1, 2, \cdots, \kappa_1\right\}$ is the set of CECR criteria with the weight vector $w_1 = \left(w_{11}, w_{12}, \cdots, w_{1\kappa_1}\right)^T$, $\mathbb{C}_2 = \left\{\mathbb{C}_{2p} \middle| p = 1, 2, \cdots, \kappa_2\right\}$ is the set of SCCR criteria with the weight vector $w_2 = \left(w_{21}, w_{22}, \cdots, w_{2\kappa_2}\right)^T$, $\mathbb{C}_3 = \left\{\mathbb{C}_{3\delta} \middle| \delta = 1, 2, \cdots, \kappa_3\right\}$ is the set of SMECR criteria with the weight vector $w_3 = \left(w_{31}, w_{32}, \cdots, w_{3\kappa_3}\right)^T$ and $D = \left\{D_\eta \middle| \eta = 1, 2, \cdots, m\right\}$ is a set of experts with the weight vector.

Assume that there are $\chi (0 \le \chi \le \kappa_1)$ quantitative criteria and $\kappa_1 - \chi$ qualitative criteria in $\mathbb{C}_1$. In this case, the quantitative assessment values can be acquired from financial statements by surveys, whereas by three exclusively designed questionaries, experts can apply linguistic terms listed in Table 1 to denote their assessment values. Let $E_1 = \left[e_{1ij}\right]_{t \times \kappa_1}$, $E_2 = \left[e_{2jp}\right]_{\kappa_1 \times \kappa_2}$, and $E_3 = \left[e_{3p\delta}\right]_{\kappa_2 \times \kappa_3}$ be the CECR matrix, relationship matrix between the CECR and SCCR criteria, and relationship matrix between the SCCR and SMECR criteria, respectively. e_{1ij}, e_{2jp}, and $e_{3p\delta}$ are the IT2FSs converted using the corresponding linguistic terms and can be expressed as follows:

$$e_{1ij} = \left[\left(\alpha_{1ij1}^L, \alpha_{1ij2}^L, \alpha_{1ij3}^L, \alpha_{1ij4}^L; h_{e_{1ij}}^L\right), \left(\alpha_{1ij1}^U, \alpha_{1ij2}^U, \alpha_{1ij3}^U, \alpha_{1ij4}^U; h_{e_{1ij}}^U\right)\right],$$

$$e_{2jp} = \left[\left(\alpha_{2jp1}^L, \alpha_{2jp2}^L, \alpha_{2jp3}^L, \alpha_{2jp4}^L; h_{e_{2jp}}^L\right), \left(\alpha_{2jp1}^U, \alpha_{2jp2}^U, \alpha_{2jp3}^U, \alpha_{2jp4}^U; h_{e_{2jp}}^U\right)\right],$$

$$e_{3p\delta} = \left[\left(\alpha_{3p\delta1}^L, \alpha_{3p\delta2}^L, \alpha_{3p\delta3}^L, \alpha_{3p\delta4}^L; h_{e_{3p\delta}}^L\right), \left(\alpha_{3p\delta1}^U, \alpha_{3p\delta2}^U, \alpha_{3p\delta3}^U, \alpha_{3p\delta4}^U; h_{e_{3p\delta}}^U\right)\right].$$

4.1. Conversion function that converts quantitative value to the corresponding IT2FS

Generally, the $\mathbb{C}_1$ contains both quantitative criteria (such as profit margin and property rate of turnover) and qualitative criteria (such as management level and strength of supply chain relationships), in which the assessment values of the quantitative criteria can be dimensionless and the assessment values of the qualitative criteria cannot be quantified according to customer need (Santos et al., 2017). To solve this problem effectively, a function that converts quantitative assessment values into IT2FSs was developed.

Definition 4. Let $G=\left\{G_\xi \left|\xi=1,2,\cdots,\chi\right.\right\}$ be a customer-needs set. $G^+=\max\left\{G_\xi\left|\xi=1,2,\cdots,\chi\right.\right\}$ and $G^-=\min\left\{G_\xi\left|\xi=1,2,\cdots,\chi\right.\right\}$. The corresponding linguistic terms and IT2FSs of G_ξ are listed in Table 1.

Table 1. Linguistic terms and their corresponding IT2FSs

Customer need intervals	Linguistic terms	IT2FSs
$\left[G^-, G^-+\frac{(G^+-G^-)}{7}\right)$	Extremely weak (EW)	$\left[(0,0,0,0.1;1),\ (0,0,0,0.05;0.9)\right]$
$\left[G^-+\frac{(G^+-G^-)}{7}, G^-+\frac{2(G^+-G^-)}{7}\right)$	Very weak (VW)	$\left[(0,0.1,0.1,0.3;1),\ (0.05,0.1,0.1,0.2;0.9)\right]$
$\left[G^-+\frac{2(G^+-G^-)}{7}, b^-+\frac{3(G^+-G^-)}{7}\right)$	Weak (W)	$\left[(0.1,0.3,0.3,0.5;1),\ (0.2,0.3,0.3,0.4;0.9)\right]$
$\left[G^-+\frac{3(G^+-G^-)}{7}, G^-+\frac{4(G^+-G^-)}{7}\right)$	Medium (M)	$\left[(0.3,0.5,0.5,0.7;1),\ (0.4,0.5,0.5,0.6;0.9)\right]$
$\left[G^-+\frac{4(G^+-G^-)}{7}, G^-+\frac{5(G^+-G^-)}{7}\right)$	Strong (S)	$\left[(0.5,0.7,0.7,0.9;1),\ (0.6,0.7,0.7,0.8;0.9)\right]$
$\left[G^-+\frac{5(G^+-G^-)}{7}, G^-+\frac{6(G^+-G^-)}{7}\right)$	Very strong (VS)	$\left[(0.7,0.9,0.9,1;1),\ (0.8,0.9,0.9,0.95;0.9)\right]$
$\left[G^-+\frac{6(G^+-G^-)}{7}, G^+\right]$	Extremely strong (ES)	$\left[(0.9,1,1,1;1),\ (0.95,1,1,1;0.9)\right]$

Example. The profit margin of core enterprises ($\mathfrak{R}_1$, $\mathfrak{R}_2$, $\mathfrak{R}_3$, $\mathfrak{R}_4$, $\mathfrak{R}_5$) are 12400.56, 10140.91, 7816.42, 5872.20, and 4805.25 (Unit: million RMB), respectively. From definition 4 and Table 1, the customer need intervals can be calculated as: $\left[4805.25,5890.25\right)$, $\left[5890.25,6975.25\right)$, $\left[6975.25,8060.25\right)$, $\left[8060.25,9145.25\right)$, $\left[9145.25,10230.25\right)$, $\left[10230.25,11315.25\right)$, and $\left[11315.25,12400.56\right]$. $12400.56\in\left[11315.25,12400.56\right]$, and the corresponding linguistic terms and IT2FSs of the assessment values of $\mathfrak{R}_1$ are $\left\{\text{Extremely strong (ES)}\right\}$ and $\left[(0.9,1,1,1;1),\ (0.95,1,1,1;0.9)\right]$.

4.2. The multi-phase QFD

This multi-phase QFD model includes three interrelated phases and the resultant matrices, as shown in Figure 2. The credit rating information of core enterprises and supply chains can be incorporated into the SMECR model. Therefore, the SMECR matrix can be acquired by integrating the CECR and SCCR matrices. The SMECR matrix can be obtained as follows:

$$E = E_1 * E_2 * E_3 = \left[w_{2p} \left[\left[w_{1j} e_{ij} \right]_{t \times \kappa_1} * \left[e_{jp} \right]_{\kappa_1 \times \kappa_2} \right] \right]_{t \times \kappa_2} * \left[w_{3\delta} e_{p\delta} \right]_{\kappa_2 \times \kappa_3} = \left[e_{i\delta} \right]_{t \times \kappa_3}, \quad (5)$$

where

$$e_{i\delta} = \left[\begin{array}{l} \left(\begin{array}{l} \sum_{p=1}^{\kappa_2} \left(w_{2p} \left(\sum_{j=1}^{\kappa_1} w_{1j} \alpha_{ij1}^L \alpha_{jp1}^L \right) \alpha_{p\delta 1}^L \right), \sum_{p=1}^{\kappa_2} \left(w_{2p} \left(\sum_{j=1}^{\kappa_1} w_{1j} \alpha_{ij2}^L \alpha_{jp2}^L \right) \alpha_{p\delta 2}^L \right), \\ \sum_{p=1}^{\kappa_2} \left(w_{2p} \left(\sum_{j=1}^{\kappa_1} w_{1j} \alpha_{ij3}^L \alpha_{jp3}^L \right) \alpha_{p\delta 3}^L \right), \sum_{p=1}^{\kappa_2} \left(w_{2p} \left(\sum_{j=1}^{\kappa_1} w_{1j} \alpha_{ij4}^L \alpha_{jp4}^L \right) \alpha_{p\delta 4}^L \right); \min_{p=1}^{\kappa_2} \left\{ \min_{j=1}^{\kappa_1} \left\{ h_{e_{ij}}^L, h_{e_{jp}}^L \right\}, h_{e_{p\delta}}^L \right\} \end{array} \right), \\ \left(\begin{array}{l} \sum_{p=1}^{\kappa_2} \left(w_{2p} \left(\sum_{j=1}^{\kappa_1} w_{1j} \alpha_{ij1}^U \alpha_{jp1}^U \right) \alpha_{p\delta 1}^U \right), \sum_{p=1}^{\kappa_2} \left(w_{2p} \left(\sum_{j=1}^{\kappa_1} w_{1j} \alpha_{ij2}^U \alpha_{jp2}^U \right) \alpha_{p\delta 2}^U \right), \\ \sum_{p=1}^{\kappa_2} \left(w_{2p} \left(\sum_{j=1}^{\kappa_1} w_{1j} \alpha_{ij3}^U \alpha_{jp3}^U \right) \alpha_{p\delta 3}^U \right), \sum_{p=1}^{\kappa_2} \left(w_{2p} \left(\sum_{j=1}^{\kappa_1} w_{1j} \alpha_{ij4}^U \alpha_{jp4}^U \right) \alpha_{p\delta 4}^U \right); \min_{p=1}^{\kappa_2} \left\{ \min_{j=1}^{\kappa_1} \left\{ h_{e_{ij}}^U, h_{e_{jp}}^U \right\}, h_{e_{p\delta}}^U \right\} \end{array} \right) \end{array} \right]$$

$$= \left[\left(\alpha_{i\delta 1}^L, \alpha_{i\delta 2}^L, \alpha_{i\delta 3}^L, \alpha_{i\delta 4}^L; h_{e_{i\delta}}^L \right), \left(\alpha_{i\delta 1}^U, \alpha_{i\delta 2}^U, \alpha_{i\delta 3}^U, \alpha_{i\delta 4}^U; h_{e_{i\delta}}^U \right) \right].$$

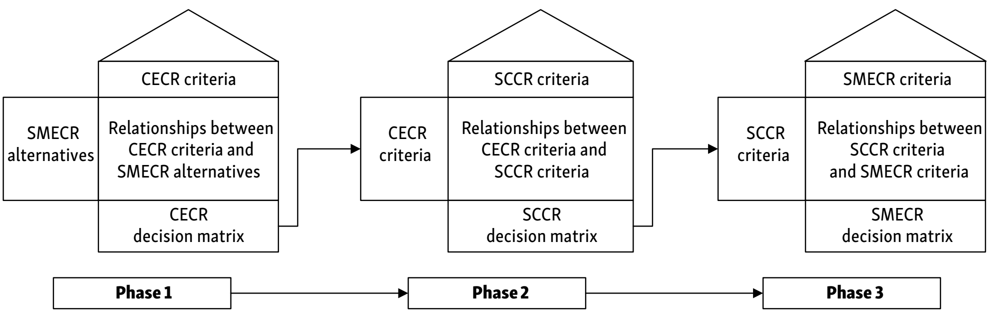

Figure 2. House of quality structure of three-phase QFD for assessing SMECR

4.3. The weight of SMECR criteria based on correlation coefficients

In this Section, a weight-determining technique based on correlation coefficients is presented. The object weights were calculated using correlation coefficients, which can stray far from bias because of highly correlated criteria. In general, most of the object weights determining techniques are on the basis of the "contrast intensity" of each criterion, which gives a higher weight to the criterion that has different behavior of alternatives. In the real SMECR assessment, the criteria are commonly correlated. Traditionally, relevant criteria are clustered together or deleted directly. However, this operation is rude and loses valuable information. Typically, it is suitable to assign small weights to criteria with high coefficients (Wu et al., 2018). Thus, misguiding rankings caused by strongly correlated criteria are avoided, and much more criteria information is retained. Therefore, the correlation coefficients between the criteria were applied to obtain the object weights. To achieve this, the correlation coefficient $\mathbb{Z}_{\delta\gamma}$ between $\mathbb{C}_\delta$ and $\mathbb{C}_\gamma$ was calculated as follows:

$$\mathbb{Z}_{\delta\gamma} = \frac{\sum_{i=1}^{t}\left[\left(\frac{d_{i\delta}}{d_\delta} - \frac{1}{t}\sum_{i=1}^{t}\frac{d_{i\delta}}{d_\delta}\right) * \left(\frac{d_{i\gamma}}{d_\gamma} - \frac{1}{t}\sum_{i=1}^{t}\frac{d_{i\gamma}}{d_\gamma}\right)\right]}{\sqrt{\sum_{i=1}^{t}\left(\frac{d_{i\delta}}{d_\delta} - \frac{1}{t}\sum_{i=1}^{t}\frac{d_{i\delta}}{d_\delta}\right)^2} * \sqrt{\sum_{i=1}^{t}\left(\frac{d_{i\gamma}}{d_\gamma} - \frac{1}{t}\sum_{i=1}^{t}\frac{d_{i\gamma}}{d_\gamma}\right)^2}}, \tag{6}$$

where $\delta,\gamma = 1,2,\cdots,\kappa_3$, $d_{i\delta} = d\left(e_\delta^+, e_{i\delta}\right)$, $d_\delta = d\left(e_\delta^+, e_\delta^-\right)$, $d_{i\gamma} = d\left(e_\gamma^+, e_{i\gamma}\right)$, $d_\gamma = d\left(e_\gamma^+, e_\gamma^-\right)$, and there into:

$$e_\delta^+ = \begin{cases} \left[\begin{array}{l} \left(\max\limits_i^t \alpha_{i\delta 1}^L, \max\limits_i^t \alpha_{i\delta 2}^L, \max\limits_i^t \alpha_{i\delta 3}^L, \max\limits_i^t \alpha_{i\delta 4}^L; \min\limits_i^t h_{i\delta}^L\right), \\ \left(\max\limits_i^t \alpha_{i\delta 1}^U, \max\limits_i^t \alpha_{i\delta 2}^U, \max\limits_i^t \alpha_{i\delta 3}^U, \max\limits_i^t \alpha_{i\delta 4}^U; \min\limits_i^t h_{i\delta}^U\right) \end{array}\right], & \text{for the benifit criterion } \mathbb{C}_\delta \\ \left[\begin{array}{l} \left(\min\limits_\delta^{\kappa_3} \alpha_{1i\delta}^L, \min\limits_\delta^{\kappa_3} \alpha_{2i\delta}^L, \min\limits_\delta^{\kappa_3} \alpha_{3i\delta}^L, \min\limits_\delta^{\kappa_3} \alpha_{4i\delta}^L; \min\limits_\delta^{\kappa_3} h_{i\delta}^L\right), \\ \left(\min\limits_\delta^{\kappa_3} \alpha_{1i\delta}^U, \min\limits_\delta^{\kappa_3} \alpha_{2i\delta}^U, \min\limits_\delta^{\kappa_3} \alpha_{3i\delta}^U, \min\limits_\delta^{\kappa_3} \alpha_{4i\delta}^U; \min\limits_\delta^{\kappa_3} h_{i\delta}^U\right) \end{array}\right], & \text{for the cost criterion } \mathbb{C}_\delta \end{cases}; \tag{7}$$

$$e_\delta^- = \begin{cases} \left[\begin{array}{l} \left(\min\limits_\delta^{\kappa_3} \alpha_{1i\delta}^L, \min\limits_\delta^{\kappa_3} \alpha_{2i\delta}^L, \min\limits_\delta^{\kappa_3} \alpha_{3i\delta}^L, \min\limits_\delta^{\kappa_3} \alpha_{4i\delta}^L; \min\limits_\delta^{\kappa_3} h_{i\delta}^L\right), \\ \left(\min\limits_\delta^{\kappa_3} \alpha_{1i\delta}^U, \min\limits_\delta^{\kappa_3} \alpha_{2i\delta}^U, \min\limits_\delta^{\kappa_3} \alpha_{3i\delta}^U, \min\limits_\delta^{\kappa_3} \alpha_{4i\delta}^U; \min\limits_\delta^{\kappa_3} h_{i\delta}^U\right) \end{array}\right], & \text{for the benifit criterion } \mathbb{C}_\delta \\ \left[\begin{array}{l} \left(\max\limits_i^t \alpha_{i\delta 1}^L, \max\limits_i^t \alpha_{i\delta 2}^L, \max\limits_i^t \alpha_{i\delta 3}^L, \max\limits_i^t \alpha_{i\delta 4}^L; \min\limits_i^t h_{i\delta}^L\right), \\ \left(\max\limits_i^t \alpha_{i\delta 1}^U, \max\limits_i^t \alpha_{i\delta 2}^U, \max\limits_i^t \alpha_{i\delta 3}^U, \max\limits_i^t \alpha_{i\delta 4}^U; \min\limits_i^t h_{i\delta}^U\right) \end{array}\right], & \text{for the cost criterion } \mathbb{C}_\delta \end{cases}. \tag{8}$$

Similarly, e_γ^+ and e_γ^- can be obtained. Subsequently, the object weights of the criteria are calculated as follows:

$$w_\delta = \frac{\sum_{\gamma=1}^{\kappa_3}\left(1 - \mathbb{Z}_{\delta\gamma}\right)}{\sum_{\delta=1}^{\kappa_3}\left(\sum_{\gamma=1}^{\kappa_3}\left(1 - \mathbb{Z}_{\delta\gamma}\right)\right)}. \tag{9}$$

4.4. IT2F-MULTIMOORA with the extended reference point and the improved Borda Rule

In this Section, the classical MULTIMOORA technique is improved using the extended reference point technique and improved Borda Rule to deal with IT2FSs. The superiorities of the three models in the MULTIMOORA technique were comprehensively captured based on the expected value function and distance measure of the IT2FSs.

The vector normalization of $\tilde{e}_{i\delta}$ is computed as follows:

$$\tilde{e}_{i\delta}^{N} = \left[\left(\frac{\alpha_{i\delta 1}^{L}}{D_\delta}, \frac{\alpha_{i\delta 2}^{L}}{D_\delta}, \frac{\alpha_{i\delta 3}^{L}}{D_\delta}, \frac{\alpha_{i\delta 4}^{L}}{D_\delta}; h_{e_{i\delta}}^{L} \right), \left(\frac{\alpha_{i\delta 1}^{U}}{D_\delta}, \frac{\alpha_{i\delta 2}^{U}}{D_\delta}, \frac{\alpha_{i\delta 3}^{U}}{D_\delta}, \frac{\alpha_{i\delta 4}^{U}}{D_\delta}; h_{e_{i\delta}}^{U} \right) \right], \tag{10}$$

where $D_\delta = \sqrt{\sum_{i=1}^{t} \sum_{\upsilon}^{4} \left(\alpha_{i\delta\upsilon}^{L} \right)^2 + \sum_{i=1}^{t} \sum_{\upsilon}^{4} \left(\alpha_{i\delta\upsilon}^{U} \right)^2}$.

Subsequently, the normalized matrix can be expressed as:

$$\tilde{E}^{N} = \left(\tilde{e}_{i\delta}^{N} \right)_{t \times \kappa_3} \left(i = 1, 2, \cdots, t; \delta = 1, 2, \cdots, \kappa_3 \right).$$

(1) The interval type-2 fuzzy ratio system (IT2F-RS) technique

A fully compensatory aggregation model was introduced to express the majority performance of the alternatives. According to this technique, the positive performance on beneficial criteria is utilized to compensate for the negative performance on cost criteria. The IT2F-RS by the weighted average operator is defined as follows:

$$U_1\left(\Re_i\right) = \sum_{\delta=1}^{\eta} w_{3\delta} \tilde{e}_{i\delta}^{N} - \sum_{\delta=\eta+1}^{\kappa_3} w_{3\delta} \tilde{e}_{i\delta}^{N}, \tag{11}$$

where $w_{3\delta}\left(\delta = 1, 2, \cdots, \kappa_3\right)$ is the weight of criteria $\mathbb{C}_{3\delta}\left(\delta = 1, 2, \cdots, \kappa_3\right)$. $\mathbb{C}_{3\delta}\left(\delta = 1, 2, \cdots, \eta\right)$ is the benefit criterion, and $\mathbb{C}_{3\delta}\left(\delta = \eta+1, \eta+2, \cdots, \kappa_3\right)$ is the cost criterion. The first ranking results are then acquired in descending order.

(2) The extended interval type-2 fuzzy reference point (IT2F-RP) technique

The purpose of the reference point technique is to detect the shortest distance from the maximal objective reference point. This technique only considers the positive ideal point and does not consider getting away from the negative ideal point. Additionally, another drawback of this technique is that the computed minimum-maximum measurements are the same for some alternatives. Consequently, it is impossible to discriminate among those alternatives and determine a unique ranking. For example, in some situations, $U_1\left(\Re_i\right)$ of any two alternatives may equal, that is, $U_1\left(\Re_i\right) = U_1\left(\Re_{i+1}\right)$. $U_1\left(\Re_i\right)$ may be centralized with majority of criteria, and $U_1\left(\Re_{i+1}\right)$ may act well with some attributes but act bad with other criteria.

Based on the characteristics of TOPSIS, an extended reference point technique is developed to resolve these two drawbacks. This extended technique can get the best alternative by considering the shortest distance from the positive ideal point and the longest distance from the negative ideal point simultaneously. Specifically, the positive ideal point is formed from all the best assessment values, and the negative ideal point is formed from the worst assessment values. The positive $\tilde{e}^{N+}$ and the negative $\tilde{e}^{N-}$ ideal vectors are constructed as follows:

$$\tilde{e}^{N+} = \left(\tilde{e}_1^{N+}, \tilde{e}_2^{N+}, \cdots, \tilde{e}_{\kappa_3}^{N+} \right), \tag{12}$$

where $\tilde{e}_\delta^{N+} = \left[\begin{array}{l} \left(\max\limits_i^t \alpha_{i\delta 1}^{L}, \max\limits_i^t \alpha_{i\delta 2}^{L}, \max\limits_i^t \alpha_{i\delta 3}^{L}, \max\limits_i^t \alpha_{i\delta 4}^{L}; \min\limits_i^t h_{i\delta}^{L} \right), \\ \left(\max\limits_i^t \alpha_{i\delta 1}^{U}, \max\limits_i^t \alpha_{i\delta 2}^{U}, \max\limits_i^t \alpha_{i\delta 3}^{U}, \max\limits_i^t \alpha_{i\delta 4}^{U}; \min\limits_i^t h_{i\delta}^{U} \right) \end{array} \right];$

$$\tilde{e}^{\text{N-}} = \left(\tilde{e}_1^{\text{N}-}, \tilde{e}_2^{\text{N}-}, \cdots, \tilde{e}_{\kappa_3}^{\text{N}-}\right), \tag{13}$$

where $\tilde{e}_\delta^{\text{N}+} = \begin{bmatrix} \left(\overset{t}{\underset{i}{\min}}\alpha_{i\delta 1}^L, \overset{t}{\underset{i}{\min}}\alpha_{i\delta 2}^L, \overset{t}{\underset{i}{\min}}\alpha_{i\delta 3}^L, \overset{t}{\underset{i}{\min}}\alpha_{i\delta 4}^L; \overset{t}{\underset{i}{\min}} h_{i\delta}^L\right), \\ \left(\overset{t}{\underset{i}{\min}}\alpha_{i\delta 1}^U, \overset{t}{\underset{i}{\min}}\alpha_{i\delta 2}^U, \overset{t}{\underset{i}{\min}}\alpha_{i\delta 3}^U, \overset{t}{\underset{i}{\min}}\alpha_{i\delta 4}^U; \overset{t}{\underset{i}{\min}} h_{i\delta}^U\right) \end{bmatrix}.$

The distance from the alternatives to the positive and negative ideal points is computed as follows:

$$d^+\left(\Re_i\right) = \sqrt{\sum\nolimits_{\delta=1}^{\kappa_3}\left(d\left(w_{3\delta}e_{i\delta}^{\text{N}}, w_{3\delta}e_\delta^{\text{N}+}\right)\right)^2}, \tag{14}$$

$$d^-\left(\Re_i\right) = \sqrt{\sum\nolimits_{\delta=1}^{\kappa_3}\left(d\left(w_{3\delta}e_{i\delta}^{\text{N}}, w_{3\delta}e_\delta^{\text{N-}}\right)\right)^2}. \tag{15}$$

Based on the relative degree of closeness, the second ranking was obtained in descending order as follows:

$$U_2\left(\Re_i\right) = \frac{d^-\left(\Re_i\right)}{d^+\left(\Re_i\right) + d^-\left(\Re_i\right)}. \tag{16}$$

Then, the second ranking result is acquired in ascending order.

(1) The interval type-2 fuzzy full multiplicative form (IT2F-FMF) technique

The IT2F-RP technique described above ensures that the selected alternatives do not acquire the most negative assessment values for all criteria. However, when the $U_1\left(\Re_i\right)$ of any two alternatives is equal, such as $U_1\left(\Re_1\right) = U_1\left(\Re_2\right)$, $\Re_1$ is likely to centralize with the majority of criteria, whereas $\Re_2$ is likely to perform well for some criteria but poorly for others. In this case, the IT2F-RP technique cannot explicitly capture the relationship between $\Re_1$ and $\Re_2$. In general, the full multiplicative form expresses the viewpoint of experts, in which the former is superior to the latter. That is, the negative performances of an alternative cannot be offset by its positive performance. Based on the geometric weighted average operator, the utility values of the IT2F-FMF technique are calculated as follows:

$$U_3\left(\Re_i\right) = \sqrt[\eta]{\prod\nolimits_{\delta=1}^{\eta}\left(1-\left(1-S\left(\tilde{e}_{i\delta}{}^{\text{N}}\right)\right)^{\omega_{3\delta}}\right)} \Big/ \sqrt[\kappa_3-\eta]{\prod\nolimits_{\delta=\eta+1}^{\kappa_3}\left(1-\left(1-S\left(\tilde{e}_{i\delta}{}^{\text{N}}\right)\right)^{\omega_{3\delta}}\right)}, \tag{17}$$

where $S\left(\tilde{e}_{i\delta}{}^{\text{N}}\right)$ is the utility value of $\tilde{e}_{i\delta}{}^{\text{N}}$, and $w_{3\delta}\left(\delta = 1,2,\cdots,\kappa_3\right)$ is the weight of the criteria $\mathbb{C}_{3\delta}\left(\delta = 1,2,\cdots,\kappa_3\right)$. $\mathbb{C}_{3\delta}\left(\delta = 1,2,\cdots,\eta\right)$ is the benefit criterion, and $\mathbb{C}_{3\delta}\left(\delta = \eta+1,\eta+2,\cdots,\kappa_3\right)$ is the cost criterion.

Then, the third ranking result is acquired in descending order.

(2) The final ranking based on the improved Borda Rule

In a previous study (Wu et al., 2018), IT2F-RS, IT2F-RP and IT2F-FMF are regarded as three criteria. Each alternative $\Re_i$ associates with three pairwise assessment values, including $U_\zeta\left(\Re_i\right)\left(\zeta = 1,2,3\right)$ and $L_\zeta\left(\Re_i\right)\left(\zeta = 1,2,3\right)$ of criteria $C_\vartheta\left(\vartheta = 1,2,3\right)$. Therefore, the final ranking can be regarded as a MCDM problem that contains the utility matrix $M\left(U\right) = \left(U_\zeta\left(\Re_i\right)\right)_{t*3}$ (shown in Table 2) and the ranking matrix $M\left(R\right) = \left(L_\zeta\left(\Re_i\right)\right)_{t*3}$ (shown in Table 3).

Table 2. Utility value matrix $M(U)$

Alternatives/ Criteria	IT2F-RS (C_1)	IT2F-RP (C_2)	IT2F-FMF (C_3)
$\Re_1$	$U_1(\Re_1)$	$U_2(\Re_1)$	$U_3(\Re_1)$
$\vdots$	$\vdots$	$\vdots$	$\vdots$
$\Re_i$	$U_1(\Re_i)$	$U_2(\Re_i)$	$U_3(\Re_i)$
$\vdots$	$\vdots$	$\vdots$	$\vdots$
$\Re_t$	$U_1(\Re_t)$	$U_2(\Re_t)$	$U_3(\Re_t)$

Table 3. Ranking matrix $M(L)$

Alternatives/ Criteria	IT2F-RS (C_1)	IT2F-RP (C_2)	IT2F-FMF (C_3)
$\Re_1$	$L_1(\Re_1)$	$L_2(\Re_1)$	$L_3(\Re_1)$
$\vdots$	$\vdots$	$\vdots$	$\vdots$
$\Re_i$	$L_1(\Re_i)$	$L_2(\Re_i)$	$L_3(\Re_i)$
$\vdots$	$\vdots$	$\vdots$	$\vdots$
$\Re_t$	$L_1(\Re_t)$	$L_2(\Re_t)$	$L_3(\Re_t)$

In the classical MULTIMOORA technique and its extensions, dominance theory is applied to aggregate the three subordinate rankings into a final ranking. However, the dominance theory has two shortcomings in actual applications.

(1) It has low computation efficiency because of the pairwise comparison;

(2) It only employs ordinal rankings for aggregation and pays no attention to the $U_\zeta\left(\Re_i\right)\left(\zeta=1,2,3\right)$ of each alternative under each technique.

The Borda Rule (Wu et al., 2018) acquires the overall ranking by aggregating the ordinal numbers of alternatives. However, this also may bias the real ranking because it considers only the ordinal relationships between alternatives. To overcome the shortcomings of dominance theory, the improved Borda Rule was utilized to integrate the assessment values and order relations derived from the three techniques. The improved Borda Rule is superior to dominance theory from the perspective of mathematics because it considers both cardinal assessment values and ordinal rankings. In reality, when the number of alternatives or criteria is relatively large, dominance theory becomes more complicated because of pairwise comparisons and circular reasoning. By contrast, the improved Borda Rule does not require manual comparison. In this study, an improved aggregation function Z_i was developed using a weighted average operator to aggregate the Borda score of alternative $U_\zeta\left(\Re_i\right)\left(\zeta=1,2,3\right)$.

First, the vector normalization of three kinds of $U_\zeta\left(\Re_i\right)\left(\zeta=1,2,3\right)$ is calculated as follows:

$$U_\zeta^{\mathrm{N}}\left(\Re_i\right)=U_\zeta\left(\Re_i\right)\Big/\sqrt{\sum_{i=1}^{t}\left(U_\zeta\left(\Re_i\right)\right)^2}\left(\zeta=1,2,3\right). \tag{18}$$

The final ranking is defined as follows:

$$V_i = \frac{U_1^{N}(\Re_i) * \left(t - L_1(\Re_i)\right) - U_2^{N}(\Re_i) * L_2(\Re_i) + U_3^{N}(\Re_i) * \left(t + 1 - L_3(\Re_i)\right)}{t(t+1)/2},\ i = 1, 2, \cdots, t. \quad (19)$$

4.5. The multi-phase QFD-based IT2F-MULTIMOORA

In this section, the multi-phase QFD-based IT2F-MULTIMOORA technique is proposed to address the SMECR problem with quantitative and qualitative criteria. Let $E_1 = \left[e_{1ij}\right]_{t\times\kappa_1}$, $E_2 = \left[e_{2jp}\right]_{\kappa_1\times\kappa_2}$, and $E_3 = \left[e_{3p\delta}\right]_{\kappa_2\times\kappa_3}$ be the CECR matrix, relationship matrix between the CECR and SCCR criteria, and relationship matrix between the SCCR and SMECR criteria, respectively.

Step 1. Identify the criteria for CECR, SCCR, SMECR and candidate SMEs. Next, we collected the qualitative criterion assessment values of all experts and quantitative criterion assessment values from the financial statements of core enterprises.

Step 2. Convert the quantitative criterion assessment values of the CECR into the corresponding linguistic terms using Definition 4, and build the initial linguistic matrices. $\left(\bar{E}_1\right)^{\eta}$ is the CECR matrix provided by the ηth expert, $\left(\bar{E}_2\right)^{\eta}$ is the relationship matrix between the CECR and SCCR criteria provided by the ηth expert, and $\left(\bar{E}_3\right)^{\eta}$ is the relationship matrix between the SCCR and SMECR criteria.

Step 3. Normalize the $\left(\bar{E}_1\right)^{\eta}$, $\left(\bar{E}_2\right)^{\eta}$, and $\left(\bar{E}_3\right)^{\eta}$. As listed in Table 4, the matrices were normalized using the following Equation:

$$L_{ij} = \begin{cases} L_{ij} & \text{for benefit indicator} \\ \left(L_{ij}\right)^{c} & \text{for cost indicator} \end{cases}, \quad (20)$$

where L_{ij} denotes the linguistic value proposed by experts.

Table 4. Complementary relations

LT	EW	VW	W	M	S	VS	ES
$(LT)^C$	ES	VS	S	M	W	VW	EW

Step 4. The normalized $\left(\bar{E}_1\right)^{\eta}$, $\left(\bar{E}_2\right)^{\eta}$, and $\left(\bar{E}_3\right)^{\eta}$ are input into the IT2FS matrices, and the converted IT2FSs are aggregated based on the weighted average operator to obtain the matrices $E_1 = \left[e_{1ij}\right]_{t\times\kappa_1}$, $E_2 = \left[e_{2jp}\right]_{\kappa_1\times\kappa_2}$, and $E_3 = \left[e_{3p\delta}\right]_{\kappa_2\times\kappa_3}$. Specifically,

$$E_1 = \begin{array}{c} \\ \Re_1 \\ \vdots \\ \Re_i \\ \vdots \\ \Re_t \end{array} \begin{array}{c} \begin{array}{ccccc} \mathbb{C}_{11} & \cdots & \mathbb{C}_{1j} & \cdots & \mathbb{C}_{1\kappa_1} \end{array} \\ \begin{bmatrix} e_{111} & \cdots & e_{11j} & \cdots & e_{11\kappa_1} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ e_{1i1} & \cdots & e_{1ij} & \cdots & e_{1i\kappa_1} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ e_{1t1} & \cdots & e_{1tj} & \cdots & e_{1t\kappa_1} \end{bmatrix} \end{array}; \quad (21)$$

$$E_2 = \begin{array}{c} \mathbb{C}_{11} \\ \vdots \\ \mathbb{C}_{1j} \\ \vdots \\ \mathbb{C}_{1\kappa_1} \end{array} \overset{\begin{array}{ccccc} \mathbb{C}_{21} & \cdots & \mathbb{C}_{2p} & \cdots & \mathbb{C}_{2\kappa_2} \end{array}}{\begin{bmatrix} e_{211} & \cdots & e_{21p} & \cdots & e_{21\kappa_2} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ e_{2j1} & \cdots & e_{2jp} & \cdots & e_{2j\kappa_2} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ e_{2\kappa_1 1} & \cdots & e_{2\kappa_1 p} & \cdots & e_{2\kappa_1\kappa_2} \end{bmatrix}}; \tag{22}$$

$$E_3 = \begin{array}{c} \mathbb{C}_{21} \\ \vdots \\ \mathbb{C}_{2p} \\ \vdots \\ \mathbb{C}_{2\kappa_2} \end{array} \overset{\begin{array}{ccccc} \mathbb{C}_{31} & \cdots & \mathbb{C}_{3\delta} & \cdots & \mathbb{C}_{3\kappa_3} \end{array}}{\begin{bmatrix} e_{311} & \cdots & e_{31\delta} & \cdots & e_{31\kappa_3} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ e_{3p1} & \cdots & e_{3p\delta} & \cdots & e_{3p\kappa_3} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ e_{3\kappa_2 1} & \cdots & e_{3\kappa_2\delta} & \cdots & e_{3\kappa_2\kappa_3} \end{bmatrix}}. \tag{23}$$

In reality, if the weights of experts are not known, the general solution is $\omega_\eta = {}^{1}\!/_{m}$, ($\eta = 1, 2, \cdots m$), and the interval type-2 fuzzy weighted average (IT2F-WA) operator is defined as follows:

$$e_{ij} = IT2F-WA\left(\left(e_{ij}\right)^1, \left(e_{ij}\right)^2, \cdots, \left(e_{ij}\right)^m\right) = \sum\nolimits_{\eta=1}^{m} \omega_\eta \left(e_{ij}\right)^\eta =$$

$$\begin{bmatrix} \left(\sum\nolimits_{\eta=1}^{m} \omega_\eta \left(a_{ij1}^L\right)^\eta, \sum\nolimits_{\eta=1}^{m} \omega_\eta \left(a_{ij2}^L\right)^\eta, \sum\nolimits_{\eta=1}^{m} \omega_\eta \left(a_{ij3}^L\right)^\eta, \sum\nolimits_{\eta=1}^{m} \omega_\eta \left(a_{ij4}^L\right)^\eta; \min\limits_{\eta=1,2,\cdots,m} \left(h_{e_{ij}}^L\right)^\eta\right), \\ \left(\sum\nolimits_{\eta=1}^{m} \omega_\eta \left(a_{ij1}^U\right)^\eta, \sum\nolimits_{\eta=1}^{m} \omega_\eta \left(a_{ij2}^U\right)^\eta, \sum\nolimits_{\eta=1}^{m} \omega_\eta \left(a_{ij3}^U\right)^\eta, \sum\nolimits_{\eta=1}^{m} \omega_\eta \left(a_{ij4}^U\right)^\eta; \min\limits_{\eta=1,2,\cdots,m} \left(h_{e_{ij}}^U\right)^\eta\right) \end{bmatrix}, \tag{24}$$

where $\left(e_{ij}\right)^\eta$ is the corresponding IT2FS presented by the ηth expert.

Step 5. Obtain the SMECR matrix E based on multi-phase QFD using Eq. (5).

$$E = E_1 * E_2 * E_3 = \begin{array}{c} \Re_1 \\ \vdots \\ \Re_i \\ \vdots \\ \Re_t \end{array} \overset{\begin{array}{ccccc} \mathbb{C}_{31} & \cdots & \mathbb{C}_{3\delta} & \cdots & \mathbb{C}_{3\kappa_3} \end{array}}{\begin{bmatrix} \tilde{e}_{11} & \cdots & \tilde{e}_{1\delta} & \cdots & \tilde{e}_{1\kappa_3} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{e}_{i1} & \cdots & \tilde{e}_{i\delta} & \cdots & \tilde{e}_{i\kappa_3} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \tilde{e}_{t1} & \cdots & \tilde{e}_{t\delta} & \cdots & \tilde{e}_{t\kappa_3} \end{bmatrix}}. \tag{25}$$

Step 6. Obtain the weight of SMECR criteria using Eqs (6)–(9).

Step 7. Obtain the normalized matrix $\tilde{\mathrm{E}}^{\mathrm{N}} = \left(\tilde{e}_{i\delta}^{\mathrm{N}}\right)_{t\times\kappa_3}$ $\left(i = 1, 2, \cdots, t; \delta = 1, 2, \cdots, \kappa_3\right)$ using Eq. (10). Calculate $U_1\left(\Re_i\right)$ in descending order using Eq. (11), $U_2\left(\Re_i\right)$ in ascending order using Eqs. (12)–(16), and $U_3\left(\Re_i\right)$ in descending order using Eq. (17).

Step 8. Build the utility value matrix $M(U)$ and ranking matrix $M(L)$. Next, we obtain the final ranking V_i using Eqs (18)–(19).

5. Application for assessing SMECR in supply chain finance

5.1. Case description

This case aims to help financial institutions find prospective SMEs in the supply chain based on the supply chain finance by assessing them against the identified criteria and determining their credit rating. Bank of Communications' supply chain finance platform is comparatively well-developed because it set an early foot in the field of supply chain finance. This platform depends upon the trading data between enterprises and assesses the SMEs based on the core enterprise qualification and supply chain transaction structure, the assessment results from which determine whether loans to SME can be proposed. The R Group on this platform is affiliated with a state-owned manufacturing enterprise and currently enjoys high credit rating. It is among the core enterprises in the supply chain finance. To be clear, the SMEs must be either the core enterprise's suppliers or its buyers. In this case, there are five upstream and downstream SMEs ($\mathfrak{R}_1$, $\mathfrak{R}_2$, $\mathfrak{R}_3$, $\mathfrak{R}_4$, $\mathfrak{R}_5$) proposed by financial institutions.

5.2. Solving the case by the proposed technique

By interviewing experts, some major credit rating criteria were identified as representing the biggest concerns for core enterprises, supply chains and SMEs, as listed in Table 5. According to the requirement of assessing, a committee of four experts $\left(D_1, D_2, D_3, D_4\right)$ from financial institutions and SMEs is built. Among them, two have rich experience in banking and SME lending, and two are from SMEs that have effectively gained access to loans from financial institutions. A fuzzy rating with linguistic terms listed in Table 1 is generated to obtain the experts' subjective judgments. In other words, the experts are required to provide linguistic terms regarding qualitative criteria of $\mathbb{C}_1$, $\mathbb{C}_2$ and $\mathbb{C}_3$. The quantitative values $\mathbb{C}_{11}$ of alternative SMEs are taken from the surveys' financial statements (Source: National enterprise credit information publicity system, https://www.gsxt.gov.cn/index.html). The detail values of $\mathbb{C}_{11}$ are presented in the second row of Table 6. As a result, the initial decision matrices $\left(\bar{E}_1\right)^{\eta}$, $\left(\bar{E}_2\right)^{\eta}$, and $\left(\bar{E}_3\right)^{\eta}$ $(\eta = 1, 2, \cdots 4)$ are established, as listed in Appendix C Table A1–A3. Each criterion of these matrices corresponds to a benefit type; therefore, it is not necessary to perform normalization. And then, the linguistic terms provide by experts are transformed into the corresponding IT2FSs. Based on Definition 4 and Table 1, the $\mathbb{C}_{11}$ of alternative SMEs is then converted into corresponding linguistic terms and IT2FSs, as listed in Table 6. Next, the $\left(\bar{E}_1\right)^{\eta}$, $\left(\bar{E}_2\right)^{\eta}$, and $\left(\bar{E}_3\right)^{\eta}$ $(\eta = 1, 2, \cdots 4)$ are converted into the IT2FS matrices, and the converted matrices are aggregated by the WA operator ($\omega_1 = \omega_2 = \omega_3 = \omega_4 = 1/4$). The aggregated IT2FSs are shown in Appendix D. Meanwhile, the SMECR matrix E is obtained using Eq. (11) ($w_{1j} = 1/5, w_{2p} = 1/5$, $j, p = 1, 2, \cdots, 5$), and the corresponding IT2FSs of the SMECR matrix E are presented in Appendix E. The weights of the SMECR criteria are obtained using Eqs (12)–(15), which is: $w_{31} = 0.1245$ $w_{32} = 0.4998$, $w_{33} = 0.1266$, $w_{34} = 0.1257$, $w_{35} = 0.1233$.

The improved IT2F-MULTIMOORA technique is used to compute the final ranking. Using Eq. (16), the matrix $\tilde{\mathrm{E}}^{\mathrm{N}} = \left(\tilde{e}_{i\delta}^{\mathrm{N}}\right)_{5\times 5}$ $\left(i = 1, 2, \cdots, 5; \delta = 1, 2, \cdots, 5\right)$ is normalized, and the corresponding IT2FSs are presented in Appendix F.

Table 5. Criteria of CECR, SCCR and SMECR

Classification	Criterion	Criterion name	Value type
CE ($\mathbb{C}_1$)	$\mathbb{C}_{11}$	Profit margin on the sales	Quantitative
	$\mathbb{C}_{12}$	Solvency	Qualitative
	$\mathbb{C}_{13}$	Credit condition	Qualitative
	$\mathbb{C}_{14}$	Financial situation	Qualitative
	$\mathbb{C}_{15}$	Market competitiveness	Qualitative
SC ($\mathbb{C}_2$)	$\mathbb{C}_{21}$	Development of the supply chain industry	Qualitative
	$\mathbb{C}_{22}$	Features of the trade products between core enterprise and SME	Qualitative
	$\mathbb{C}_{23}$	Cooperation degree between SME and the core enterprise	Qualitative
	$\mathbb{C}_{24}$	Supply chain industry trends	Qualitative
	$\mathbb{C}_{25}$	SCM performance	Qualitative
SME ($\mathbb{C}_3$)	$\mathbb{C}_{31}$	Credit history	Qualitative
	$\mathbb{C}_{32}$	Product liquidity	Qualitative
	$\mathbb{C}_{33}$	Financial management capability	Qualitative
	$\mathbb{C}_{34}$	Product price stability	Qualitative
	$\mathbb{C}_{35}$	Quality of accounts receivable	Qualitative

Table 6. Convert assessment values of $\mathbb{C}_{11}$ into the linguistic terms

CE	$\mathfrak{R}_1$	$\mathfrak{R}_2$	$\mathfrak{R}_3$	$\mathfrak{R}_4$	$\mathfrak{R}_5$
$\mathbb{C}_{11}$	0.22	0.31	0.25	0.19	0.28
LT	W	ES	M	EW	S
IT2FS	$\begin{bmatrix}(0.1,0.3,0.3,0.5;1),\\(0.2,0.3,0.3,0.4;0.9)\end{bmatrix}$	$\begin{bmatrix}(0.9,1,1,1;1),\\(0.95,1,1,1;0.9)\end{bmatrix}$	$\begin{bmatrix}(0.3,0.5,0.5,0.7;1),\\(0.4,0.5,0.5,0.6;0.9)\end{bmatrix}$	$\begin{bmatrix}(0,0,0,0.1;1),\\(0,0,0,0.05;0.9)\end{bmatrix}$	$\begin{bmatrix}(0.5,0.7,0.7,0.9;1),\\(0.6,0.7,0.7,0.8;0.9)\end{bmatrix}$

The ranking result $U_1(\mathfrak{R}_i)$ was then calculated in descending order using Eq. (17), which is expressed as follows:

$$U_1(\mathfrak{R}_1)=\begin{bmatrix}(0.0501,0.1590,0.1591,0.3603;1),\\(0.0944,0.1590,0.1591,0.2462;0.9)\end{bmatrix},\ U_1(\mathfrak{R}_2)=\begin{bmatrix}(0.0504,0.1528,0.1528,0.3447;1),\\(0.0923,0.1528,0.1528,0.2361;0.9)\end{bmatrix},$$

$$U_1(\mathfrak{R}_3)=\begin{bmatrix}(0.0399,0.1296,0.1296,0.3145;1),\\(0.0762,0.1296,0.1296,0.2085;0.9)\end{bmatrix},\ U_1(\mathfrak{R}_4)=\begin{bmatrix}(0.0281,0.1013,0.1013,0.2623;1),\\(0.0571,0.1013,0.1013,0.1692;0.9)\end{bmatrix},$$

$$U_1(\mathfrak{R}_5)=\begin{bmatrix}(0.0401,0.1379,0.1379,0.3373;1),\\(0.0794,0.1379,0.1379,0.2232;0.9)\end{bmatrix}.$$

Using Eq. (10), the $S(U_1(\mathfrak{R}_i))$ of $U_1(\mathfrak{R}_i)$ are: $U_1(\mathfrak{R}_1)=0.1650$, $U_1(\mathfrak{R}_2)=0.1585$, $U_1(\mathfrak{R}_3)=0.1375$, $U_1(\mathfrak{R}_4)=0.1095$, and $U_1(\mathfrak{R}_5)=0.1462$, and the first ranking is acquired as follows: $U_1(\mathfrak{R}_1)\succ U_1(\mathfrak{R}_2)\succ U_1(\mathfrak{R}_5)\succ U_1(\mathfrak{R}_3)\succ U_1(\mathfrak{R}_4)$.

Using Eqs (18)–(22), the $S\left(U_2\left(\Re_i\right)\right)$ of $U_2\left(\Re_i\right)$ are: $U_2\left(\Re_1\right)=1.0000$, $U_2\left(\Re_2\right)=0.8973$, $U_2\left(\Re_3\right)=0.5721$, $U_2\left(\Re_4\right)=0.0000$, and $U_2\left(\Re_5\right)=0.7295$, and the second ranking is acquired as follows: $U_2\left(\Re_4\right)\prec U_2\left(\Re_3\right)\prec U_2\left(\Re_5\right)\prec U_2\left(\Re_2\right)\prec U_2\left(\Re_1\right)$.

By Eq. (23), the $S\left(U_3\left(\Re_i\right)\right)$ of $U_3\left(\Re_i\right)$ are: $U_3\left(\Re_1\right)=0.0291$, $U_3\left(\Re_2\right)=0.2796$, $U_3\left(\Re_3\right)=0.2403$, $U_3\left(\Re_4\right)=0.1881$, and $U_3\left(\Re_5\right)=0.0257$, and the third ranking is acquired as follows: $U_3\left(\Re_2\right)\succ U_3\left(\Re_3\right)\succ U_3\left(\Re_4\right)\succ U_3\left(\Re_1\right)\succ U_3\left(\Re_5\right)$.

On this basis, the matrices $M(U)$ and $M(L)$ were built, as listed in Table 7. Using Eqs (24)–(25), the final ranking V_i is: $V_1=0.0805$, $V_2=0.0878$, $V_3=0.0679$, $V_4=0.0452$, and $V_5=-0.0125$. In other words, $V_2\succ V_1\succ V_3\succ V_4\succ V_5$ and financial institutions provide loans to SME $\Re_2$.

Table 7. $M(U)$ and $M(L)$

Alternatives/ Criteria	IT2F-RS (C_1)		IT2F-RP (C_2)		IT2F-FMF (C_3)	
$\Re_1$	0.1650	1	1.0000	5	0.0291	4
$\Re_2$	0.1585	2	0.8973	4	0.2796	1
$\Re_3$	0.1375	4	0.5721	2	0.2403	2
$\Re_4$	0.1095	5	0.0000	1	0.1881	3
$\Re_5$	0.1462	3	0.7295	3	0.0257	5

In a real SMECR assessment, financial institutions emphasize product liquidity in the SC to take back loans on time. As a manufacturing enterprise, SME V_4 has good product liquidity, an impeccable credit history, favorable financial management capability, better product price stability, and excellent accounts receivable quality. Experts expressed higher satisfaction with these SMEs. Therefore, the theoretical analysis therefore aligns with the real SMECR assessment practice.

5.3. Sensitivity analysis

A sensitivity analysis was performed to investigate the effects of fluctuations in criteria weight on the final rankings. To identify the most sensitive criterion for this case, referring to the standard method (Triantaphyllou, 2000), a sensitivity analysis was conducted as follows:

Let $Q_{x,y,\varphi}$ denote the minimum change in the weight $w_{3\varphi}$ of the criterion $\mathbb{C}_{3\varphi}$, which may generate the ranking of SMEs $\Re_x$ and $\Re_y$ to be reversed ($1\le x<y\le 5$ and $1\le\varphi\le 5$). The changes in the relative term can be defined as follows:

$$\tilde{Q}_{x,y,\varphi}=Q_{x,y,\varphi}\times\frac{100}{w_{3\varphi}}. \tag{26}$$

In this case, the changes in the ranking of any SME are investigated; that is, the percentany critical criterion is applied to denote the criterion with the corresponding minimum value $\left|\tilde{Q}_{x,y,\varphi}\right|$.

Let F_φ denote the criticality degree of criterion $\mathbb{C}_{3\varphi}$, which signifies the minimum percentage when the value of $w_{3\varphi}$ fluctuates, the corresponding ranking of SMEs will be changed as follows:

$$F_{\varphi} = \min_{1 \le x < y \le 5} \left\{ \left| \tilde{Q}_{x,y,\varphi} \right| \right\}, \text{ for all } 1 \le \varphi \le 5. \quad (27)$$

Let Z_{φ} denote the sensitivity coefficient of $\mathbb{C}_{3\varphi}$, which signifies the reciprocal of criticality degree as follows:

$$Z_{\varphi} = \frac{1}{F_{\varphi}}, \text{ for all } 1 \le \varphi \le 5. \quad (28)$$

Triantaphyllou (2000) obtained the value of $Q_{x,y,\varphi}$ using AHP and the weighted product technique. However, the proposed technique is IT2FS-MULTIMOORA with three sub-techniques. The data are denoted as IT2FS, rather than as definite data. Therefore, the derivations proposed by Triantaphyllou (2000) are not applicable to the proposed technique. By dynamically setting the values of the weight vector, Table 8 can be obtained.

Table 8. All possible values of $\tilde{Q}_{x,y,\varphi}$

Pair of SMEs	$\mathbb{C}_{31}$	$\mathbb{C}_{32}$	$\mathbb{C}_{33}$	$\mathbb{C}_{34}$	$\mathbb{C}_{35}$
$\mathfrak{R}_1$–$\mathfrak{R}_2$	159.48	N/F	–126.58	98.27	N/F
$\mathfrak{R}_1$–$\mathfrak{R}_3$	N/F	25.90	N/F	77.38	N/F
$\mathfrak{R}_1$–$\mathfrak{R}_4$	N/F	86.95	N/F	–69.53	N/F
$\mathfrak{R}_1$–$\mathfrak{R}_5$	–119.86	N/F	148.39	N/F	119.54
$\mathfrak{R}_2$–$\mathfrak{R}_3$	N/F	–77.49	139.64	N/F	86.96
$\mathfrak{R}_2$–$\mathfrak{R}_4$	127.35	100.03	N/F	N/F	N/F
$\mathfrak{R}_2$–$\mathfrak{R}_5$	108.70	N/F	–155.74	–76.19	N/F
$\mathfrak{R}_3$–$\mathfrak{R}_4$	130.53	94.29	183.49	50.76	153.78
$\mathfrak{R}_3$–$\mathfrak{R}_5$	N/F	–99.57	N/F	–86.67	–139.50
$\mathfrak{R}_4$–$\mathfrak{R}_5$	111.44	N/F	N/F	N/F	102.69

Note: Non-feasible (N/F) means that the fluctuation in weight does not affect the rankings.

As listed in Table 9, the percent-any critical criterion can be produced by the minimum value of $\tilde{Q}_{x,y,\varphi}$, i.e., $\tilde{Q}_{x,y,\varphi}$. It can be concluded that the percent-any critical criterion is $\tilde{Q}_{1,3,2}$. According to Eq. (27), the criticality degree of $\mathbb{C}_{3\varphi}$ are $F_1 = 108.70$, $F_2 = 25.90$, $F_3 = 126.58$, $F_4 = 50.76$ and $F_5 = 86.96$. The sensitivity coefficients of $\mathbb{C}_{3\varphi}$ are: $Z_1 = 0.0092$, $Z_2 = 0.0386$, $Z_3 = 0.0079$, $Z_4 = 0.0197$ and $Z_5 = 0.0115$. Correspondingly, the sensitivity ranking of $\mathbb{C}_{3\varphi}$ was: $\mathbb{C}_{32} > \mathbb{C}_{34} > \mathbb{C}_{35} > \mathbb{C}_{31} > \mathbb{C}_{33}$. The most sensitive criterion is $\mathbb{C}_{32}$. In other words, even if the weight of product liquidity fluctuates slightly during the calculation, it can affect the final ranking of SMEs.

5.4. Comparative analysis

In general, the ration system and FMF belong to the value measurement technique, whereas the reference point falls within the goal or reference-level techniques. Therefore, to demonstrate the availability and superiority of the proposed technique, related techniques were compared with this technique. The WASPAS (Ghorabaee et al., 2016), TOPSIS (Yiilmaz & Polat, 2023), VIKOR (Meniz & Özkan, 2023), and traditional MULTIMOORA (Qin & Ma, 2022) are applied to the same case described in above. Table 9 shows the characteristics of mentioned techniques. And the comparison results of ranking are shown in Table 10. To ensure consistency, a distance measure based on Eq. (9) and the expected value function based on Eq. (10) are used to determine the distance between the IT2FSs and the expected value of the IT2FS.

It can be seen from Table 10 that the rankings produced by the five techniques are different. Among the rankings acquired by the above five techniques, those of $\Re_1$ and $\Re_2$ were higher than those of $\Re_3$, $\Re_4$ and $\Re_5$, which verified the applicable of the proposed technique. The main reason for these differences is that the proposed utility value-based ranking technique differs from the normalization technique and aggregation formulas, as listed in Table 10. In reality, some discrepancies may be regarded as common phenomena because the proposed technique collaborates with more ranking techniques and ranking information. Because of its intrinsic nature, it should provide more reasonable and precise ranking results. Furtherly, these specific differences can be explained by the following analysis.

WASPAS is the simplest technique which merely applies an arithmetic formula to aggregate the linear normalization values of $\tilde{e}_{i\delta}$. This provides objective ranking results for cases in which the assessment values are uniform in the initial matrix. Nevertheless, compared with the proposed technique, when experts provided extreme assessment values for the most significant criteria, extreme changes occurred in the assessment values of the weighted linear

Table 9. Characteristics of mentioned techniques

Techniques	Normalization	Aggregation function	Integration theory
IT2F-WASPAS	Linear	Arithmetic	–
IT2F-TOPSIS	Vector	Arithmetic	Addition
IT2F-VIKOR	Linear	Arithmetic, max	Compromise
Traditional IT2F-MULTIMOOR	Vector	Arithmetic, max, geometry	Dominate
The proposed technique	Linear, vector	Arithmetic, max, geometry	Enhanced Borda Rule, positive ideal point and negative ideal point

Table 10. Rankings of mentioned techniques

Techniques	Ranking values	Ranking orders
IT2F-WASPAS	$V_1^1 = 0.1647,\ V_2^1 = 0.1585, V_3^1 = 0.1375,$ $V_4^1 = 0.1095,\ V_5^1 = 0.1462$	$V_1^1 \succ V_2^1 \succ V_5^1 \succ V_3^1 \succ V_4^1$
IT2F-TOPSIS	$V_1^2 = 1.0000,\ V_2^2 = 0.8973, V_3^2 = 0.5721,$ $V_4^2 = 0.0000,\ V_5^2 = 0.7295$	$V_1^2 \succ V_2^2 \succ V_5^2 \succ V_3^2 \succ V_4^2$
IT2F-VIKOR	$V_1^3 = 0.0172, V_2^3 = 0.0168, V_3^3 = 0.0152,$ $V_4^3 = 0.0131,\ V_5^3 = 0.0160$	$V_1^3 \succ V_2^3 \succ V_5^3 \succ V_3^3 \succ V_4^3$
Traditional IT2F-MULTIMOOR	$V_1^3 = 0.0625, V_2^3 = 0.0614, V_3^3 = 0.0445,$ $V_4^3 = 0.0295,\ V_5^3 = 0.0526$	$V_1^4 \succ V_2^4 \succ V_5^4 \succ V_3^4 \succ V_4^4$
The proposed technique	$V_1 = 0.0805,\ V_2 = 0.0878,\ V_3 = 0.0679,$ $V_4 = 0.0452,\ V_5 = -0.0125$	$V_2 \succ V_1 \succ V_3 \succ V_4 \succ V_5$

functions occur. This may generate a disproportionate increase in the assessment values of the SME criteria. This situation is most often a consequence of the linear character of the weighted linear functions in the WASPAS technique.

TOPSIS calculates the distance from each SME to the positive ideal point and the distance to the negative ideal point to calculate the utility values using the average addition formula. However, compared with the proposed technique, it suffers from two remarkable limitations in actual applications: (1) the insignificance of the rankings in the context of complicated information (rankings of SMEs may differ from possible transformations of the initial preference values), and (2) rank reversals or ranking irregularities (the ranking result of SMEs may change when a new SME is added to the candidate SMEs or a previous SME is removed). In other words, TOPSIS magnifies the difference and weakens the impact of the total utility value. A possible cause of the different rankings of $\mathfrak{R}_1$ and $\mathfrak{R}_2$ is that the total utility value of $\mathfrak{R}_1$ is small; however, the distribution of linguistic terms is more uniform. When focusing on the distance between PLTSs, $\mathfrak{R}_2$ was more concentrated in expressions than $\mathfrak{R}_1$. The utility value of $\mathfrak{R}_2$ becomes higher than that of $\mathfrak{R}_1$ by applying the TOPSIS.

VIKOR takes advantage of the compromise theory to provide an optimal compromise solution on the basis of the group utility values calculated by the arithmetic technique and the individual utility values calculated by the max technique. However, compared with the proposed technique, it is difficult in the actual applications to acquire the reasonable ranking result of all SMEs because of the complex relative between the group utility values and individual utility values. In addition, the integrated utility values are sensitive to the relative importance of two subordinate utility values, which causes this technique with less robust. Meanwhile, when ε = 0.7, the ranking becomes $V_2^3 \succ V_1^3 \succ V_3^3 \succ V_4^3 \succ V_5^3$, which is consistent with proposed technique. The ranking displays that the proposed technique is valid to some degree. The VIKOR cannot acquire the unique best solution, however, it can acquire the set of compromise solutions. It may be because the presence of parameter ε weakens the original information and results in an inability to obtain a reliable ranking by applying VIKOR.

Traditional IT2F-MULTIMOORA uses the dominance theory to aggregate the three subordinate rankings into a final ranking. However, subordinate rankings are referred to by dominance theory, and their utility values are completely overlooked. In other words, it does not consider the utility values of SMEs and the consistency of the rankings of the three techniques. Meanwhile, the dominance theory fails with a large number of SMEs because of a complex pairwise comparison. Moreover, this technique only focuses on the distance from the SMEs to the positive ideal point, but loses sight of the distance from the SMEs to the negative ideal point. In reality, if the SMEs are at an equal distance from positive ideal point, they cannot effectively assess or rank them. That is, it maintains a less positive aspect of aggregating the rankings from the three aggregation techniques. In addition, the enhanced Borda Rule improves the stability and applicability of the proposed technique by applying subordinate utility values and rankings. The proposed reference point technique focuses on both positive and negative ideal point; subsequently, the potential solutions constrain and compensate for each other. This is much less likely than using a traditional reference point to obtain extreme values. In other words, the proposed technique has some advantages in terms of normalization, aggregation function and integration theory, which are more consistent with actual SMECR assessment practice.

Furthermore, compared to these existing techniques, the proposed technique offers significant advantages that is not included in other existing literature: (1) The existing IT2F-MULTIMOORA techniques can solve decision-making problems in which the assessment values are represented as IT2FSs. The proposed conversion function, which converts the quantitative criteria assessment values to the corresponding IT2FSs, can help address SMECR problems with quantitative and qualitative information. (2) The multi-phase QFD model was used to establish a bridge between the criteria of CECR, SCCR, and SMECR. Specifically, it can be applied to translate the credit rating information of core enterprises into one of the supply chains, and then translate the credit rating information of the supply chains into a SME. Therefore, the multi-phase QFD model ensures that credit rating information of the corresponding core enterprises and supply chains is incorporated into the SMECR model. Consequently, it can largely compensate for the assessment of information deficiencies in the traditional SMECR model.

In summary, the proposed technique has been improved significantly compared with other techniques, and the ranking is more reliable. In other words, the proposed technique provided a useful reference for financial institutions to make final credit decisions.

5.5. Managerial implications

To resolve the financing difficulty problem of SMEs, some important suggestions based on the above analysis results are as follows:

(1) SMECR is essentially elicited by the asymmetry of information between the SME and the core enterprise. As a result, it is necessary to collect as much information as possible from various channels to completely characterize SMEs and improve the performance of SMECR. Furthermore, the supply chain finance platform has more information than SMEs and core enterprises, and it is necessary to build an information platform to assess SMECR in supply chain finance.

(2) Organizational models are needed to constantly realign based on the multiple channel information of SME credit because this study shows that the sustainability and stability of SMEs are crucial factors for core enterprises to make loan decisions and not just depend on financial-based data. Moreover, to attract more attention from core enterprise, more attention should be paid to core market capabilities, commercial prestige and profitability.

(3) SME's financial competency assures their solvency, which also relates directly to the sustainability and stability of the supply chain finance system. As a consequence, for developing and constructing financial competencies of SMEs, creating a multiple-channel supply chain finance service platform may also be one of the primary measures to give SMEs a boost.

6. Conclusions and future directions

Assessing SMECR in supply chain finance has become a crucial issue because financial institutions must decide whether to loan to an SME that collaborates with a core enterprise and applies for supply chain finance. In this study, the IT2FS can precisely handle high-order ambiguity and uncertainty, and some formulas have been developed to convert quantitative assessment values to IT2FSs and a hybrid MCDM technique with quantitative and qualitative criteria called multi-phase QFD-based IT2F-MULTIMOORA is proposed to improve the performance in assessing the SMECR in supply chain finance. According to the case study, the proposed technique outperformed the four existing techniques. Therefore, because of the complexity of the SMECR problem, a comprehensive technique that can generate competitive is proposed.

Compared with previous techniques, the proposed technique has several advantages. For example, the developed multi-phase QFD model can ensure that the credit rating information of the corresponding core enterprises and supply chains can be incorporated into the SMECR model. The enhanced MULTIMOORA with the new reference point technique and improved Borda Rule can propose a compromise improvement scheme for ranking SMECR. The proposed multi-phase QFD-based IT2F-MULTIMOORA technique can more accurately and reasonably assess the SMECR in supply chain finance. The transformation function can help address SMECR problems using quantitative and qualitative information.

This study has some limitations, particularly regarding application problems. Future suggestions can include seeking cooperation with financial institutions to investigate the main influential factors of difficult SME financing problems and studying the application of the multi-phase QFD model in real cases in combination with the current situation of SME. This can also be extended by considering two other subsystems, (IT2F-RS and IT2F-FMF), to make the IT2F-MULTIMOORA technique more robust. Another suggestion for future work is to combine the proposed technique with different assessment-expressing models to apply it widely. Additionally, this technique can be applied to other areas that present MCDM problems related to the assessment of alternatives, including inventory risk, product design, and service quality.

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APPENDIX

Appendix A

Definition A1 (Li et al., 2024)

Let $\tilde{A}_1 = \left(\tilde{A}_1^L, \tilde{A}_1^U\right) = \left[\left(\alpha_{11}^L, \alpha_{12}^L, \alpha_{13}^L, \alpha_{14}^L; h_{\tilde{A}}^L\right), \left(\alpha_{11}^U, \alpha_{12}^U, \alpha_{13}^U, \alpha_{14}^U; h_{\tilde{A}}^U\right)\right]$

and $\tilde{A}_2 = \left(\tilde{A}_2^L, \tilde{A}_2^U\right) = \left[\left(\alpha_{21}^L, \alpha_{22}^L, \alpha_{23}^L, \alpha_{24}^L; h_{\tilde{A}_2}^L\right), \left(\alpha_{21}^U, \alpha_{22}^U, \alpha_{23}^U, \alpha_{24}^U; h_{\tilde{A}_2}^U\right)\right]$

be any two IT2FSs, then the arithmetic operations between $\tilde{A}_1$ and $\tilde{A}_2$ are defined as:

$$\tilde{A}_1 \oplus \tilde{A}_2 = \begin{bmatrix} \left(\alpha_{11}^L + \beta_{21}^L, \alpha_{12}^L + \beta_{22}^L, \alpha_{13}^L + \beta_{23}^L, \alpha_{14}^L + \beta_{24}^L; \min\left\{h_{\tilde{A}_1}^L, h_{\tilde{A}_2}^L\right\}\right), \\ \left(\alpha_{11}^U + \beta_{21}^U, \alpha_{12}^U + \beta_{22}^U, \alpha_{13}^U + \beta_{23}^U, \alpha_{14}^U + \beta_{24}^U; \min\left\{h_{\tilde{A}_1}^U, h_{\tilde{A}_2}^U\right\}\right) \end{bmatrix}; \tag{1}$$

$$\tilde{A}_1 \otimes \tilde{A}_2 = \left[\left(\alpha_{11}^L\beta_{21}^L, \alpha_{12}^L\beta_{22}^L, \alpha_{13}^L\beta_{23}^L, \alpha_{14}^L\beta_{24}^L; \min\left\{h_{\tilde{A}_1}^L, h_{\tilde{A}_2}^L\right\}\right),\right.$$
$$\left.\left(\alpha_{11}^U\beta_{21}^U, \alpha_{12}^U\beta_{22}^U, \alpha_{13}^U\beta_{23}^U, \alpha_{14}^U\beta_{24}^U; \min\left\{h_{\tilde{A}_1}^U, h_{\tilde{A}_2}^U\right\}\right)\right]; \tag{2}$$

$$\chi\tilde{A}_1 = \left[\left(\chi\alpha_{11}^L, \chi\alpha_{12}^L, \chi\alpha_{13}^L, \chi\alpha_{14}^L; h_{\tilde{A}_1}^L\right), \left(\chi\alpha_{11}^U, \chi\alpha_{12}^U, \chi\alpha_{13}^U, \chi\alpha_{14}^U; h_{\tilde{A}_1}^U\right)\right], \chi \geq 0; \tag{3}$$

$$\tilde{A}_1^{\chi} = \left[\left(\left(\alpha_{11}^L\right)^{\chi}, \left(\alpha_{12}^L\right)^{\chi}, \left(\alpha_{13}^L\right)^{\chi}, \left(\alpha_{14}^L\right)^{\chi}; h_{\tilde{A}_1}^L\right), \left(\left(\alpha_{11}^U\right)^{\chi}, \left(\alpha_{12}^U\right)^{\chi}, \left(\alpha_{13}^U\right)^{\chi}, \left(\alpha_{14}^U\right)^{\chi}; h_{\tilde{A}_1}^U\right)\right], \chi \geq 0. \tag{4}$$

Definition A2 (Hernandez et al., 2022)

Let $\tilde{A}_1 = \left(\tilde{A}_1^L, \tilde{A}_1^U\right) = \left[\left(\alpha_{11}^L, \alpha_{12}^L, \alpha_{13}^L, \alpha_{14}^L; h_{\tilde{A}_1}^L\right), \left(\alpha_{11}^U, \alpha_{12}^U, \alpha_{13}^U, \alpha_{14}^U; h_{\tilde{A}_1}^U\right)\right]$ and $\tilde{A}_2 = \left(\tilde{A}_2^L, \tilde{A}_2^U\right) = \left[\left(\alpha_{21}^L, \alpha_{22}^L, \alpha_{23}^L, \alpha_{24}^L; h_{\tilde{A}_2}^L\right), \left(\alpha_{21}^U, \alpha_{22}^U, \alpha_{23}^U, \alpha_{24}^U; h_{\tilde{A}_2}^U\right)\right]$ be two any IT2FSs, then the distance measure based on the extend vertex technique between $\tilde{A}_1$ and $\tilde{A}_2$ are defined as:

$$d\left(\tilde{A}_1, \tilde{A}_2\right) = \sqrt{\frac{1}{8}\left(\begin{array}{l} \left(\alpha_{11}^L - \alpha_{21}^L\right)^2 + \left(\alpha_{12}^L - \alpha_{22}^L\right)^2 + \left(\alpha_{13}^L - \alpha_{23}^L\right)^2 + \left(\alpha_{14}^L - \alpha_{24}^L\right)^2 + \left(\alpha_{11}^U - \alpha_{21}^U\right)^2 + \left(\alpha_{12}^U - \alpha_{22}^U\right)^2 \\ + \left(\alpha_{13}^U - \alpha_{23}^U\right)^2 + \left(\alpha_{14}^U - \alpha_{24}^U\right)^2 + 2\left(h_{\tilde{A}_1}^L - h_{\tilde{A}_2}^L\right)^2 + 2\left(h_{\tilde{A}_1}^U - h_{\tilde{A}_2}^U\right)^2 \end{array}\right)}. \tag{5}$$

Definition A3 (Hernandez et al., 2022)

Let $\tilde{A} = \left(\tilde{A}^L, \tilde{A}^U\right) = \left[\left(\alpha_1^L, \alpha_2^L, \alpha_3^L, \alpha_4^L; h_{\tilde{A}}^L\right), \left(\alpha_1^U, \alpha_2^U, \alpha_3^U, \alpha_4^U; h_{\tilde{A}}^U\right)\right]$ be an IT2FS.

Then, the expected value is:

$$S_{\tilde{A}} = \frac{1}{16}\left(h_{\tilde{A}}^L + h_{\tilde{A}}^U\right)\left(\alpha_1^L + \alpha_2^L + \alpha_3^L + \alpha_4^L + \alpha_1^U + \alpha_2^U + \alpha_3^U + \alpha_4^U\right). \tag{6}$$

For any two IT2FSs $\tilde{A}_1$ and $\tilde{A}_2$, if $S_{\tilde{A}_1} > S_{\tilde{A}_2}$, then $\tilde{A}_1 > \tilde{A}_2$.

Appendix B

The detailed procedures of classic MULTIMOORA:

Step 1. Acquire the dimensionless value $\overline{e}_{ij}$ as:

$$\overline{e}_{ij} = e_{ij} \Big/ \sum_{i=1}^{t} \left(e_{ij}\right)^2. \tag{7}$$

Step 2. Acquire the first subordinate ranking in descending order of utility values $\tilde{\theta}_1\left(\mathfrak{R}_i\right)$ using the ration system technique as:

$$\tilde{\theta}_1\left(\mathfrak{R}_i\right) = \sum_{j=1}^{\gamma} \overline{e}_{ij} - \sum_{j=\gamma+1}^{\kappa} \overline{e}_{ij}. \tag{8}$$

Step 3. Acquire the second subordinate ranking in ascending order of $\tilde{\theta}_2\left(\mathfrak{R}_i\right)$ by the reference point technique, which based on the maximum distance between the maximum value $\overline{e}_j^{\,+}$ of each criterion and the associate assessments of the alternative, as:

$$\tilde{\theta}_2\left(\mathfrak{R}_i\right) = \max_j \left|\overline{e}_j^{\,+} - \overline{e}_{ij}\right| \text{ where } \overline{e}_j^{\,+} = \max_i \overline{e}_{ij}. \tag{9}$$

Step 4. Acquire the third subordinate ranking in descending order of $\tilde{\theta}_3\left(\mathfrak{R}_i\right)$ by the full multiplicative form technique as:

$$\tilde{\theta}_3\left(\mathfrak{R}_i\right) = \prod_{j=1}^{\gamma} \overline{e}_{ij} \Big/ \prod_{j=\gamma+1}^{\kappa} \overline{e}_{ij}. \tag{10}$$

Step 5. Integrate the three subordinate rankings into a comprehensive ranking by the dominance theory and acquire the final ranking of $\mathfrak{R}_i\left(i = 1, 2, \cdots, t\right)$.

Appendix C

Table A1. Linguistic matrix $\overline{E}_1$ proposed by experts

*D*1						*D*$_2$					
$\mathfrak{R}_i / \mathbb{C}_1$j	$\mathbb{C}_{11}$	$\mathbb{C}_{12}$	$\mathbb{C}_{13}$	$\mathbb{C}_{14}$	$\mathbb{C}_{15}$	$\mathfrak{R}_i / \mathbb{C}_{1j}$	$\mathbb{C}_{11}$	$\mathbb{C}_{12}$	$\mathbb{C}_{13}$	$\mathbb{C}_{14}$	$\mathbb{C}_{15}$
$\mathfrak{R}_1$	0.22	W	VW	ES	M	$\mathfrak{R}_1$	0.22	ES	VS	ES	EW
$\mathfrak{R}_2$	0.31	S	VS	S	W	$\mathfrak{R}_2$	0.31	EW	M	W	W
$\mathfrak{R}_3$	0.25	VW	EW	M	VW	$\mathfrak{R}_3$	0.25	VS	VW	VW	ES
$\mathfrak{R}_4$	0.19	W	M	W	W	$\mathfrak{R}_4$	0.19	W	W	S	W
$\mathfrak{R}_5$	0.28	EW	S	VW	M	$\mathfrak{R}_5$	0.28	VW	VS	EW	M
D$_3$						*D*$_4$					
$\mathfrak{R}_i / \mathbb{C}_{1j}$	$\mathbb{C}_{11}$	$\mathbb{C}_{12}$	$\mathbb{C}_{13}$	$\mathbb{C}_{14}$	$\mathbb{C}_{15}$	$\mathfrak{R}_i / \mathbb{C}_{1j}$	$\mathbb{C}_{11}$	$\mathbb{C}_{12}$	$\mathbb{C}_{13}$	$\mathbb{C}_{14}$	$\mathbb{C}_{15}$
$\mathfrak{R}_1$	0.22	W	ES	VS	VW	$\mathfrak{R}_1$	0.22	M	S	W	VS
$\mathfrak{R}_2$	0.31	ES	EW	M	W	$\mathfrak{R}_2$	0.31	VW	EW	M	M
$\mathfrak{R}_3$	0.25	VW	VW	VS	VS	$\mathfrak{R}_3$	0.25	S	W	VS	EW
$\mathfrak{R}_4$	0.19	VS	VW	M	EW	$\mathfrak{R}_4$	0.19	ES	EW	M	M
$\mathfrak{R}_5$	0.28	W	VS	ES	W	$\mathfrak{R}_5$	0.28	M	W	VW	W

Table A2. Linguistic matrix $\overline{E}_2$ proposed by experts

D_1						D_2					
$\mathbb{C}_{1j}/\mathbb{C}_{2p}$	$\mathbb{C}_{21}$	$\mathbb{C}_{22}$	$\mathbb{C}_{23}$	$\mathbb{C}_{24}$	$\mathbb{C}_{25}$	$\mathbb{C}_{1j}/\mathbb{C}_{2p}$	$\mathbb{C}_{21}$	$\mathbb{C}_{22}$	$\mathbb{C}_{23}$	$\mathbb{C}_{24}$	$\mathbb{C}_{25}$
$\mathbb{C}_{11}$	VW	M	VS	EW	W	$\mathbb{C}_{11}$	EW	ES	W	W	ES
$\mathbb{C}_{12}$	VS	EW	W	VW	S	$\mathbb{C}_{12}$	VS	M	VW	EW	M
$\mathbb{C}_{13}$	VW	VW	S	M	ES	$\mathbb{C}_{13}$	S	W	VW	S	M
$\mathbb{C}_{14}$	EW	M	W	VW	S	$\mathbb{C}_{14}$	W	M	VW	M	ES
$\mathbb{C}_{15}$	M	VW	W	ES	VS	$\mathbb{C}_{15}$	S	ES	S	VS	EW
D_3						D_4					
$\mathbb{C}_{1j}/\mathbb{C}_{2p}$	$\mathbb{C}_{21}$	$\mathbb{C}_{22}$	$\mathbb{C}_{23}$	$\mathbb{C}_{24}$	$\mathbb{C}_{25}$	$\mathbb{C}_{1j}/\mathbb{C}_{2p}$	$\mathbb{C}_{21}$	$\mathbb{C}_{22}$	$\mathbb{C}_{23}$	$\mathbb{C}_{24}$	$\mathbb{C}_{25}$
$\mathbb{C}_{11}$	W	EW	EW	VW	W	$\mathbb{C}_{11}$	EW	S	ES	VS	M
$\mathbb{C}_{12}$	S	M	VS	W	VS	$\mathbb{C}_{12}$	VS	W	EW	M	S
$\mathbb{C}_{13}$	S	ES	EW	VW	M	$\mathbb{C}_{13}$	M	VS	M	VW	M
$\mathbb{C}_{14}$	W	EW	M	S	VW	$\mathbb{C}_{14}$	VW	S	S	EW	M
$\mathbb{C}_{15}$	M	VS	ES	VS	W	$\mathbb{C}_{15}$	VS	W	EW	VW	S

Table A3. Linguistic matrix $\overline{E}_3$ proposed by experts

D_1						D_2					
$\mathbb{C}_{2p}/\mathbb{C}_{3\delta}$	$\mathbb{C}_{31}$	$\mathbb{C}_{32}$	$\mathbb{C}_{33}$	$\mathbb{C}_{34}$	$\mathbb{C}_{35}$	$\mathbb{C}_{2p}/\mathbb{C}_{3\delta}$	$\mathbb{C}_{31}$	$\mathbb{C}_{32}$	$\mathbb{C}_{33}$	$\mathbb{C}_{34}$	$\mathbb{C}_{35}$
$\mathbb{C}_{21}$	VW	VS	ES	W	VW	$\mathbb{C}_{21}$	M	VS	VS	S	M
$\mathbb{C}_{22}$	M	M	S	EW	S	$\mathbb{C}_{22}$	ES	EW	M	W	W
$\mathbb{C}_{23}$	W	VS	EW	M	VW	$\mathbb{C}_{23}$	M	S	VS	S	W
$\mathbb{C}_{24}$	M	VW	ES	W	W	$\mathbb{C}_{24}$	W	W	VW	M	VS
$\mathbb{C}_{25}$	EW	M	S	VS	VS	$\mathbb{C}_{25}$	S	S	EW	W	VW
D_3						D_4					
$\mathbb{C}_{2p}/\mathbb{C}_{3\delta}$	$\mathbb{C}_{31}$	$\mathbb{C}_{32}$	$\mathbb{C}_{33}$	$\mathbb{C}_{34}$	$\mathbb{C}_{35}$	$\mathbb{C}_{2p}/\mathbb{C}_{3\delta}$	$\mathbb{C}_{31}$	$\mathbb{C}_{32}$	$\mathbb{C}_{33}$	$\mathbb{C}_{34}$	$\mathbb{C}_{35}$
$\mathbb{C}_{21}$	ES	S	VW	VS	W	$\mathbb{C}_{21}$	ES	W	VS	S	S
$\mathbb{C}_{22}$	M	W	W	M	S	$\mathbb{C}_{22}$	EW	W	VW	S	VW
$\mathbb{C}_{23}$	S	VS	ES	S	EW	$\mathbb{C}_{23}$	M	EW	S	W	EW
$\mathbb{C}_{24}$	W	W	M	VS	VS	$\mathbb{C}_{24}$	W	VW	VW	EW	W
$\mathbb{C}_{25}$	M	VW	VS	W	S	$\mathbb{C}_{25}$	S	ES	W	S	S

Appendix D

$$e_{111}=\left[(0.10,0.30,0.30,0.50;1),(0.20,0.30,0.30,0.40;0.9)\right];$$
$$e_{112}=\left[(0.35,0.53,0.53,0.68;1),(0.44,0.53,0.53,0.60;0.9)\right];$$
$$e_{113}=\left[(0.53,0.68,0.68,0.80;1),(0.60,0.68,0.68,0.74;0.9)\right];$$
$$e_{114}=\left[(0.65,0.80,0.80,0.88;1),(0.73,0.80,0.80,0.84;0.9)\right];$$
$$e_{115}=\left[(0.25,0.38,0.38,0.53;1),(0.31,0.38,0.38,0.45;0.9)\right];$$
$$e_{121}=\left[(0.90,1.00,1.00,1.00;1),(0.95,1.00,1.00,1.00;0.9)\right];$$
$$e_{122}=\left[(0.35,0.45,0.45,0.58;1),(0.40,0.45,0.45,0.51;0.9)\right];$$
$$e_{123}=\left[(0.25,0.35,0.35,0.48;1),(0.30,0.35,0.35,0.41;0.9)\right];$$
$$e_{124}=\left[(0.30,0.50,0.50,0.70;1),(0.40,0.50,0.50,0.60;0.9)\right];$$
$$e_{125}=\left[(0.15,0.35,0.35,0.55;1),(0.25,0.35,0.35,0.45;0.9)\right];$$
$$e_{131}=\left[(0.30,0.50,0.50,0.70;1),(0.40,0.50,0.50,0.60;0.9)\right];$$
$$e_{132}=\left[(0.30,0.45,0.45,0.63;1),(0.38,0.45,0.45,0.54;0.9)\right];$$
$$e_{133}=\left[(0.03,0.13,0.13,0.30;1),(0.08,0.13,0.13,0.21;0.9)\right];$$
$$e_{134}=\left[(0.43,0.60,0.60,0.75;1),(0.51,0.60,0.60,0.68;0.9)\right];$$
$$e_{135}=\left[(0.40,0.50,0.50,0.60;1),(0.45,0.50,0.50,0.55;0.9)\right];$$
$$e_{141}=\left[(0.00,0.00,0.00,0.10;1),(0.00,0.00,0.00,0.05;0.9)\right];$$
$$e_{142}=\left[(0.45,0.63,0.63,0.75;1),(0.54,0.63,0.63,0.69;0.9)\right];$$
$$e_{143}=\left[(0.10,0.23,0.23,0.40;1),(0.16,0.23,0.23,0.31;0.9)\right];$$
$$e_{144}=\left[(0.30,0.50,0.50,0.70;1),(0.40,0.50,0.50,0.60;0.9)\right];$$
$$e_{145}=\left[(0.13,0.28,0.28,0.45;1),(0.20,0.28,0.28,0.36;0.9)\right];$$
$$e_{151}=\left[(0.50,0.70,0.70,0.90;1),(0.60,0.70,0.70,0.80;0.9)\right];$$
$$e_{152}=\left[(0.10,0.23,0.23,0.40;1),(0.16,0.23,0.23,0.31;0.9)\right];$$
$$e_{153}=\left[(0.50,0.70,0.70,0.85;1),(0.60,0.70,0.70,0.78;0.9)\right];$$
$$e_{154}=\left[(0.23,0.30,0.30,0.43;1),(0.26,0.30,0.30,0.36;0.9)\right];$$
$$e_{155}=\left[(0.20,0.40,0.40,0.60;1),(0.30,0.40,0.40,0.50;0.9)\right];$$
$$e_{211}=\left[(0.03,0.10,0.10,0.25;1),(0.06,0.10,0.10,0.40;0.9)\right];$$
$$e_{212}=\left[(0.43,0.55,0.55,0.68;1),(0.49,0.55,0.55,0.61;0.9)\right];$$
$$e_{213}=\left[(0.43,0.55,0.55,0.65;1),(0.49,0.55,0.55,0.60;0.9)\right];$$
$$e_{214}=\left[(0.20,0.33,0.33,0.48;1),(0.26,0.33,0.33,0.40;0.9)\right];$$
$$e_{215}=\left[(0.35,0.53,0.53,0.68;1),(0.44,0.53,0.53,0.60;0.9)\right];$$
$$e_{221}=\left[(0.65,0.85,0.85,0.98;1),(0.75,0.85,0.85,0.91;0.9)\right];$$

$$e_{222}=\left[\left(0.18,0.33,0.33,0.50;1\right),\left(0.25,0.33,0.33,0.41;0.9\right)\right];$$
$$e_{223}=\left[\left(0.20,0.33,0.33,0.48;1\right),\left(0.26,0.33,0.33,0.40;0.9\right)\right];$$
$$e_{224}=\left[\left(0.10,0.23,0.23,0.40;1\right),\left(0.16,0.23,0.23,0.31;0.9\right)\right];$$
$$e_{225}=\left[\left(0.50,0.70,0.70,0.88;1\right),\left(0.60,0.70,0.70,0.79;0.9\right)\right];$$
$$e_{231}=\left[\left(0.33,0.50,0.50,0.70;1\right),\left(0.41,0.50,0.50,0.60;0.9\right)\right];$$
$$e_{232}=\left[\left(0.43,0.58,0.58,0.70;1\right),\left(0.50,0.58,0.58,0.64;0.9\right)\right];$$
$$e_{233}=\left[\left(0.20,0.33,0.33,0.50;1\right),\left(0.26,0.33,0.33,0.41;0.9\right)\right];$$
$$e_{234}=\left[\left(0.20,0.35,0.35,0.55;1\right),\left(0.28,0.35,0.35,0.45;0.9\right)\right];$$
$$e_{235}=\left[\left(0.45,0.63,0.63,0.78;1\right),\left(0.54,0.63,0.63,0.70;0.9\right)\right];$$
$$e_{241}=\left[\left(0.05,0.18,0.18,0.35;1\right),\left(0.11,0.18,0.18,0.26;0.9\right)\right];$$
$$e_{242}=\left[\left(0.28,0.43,0.43,0.60;1\right),\left(0.35,0.43,0.43,0.51;0.9\right)\right];$$
$$e_{243}=\left[\left(0.23,0.40,0.40,0.60;1\right),\left(0.31,0.40,0.40,0.50;0.9\right)\right];$$
$$e_{244}=\left[\left(0.20,0.33,0.33,0.50;1\right),\left(0.26,0.33,0.33,0.41;0.9\right)\right];$$
$$e_{245}=\left[\left(0.43,0.58,0.58,0.73;1\right),\left(0.50,0.58,0.58,0.65;0.9\right)\right];$$
$$e_{251}=\left[\left(0.45,0.65,0.65,0.83;1\right),\left(0.55,0.65,0.65,0.74;0.9\right)\right];$$
$$e_{252}=\left[\left(0.43,0.58,0.58,0.70;1\right),\left(0.50,0.58,0.58,0.64;0.9\right)\right];$$
$$e_{253}=\left[\left(0.38,0.50,0.50,0.63;1\right),\left(0.44,0.50,0.50,0.56;0.9\right)\right];$$
$$e_{254}=\left[\left(0.58,0.73,0.73,0.83;1\right),\left(0.65,0.73,0.73,0.78;0.9\right)\right];$$
$$e_{255}=\left[\left(0.33,0.48,0.48,0.63;1\right),\left(0.40,0.48,0.48,0.55;0.9\right)\right];$$
$$e_{311}=\left[\left(0.53,0.65,0.65,0.75;1\right),\left(0.59,0.65,0.65,0.70;0.9\right)\right];$$
$$e_{312}=\left[\left(0.50,0.70,0.70,0.85;1\right),\left(0.60,0.70,0.70,0.78;0.9\right)\right];$$
$$e_{313}=\left[\left(0.58,0.73,0.73,0.83;1\right),\left(0.65,0.73,0.73,0.78;0.9\right)\right];$$
$$e_{314}=\left[\left(0.45,0.65,0.65,0.83;1\right),\left(0.55,0.65,0.65,0.74;0.9\right)\right];$$
$$e_{315}=\left[\left(0.23,0.40,0.40,0.60;1\right),\left(0.31,0.40,0.40,0.50;0.9\right)\right];$$
$$e_{321}=\left[\left(0.38,0.50,0.50,0.63;1\right),\left(0.44,0.50,0.50,0.56;0.9\right)\right];$$
$$e_{322}=\left[\left(0.13,0.28,0.28,0.45;1\right),\left(0.20,0.28,0.28,0.36;0.9\right)\right];$$
$$e_{323}=\left[\left(0.23,0.40,0.40,0.60;1\right),\left(0.31,0.40,0.40,0.50;0.9\right)\right];$$
$$e_{324}=\left[\left(0.23,0.38,0.38,0.55;1\right),\left(0.30,0.38,0.38,0.46;0.9\right)\right];$$
$$e_{325}=\left[\left(0.28,0.45,0.45,0.65;1\right),\left(0.36,0.45,0.45,0.55;0.9\right)\right];$$
$$e_{331}=\left[\left(0.28,0.45,0.45,0.65;1\right),\left(0.36,0.45,0.45,0.55;0.9\right)\right];$$
$$e_{332}=\left[\left(0.48,0.63,0.63,0.75;1\right),\left(0.55,0.63,0.63,0.69;0.9\right)\right];$$
$$e_{333}=\left[\left(0.53,0.65,0.65,0.75;1\right),\left(0.59,0.65,0.65,0.70;0.9\right)\right];$$
$$e_{334}=\left[\left(0.35,0.55,0.55,0.75;1\right),\left(0.45,0.55,0.55,0.65;0.9\right)\right];$$

$$e_{335} = \left[\left(0.03, 0.10, 0.10, 0.25; 1\right), \left(0.06, 0.10, 0.10, 0.18; 0.9\right)\right];$$
$$e_{341} = \left[\left(0.15, 0.35, 0.35, 0.55; 1\right), \left(0.25, 0.35, 0.35, 0.45; 0.9\right)\right];$$
$$e_{342} = \left[\left(0.05, 0.20, 0.20, 0.40; 1\right), \left(0.13, 0.20, 0.20, 0.30; 0.9\right)\right];$$
$$e_{343} = \left[\left(0.30, 0.43, 0.43, 0.58; 1\right), \left(0.36, 0.43, 0.43, 0.50; 0.9\right)\right];$$
$$e_{344} = \left[\left(0.28, 0.43, 0.43, 0.58; 1\right), \left(0.35, 0.43, 0.43, 0.50; 0.9\right)\right];$$
$$e_{345} = \left[\left(0.40, 0.60, 0.60, 0.75; 1\right), \left(0.50, 0.60, 0.60, 0.68; 0.9\right)\right];$$
$$e_{351} = \left[\left(0.33, 0.48, 0.48, 0.65; 1\right), \left(0.40, 0.48, 0.48, 0.56; 0.9\right)\right];$$
$$e_{552} = \left[\left(0.43, 0.58, 0.58, 0.73; 1\right), \left(0.50, 0.58, 0.58, 0.65; 0.9\right)\right];$$
$$e_{553} = \left[\left(0.33, 0.48, 0.48, 0.63; 1\right), \left(0.40, 0.48, 0.48, 0.55; 0.9\right)\right];$$
$$e_{554} = \left[\left(0.35, 0.55, 0.55, 0.73; 1\right), \left(0.45, 0.55, 0.55, 0.64; 0.9\right)\right];$$
$$e_{555} = \left[\left(0.43, 0.60, 0.60, 0.78; 1\right), \left(0.51, 0.60, 0.60, 0.69; 0.9\right)\right].$$

Appendix E

$$\tilde{e}_{11} = \left[\left(0.0387, 0.1197, 0.1197, 0.2703; 1\right), \left(0.0718, 0.1197, 0.1197, 0.1851; 0.9\right)\right];$$
$$\tilde{e}_{12} = \left[\left(0.0372, 0.1184, 0.1184, 0.2680; 1\right), \left(0.0702, 0.1184, 0.1184, 0.1833; 0.9\right)\right];$$
$$\tilde{e}_{13} = \left[\left(0.0433, 0.1297, 0.1297, 0.2813; 1\right), \left(0.0790, 0.1297, 0.1297, 0.1962; 0.9\right)\right];$$
$$\tilde{e}_{14} = \left[\left(0.0378, 0.1253, 0.1253, 0.2871; 1\right), \left(0.0731, 0.1253, 0.1253, 0.1955; 0.9\right)\right];$$
$$\tilde{e}_{15} = \left[\left(0.0327, 0.1081, 0.1081, 0.2567; 1\right), \left(0.0631, 0.1081, 0.1081, 0.1720; 0.9\right)\right];$$
$$\tilde{e}_{21} = \left[\left(0.0386, 0.1151, 0.1151, 0.2591; 1\right), \left(0.0700, 0.1151, 0.1151, 0.1777; 0.9\right)\right];$$
$$\tilde{e}_{22} = \left[\left(0.0377, 0.1138, 0.1138, 0.2560; 1\right), \left(0.0688, 0.1138, 0.1138, 0.1755; 0.9\right)\right];$$
$$\tilde{e}_{23} = \left[\left(0.0440, 0.1251, 0.1251, 0.2696; 1\right), \left(0.0777, 0.1251, 0.1251, 0.1885; 0.9\right)\right];$$
$$\tilde{e}_{24} = \left[\left(0.0379, 0.1207, 0.1207, 0.2750; 1\right), \left(0.0716, 0.1207, 0.1207, 0.1876; 0.9\right)\right];$$
$$\tilde{e}_{25} = \left[\left(0.0318, 0.1034, 0.1034, 0.2455; 1\right), \left(0.0609, 0.1034, 0.1034, 0.1646; 0.9\right)\right];$$
$$\tilde{e}_{31} = \left[\left(0.0306, 0.0975, 0.0975, 0.2361; 1\right), \left(0.0578, 0.0975, 0.0975, 0.1567; 0.9\right)\right];$$
$$\tilde{e}_{32} = \left[\left(0.0296, 0.0965, 0.0965, 0.2338; 1\right), \left(0.0566, 0.0965, 0.0965, 0.1551; 0.9\right)\right];$$
$$\tilde{e}_{33} = \left[\left(0.0353, 0.1064, 0.1064, 0.2458; 1\right), \left(0.0645, 0.1064, 0.1064, 0.1665; 0.9\right)\right];$$
$$\tilde{e}_{34} = \left[\left(0.0304, 0.1025, 0.1025, 0.2508; 1\right), \left(0.0593, 0.1025, 0.1025, 0.1657; 0.9\right)\right];$$
$$\tilde{e}_{35} = \left[\left(0.0258, 0.0877, 0.0877, 0.2236; 1\right), \left(0.0505, 0.0877, 0.0877, 0.1452; 0.9\right)\right];$$
$$\tilde{e}_{41} = \left[\left(0.0215, 0.0758, 0.0758, 0.1961; 1\right), \left(0.0431, 0.0758, 0.0758, 0.1266; 0.9\right)\right];$$
$$\tilde{e}_{42} = \left[\left(0.0213, 0.0761, 0.0761, 0.1956; 1\right), \left(0.0430, 0.0761, 0.0761, 0.1265; 0.9\right)\right];$$
$$\tilde{e}_{43} = \left[\left(0.0242, 0.0824, 0.0824, 0.2044; 1\right), \left(0.0476, 0.0824, 0.0824, 0.1344; 0.9\right)\right];$$
$$\tilde{e}_{44} = \left[\left(0.0209, 0.0795, 0.0795, 0.2088; 1\right), \left(0.0439, 0.0795, 0.0795, 0.1339; 0.9\right)\right];$$
$$\tilde{e}_{45} = \left[\left(0.0172, 0.0675, 0.0675, 0.1859; 1\right), \left(0.0369, 0.0675, 0.0675, 0.1170; 0.9\right)\right];$$

$$\tilde{e}_{51} = \left[(0.0312, 0.1044, 0.1044, 0.2537; 1), (0.0608, 0.1044, 0.1044, 0.1683; 0.9) \right];$$
$$\tilde{e}_{52} = \left[(0.0296, 0.1022, 0.1022, 0.2502; 1), (0.0587, 0.1022, 0.1022, 0.1655; 0.9) \right];$$
$$\tilde{e}_{53} = \left[(0.0352, 0.1131, 0.1131, 0.2640; 1), (0.0670, 0.1131, 0.1131, 0.1784; 0.9) \right];$$
$$\tilde{e}_{54} = \left[(0.0305, 0.1090, 0.1090, 0.2690; 1), (0.0618, 0.1090, 0.1090, 0.1774; 0.9) \right];$$
$$\tilde{e}_{55} = \left[(0.0263, 0.0944, 0.0944, 0.2410; 1), (0.0534, 0.0944, 0.0944, 0.1565; 0.9) \right].$$

Appendix F

$$\tilde{e}_{11}^{N} = \left[(0.0515, 0.1592, 0.1592, 0.3595; 1), (0.0955, 0.1592, 0.1592, 0.2462; 0.9) \right];$$
$$\tilde{e}_{12}^{N} = \left[(0.0500, 0.1594, 0.1591, 0.3604; 1), (0.0945, 0.1594, 0.1594, 0.2466; 0.9) \right];$$
$$\tilde{e}_{13}^{N} = \left[(0.0545, 0.1631, 0.1631, 0.3538; 1), (0.0994, 0.1361, 0.1361, 0.2468; 0.9) \right];$$
$$\tilde{e}_{14}^{N} = \left[(0.0476, 0.1579, 0.1579, 0.3617; 1), (0.0922, 0.1579, 0.1579, 0.2463; 0.9) \right];$$
$$\tilde{e}_{15}^{N} = \left[(0.0467, 0.1544, 0.1544, 0.3667; 1), (0.0901, 0.1544, 0.1544, 0.2457; 0.9) \right];$$
$$\tilde{e}_{21}^{N} = \left[(0.0514, 0.1531, 0.1531, 0.3446; 1), (0.0932, 0.1531, 0.1531, 0.2363; 0.9) \right];$$
$$\tilde{e}_{22}^{N} = \left[(0.0507, 0.1530, 0.1530, 0.3443; 1), (0.0926, 0.1530, 0.1530, 0.2360; 0.9) \right];$$
$$\tilde{e}_{23}^{N} = \left[(0.0553, 0.1574, 0.1574, 0.3390; 1), (0.0978, 0.1574, 0.1574, 0.2371; 0.9) \right];$$
$$\tilde{e}_{24}^{N} = \left[(0.0478, 0.1521, 0.1521, 0.3464; 1), (0.0903, 0.1521, 0.1521, 0.2363; 0.9) \right];$$
$$\tilde{e}_{25}^{N} = \left[(0.0455, 0.1477, 0.1477, 0.3507; 1), (0.0870, 0.1477, 0.1477, 0.2351; 0.9) \right];$$
$$\tilde{e}_{31}^{N} = \left[(0.0407, 0.1297, 0.1297, 0.3140; 1), (0.0768, 0.1297, 0.1297, 0.2085; 0.9) \right];$$
$$\tilde{e}_{32}^{N} = \left[(0.0398, 0.1298, 0.1298, 0.3144; 1), (0.0761, 0.1298, 0.1298, 0.2086; 0.9) \right];$$
$$\tilde{e}_{33}^{N} = \left[(0.0445, 0.1338, 0.1338, 0.3092; 1), (0.0811, 0.1338, 0.1338, 0.2095; 0.9) \right];$$
$$\tilde{e}_{34}^{N} = \left[(0.0383, 0.1291, 0.1291, 0.3160; 1), (0.0748, 0.1291, 0.1291, 0.2088; 0.9) \right];$$
$$\tilde{e}_{35}^{N} = \left[(0.0368, 0.1253, 0.1253, 0.3195; 1), (0.0722, 0.1253, 0.1253, 0.2074; 0.9) \right];$$
$$\tilde{e}_{41}^{N} = \left[(0.0286, 0.1009, 0.1009, 0.2609; 1), (0.0573, 0.1009, 0.1009, 0.1683; 0.9) \right];$$
$$\tilde{e}_{42}^{N} = \left[(0.0287, 0.1024, 0.1024, 0.2630; 1), (0.0578, 0.1024, 0.1024, 0.1701; 0.9) \right];$$
$$\tilde{e}_{43}^{N} = \left[(0.0304, 0.1036, 0.1036, 0.2571; 1), (0.0599, 0.1036, 0.1036, 0.1691; 0.9) \right];$$
$$\tilde{e}_{44}^{N} = \left[(0.0263, 0.1002, 0.1002, 0.2630; 1), (0.0553, 0.1002, 0.1002, 0.1687; 0.9) \right];$$
$$\tilde{e}_{45}^{N} = \left[(0.0246, 0.0965, 0.0965, 0.2656; 1), (0.0527, 0.0965, 0.0965, 0.1672; 0.9) \right];$$
$$\tilde{e}_{51}^{N} = \left[(0.0415, 0.1389, 0.1389, 0.3374; 1), (0.0808, 0.1389, 0.1389, 0.2239; 0.9) \right];$$
$$\tilde{e}_{52}^{N} = \left[(0.0398, 0.1374, 0.1374, 0.3365; 1), (0.0789, 0.1374, 0.1374, 0.2225; 0.9) \right];$$
$$\tilde{e}_{53}^{N} = \left[(0.0442, 0.1422, 0.1422, 0.3320; 1), (0.0843, 0.1422, 0.1422, 0.2243; 0.9) \right];$$
$$\tilde{e}_{54}^{N} = \left[(0.0384, 0.1374, 0.1374, 0.3389; 1), (0.0779, 0.1374, 0.1374, 0.2235; 0.9) \right];$$
$$\tilde{e}_{55}^{N} = \left[(0.0376, 0.1348, 0.1348, 0.3442; 1), (0.0762, 0.1348, 0.1348, 0.2236; 0.9) \right].$$