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Research Article

Digital transformation solutions of entrepreneurial SMEs based on an information error-driven T-spherical fuzzy cloud algorithm

Zaoli Yang [a], Jinping Chang [b,*], Lucheng Huang [a], Abbas Mardani [c]

[a] College of Economics and Management, Beijing University of Technology, Beijing 100124, China
[b] College of Management, Beijing Union University, Beijing 100101, China
[c] Muma College of Business, University of South Florida, Tampa, FL 33620, USA

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ABSTRACT

The digital transformation of enterprises has become an inevitable development trend and one of the key driving forces that promotes the sustainable development of enterprises. However, due to the many obstacles of financial burdens, technical thresholds, and talent shortages, digital transformation has become a challenging task for entrepreneurial Small and Medium-Sized Enterprises (SMEs). Additionally, many competitive digital transformation solutions on the market cause confusion when enterprises must choose one. This study drew a new information error-driven T-spherical fuzzy cloud algorithm to evaluate digital transformation solutions of entrepreneurial SMEs and support its selection. First, an evaluation index system for the digital transformation solution of entrepreneurial SMEs was established from four aspects. Then, a new concept of a T-spherical fuzzy cloud was defined to represent the evaluation information of the indicators. Additionally, a T-spherical Fuzzy Cloud Weighted Heronian Mean (T-SFCWHM) operator was used to aggregate the evaluation information. Afterward, an evaluation and selection decision framework for the digital transformation solution of entrepreneurial SMEs based on the T-SFCWHM operator was developed. Further, a practical example was given to illustrate the effectiveness of the proposed method. Finally, a discussion of the findings in our study was conducted, and the conclusions were summarized.

1. Introduction

Being digital is a new way of life supported by information technology in modern society where people's production, lifestyle, behavior, and thinking modes take on a new look (Nicholas, 1995; Sun, Yang, Shen, & Wang, 2020). Especially at present, digitalization triggered by social media, mobile devices, the Internet of Things, and big data changes people's lifestyles and requires businesses to rethink their original operation modes (Bresciani, Ferraris, & Del Giudice, 2018). In other words, the market in the digital age changes very rapidly (Saura, Ribeiro-Soriano, & Palacios-Marqués, 2021), which makes businesses face ubiquitous challenges and faster competition, thus driving them to strengthen their own digital transformation. Therefore, understanding the indicators in the digital transformation era is crucial for new technology adoption (Manfreda, Ljubi, & Groznik, 2021). "Digitalization" is not only related to technology but also a way of thinking and the source of new business and consumption modes, which provides a new way for enterprises to organize, produce, operate and innovate and drives in-depth changes in the production model, organizational structure and business model of enterprises (Verhoef et al., 2021).

Digital transformation is an inevitable choice for enterprises to keep afloat, create core competitiveness and achieve sustainable development. In recent years, the role of digital transformation in highlighted in various applications areas such as service providers (Mazumder & Garg, 2021), smart cities (Ćukušić, 2021), public sector service (Tangi, Janssen, Benedetti, & Noci, 2021), healthcare, and infectious disease (Iivari, Sharma, & Ventä-Olkkonen, 2020; Kodama, 2020), marketing (Sun et al., 2020), Small And Medium-Sized Enterprises (SMEs) (Costa, Soares, & de Sousa, 2020), etc.

However, digital transformation is very difficult for enterprises, especially entrepreneurial SMEs, due to many practical predicaments (Albukhitan, 2020), which are manifested in the fact that entrepreneurial SMEs have insufficient financial budgets and high-quality talent (Albukhitan, 2020; Pelletier & Cloutier, 2019) and do not easily adjust the organizational structure (Gray & Rumpe, 2017; Stich, Zeller, Hicking, & Kraut, 2020). In addition, the current market is full of many

* Corresponding author.
E-mail address: gltjinping@buu.edu.cn (J. Chang).

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different digital transformation solutions in performance, benefit, price, and other aspects, which poses a challenge when enterprises must choose one. If the choice is wrong, it will cause significant losses to entrepreneurial SMEs and lead them to bankruptcy. Therefore, to reduce the negative impact of these difficulties on the digital transformation of entrepreneurial SMEs and avoid irretrievable damage, entrepreneurial SMEs must evaluate alternative solutions before digital transformation to determine feasible solutions in advance to finally determine a reasonable solution according to their own preference. In this way, they will not be hindered or even interrupted by factors such as investment in maintenance funds, adjustment of company structure, and talent matching in the later period in the path of digitalization transformation after the implementation of the solution.

The evaluation and selection processes of digital transformation solutions for entrepreneurial SMEs involve many factors and indicators (Annaële, Christophe, & Rico, 2020), most of which are difficult to quantify, such as the compatibility of the system software and the degree of adjustment of the organizational structure, and thus, these aspects need to be scored by experts. However, experts will score some problems in scoring, which means that the experts could give different answers' scores to the same indicator, such as approval, objection, waiver, and refusal (Ali, Mahmood, & Yang, 2020). In addition, scores by experts always involve personal preferences, thus resulting in deviations in evaluation, which will interfere with the accuracy of indicator evaluations and the correctness of alternative selections. In summary, what are the gaps in the existing research: how can the evaluation information and deviation characteristics of evaluation indicators be represented? How can we aggregate the evaluation information of multiple indicators and build a reasonable evaluation and decision model for SME digital transformation solutions?

Therefore, this paper aims to establish an evaluation and selection decision method for the digital transformation solution of entrepreneurial SMEs based on an information error-driven T-spherical fuzzy cloud algorithm. To do so, a novel concept of a T-spherical fuzzy cloud was developed to evaluate the related indicators. Additionally, a new T-spherical Fuzzy Cloud Weighted Heronian Mean (T-SFCWHM) operator was introduced to aggregate the evaluation information. The findings determine four aspects of evaluation indicators' multilayer structure and interactive relationships. Then, a decision framework for the digital transformation solution of entrepreneurial SMEs based on the T-SFCWHM operator was suggested. In this regard, various heterogeneous opinions in evaluation information are represented by integrating the cloud and T-spherical fuzzy sets into the same framework for analysis. Additionally, the findings show that the proposed approach provides a more accurate evaluation of digital transformation solutions.

The remainder of this paper includes the following: Section 2 reviews the progress of the research on the digital transformation of enterprises and T-spherical fuzzy sets. Section 3 develops the concept of T-spherical fuzzy clouds and their operational rules. Section 4 presents the T-SFCWHM aggregation operators and analyses their properties. Section 5 establishes an evaluation and selection decision framework for the digital transformation solution of entrepreneurial SMEs based on the T-SFCWHM operator. Section 6 conducts a practical example of the evaluation and selection decision of the digital transformation solution of entrepreneurial SMEs and establishes an evaluation index system. Section 7 provides a discussion that includes the synthesis analysis of study findings, theoretical contributions, implications for practice, limitations, and future research directions. Section 8 summarizes the conclusions.

2. Literature review

2.1. Digital transformation of enterprises

The concept of digitalization originates from a series of explorations of being digital after the impact of the Internet on the traditional media industry (Nicholas, 1995). Compared with traditional technology, digital technology is characterized by re-programmability, data homogeneity, and positive network externalities (Yoo, Harman, Tonella, & Susi, 2009) and can be divided into four categories: social, mobile, analysis, and cloud technology according to the different application fields (Ackx, 2014). Their key function is to provide enterprises with a method to improve the integration of products and production processes, of which the key technology is its simulation and optimization capabilities (Kuehn, 2006). Digital technology and digital factories have together driven the concept of digital transformation of enterprises (Westerman, Bonnet, & McAfee, 2014). Different scholars have different understandings of the concept of the "digital transformation of enterprise" (de Corbière, Rowe, & Saunders, 2019; Grover & Sabherwal, 2020; Mäntymäki, Baiyere, & Islam, 2019). However, the core connotations mainly include "organizational transformation integrating digital technology and business processes" (Nwankpa & Roumani, 2016), "performance improvement of enterprises based on digital technology" (Bekkhus, 2016), and "rebuilding customer value proposition" (Haffke, Kalgovas, & Benlian, 2016).

Many scholars have conducted in-depth research on the influencing factors of digital enterprise transformation, the impact of digital transformation on enterprise performance and the evaluation of digital transformation capacity. First, some scholars have identified the influencing factors of how enterprises actively cater to opportunities for digital transformation from the aspects of internal and external resources (Stich et al., 2020), digital technology integration ability (Li, Wu, Cao, & Wang, 2021), business models, and process transformation modes (Matthess & Kunkel, 2020). Second, Nwankpa and Roumani (2016) pointed out that digital transformation has a positive impact on innovation and enterprise performance based on the theory of the resource-based view. Especially at present, the digital transformation is characterized by big data applications, intelligentization, and networking, which brought revolutionary changes and unprecedented opportunities and challenges to social and economic development (Rothberg & Erickson, 2017). For example, the application of big data promotes the flattened development of organizational structure and improves the efficiency of organizational operation and management (Ranjan & Foropon, 2021), leading to the intelligence of financial management and strengthening the prediction of financial risk (Du, Liu, & Lu, 2021; Lin, Sun, & Yu, 2020). Intelligentization improves enterprise productivity, reduces production costs (Liu, Chen, Zhang, Yang, & Cheng, 2021), and optimizes supply chain management and customer service models (Ebner, Young, & Geraghty, 2019). Networking promotes the smooth exchange of information among traders (de Boer, van Deursen, & van Rompay, 2019), enables enterprises to realize business process re-engineering by means of network platforms, drives production and manufacturing to shift from scale production to scale customization, and meets customer personalized needs (Guo et al., 2021), which greatly solves the problem of high cost and high energy consumption. Third, O'Hea (2011) pointed out that digitalization is a measure of the potential of companies to obtain business value from the Internet. For this reason, some scholars analyze the level of digital application of enterprises by building indicators (Ottesjö et al., 2020) or their digital transformation ability by comparing the changes in the enterprise performance level before and after digital transformation (Stich et al., 2020).

2.2. Evaluation algorithm for the digital transformation of entrepreneurial SMEs

Because entrepreneurial SMEs are the most active part of the economic development of a country or a region and play an extremely important role in the national economy, their digital transformation has been widely considered by the academic community. Currently, scholars have researched the pathway (Ulas, 2019), influencing factors (Bouwman, Nikou, & de Reuver, 2019), effects (Gavrila Gavrila & de Lucas Ancillo, 2021; Matarazzo, Penco, Profumo, & Quaglia, 2021), relevant public policies (Henderson, 2020), and maturity evaluation of digital transformation (Thomas, 2020), among which the evaluation of digital transformation in entrepreneurial SMEs is one of the key concerns. Stich et al. (2020) constructed 18 measurement indicators from four aspects of resources, information systems, organizational structure, and culture to evaluate the digital transformation level in SMEs by a qualitative approach. Gamache, Abdul-Nour, and Baril (2019) assessed the relevant performance indicators of promoting digital transformation in SMEs through field investigation methods, mainly including management services, technology acquisition and development, digital architecture, automation, data quality, and e-commerce. Ottesjö et al. (2020) applied the hierarchical tree structure of the tool to evaluate the overall digital capabilities of SMEs. Garzoni, De Turi, Secundo, and Del Vecchio (2020) assessed the degree of digital utilization of SMEs from digital awareness, digital requirements, digital collaboration, and digital transformation using a four-level approach. Li et al. (2021) identified the emerging trends in the digital transformation of business models in creative industries using the bibliometric method. The above algorithms provide a guide for constructing an indicator system for evaluating digital transformation in SMEs, but they did not conduct a quantitative analysis of the indicator system. In addition, although some methods by Gamache et al. (2019) and Garzoni et al. (2020) obtained measurement data of indicators through questionnaires, they did not investigate the error characteristics of these measurement data, which easily lead to the distortion of the evaluation data and eventually lead to unreasonable results.

In addition, some scholars evaluated the influencing factors of the digital transformation of entrepreneurial SMEs and their effects by multilayer regression or structural equation models. For example, Khayer, Talukder, Bao, and Hossain (2020) evaluated the influence of cloud computing adoption on SMEs' performance using partial least squares structural equation modeling. Based on the perspective of dynamic capability, (Matarazzo et al., 2021) evaluated the impact of digital transformation on the improvement of customer value creation ability of SMEs. Cannas (2021) established a framework for the path of digital transformation in entrepreneurial SMEs based on the dynamic capability perspective. In addition, El Hilali, El Manouar, and Janati Idrissi (2020) evaluated what factors affect the company's sustainable development during the company's transformation. Finally, Denicolai, Zucchella, and Magnani (2021) assessed the relationships among the internationalization, digitalization, and sustainability of entrepreneurial SMEs and the synergies and substituting effects among the above relationships. The above algorithms effectively support the digital transformation of entrepreneurial SMEs. However, since these algorithms can only be used to measure the influence of path effects, they cannot evaluate things with multiple indicators; in other words, it is difficult to measure the performance level of each indicator and aggregate the evaluation data from multiple indicators. As such, existing methods cannot handle the evaluation of digital transformation solutions and must be extensively expanded.

2.3. T-spherical fuzzy set

There is a wide range of evaluation and decision-making problems in enterprise management, project management, business, military, and economic areas (Aydiner, Tatoglu, Bayraktar, & Zaim, 2019; Denicolai et al., 2021; Duan, Edwards, & Dwivedi, 2019), which involve many factors and indicators. The key to solving the problem of evaluation and decision-making is to characterize and aggregate the information of evaluation indicators. In the actual evaluation process, it is difficult for decision-makers to accurately quantify the evaluation indicators (Yang, Garg, Li, Srivastava, & Cao, 2020), such as the innovative spirit of entrepreneurs and the learning ability of employees due to the uncertainty of the objective environment and the limitations of human cognition. To characterize these uncertainty evaluation indicators, Zadeh (1965) proposed the concept of a fuzzy set (FS) based on a membership function that uses membership to represent the information of the evaluation indicator, which has been widely used in evaluation and decision-making problems since then. Since only one membership function is used to describe the degree to which the thing belongs to the evaluation level, the evaluation information of the thing is incomplete. For example, the opposite information of membership information is ignored, i.e., non-membership. Atanassov (1986) believed that membership and non-membership should be considered in evaluating a thing, i.e., the degree to which the thing does not belong to the evaluation level.

For this reason, Atanassov (1986) developed the concept of intuitionistic fuzzy sets (IFSs) based on fuzzy sets, which include the two elements of membership and non-membership; this approach further expanded the representation range of evaluation information. However, in the IFS and its extended forms, it is strictly required that the sum of the values of membership and non-membership should not be greater than 1. In the real environment, when decision-makers independently evaluate the membership and non-membership of one indicator, there could be a situation where the sum of the two values is greater than 1 (Yager, 2014). To solve this problem, (Yager, 2014, 2017) proposed the Pythagorean Fuzzy Set (PFS) and Q-Rung Orthopair Fuzzy Set (q-ROFS). The q-ROFS requires that the sum of the q-th power of membership and non-membership be less than 1. In this way, when $q = 2$, the q-ROFS will be converted into the PFS, and when $q = 1$, it will be converted into the IFS accordingly, i.e., FS, IFS, and PFS are all special forms of q-ROFSs (Yang, Garg et al., 2020). Consequently, the q-ROFS further expands the representational space of evaluation information with the type of FS and IFS and can respond to different complexities of the evaluation information environment by modifying the parameter q, with stronger flexibility and representational information ability (Yang, Ouyang, Fu, & Peng, 2020; Yang, Garg et al., 2020).

In the IFS, PFS, and q-ROFS mentioned above, a decision unit includes membership and non-membership. However, in many practical evaluation and decision-making issues, the evaluation direction given by decision-makers can also include waivers. For example, there are opinions of approval, objection, and even waiver in the voting. To address this circumstance, Mahmood, Ullah, Khan, and Jan (2019) added a waiver function based on the q-ROFS, thus putting forward the T-spherical Fuzzy Set (T-SFS), which is characterized by the sum of the q-th power of approval, objection, and waiver degrees of no more than 1. In this way, the T-SFS can express more heterogeneity evaluation views and integrate them into a framework for comprehensive analysis. In addition, when the waiver degree in the T-SFS is 0, the T-SFS degenerates to the q-ROFS.

In summary, there are abundant studies on the definition, influencing factors, path mechanism, and effect of digital transformation of enterprises, and the evaluation algorithms of digital transformation in entrepreneurial SMEs have also been considered by more scholars. However, the existing research has not yet involved the evaluation and decision of digital transformation solutions, and thus, it is difficult to provide a pre-plan reference for entrepreneurial SMEs. In addition, fuzzy set theory has significant advantages in representing evaluation information and the aggregation of qualitative indicators, which provides an important tool and idea for evaluation problems in uncertain environments. However, since the evaluation information is based on the score by experts, expert preferences and environmental uncertainties can lead to deviation in the evaluation values, which is ignored in the existing research on the fuzzy set and its application, thus reducing the accuracy of the evaluation value and the rationality of the decision results. Consequently, the purpose of this article is to present an information error-driven T-spherical fuzzy cloud algorithm to assess the digital transformation solutions of entrepreneurial SMEs. First, from the perspective of information error, the cloud model is combined with the T-SFS to build the T-spherical fuzzy cloud to investigate the error in the evaluation information and its distribution characteristics. Then, considering the interactive relationship between evaluation indexes, the T-SFCWHM operator is proposed to aggregate the evaluation information. Finally, the evaluation and selection decision for digital transformation solutions of entrepreneurial SMEs based on the T-SFCWHM operator is established.

3. T-spherical fuzzy cloud model

Definition 1. (Mahmood et al., 2019). A T-spherical fuzzy set on a regular set X comprises three elements of membership, abstinence, and non-membership functions denoted as:

$$R = \{\langle x, u(x), v(x), z(x)\rangle | x \in X\} \tag{1}$$

where $u(x)$,$v(x)$,$z(x)$:$X\rightarrow[0,1]$ and satisfies $0\leq u(x)^q+v(x)^q+z(x)^q\leq 1$ for any q, q $=1,2,\ldots$,k. In addition, the refusal degree of x in P can be obtained by $\sqrt[q]{1-u(x)^q-v(x)^q-z(x)^q}$. For the convenience of expression and operation, we call $p=\langle u,v,z\rangle$ a T-spherical fuzzy number.

Definition 2. (Li, Liu, & Gan, 2009). Let set K be a qualitative element of a regular universe Q. If $x \in Q$ is a stochastic exemplum of K with the condition that $x \sim N(Ex, En^2)$, $En \sim N(En, He^2)$, and the uncertainty degree y of x concerning K is defined as:

$$y = e^{-\frac{(x-En)^2}{2En^2}} \tag{2}$$

Then we call y a normal cloud on the distribution of x in Q and (x, y) a cloud droplet.

Furthermore, three concepts of expectation, Ex, entropy En, and hyper-entropy He are used to depict the qualitative properties of a qualitative element K of a cloud C in Q, which is represented as C $=(Ex, En, He)$. Statistically, Ex is the central value of K of cloud C in Q, En is the divergence degree of the cloud droplets, and He is expressed as the thickness of cloud C.

As such, according to Definition 1, we regard the membership function $u(x)$ of the T-SFS as the favor degree of expert evaluation, the abstinence function $v(x)$ as the renunciation degree, and the membership function $z(x)$ as the opposition degree. We further examine the error and its distribution characteristics (hyper error) of the three notations. Therefore, based on Definition 2, we treat the three notations as their expectation Ex , the error as the entropy En, the hyper error as the hyper entropy He. Consequently, integrating Definitions 1 and 2, we can obtain the following in Definition 3.

Definition 3. A T-spherical fuzzy cloud set A on a regular set Xexpressed as.

$$A=\{\langle x,(f_{Ex}(x),f_{En}(x),f_{He}(x)),(g_{Ex}(x),g_{En}(x),g_{He}(x)),(o_{Ex}(x),o_{En}(x),o_{He}(x))|x\in X\rangle\}$$

where $(f_{Ex}(x),f_{En}(x),f_{He}(x))$ is the favor function, $f_{En}(x)$ and $f_{He}(x)$ are the error and hyper error of favor degree $f_{Ex}(x)$; $(g_{Ex}(x),g_{En}(x),g_{He}(x))$ is the renunciation function, $g_{En}(x)$ and $g_{He}(x)$ are the error and hyper error of renunciation degree $g_{Ex}(x)$; $(o_{Ex}(x),o_{En}(x),o_{He}(x))$ is the opposition function, and $o_{En}(x)$ and $o_{He}(x)$ are the error and hyper error of favor degree $o_{Ex}(x)$. For convenience, the T-spherical fuzzy cloud set can be denoted as

$$A = \langle(f_{Ex},f_{En},f_{He}),(g_{Ex},g_{En},g_{He}),(o_{Ex},o_{En},o_{He})\rangle$$

which consists of favoring clouds (f_{Ex},f_{En},f_{He}), renunciation (g_{Ex},g_{En},g_{He}) and opposition clouds (o_{Ex},o_{En},o_{He}).

Based on Definition 2 and Definition 3, we obtain the calculation steps of T-spherical fuzzy cloud A as follows:

Step 1. Generate the favor function's normal stochastic number f_{x_i} and its expectation f_{Ex} and error f_{En}, the renunciation function's normal stochastic number g_{x_i} and its expectation g_{Ex} and error g_{En}, and the opposition function's normal stochastic number o_{x_i} and its expectation o_{Ex} and erroro_{En}.

Step 2. Based on the results derived by Step 1, we generate the normal stochastic number f_{En_i} and its expectation f_{En} and error f_{He}, g_{En_i} and its expectation f_{En} and error f_{He}, as well as o_{En_i} and its expectation o_{En} and error o_{He}.

Step 3. According to Eq. (2), we compute:

$$f_{y_i} = e^{-\frac{\left(f_{x_i}-f_{En_i}\right)^2}{2f_{En_i}^2}} \tag{3}$$

$$g_{y_i} = e^{-\frac{\left(g_{x_i} - g_{En_i}\right)^2}{2g_{En_i}^2}} \tag{4}$$

$$o_{y_i} = e^{-\frac{\left(o_{x_i} - o_{En_i}\right)^2}{2o_{En_i}^2}} \tag{5}$$

(4) Let (f_{x_i}, f_{y_i}), (g_{x_i}, g_{y_i}) and (o_{x_i}, o_{y_i}) be cloud droplets of favor, renunciation, and opposition clouds. Then, f_{x_i}, g_{x_i} and o_{x_i} mean the values of the favor, renunciation, and opposition clouds in this domain, while f_{y_i}, g_{y_i} and o_{y_i} mean the measure of the degree to which favor, renunciation, and opposition clouds belong to this number.

(5) Redo step (1) to step (4) until the appropriate number of cloud droplets appears, and then count the overall expectations of the favor, renunciation, and opposition clouds, which will be introduced in the following definition.

Definition 4. Let $C = \langle (f_{Ex}, f_{En}, f_{He}), (g_{Ex}, g_{En}, g_{He}), (o_{Ex}, o_{En}, o_{He}) \rangle$, $C_1 = \langle (f_{Ex_1}, f_{En_1}, f_{He_1}), (g_{Ex_1}, g_{En_1}, g_{He_1}), (o_{Ex_1}, o_{En_1}, o_{He_1}) \rangle$ and $C_2 = \langle (f_{Ex_2}, f_{En_2}, f_{He_2}), (g_{Ex_2}, g_{En_2}, g_{He_2}), (o_{Ex_2}, o_{En_2}, o_{He_2}) \rangle$ be three T-SFCs, $\lambda, \lambda_1, \lambda_2 > 0$; then, we obtain some operational rules between T-SFCs as follows:

$$(1)\ C_1 \oplus C_2 = \begin{pmatrix} \sqrt[q]{f_{Ex_1}^q + f_{Ex_2}^q - f_{Ex_1}^q f_{Ex_2}^q}, f_{En_1} + f_{En_2}, f_{He_1} + f_{He_2}; \\ g_{Ex_1} g_{Ex_2}, g_{En_1} + g_{En_2}, g_{He_1} + g_{He_2}; \\ o_{Ex_1} o_{Ex_2}, o_{En_1} + o_{En_2}, o_{He_1} + o_{He_2} \end{pmatrix},$$

$$(2)\ C_1 \otimes C_2 = \begin{pmatrix} f_{Ex_1} f_{Ex_2}, f_{En_1} f_{En_2}, f_{He_1} f_{He_2}; \\ \sqrt[q]{g_{Ex_1}^q + g_{Ex_2}^q - g_{Ex_1}^q g_{Ex_2}^q}, g_{En_1} g_{En_2}, g_{He_1} g_{He_2}; \\ \sqrt[q]{o_{Ex_1}^q + o_{Ex_2}^q - o_{Ex_1}^q o_{Ex_2}^q}, o_{En_1} o_{En_2}, o_{He_1} o_{He_2} \end{pmatrix},$$

$$(3)\ \lambda C = \left(\sqrt[q]{1 - (1 - f_{Ex}^q)^\lambda}, \lambda f_{En}, \lambda f_{He}; g_{Ex}^\lambda, \lambda g_{En}, \lambda g_{He}; o_{Ex}^\lambda, \lambda o_{En}, \lambda o_{He}\right),$$

$$(4)\ C^\lambda = \left(f_{Ex}^\lambda, f_{En}^\lambda, f_{He}^\lambda; \sqrt[q]{1 - (1 - g_{Ex}^q)^\lambda}, g_{En}^\lambda, g_{He}^\lambda; \sqrt[q]{1 - (1 - o_{Ex}^q)^\lambda}, o_{En}^\lambda, o_{He}^\lambda\right)$$

.

Furthermore, some properties of the operational rules of T-SFCs are investigated as follows:

(1) $C_1 \oplus C_2 = C_2 \oplus C_1$,
(2) $C_1 \otimes C_2 = C_2 \otimes C_1$,
(3) $\lambda(C_1 \oplus C_2) = \lambda C_1 \oplus \lambda C_2$,
(4) $(C_1 \otimes C_2)^\lambda = C_1^\lambda \otimes C_2^\lambda$,
(5) $\lambda_1 C \oplus \lambda_2 C = (\lambda_1 \oplus \lambda_2) C$,
(6) $C^{\lambda_1} \otimes C^{\lambda_2} = C^{\lambda_1 + \lambda_2}$.

Definition 5. Let $C = \langle (f_{Ex}, f_{En}, f_{He}), (g_{Ex}, g_{En}, g_{He}), (o_{Ex}, o_{En}, o_{He}) \rangle$ be a T-SFC, $\{(x_{f_1}, y_{f_1}), (x_{f_2}, y_{f_2}), \ldots, (x_{f_n}, y_{f_n})\}$ be n cloud droplets of the favor cloud (f_{Ex}, f_{En}, f_{He}), $\{(x_{g_1}, y_{g_1}), (x_{g_2}, y_{g_2}), \ldots, (x_{g_n}, y_{g_n})\}$ be n cloud droplets of the renunciation cloud (g_{Ex}, g_{En}, g_{He}), and $\{(o_{g_1}, o_{g_1}), (o_{g_2}, o_{g_2}), \ldots, (o_{g_n}, o_{g_n})\}$ be n cloud droplets of the opposition cloud (o_{Ex}, o_{En}, o_{He}). Motivated by Liang and Wang (2019), we obtain the score function $S(C)$ of C.

$$S(C) = \frac{1}{n^2} \sum_{i=1}^{n} f_{x_i} \cdot \sum_{i=1}^{n} f_{y_i} - \frac{1}{n^2} \sum_{i=1}^{n} g_{x_i} \cdot \sum_{i=1}^{n} g_{y_i} - \frac{1}{n^2} \sum_{i=1}^{n} o_{x_i} \cdot \sum_{i=1}^{n} o_{y_i} \tag{6}$$

where $\frac{1}{n^2} \sum_{i=1}^{n} f_{x_i} \cdot \sum_{i=1}^{n} f_{y_i}$, $\frac{1}{n^2} \sum_{i=1}^{n} g_{x_i} \cdot \sum_{i=1}^{n} g_{y_i}$ and $\frac{1}{n^2} \sum_{i=1}^{n} o_{x_i} \cdot \sum_{i=1}^{n} o_{y_i}$ are the overall expectations of the favor, renunciation, and opposition clouds mentioned in Step 5. Hence, the larger the value of $S(C)$, the better the T-SFC is.

In addition, it should be noted that since this study evaluates the digital transformation solutions of entrepreneurial SMEs, many qualitative indicators with multilevel and multi-aspect features are involved in the process. In the actual evaluation process, the evaluation of sub-indicators of each aspect will interact with each other; in other words, the evaluation value of one indicator will be affected by another under the same aspect, which is unavoidable in expert evaluation systems (Yang, Garg et al., 2020). The Heronian Mean (HM) operator can effectively investigate the interaction relationship between indicators, and thus, it is introduced to build the aggregation model of evaluation indicators of digital transformation solutions. The HM operator is defined as follows:

Definition 6. (Sýkora, 2009) Let $\phi_i\ (i = 1, 2, \ldots, n)$ be a regular real number set and the parameters $\eta \geq 0, \gamma \geq 0$, and $\eta + \gamma > 0$. The Heronian mean (HM) operator is regarded as:

$$HM\left(\phi_1, \phi_2, \ldots, \phi_n\right) = \left(\frac{2}{n(n+1)} \sum_{\substack{i,j=1 \\ i \neq j}}^{n} \phi_i^\eta \phi_j^\gamma\right)^{\frac{1}{\eta+\gamma}} \tag{7}$$

This section defines the new concept of the T-SFC and its operational rules and introduces the HM operator, which provides the basis for the proposed T-SFCWHM operator, as follows:

4. The T-SFCWHM operator

In this section, according to the operational rules of T-SFCs, we integrated the HM operator and the T-SFCs to present the T-SFCWHM operator and examine some of its important properties.

Definition 7. Let $C = (C_1, C_2, \ldots, C_n)$ be a set that consists of n T-SFCs, where $C_i = \langle (f_{Ex_i}, f_{En_i}, f_{He_i}), (f_{Ex_i}, f_{En_i}, f_{He_i}), (o_{Ex_i}, o_{En_i}, o_{He_i}) \rangle$, letting $w = (w_1, w_2, \ldots, w_n)$ be the weight vector of set C, and $w_i \geq 0$ and $\sum_{i=1}^{n} w_i = 1$. Then, we define:

$$S-TFCWHM(C_1, C_2, \ldots, C_n) = \left(\frac{2}{n(n+1)} \sum_{i=1}^{n} \sum_{\substack{j=1, \\ i \neq j}}^{n} (C_i n w_i)^\eta \otimes (C_j n w_j)^\gamma\right)^{\frac{1}{\eta+\gamma}} \tag{8}$$

As the T-SFCWHM operator, where n is the equilibrium coefficient.

Theorem 1. Let $C = (C_1, C_2, \ldots, C_n)$ be a T-SFCs set, where $C_i = \langle (f_{Ex_i}, f_{En_i}, f_{He_i}), (f_{Ex_i}, f_{En_i}, f_{He_i}), (o_{Ex_i}, o_{En_i}, o_{He_i}) \rangle$; then, the value aggregated by the T-SFCWHM operator is also a T-SFC, in other words:

$$
\begin{aligned}
&S-TFCWHM(C_1, C_2, \cdots, C_n)\\
&= \left(\begin{array}{l}
\left(\left(1-\left(\prod_{\substack{i,j=1\\ i\neq j}}^{n} \left(1-\left(1-\left(1-f_{Ex_i}^{q}\right)^{nw_i}\right)^{\eta}\left(1-\left(1-f_{Ex_j}^{q}\right)^{nw_j}\right)^{\gamma}\right) \right)^{\frac{2}{n(n+1)}} \right)^{\frac{1}{(\eta+\gamma)q}}, \right.\\
\left. \left(\frac{2}{n(n+1)} \sum_{\substack{i,j=1\\ i\neq j}}^{n} \left(f_{En_i} nw_i\right)^{\eta}\left(f_{En_j} nw_j\right)^{\gamma} \right)^{\frac{1}{\eta+\gamma}}, \left(\frac{2}{n(n+1)} \sum_{\substack{i,j=1\\ i\neq j}}^{n} \left(f_{He_i} nw_i\right)^{\eta}\left(f_{He_j} nw_j\right)^{\gamma} \right)^{\frac{1}{\eta+\gamma}} \right);\\
\left(\left(1-\left(1-\left(\prod_{\substack{i,j=1\\ i\neq j}}^{n} \left(1-\left(1-\left(g_{Ex_i}^{nw_i}\right)^{q}\right)^{\eta}\right)\left(1-\left(1-\left(g_{Ex_j}^{nw_j}\right)^{q}\right)^{\gamma}\right) \right)^{\frac{2}{n(n+1)}} \right)^{\frac{1}{\eta+\gamma}} \right)^{\frac{1}{q}}, \right.\\
\left. \left(\frac{2}{n(n+1)} \sum_{\substack{i,j=1\\ i\neq j}}^{n} \left(g_{En_i} nw_i\right)^{\eta}\left(g_{En_j} nw_j\right)^{\gamma} \right)^{\frac{1}{\eta+\gamma}}, \left(\frac{2}{n(n+1)} \sum_{\substack{i,j=1\\ i\neq j}}^{n} \left(g_{He_i} nw_i\right)^{\eta}\left(g_{He_j} nw_j\right)^{\gamma} \right)^{\frac{1}{\eta+\gamma}} \right);\\
\left(\left(1-\left(1-\left(\prod_{\substack{i,j=1\\ i\neq j}}^{n} \left(1-\left(1-\left(o_{Ex_i}^{nw_i}\right)^{q}\right)^{\eta}\right)\left(1-\left(1-\left(o_{Ex_j}^{nw_j}\right)^{q}\right)^{\gamma}\right) \right)^{\frac{2}{n(n+1)}} \right)^{\frac{1}{\eta+\gamma}} \right)^{\frac{1}{q}}, \right.\\
\left. \left(\frac{2}{n(n+1)} \sum_{\substack{i,j=1\\ i\neq j}}^{n} \left(o_{En_i} nw_i\right)^{\eta}\left(o_{En_j} nw_j\right)^{\gamma} \right)^{\frac{1}{\eta+\gamma}}, \left(\frac{2}{n(n+1)} \sum_{\substack{i,j=1\\ i\neq j}}^{n} \left(o_{He_i} nw_i\right)^{\eta}\left(o_{He_j} nw_j\right)^{\gamma} \right)^{\frac{1}{\eta+\gamma}} \right)
\end{array} \right)
\end{aligned}
\tag{9}
$$

The proof is shown in Appendix A.

Moreover, to test that the T-SFCWHM operator can effectively aggregate the evaluation information with the type of T-SFC, we investigate its three properties, namely, idempotency, monotonicity, and boundedness, as follows:

Theorem 2. (Idempotency). Let $C_i = \langle (f_{Ex_i}, f_{En_i}, f_{He_i}), (g_{Ex_i}, g_{En_i}, g_{He_i}), (o_{Ex_i}, o_{En_i}, o_{He_i}) \rangle$ $(i = 1, 2, \ldots, n)$ be equal to C for any i; then:

$$S - TFCWHM(C_1, C_2, \ldots, C_n) = C \tag{10}$$

The proof is shown in Appendix B.

Theorem 3. (Boundedness). Let $C_i = \langle (f_{Ex_i}, f_{En_i}, f_{He_i}), (g_{Ex_i}, g_{En_i}, g_{He_i}), (o_{Ex_i}, o_{En_i}, o_{He_i}) \rangle$ $(i = 1, 2, \ldots, n)$ be a T-SFCs set, and $C^- = \min_{\le i \le n}\{C_i\}$, and $C^+ = \max_{\le i \le n}\{C_i\}$; then,

$$C^- \le S - TFCWHM(C_1, C_2, \ldots, C_n) \le C^+ \tag{11}$$

The proof is shown in Appendix B.

Theorem 4. (Monotonicity). Let $(C_1, C_2, \ldots, C_n)$ and $(D_1, D_2, \ldots, D_n)$ be two T-SFC sets, $C_i = \langle (f_{Ex_{C_i}}, f_{En_{C_i}}, f_{He_{C_i}}), (g_{Ex_{C_i}}, g_{En_{C_i}}, g_{He_{C_i}}), (o_{Ex_{C_i}}, o_{En_{C_i}}, o_{He_{C_i}}) \rangle$, and $B_i = \langle (f_{Ex_{B_i}}, f_{En_{B_i}}, f_{He_{B_i}}), (g_{Ex_{B_i}}, g_{En_{B_i}}, g_{He_{B_i}}), (o_{Ex_{B_i}}, o_{En_{B_i}}, o_{He_{B_i}}) \rangle$. For $\forall i$, if $C_i \le D_i$, then:

$$S - TFCWHM(C_1, C_2, \ldots, C_n) \le S - TFCWHM(D_1, D_2, \ldots, D_n) \tag{12}$$

Proof. According to Theorems 2 and 3, we can easily prove that the T-SFCWHM operator meets monotonicity properties, and the proof process is omitted here.

5. Evaluation and selection framework for the digital transformation solution of entrepreneurial SMEs based on the T-SFCWHM operator

For the evaluation and selection of digital solutions for an SME, m alternatives $S = (S1, S2, S3., Sm)$ and n indicators $I = (I1, I2, I3. In)$ are selected to evaluate m alternatives according to the actual factors, such as the financial capacity, technical level, talent attraction, and organizational structure adjustment, to select the optimal scheme according to the evaluation result. In practice, the indicators of the alternatives are evaluated and scored by experts who are chosen within and outside the enterprise in terms of favor, renunciation, and opposition degree of the indicators, which are all limited to the range of [0,1]. The higher the score is, the closer it is to 1, and the stronger the degree, and vice versa. In addition, a certain percentage of the evaluation value error can be set to address the inaccuracy of the expert evaluation and the interference of objective environmental factors. To accomplish this goal, the evaluation value of the j-th indicator of the i-th scheme is V_{ij} with the form of T-SFC $V_{ij} = < (f_{Ex_{V_{ij}}}, f_{En_{V_{ij}}}, f_{He_{V_{ij}}}), (g_{Ex_{V_{ij}}}, g_{En_{a_{V_{ij}}}}, g_{He_{V_{ij}}}), (o_{Ex_{V_{ij}}}, o_{En_{V_{ij}}}, o_{He_{V_{ij}}}) >$, in which $(f_{Ex_{V_{ij}}}, f_{En_{V_{ij}}}, f_{He_{V_{ij}}})$ is the favor function, $f_{Ex_{V_{ij}}}$ is the degree of favor, $f_{En_{V_{ij}}}$ is the error of the degree of favor, and $f_{He_{V_{ij}}}$ is the hyper error; $(g_{Ex_{V_{ij}}}, g_{En_{a_{V_{ij}}}}, g_{He_{V_{ij}}})$ is the renunciation function, $g_{Ex_{V_{ij}}}$ is the degree of renunciation, $g_{En_{V_{ij}}}$ is the error of the degree of renunciation, and $g_{He_{V_{ij}}}$ is the hyper error of the renunciation degree; $(o_{Ex_{V_{ij}}}, o_{En_{V_{ij}}}, o_{He_{V_{ij}}})$is the opposition function, $o_{Ex_{V_{ij}}}$ is the degree of opposition, $o_{En_{V_{ij}}}$ is the error of the degree of opposition, and $o_{He_{V_{ij}}}$ is the hyper error of the degree of opposition. In addition, different entrepreneurial SMEs will have personalized needs for digital transformation solutions. In other words, different enterprises have different preferences for evaluation indicators in the evaluation process. Therefore, different weights are assigned to the indicators as $w = (w_1, w_2, \ldots, w_n)$. The indicators of different schemes are scored, and an evaluation and decision information matrix are finally obtained, $V = [V_{ij}]_{m \times n}$. Based on the information above, an evaluation and selection decision framework for digital transformation solutions of entrepreneurial SMEs is constructed, and its calculation steps include the following parts:

Table 1
Introduction to five alternative digital transformation solutions.

Names	Functions and features	Website
AETIB	It enables machines to perceive, transfer and self-diagnose problems and optimize machine output and reduce waste costs by analyzing data collected in industrial production. With inexpensive sensors, intelligent algorithms, and powerful computing power, the ET industrial brain can address the core issues of manufacturing.	https://et.aliyun.com/brain/industry
ICIIP	It is applicable to all walks of life for resolving common needs and comprehensive information management. Intelligent products and equipment are fully connected to provide excellent equipment connection and management services for smart manufacturing, smart factories, and smart workshops.	https://cloud.inspur.com/
ICCMSS	It can provide APP support for all elements, processes, and life cycles of production for the manufacturing industry chain. An innovative ecosystem with a comprehensive system, open sharing, and convenient use is built by implementing intelligent transformation and supporting an enterprise equipment and data access platform.	http://www.casicloud.com/
CCMP	It enables enterprises and users to build flexible and automated infrastructure, pay-for-demand service models, and low-cost operational IT service systems to help enterprise customers build stations quickly.	https://www.chinac.com/
RCP	It has a simplified development process and requires no significant effort from the manufacturer to build a complex network architecture, a rapidly expanding platform architecture that can be rapidly extended to meet the needs of customers, allows enterprises to choose different deployment methods according to their actual business, and a distributed multi-backup encrypted storage with pay-per-volume.	https://www.rootcloud.com/

Step 1. Establish an evaluation index system on digital transformation solutions of entrepreneurial SMEs;

Step 2. Gather the data of evaluation indexes given by experts, then build an evaluation and decision matrix $V = [V_{ij}]_{m \times n}$ with the type of T-SFC information;

Step 3. Apply the T-SFCWHM operator to aggregate $V_{ij} =< (f_{Ex_{V_{ij}}}, f_{En_{V_{ij}}}, f_{He_{V_{ij}}}), (g_{Ex_{V_{ij}}}, g_{En_{a_{V_{ij}}}}, g_{He_{V_{ij}}}), (o_{Ex_{V_{ij}}}, o_{En_{V_{ij}}}, o_{He_{V_{ij}}}) >$ into$V_i = < (f_{Ex_{a_i}}, f_{En_{a_i}}, f_{He_{a_i}}), (g_{Ex_{a_i}}, g_{En_{a_i}}, g_{He_{a_i}}), (o_{Ex_{a_i}}, o_{En_{a_i}}, o_{He_{a_i}}) >$;

Step 4. Produce n cloud drops $\{(x_{f_1}, y_{f_1}), (x_{f_2}, y_{f_2}), \ldots, (x_{f_n}, y_{f_n})\}$ of the favor cloud (f_{Ex}, f_{En}, f_{He}), $\{(x_{g_1}, y_{g_1}), (x_{g_2}, y_{g_2}), \ldots, (x_{g_n}, y_{g_n})\}$ of the renunciation cloud (g_{Ex}, g_{En}, g_{He}), and $\{(o_{g_1}, o_{g_1}), (o_{g_2}, o_{g_2}), \ldots, (o_{g_n}, o_{g_n})\}$ of the opposition cloud (o_{Ex}, o_{En}, o_{He}) using MATLAB software. Then, calculate the overall expectations $\frac{1}{n^2}\sum_{i=1}^{n} f_{x_i} \cdot \sum_{i=1}^{n} f_{y_i}$ of the favor cloud, $\frac{1}{n^2}\sum_{i=1}^{n} g_{x_i} \cdot \sum_{i=1}^{n} g_{y_i}$ of the renunciation cloud, and $\frac{1}{n^2}\sum_{i=1}^{n} o_{x_i} \cdot \sum_{i=1}^{n} o_{y_i}$ of the opposition cloud.

Step 5. Count the score value S(C) of each alternative based on Eq. (6);

Step 6. Rank the alternatives based on the score values to make the final choice.

Table 2
The evaluation index system for digital transformation solutions of entrepreneurial SMEs.

First-grade index	Second-grade index	References
The matching degree between the investment in digital transformation resources needed and the original resource level of the enterprise (I_1)	The matching of digital resources investment at the equipment level (I_{11})	(Garzoni et al., 2020)
	The matching of digital resources Investment at the network level (I_{12})	(İnel, 2019)
	The matching of investment in Digital talents construction (I_{13})	(Albukhitan, 2020)
	The matching of investment in Digital production, operation, and maintenance (I_{14})	(Stich et al., 2020)
The extent to which an enterprise accepts the required digital strategic planning and organizational change (I_2)	The level of management's Digitalization concept (I_{21})	(Garzoni et al., 2020)
	The degree of enterprise's acceptance of strategic planning adjustment (I_{22})	(Bogner, Voelklein, Schroedel, & Franke, 2016)
	The degree of enterprise's acceptance of organizational structure change (I_{23})	(Gray & Rumpe, 2017)
	The enterprise's execution of digitalization strategy and organizational change (I_{24})	(Isensee, Teuteberg, Griese, & Topi, 2020)
The expected application level of digital transformation solutions (I_3)	The application of R&D and production (I_{31})	(Ottesjö et al., 2020)
	The application of daily business management (I_{32})	(Pelletier & Cloutier, 2019)
	The application of integrated decision support (I_{33})	(Gupta & Bose, 2019)
	The application of the business model and market service (I_{34})	(Ottesjö et al., 2020)
The expected benefits created by the digital transformation solution (I_4)	Product innovation benefits (I_{41})	(Nwankpa & Roumani, 2016)
	Business growth benefits (I_{42})	(Matarazzo et al., 2021)
	Business model and customer Service optimization benefits (I_{43})	(Gamache et al., 2019)
	Risk prevention and control benefits (I_{44})	(Lin et al., 2020)

6. Illustrative example

6.1. Problem description

Small and medium-sized manufacturing enterprises refer to enterprises with relatively small personnel scales and operation scales. Each country has different definitions for them. For example, the definition of SMEs in the USA is that the number of employees is no more than 500, while China stipulates those with less than 1000 employees or less than 400 million yuan of revenue. Although the definitions of small and medium-sized manufacturing enterprises are different in various countries, they all face the same problem: choosing a reasonable digital transformation solution to support the sustainable development of the enterprise. As such, this study aims to develop a method to address this issue. To show the practical application of the proposed method, we portray an application scenario in which a small and medium-sized manufacturing enterprise is preparing for digital transformation. First, the enterprise selects five digital transformation solutions from the market, namely, the Aliyun ET Industrial Brain (AETIB), Inspur cloud industrial Internet platform (ICIIP), "INDICS+CMSS" Cloud Manufacturing Support System (ICCMSS), China Cloud Manufacturing Platform (CCMP) and Rootcloud Platform (RCP), as detailed in Table 1. Then, the five digital transformation solutions are evaluated according to the evaluation indicator system in Table 2, and the optimal solution is selected according to the evaluation results. Additionally, we organized a team of 20 experts, which includes the relevant technical directors, Chief Executive Officers (CEOs), financial directors of enterprises, relevant researchers in universities or research institutes, and experts from industry associations. Afterward, the 20 experts were requested to score the indicators in Table 2 with the type of T-SFC information to obtain the evaluation data. To accomplish this goal, the evaluation information for five schemes is obtained according to expert evaluation with the form of T-SFC, as shown in Table 3.

6.2. The evaluation index system for the digital transformation solution of entrepreneurial SMEs

According to the definition of the digitized transformation in entrepreneurial SMEs (Ackx, 2014; Nicholas, 1995; Yoo et al., 2009) and the actual influencing factors faced therefrom, the evaluation indicator system of digital transformation solutions for entrepreneurial SMEs is established in this paper from four aspects combined with the existing research results: the investment in digital transformation resources needed, the digital strategic planning and organizational changeability needed, the expected application level of digital transformation solutions and the expected benefits created by digital transformation solutions. On this basis, as shown in Table 2, the first-level indicators are refined in combination with existing studies.

Specifically, the first is the matching degree between the investment in digital transformation resources needed and the original resource level of the enterprise, which is designed to measure the gap between the investment in the digital infrastructure construction, personnel, operation, and maintenance required by digital transformation solutions and the existing resources of enterprises. The second is the extent to which an enterprise accepts the required digital strategic planning and organizational change, which is designed to measure the impact of digital strategic planning and organizational change required in digital transformation solutions on the original strategic layout and organizational structure framework of enterprises. The third is the expected application level of digital transformation solutions, which is the key and substantive content for implementing digital transformation in entrepreneurial SMEs (Pelletier & Cloutier, 2019). It is measured on all aspects of the enterprise's value chain by investigating the application and system integration of digital technology in R&D and design, production, operation and management, business model, and market service. The fourth is the expected benefits created by the digital transformation solution. As the output of digitalizing entrepreneurial SMEs, it is a direct indicator to test whether the digital transformation solution is acceptable to enterprises.

6.3. Calculation process and results

Based on the above information, the proposed algorithm is used for evaluation and decision-making. The specific calculation process is as follows:

Step 1. Build the evaluation index system for the alternatives, as shown in Table 2.

Step 2. Collect the evaluation information based on the score by experts to obtain the evaluation data matrix, as shown in Table 3.

Step 3. Apply the T-SFCWHM operator to aggregate the evaluation data. Here, the weights of the secondary indexes under each primary index are set to be equal, in other words, $w_{1i} = (0.25, 0.25, 0.25, 0.25)$, $w_{2i} = (0.25, 0.25, 0.25, 0.25)$, $w_{3i} = (0.25, 0.25, 0.25, 0.25) w_{4i} = (0.25, 0.25, 0.25, 0.25)$, and, to obtain a comprehensive evaluation matrix, as shown in Table 4.

Then, the T-SFCWHM operator is utilized to aggregate the data in Table 4 again, and the weight of the first-level index $w = (0.3, 0.15,$

Table 3
Evaluation information matrix.

	AETIB	ICIIP	ICCMSS	CCMP	RCP
I_{11}	<0.78, 0.07, 0.006; 0.49, 0.044, 0.0037; 0.28, 0.025, 0.0021>	<0.59,0.053,0.0045; 0.51,0.046,0.0039; 0.66,0.059,0.005>	<0.3,0.027,0.0023; 0.55,0.05,0.0042; 0.67,0.06,0.0051>	<0.81,0.073,0.0062; 0.31,0.028,0.0024; 0.41,0.037,0.0031>	<0.71,0.064,0.0054; 0.45,0.041,0.0034; 0.33,0.03,0.0025>
I_{12}	<0.81,0.073,0.0062; 0.39,0.035,0.003; 0.26,0.023,0.002>	<0.47,0.042,0.0036; 0.59,0.053,0.0045; 0.68,0.061,0.0052>	<0.3,0.027,0.0023; 0.55,0.05,0.0042; 0.67,0.06,0.0051>	<0.78,0.07,0.006; 0.43,0.039,0.0033; 0.41,0.037,0.0031>	<0.69,0.062,0.0053; 0.54,0.049,0.0041; 0.36,0.032,0.0028>
I_{13}	<0.77,0.069,0.0059; 0.57,0.051,0.0044; 0.34,0.031,0026>	<0.51,0.046,0.0039; 0.71,0.064,0.0054; 0.52,0.047,0.004>	<0.41,0.037,0.003; 0.62,0.056,0.0047; 0.73,0.066,0.0056>	<0.8,0.072,0.0061; 0.47,0.042,0.0036; 0.49,0.044,0.0037>	<0.66,0.059,0.005; 0.37,0.033,0.0028; 0.29,0.026,0.0022>
I_{14}	<0.88,0.079,0.0067; 0.43,0.039,0.0033; 0.27,0.024,0.0021>	<0.6,0.054,0.0046; 0.53,0.048,0.0041; 0.6,0.054,0.0046>	<0.33,0.03,0.0025; 0.71,0.064,0.0054; 0.69,0.062,0.0053>	<0.81,0.073,0.0062; 0.52,0.047,0.004; 0.33,0.03,0.0025>	<0.74,0.067,0.0057; 0.43,0.039,0.0033; 0.37,0.033,0.0028>
I_{21}	<0.61,0.055,0.0047; 0.51,0.046,0.0039; 0.47,0.042,0.0036>	<0.5,0.045,0.0038; 0.7,0.063,0.0054; 0.81,0.073,0.0062>	<0.27,0.024,0.002; 0.64,0.058,0.0049; 0.74,0.067,0.0057>	<0.88,0.079,0.0067; 0.21,0.019,0.0016; 0.29,0.026,0.0022>	<0.85,0.077,0.0065; 0.2,0.018,0.0015; 0.2,0.018,0.0015>
I_{22}	<0.64,0.058,0.0049; 0.53,0.048,0.0041; 0.37,0.033,0.0028>	<0.22,0.02,0.0017; 0.77,0.069,0.0059; 0.78,0.07,0.006>	<0.29,0.026,0.002; 0.74,0.067,0.0057; 0.84,0.076,0.0064>	<0.79,0.071,0.006; 0.21,0.019,0.0016; 0.51,0.046,0.0039>	<0.84,0.076,0.0064; 0.33,0.03,0.0025; 0.41,0.037,0.0031>
I_{23}	<0.59,0.053,0.0045; 0.5,0.045,0.0038; 0.4,0.036,0.0031>	<0.25,0.023,0.0019; 0.69,0.062,0.0053; 0.73,0.066,0.0056>	<0.33,0.03,0.0025; 0.67,0.06,0.0051; 0.72,0.065,0.0055>	<0.8,0.072,0.0061; 0.18,0.016,0.0014; 0.42,0.038,0.0032>	<0.77,0.069,0.0059; 0.41,0.037,0.0031; 0.38,0.034,0.0029>
I_{24}	<0.49,0.044,0.0037; 0.58,0.052,0.0044; 0.77,0.069,0.0059>	<0.28,0.025,0.0021; 0.73,0.066,0.0056; 0.69,0.062,0.0053>	<0.4,0.036,0.0031; 0.44,0.04,0.0034; 0.44,0.04,0.0034>	<0.76,0.068,0.0058; 0.2,0.018,0.0015; 0.27,0.024,0.0021>	<0.86,0.077,0.0066; 0.17,0.015,0.0013; 0.14,0.013,0.0011>
I_{31}	<0.57,0.051,0.0044; 0.62,0.056,0.0047; 0.49,0.044,0.0037>	<0.77,0.069,0.0059; 0.32,0.029,0.0024; 0.15,0.014,0.0011>	<0.82,0.074,0.006; 0.28,0.025,0.0021; 0.18,0.016,0.0014>	<0.58,0.052,0.0044; 0.51,0.046,0.0039; 0.58,0.052,0.0044>	<0.47,0.042,0.0036; 0.52,0.047,0.004; 0.44,0.04,0.0034>
I_{32}	<0.68,0.061,0.0052; 0.52,0.047,0.004; 0.43,0.039,0.0033>	<0.81,0.073,0.0062; 0.31,0.028,0.0024; 0.16,0.014,0.0012>	<0.84,0.076,0.006; 0.29,0.026,0.0022; 0.19,0.017,0.0015>	<0.6,0.054,0.0046; 0.46,0.041,0.0035; 0.53,0.048,0.0041>	<0.45,0.041,0.0034; 0.45,0.041,0.0034; 0.51,0.046,0.0039>
I_{33}	<0.66,0.059,0.005; 0.44,0.04,0.0034; 0.43,0.039,0.0033>	<0.83,0.075,0.0063; 0.34,0.031,0.0026; 0.21,0.019,0.0016>	<0.78,0.07,0.006; 0.32,0.029,0.0024; 0.22,0.02,0.0017>	<0.59,0.053,0.0045; 0.46,0.041,0.0035; 0.44,0.04,0.0034>	<0.42,0.038,0.0032; 0.43,0.039,0.0033; 0.56,0.05,0.0043>
I_{34}	<0.55,0.05,0.0042; 0.42,0.038,0.0032; 0.41,0.037,0.0031>	<0.81,0.073,0.0062; 0.4,0.036,0.0031; 0.32,0.029,0.0024>	<0.79,0.071,0.006; 0.3,0.027,0.0023; 0.2,0.018,0.0015>	<0.61,0.055,0.0047; 0.42,0.038,0.0032; 0.49,0.044,0.0037>	<0.4,0.036,0.0031; 0.4,0.036,0.0031; 0.5,0.045,0.0038>
I_{41}	<0.47,0.042,0.0036; 0.34,0.031,0.0026; 0.54,0.049,0.0041>	<0.51,0.046,0.0039; 0.36,0.032,0.0028; 0.3,0.027,0.0023>	<0.63,0.057,0.004; 0.32,0.029,0.0024; 0.31,0.028,0.0024>	<0.56,0.05,0.0043; 0.41,0.037,0.0031; 0.47,0.042,0.0036>	<0.61,0.055,0.0047; 0.31,0.028,0.0024; 0.41,0.037,0.0031>
I_{42}	<0.62,0.056,0.0047; 0.44,0.04,0.0034; 0.34,0.031,0.0026>	<0.6,0.054,0.0046; 0.5,0.045,0.0038; 0.3,0.027,0.0023>	<0.6,0.054,0.0046; 0.42,0.038,0.0032; 0.35,0.032,0.0027>	<0.52,0.047,0.004; 0.51,0.046,0.0039; 0.44,0.04,0.0034>	<0.58,0.042,0.0044; 0.42,0.038,0.0032; 0.39,0.035,0.003>
I_{43}	<0.61,0.055,0.0047; 0.47,0.042,0.0036; 0.41,0.037,0.0031>	<0.6,0.054,0.0046; 0.51,0.046,0.0039; 0.35,0.032,0.0027>	<0.57,0.051,0.004; 0.48,0.043,0.0037; 0.46,0.041,0.0035>	<0.6,0.054,0.0046; 0.44,0.04,0.0034; 0.33,0.03,0.0025>	<0.59,0.053,0.0045; 0.4,0.036,0.0031; 0.3,0.027,0.0023>
I_{41}	<0.58,0.052,0.0044; 0.4,0.036,0.0031; 0.51,0.046,0.0039;>	<0.62,0.056,0.0047; 0.4,0.036,0.0031; 0.42,0.038,0.0032;>	<0.53,0.048,0.004; 0.43,0.039,0.0033; 0.4,0.036,0.0031;>	<0.62,0.056,0.0047; 0.4,0.036,0.0031; 0.3,0.027,0.0023;>	<0.52,0.047,0.004; 0.5,0.045,0.0038; 0.19,0.017,0.0015;>

Table 4
Comprehensive evaluation information matrix.

	AETIB	ICIIP	ICCMSS	CCMP	RCP
T1	<0.75,0.061,0.0052; 0.34,0.036,0.003; 0.2,0.022,0.0019>	<0.5,0.041,0.0035; 0.43,0.044,0.0038; 0.46,0.047,0.004>	<0.31,0.025,0.0022; 0.45,0.046,0.0039; 0.52,0.052,0.0044>	<0.74,0.061,0.0051; 0.31,0.033,0.0028; 0.29,0.031,0.0026>	<0.64,0.053,0.0045; 0.32,0.034,0.0029; 0.24,0.026,0.0022>
T2	<0.54,0.044,0.0038; 0.39,0.04,0.0034; 0.34,0.038,0.0033>	<0.3,0.024,0.002; 0.55,0.055,0.0046; 0.58,0.057,0.0048>	<0.3,0.024,0.0021; 0.45,0.047,0.004; 0.49,0.052,0.0045>	<0.75,0.061,0.0052; 0.14,0.015,0.0013; 0.26,0.028,0.0024>	<0.77,0.063,0.0053; 0.18,0.021,0.0018; 0.18,0.022,0.0019>
T3	<0.57,0.047,0.004; 0.36,0.038,0.0032; 0.32,0.033,0.0028>	<0.74,0.061,0.0052; 0.24,0.026,0.0022; 0.14,0.016,0.0014>	<0.75,0.061,0.0052; 0.21,0.023,0.0019; 0.14,0.015,0.0013>	<0.55,0.045,0.0038; 0.34,0.035,0.003; 0.37,0.039,0.0033>	<0.4,0.033,0.0028; 0.32,0.034,0.0029; 0.37,0.038,0.0032>
T4	<0.53,0.043,0.0037; 0.3,0.031,0.0027; 0.32,0.034,0.0029>	<0.54,0.044,0.0038; 0.32,0.034,0.0029; 0.24,0.026,0.0022>	<0.54,0.044,0.0037; 0.29,0.031,0.0027; 0.27,0.029,0.0025>	<0.53,0.044,0.0037; 0.32,0.033,0.0028; 0.27,0.029,0.0025>	<0.53,0.044,0.0037; 0.29,0.031,0.0026; 0.22,0.025,0.0021>

$0.25, 0.3)$ is set to obtain the overall evaluation value of each alternative, as follows:

AETIB $= <0.43,0.027,0.0023; 0.19,0.02,0.0017; 0.2,0.019,0.0016>$,
ICIIP $= <0.42,0.026,0.0022; 0.2,0.022,0.0019; 0.16,0.02,0.0017>$,
ICCMSS $= <0.42,0.0250.0021; 0.19,0.021,0.0018; 0.17,0.021,0.0018>$,
CCMP $= <0.46,0.029,0.0025; 0.2,0.018,0.0015; 0.17,0.018,0.0015>$,
RCP $= <0.44,0.028,0.0023; 0.18,0.018,0.0015; 0.14,0.016,0.0013>$.

Step 4. Calculate the overall expectation of each alternative using MATLAB software, including the overall expectations $\frac{1}{n^2}\sum_{i=1}^{n} f_{x_i}\cdot\sum_{i=1}^{n} f_{y_i}$ of the favor cloud, $\frac{1}{n^2}\sum_{i=1}^{n} g_{x_i}\cdot\sum_{i=1}^{n} g_{y_i}$ of the renunciation cloud, and

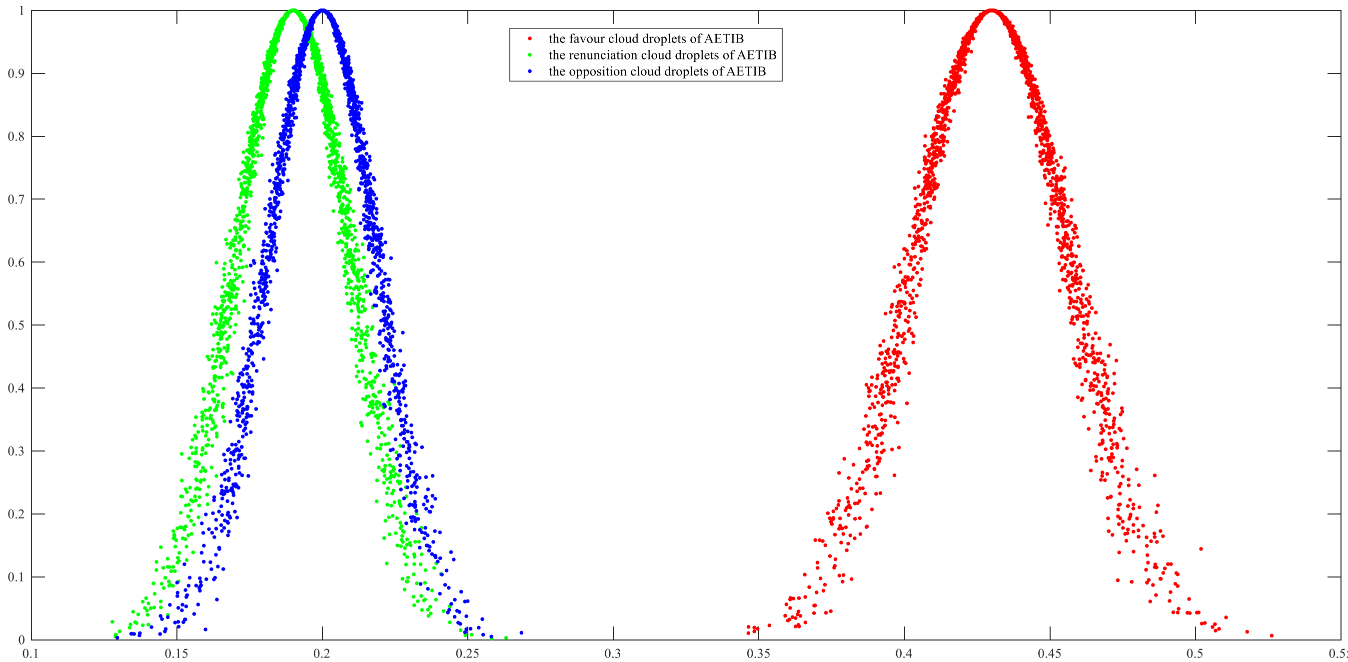

Fig. 1. The cloud droplets of the AETIB.

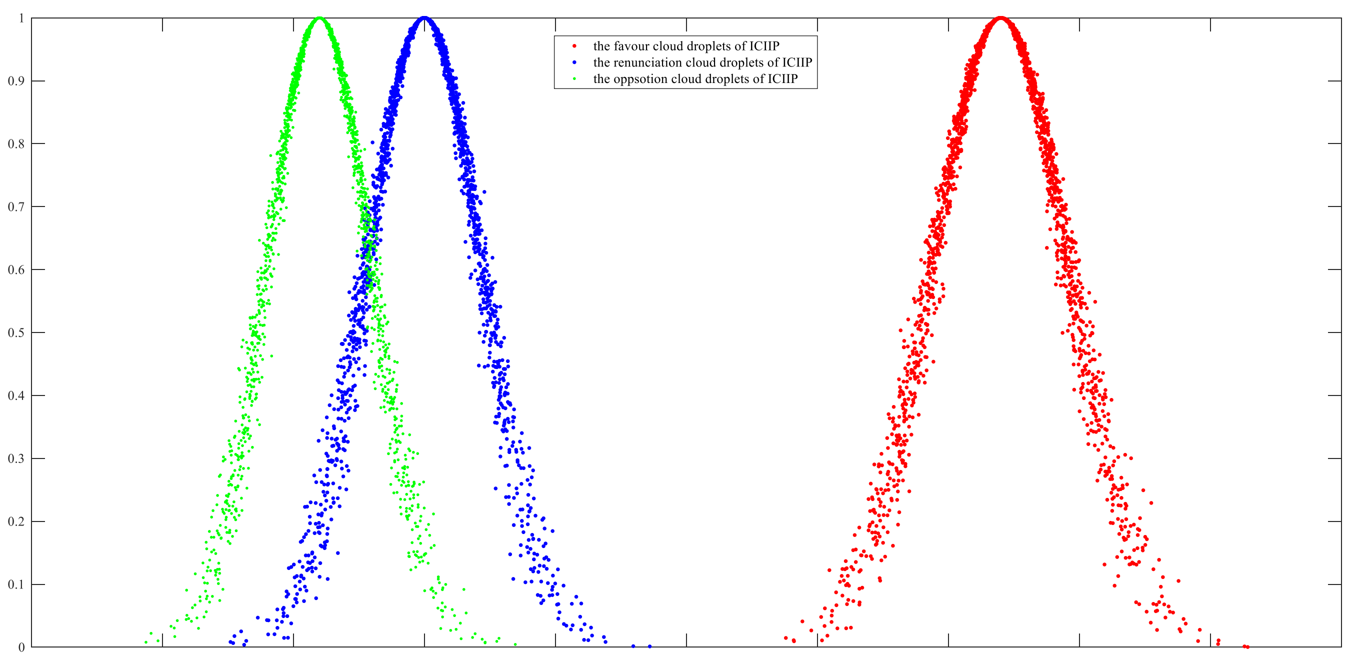

Fig. 2. The cloud droplets of the ICIIP.

$\frac{1}{n^2}\sum_{i=1}^{n} o_{x_i} \cdot \sum_{i=1}^{n} o_{y_i}$ of the opposition cloud. Here, we take the AETIB scheme as an example and calculate three types of overall expectations of the AETIB scheme by MATLAB programming with 2000 cloud droplets. We obtain the cloud droplets of the AETIB, as shown in Fig. 1.

Similarly, we also obtain the cloud droplets of other alternatives as shown in Figs. 2–5.

The overall expectations of the AETIB are obtained as shown in Table 5 according to Fig. 1; similarly, we also obtained the overall expectations of the other four alternatives, as shown in Table 5 based on Figs. 2–5.

Step 5. Count the score value S(C) of each alternative based on Eq. (6) as follows:

S(AETIB) $= 0.0326$, S(ICIIP) $= 0.0388$, S(ICCMSS) $= 0.0504$, S (CCMP) $= 0.0651$, S(RCP) $= 0.77$.

Step 6. According to the score values, we obtain the ranking result of all alternatives as RCP $>$ CCMP $>$ ICCMSS $>$ ICIIP $>$ AETIB, and the best alternative is RCP.

6.4. Analysis of parameters

The proposed method in this paper involves parameters η, γ and weight w, whose impact on the evaluation result should be examined to guide practice better.

The first step is to analyze the impact of η and γ on the evaluation

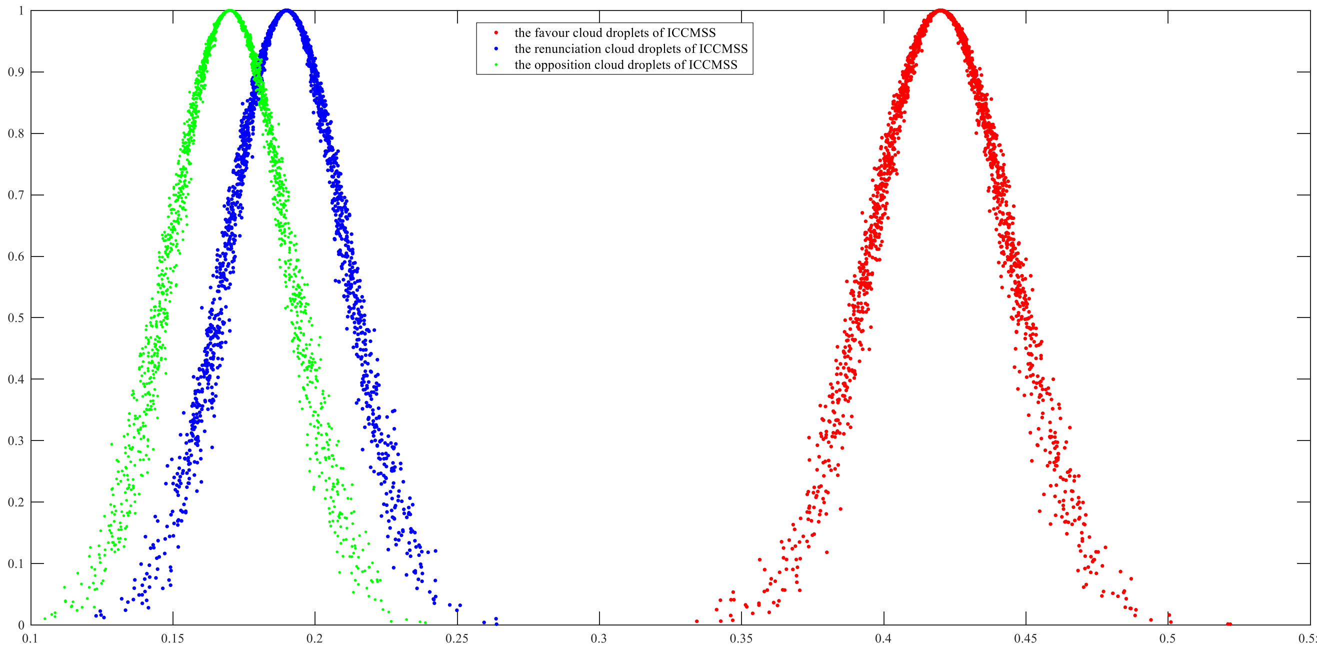

Fig. 3. The cloud droplets of the ICCMSS.

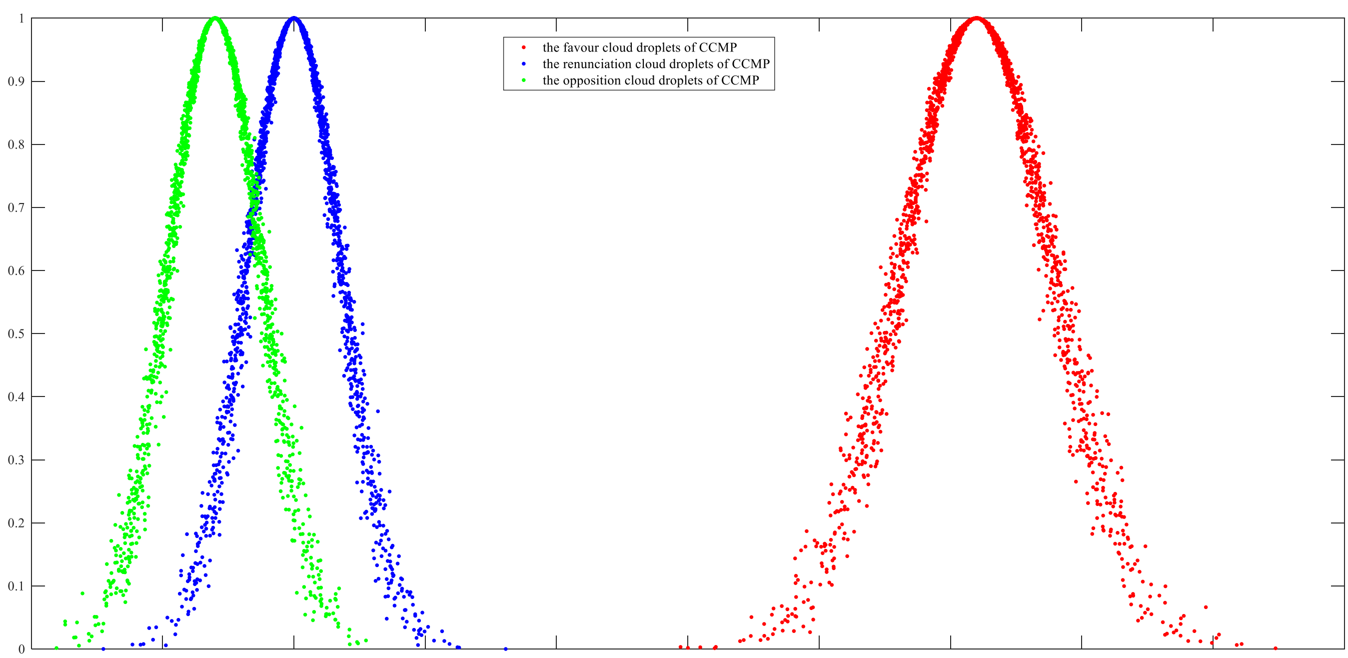

Fig. 4. The cloud droplets of the CCMP.

result by making either of them constant as shown in Table 6. For example, when $\eta = 2$ and γ is 5, 7, and 9, the corresponding ranking will change, and the optimal digital transformation solution for entrepreneurial SMEs will change from the RCP to the ICIIP. Similarly, when $\gamma = 2$ and η is 5, 7, and 9, the corresponding ranking will also change. In addition, when η and γ change together, $\gamma = \eta = 5$, and the corresponding scheme ranking is CCMP $>$ RCP $>$ AETIB $>$ ICIIP $>$ ICCMSS; when $\gamma = \eta = 12$, RCP $>$ CCMP $>$ AETIB $>$ ICIIP $>$ ICCMSS. Thus, it is clear that η and γhave a significant impact on the ranking result. Since parameters η and γ represent the intensity of the internal relationship between the indicators, the corresponding decision results can be obtained by adjusting the parameter values according to the mutual relationship between the indicators in the actual evaluation process.

The next step is to analyze the impact of weight w on the evaluation result. Different weight combinations are taken to clearly analyze the changes in the weight that result in the evaluation results, as shown in Table 7. Here, $w = (0.85, 0.05, 0.05, 0.05)$ shows that the enterprise pays attention to the matching degree between the investment in digital

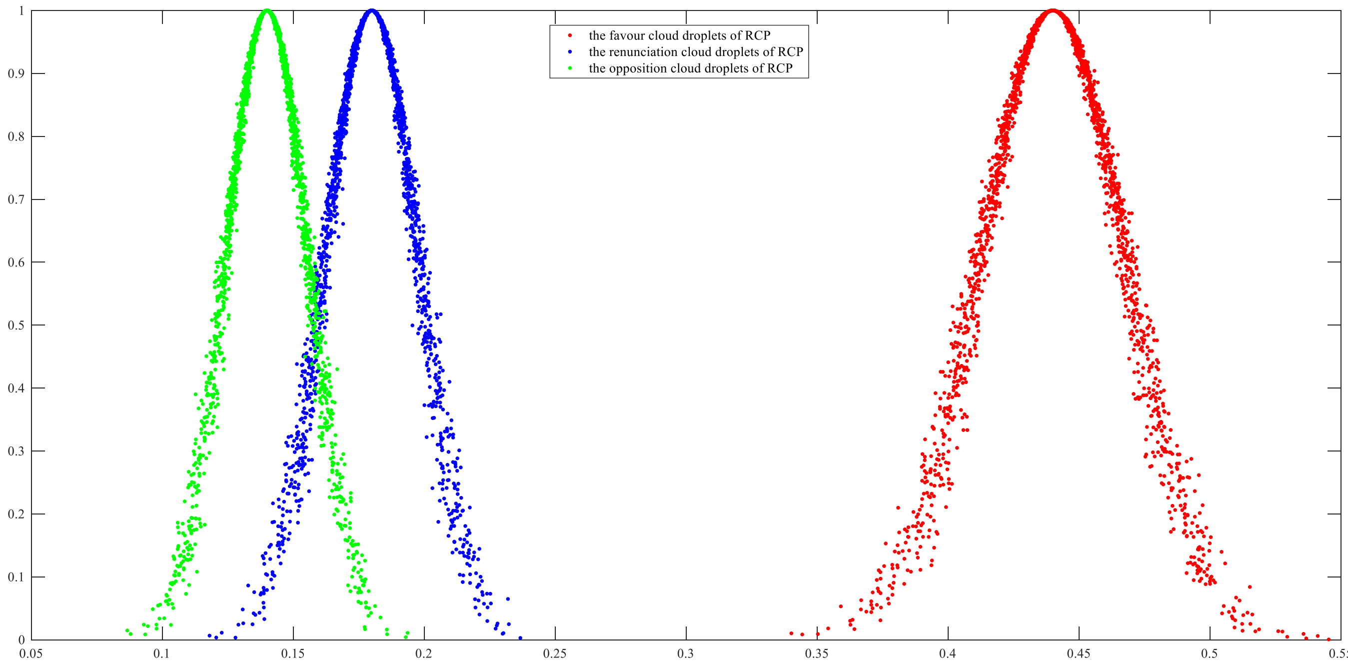

Fig. 5. The cloud droplets of the RCP.

Table 5
The expectation and score value of each scheme.

	$\frac{1}{n}\sum_{i=1}^{n} f_{x_i}$	$\frac{1}{n}\sum_{i=1}^{n} f_{y_i}$	$\frac{1}{n}\sum_{i=1}^{n} g_{x_i}$	$\frac{1}{n}\sum_{i=1}^{n} g_{y_i}$	$\frac{1}{n}\sum_{i=1}^{n} o_{x_i}$	$\frac{1}{n}\sum_{i=1}^{n} o_{y_i}$	S (Ci)
AETIB	0.4308	0.7196	0.1898	0.7078	0.1996	0.7168	0.0326
ICIIP	0.4198	0.698	0.1992	0.7077	0.16	0.7079	0.0388
ICCMSS	0.4199	0.7218	0.1896	0.7027	0.1695	0.7048	0.0504
CCMP	0.4593	0.7102	0.2004	0.708	0.1694	0.704	0.0651
RCP	0.4409	0.6913	0.1795	0.7119	0.14	0.7147	0.77

Table 6
The impact of η, γ on the evaluation results.

η	γ	S (AETIB)	S (ICIIP)	S (ICCMSS)	S (CCMP)	S (RCP)	Ranking
2	5	0.142	0.152	0.12	0.17	0.177	RCP > CCMP > ICIIP > AETIB > ICCMSS
2	7	0.181	0.208	0.175	0.202	0.216	RCP > ICIIP > CCMP > AETIB > ICCMSS
2	9	0.212	0.252	0.222	0.23	0.249	ICIIP > RCP > CCMP > ICCMSS > AETIB
5	2	0.198	0.158	0.163	0.222	0.2	CCMP > RCP > AETIB > ICCMSS > ICIIP
7	2	0.254	0.215	0.225	0.273	0.243	CCMP > AETIB > RCP > ICCMSS > ICIIP
9	2	0.297	0.259	0.27	0.312	0.276	CCMP > AETIB > RCP > ICCMSS > ICIIP
5	5	0.161	0.144	0.135	0.183	0.181	CCMP > RCP > AETIB > ICIIP > ICCMSS
12	12	0.223	0.211	0.209	0.232	0.233	RCP > CCMP > AETIB > ICIIP > ICCMSS

Table 7
The impact of w on the evaluation results.

w	S (AETIB)	S (ICIIP)	S (ICCMSS)	S (CCMP)	S (RCP)	Ranking
(0.85, 0.05, 0.05, 0.05)	0.051	-0.09	-0.174	0.064	0.073	RCP > CCMP > AETIB > ICIIP > ICCMSS
(0.05, 0.85, 0.05, 0.05)	-0.015	-0.244	-0.164	0.141	0.13	CCMP > RCP > CCMP > ICCMSS > ICIIP
(0.05, 0.05, 0.85, 0.05)	0.01	0.0912	0.091	0.018	-0.013	ICIIP > ICCMSS > CCMP > AETIB > RCP
(0.05, 0.05, 0.05, 0.85)	0.03	0.042	0.038	0.061	0.083	RCP > CCMP > ICIIP > ICCMSS > AETIB

transformation resources and the original resource level in the process of digital transformation. In other words, enterprises hope to invest no more resources than the burden they bear and hope that the investment in a digital transformation solution in human resources and material resources will match their existing capacities. Then, the corresponding ranking result is RCP > CCMP > AETIB > ICIIP > ICCMSS. According to the features and functions of the scheme, payment by volume is an important reason to attract the enterprise to choose because it better meets the problem of limited resource investment. Here, w = (0.85, 0.05, 0.05, 0.05) indicates that the enterprise attaches importance to the degree to which it accepts the needed digital strategic planning and organizational change, which means that the enterprise has more room for strategic planning and organizational change and is suitable for a digital transformation solution that requires a large degree of organizational change. The corresponding ranking result is CCMP > RCP > CCMP > ICCMSS > ICIIP, i.e., the CCMP is the optimal choice. The CCMP can realize flexible and automated infrastructure construction for enterprises and users according to its functions and features, which meet the actual needs of the enterprise. Similarly, when $w = (0.05, 0.05, 0.85, 0.05)$, the ranking result is ICIIP > ICCMSS > CCMP > AETIB > RCP; in other words, ICIIP is the optimal digital transformation solution chosen for the enterprise owing to its advantages of comprehensive information management, the full connection of smart products and devices, and excellent equipment connection and management services for smart manufacturing, smart factories and smart workshops. In other words, it caters to the indicator that enterprises attach importance to the comprehensive application of digitalization. In addition, when $w = (0.05, 0.05, 0.05, 0.85)$, enterprises value the expected benefits created by digital solutions. The optimal scheme based on this weight combination is the RCP, which benefits from the advantages of simplifying the development process and eliminating the need for manufacturers to invest significant effort in structuring complex network architectures, which is conducive to the improvement of expected benefits.

7. Discussion

Many fiercely competitive digital transformation solutions in the current market have created barriers to the choice of entrepreneurial SMEs due to their differences in cost, expected income, and technology. At the same time, the weak strength of the entrepreneurial SME itself also makes it extremely cautious in the selection of digital transformation solutions to avoid the loss caused by the wrong choice. As such, this study develops an evaluation and selection method to support the digital transformation of entrepreneurial SMEs. Additionally, we conducted an empirical analysis based on a practical case to obtain some important findings, as follows:

First, the evaluation of digital transformation solutions involves many factors, as mentioned above, which together affect the accuracy of the evaluation results. Therefore, based on these factors, this study has constructed an indicator system for evaluating digital transformation solutions. The findings of this study show that this developed indicator system can accurately measure the factors of capital investment, digital awareness of leadership, organizational reform, talent attraction, and expected benefits considered by entrepreneurial SMEs when choosing a digital transformation solution. In reality, these factors are the main obstacles faced by entrepreneurial SMEs in their digital transformation. Therefore, the indicator system constructed in this study quantifies the relevant obstacles and provides a reasonable reference coefficient for enterprises. In addition, entrepreneurial SMEs can effectively investigate the matching degree of their own capabilities, needs, and solution requirements through the proposed index system and obtain a reasonable evaluation standard and the optimal selection strategy.

Second, in the actual evaluation process of the digital transformation solutions, the opinions by the expert group on the evaluation indicators often show diversity and heterogeneity, such as support, opposition, and abstention. The score values of different opinions are often affected by subjective preferences and a complex objective environment, which eventually leads to errors in the actual evaluation value. To address those concerns, this study defined a novel concept of the T-SFC combining the T-SFS and the cloud model. Our results show that the proposed T-SFC can represent three types of heterogeneous opinions, i.e., favor, renunciation, and opposition in the expert evaluation, and incorporate them into a framework for analysis, thus facilitating the integration of multiple heterogeneous evaluation information. Hence, the proposed method has a wider space for information characterization of index evaluation and helps decision-makers evaluate digital transformation solutions effectively. Additionally, the error range and its distribution characteristics of three types of opinions in expert evaluation information are measured by the T-SFC. This approach indicates that the T-SFC can adequately capture the error characteristics caused by subjective preference in the evaluation information. Consequently, the T-SFC has a high degree of uncertainty information processing ability.

Furthermore, the constructed evaluation index system is characterized by a multilayer and multifaceted structure, and the subindexes of each aspect influence each other. This structure means that the evaluation value of an indicator is often affected by the evaluation value of another subindex under the same aspect. For this reason, when gathering the multi-index information, it must not only aggregate multiple heterogeneous evaluation viewpoints but also examine the characteristics of the interactive relationship between the indexes. In response, the entrepreneurial SMEs can aggregate the 16 indicator information listed in Table 2 to a synthetic value by our T-SFCWHM operator to obtain a reasonable ranking result for the digital transformation solutions of entrepreneurial SMEs.

Finally, an algorithm framework was constructed to evaluate and select digital transformation solutions for entrepreneurial SMEs. The results show that the evaluation results are easily affected by the changes in relevant parameters, which shows that the proposed method has high sensitivity and can obtain the corresponding evaluation results by adjusting the relevant parameters according to the actual evaluation environment. In addition, a comparison of different methods has also been conducted, and the results show that this method has significant advantages in capturing the intrinsic mutual relationship between indicators and investigating the error characteristics of evaluation information.

7.1. Theoretical contributions

The theoretical contribution is fourfold. First, this paper constructs an evaluation index system for the digital transformation solution of entrepreneurial SMEs, thereby enriching and perfecting the evaluation theory of digital transformation. Specifically, existing relevant studies mainly focus on the evaluation of maturity (Thomas, 2020), influencing factors (Cannas, 2021; El Hilali et al., 2020) and effects of the digital transformation of entrepreneurial SMEs Matarazzo et al. (2021), and less on the evaluation and selection of those. As a result, the achievements of existing research cannot solve the key issue of providing pre-plan references for the digital transformation of entrepreneurial SMEs. Moreover, the existing studies for the establishment of the evaluation index system stem from the macroscopic aspects of economic, political, and environmental factors Stich et al. (2020) and seldom consider the specific actual needs of enterprises at the micro-level. To compensate for the lack of existing studies, this study explores the issue of an evaluation index system for digital transformation solutions of entrepreneurial SMEs from four aspects. The evaluation index system established in this paper further optimizes and improves the existing relevant evaluation indexes.

Second, the T-SFC is introduced into the evaluation work of digital transformation solutions, and the diverse and heterogeneous evaluation opinions given by experts are integrated into the same framework for analysis, which enriches the representation theory of the evaluation information. To highlight the differences between our method and existing methods, we apply the methods by Yager (2017), Yang, Garg et al. (2020), and Liao, Wu, Mi, and Herrera (2020) to address the case in this paper, and the corresponding ranking is ICIIP > RCP > AETIB > ICCMSS > ICIIP. The best solution is ICIIP, which is totally different from the ranking of RCP > CCMP > ICCMSS > ICIIP > AETIB by the proposed method.

Since our method simultaneously considers and effectively integrates various heterogeneous opinions by experts, the results based on this method are more realistic.

Third, this paper defines a novel concept of T-SFC by embedding the cloud model into the T-SFS to extend the T-SFS theory. In it, to consider the influence of information error on the evaluation results, the cloud model is introduced in this paper to analyze the error and error distribution characteristics of expert evaluation and decision information. To further verify the effect of the error, we use the methods without considering the error characteristics by Ali et al. (2020) to handle the case in this paper, and the ranking result obtained is RCP $>$ CCMP $>$ ICIIP $>$ ICCMSS $>$ AETIB. The optimal solution of the RCP is the same as that of our method, but there are differences in their overall ranking. In addition, although the existing methods by Ali et al. (2020) examined a variety of different opinions by experts, they ignored the error information of opinions. In contrast, this paper uses the cloud model to calculate the error information, to express the evaluation information more objectively.

Fourth, we present a new T-SFCWHM operator, which can be applied to aggregate the multi-index information by investigating the interaction relationship between indexes. The proposed T-SFCWHM operator expands the existing information aggregation system and enriches the information fusion theory. In the existing approaches (Ali et al., 2020; Mahmood et al., 2019; Ullah, Mahmood, & Garg, 2020), the aggregation of indicator information is based on the traditional weighted average idea, including the geometric weighted average and the arithmetic weighted average, not accounting for the relationship between indicators. Furthermore, we handle the cases in this study using the weighted average operator by Mahmood et al. (2019), Ali et al. (2020), and Ullah et al. (2020) and obtain the ranking result of RCP $>$ CCMP $>$ ICIIP $>$ AETIB $>$ ICCMSS. Although the optimal solution RCP is consistent with our result, the total ordering is different. In the face of an index system with a multilayer structure, the interrelationship between sub-indices must be considered. Unfortunately, the existing methods ignored these relationships. In comparison, the proposed method takes the HM operator to examine the internal relationships between the indicators to obtain a more reasonable ranking result.

Then, the T-SFC model is defined by integrating the T-SFS and the cloud model, which can provide an expression function for various opinions of the same index by the expert group and bring various heterogeneous opinions into the same framework for analysis, instead of making final evaluation and decision only according to positive or negative single opinions and attitudes. At the same time, the model can examine the error characteristics of evaluation values given by experts in such a way that decision-makers can investigate the influence of information error on the accuracy of index scoring. This approach ensures that the evaluation value is reasonable and objective, affording accurate data sources for final evaluation and decision-making and increasing the rationality and robustness of decision-making results.

Furthermore, multi-index information aggregation is a key step in evaluation and decision-making. The evaluation index system of the digital transformation solution constructed in this paper consists of 2 levels, 4 aspects, and 16 specific indicators. In addition, the scoring values of the sub-indicators will have an impact on each other. The proposed T-SFCWHM operator can examine the interactive relationship between different indexes and their influence on information aggregation. Therefore, the T-SFCWHM operator can afford a scientific tool for entrepreneurial SMEs to gather information on multilevel structural indicators to evaluate digital transformation solutions.

Apart from that, the constructed methodology framework can support entrepreneurial SMEs in flexibly evaluating and making decisions on digital transformation solutions under different environments and conditions due to its many parameters. For example, parameters η and γ represent the strength of the actual relationship between the indicators. Moreover, the parameter w means the subjective preferences of the decision-makers. Therefore, the changes in the actual environment can be described by changing the parameter values to obtain the evaluation and decision results in different situations. Thus, it is clear that this method has strong flexibility, a wide application range, and more accurate decision results in evaluating digital transformation solutions for entrepreneurial SMEs.

7.2. Implications for practice

The findings of this study can provide effective suggestions for the evaluation and selection of digital transformation solutions for entrepreneurial SMEs. First, an evaluation index system is constructed in this paper, through which entrepreneurial SMEs can accurately evaluate alternative digital transformation solutions and provide a standardized reference for enterprises' final decisions. Specifically, one of the primary difficulties faced by entrepreneurial SMEs in digital transformation is the ability to input resources, i.e., the small size and weak financial position of SMEs restrict their digital transformation. Therefore, enterprises can examine the gap between the required input of the alternative and the resource capacity of enterprises through the constructed index to obtain a reasonable matching evaluation of cost requirements and input. Furthermore, in the digital transformation process, to stabilize the management and activate the management's enthusiasm for organizational strategic planning and organizational change, enterprises can use the index to measure the impact of the introduced digital transformation solution on the strategic planning and organizational change of the organization the enterprises. At the application level, because the application level of various alternatives in the market is uneven, entrepreneurial SMEs can use the index of the expected application level of digital transformation solutions to measure it reasonably. In addition, to identify the expected benefits of alternatives to the enterprise, the enterprise can use the index of the expected benefits created by the digital transformation solution to evaluate it and avoid blind selection.

7.3. Limitations and future research direction

This study also has some limitations and future development directions. First, this paper presented a technical support method for resolving the difficulty in quantifying the evaluation indicators, in which other objective quantitative indicators, such as the specific financial data and cost input data, are not considered. Therefore, we can attempt to overcome incomplete indicators herein by setting more comprehensive or preferential evaluation indicators to obtain the evaluation results in the corresponding environment.

In addition, there is always an error in the evaluation value obtained subjectively by individuals in the expert-based evaluation and decision-making system for the digital transformation solutions of entrepreneurial SMEs. To make the error description more comprehensive, an artificial intelligence algorithm can be introduced to accurately predict the error situation in future research to further improve the characterization ability of the cloud model to the evaluation information of the digital transformation solution.

In addition, the proposed algorithm involves many parameters, which can be used to describe the evaluation and decision-making process of digital transformation solutions of entrepreneurial SMEs in different complex environments. However, the algorithm does not give an optimal parameter for evaluating and decision-making of the solution, nor does it analyze and obtain an optimal evaluation and decision-making result based on the optimal parameter. Therefore, in future work, orthogonal optimization experiments and multiobjective optimization functions can be introduced to investigate the optimal parameter values to provide entrepreneurial SMEs with decision support for choosing the optimal digital transformation solution in a complex environment.

8. Conclusions

It is necessary to establish an effective evaluation method for digital transformation solutions of entrepreneurial SMEs due to many problems in the digital transformation of entrepreneurial SMEs, such as more indicators involved in scheme evaluation, mutual interaction among indicators, and information error in evaluation based on expert preference. In addition, the multilevel interactive relationships of the evaluation indicators will also affect the results. Therefore, to overcome these limitations, an evaluation method based on the T-SFCWHM operator is proposed in this study to evaluate the digital transformation solutions for entrepreneurial SMEs. In this method, a new digital transformation evaluation index system is constructed to provide an evaluation standard and criterion of digital transformation solutions for entrepreneurial SMEs. Additionally, a new T-SFC concept is defined to characterize the evaluation score of the indicators accurately. Then, the T-SFCWHM operator is developed for aggregating multi hierarchy index information. Afterward, a comprehensive framework based on this presented operator is established to support the evaluation and decision-making of digital transformation solutions of entrepreneurial SMEs. Finally, we conduct an empirical analysis of a case based on this method. According to the empirical results, we sort out the theoretical contributions and practical significance of this study and point out the research limitations and future development directions.

CRediT authorship contribution statement

Zaoli Yang: Conceptualization, Funding acquisition, Software, Resources, Data curation, Supervision, Writing - review & editing. **Jinping Chang**: Software, Resources, Data curation. **Lucheng Huang**: Formal analysis, Investigation, Supervision. **Abbas Mardani**: Conceptualization, Software, Resources, Supervision.

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Conflict of Interest Statement

We declare that there are no conflicts of interest regarding the publication of this paper.

Appendix A

The Proof of the Theorem 1.

First, based on the scalar multiplication rule on T-SFCs in Definition 4, we get

$$C_i nw_i = \left(\left(\left(1-\left(1-f_{Ex_i}^q\right)^{nw_i}\right)^{\frac{1}{q}}, f_{En_i} nw_i, f_{He_i} nw_i\right); \left(g_{Ex_i}^{nw_i}, g_{En_i} nw_i, g_{He_i} nw_i\right); \left(o_{Ex_i}^{nw_i}, o_{En_i} nw_i, o_{He_i} nw_i\right)\right),$$

$$C_j nw_j = \left(\left(\left(1-\left(1-f_{Ex_j}^q\right)^{nw_j}\right)^{\frac{1}{q}}, f_{En_j} nw_j, f_{He_j} nw_j\right); \left(g_{Ex_j}^{nw_j}, g_{En_j} nw_j, g_{He_j} nw_j\right); \left(o_{Ex_j}^{nw_j}, o_{En_j} nw_j, o_{He_j} nw_j\right)\right)$$

At the same time, based on the exponential operation rule in Definition 4, we get

$$(C_i nw_i)^\eta = \left(\begin{array}{l} \left(\left(1-\left(1-f_{Ex_i}^q\right)^{nw_i}\right)^{\frac{\eta}{q}}, \left(f_{En_i} nw_i\right)^\eta, \left(f_{He_i} nw_i\right)^\eta\right); \\ \left(\left(1-\left(1-\left(g_{Ex_i}^{nw_i}\right)^q\right)^\eta\right)^{\frac{1}{q}}, \left(g_{En_i} nw_i\right)^\eta, \left(g_{He_i} nw_i\right)^\eta\right); \\ \left(\left(1-\left(1-\left(o_{Ex_i}^{nw_i}\right)^q\right)^\eta\right)^{\frac{1}{q}}, \left(o_{En_i} nw_i\right)^\eta, \left(o_{He_i} nw_i\right)^\eta\right) \end{array}\right),$$

$$(C_j nw_j)^\gamma = \left(\begin{array}{l} \left(\left(1-\left(1-f_{Ex_j}^q\right)^{nw_i}\right)^{\frac{\gamma}{q}}, \left(f_{En_j} nw_j\right)^\gamma, \left(f_{He_j} nw_j\right)^\gamma\right); \\ \left(\left(1-\left(1-\left(g_{Ex_j}^{nw_j}\right)^q\right)^\gamma\right)^{\frac{1}{q}}, \left(g_{En_j} nw_j\right)^\gamma, \left(g_{He_j} nw_j\right)^\gamma\right); \\ \left(\left(1-\left(1-\left(o_{Ex_j}^{nw_j}\right)^q\right)^\gamma\right)^{\frac{1}{q}}, \left(o_{En_j} nw_j\right)^\gamma, \left(o_{He_j} nw_j\right)^\gamma\right) \end{array}\right)$$

Secondly, according the product operation rule of T-SFCs, we get

$$(C_i nw_i)^{\eta} \otimes \left(C_j nw_j\right)^{\gamma}$$

$$= \begin{pmatrix} \left(\left(1-\left(1-f^{q}_{Ex_i}\right)^{nw_i}\right)^{\frac{\eta}{q}}\left(1-\left(1-f^{q}_{Ex_j}\right)^{nw_j}\right)^{\frac{\gamma}{q}}, (f_{En_i}nw_i)^{\eta}\left(f_{En_j}nw_j\right)^{\gamma}, (f_{He_i}nw_i)^{\eta}\left(f_{He_j}nw_j\right)^{\gamma}\right); \\ \left(\left(\begin{array}{l}\left(\left(1-\left(1-\left(g^{nw_i}_{Ex_i}\right)^{q}\right)^{\eta}\right)^{\frac{1}{q}}\right)^{q}+\left(\left(1-\left(1-\left(g^{nw_j}_{Ex_j}\right)^{q}\right)^{\gamma}\right)^{\frac{1}{q}}\right)^{q}- \\ \left(\left(1-\left(1-\left(g^{nw_i}_{Ex_i}\right)^{q}\right)^{\eta}\right)^{\frac{1}{q}}\right)^{q}\left(\left(1-\left(1-\left(g^{nw_j}_{Ex_j}\right)^{q}\right)^{\gamma}\right)^{\frac{1}{q}}\right)^{q}\end{array}\right)^{\frac{1}{q}}, (g_{En_i}nw_i)^{\eta}\left(g_{En_j}nw_j\right)^{\gamma}, (g_{He_i}nw_i)^{\eta}\left(g_{He_j}nw_j\right)^{\gamma}\right); \\ \left(\left(\begin{array}{l}\left(\left(1-\left(1-\left(o^{nw_i}_{Ex_i}\right)^{q}\right)^{\eta}\right)^{\frac{1}{q}}\right)^{q}+\left(\left(1-\left(1-\left(o^{nw_j}_{Ex_j}\right)^{q}\right)^{\gamma}\right)^{\frac{1}{q}}\right)^{q}- \\ \left(\left(1-\left(1-\left(o^{nw_i}_{Ex_i}\right)^{q}\right)^{\eta}\right)^{\frac{1}{q}}\right)^{q}\left(\left(1-\left(1-\left(o^{nw_j}_{Ex_j}\right)^{q}\right)^{\gamma}\right)^{\frac{1}{q}}\right)^{q}\end{array}\right)^{\frac{1}{q}}, (o_{En_i}nw_i)^{\eta}\left(o_{En_j}nw_j\right)^{\gamma}, (o_{He_i}nw_i)^{\eta}\left(o_{He_j}nw_j\right)^{\gamma}\right) \end{pmatrix}$$

$$= \begin{pmatrix} \left(\left(1-\left(1-f^{q}_{Ex_i}\right)^{nw_i}\right)^{\frac{\eta}{q}}\left(1-\left(1-f^{q}_{Ex_j}\right)^{nw_j}\right)^{\frac{\gamma}{q}}, (f_{En_i}nw_i)^{\eta}\left(f_{En_j}nw_j\right)^{\gamma}, (f_{He_i}nw_i)^{\eta}\left(f_{He_j}nw_j\right)^{\gamma}\right); \\ \left(\left(1-\left(1-\left(\left(1-\left(1-\left(g^{nw_i}_{Ex_i}\right)^{q}\right)^{\eta}\right)^{\frac{1}{q}}\right)^{q}\right)\left(1-\left(\left(1-\left(1-\left(g^{nw_j}_{Ex_j}\right)^{q}\right)^{\gamma}\right)^{\frac{1}{q}}\right)^{q}\right)\right)^{\frac{1}{q}}, (g_{En_i}nw_i)^{\eta}\left(g_{En_j}nw_j\right)^{\gamma}, (g_{He_i}nw_i)^{\eta}\left(g_{He_j}nw_j\right)^{\gamma}\right); \\ \left(\left(1-\left(1-\left(\left(1-\left(1-\left(o^{nw_i}_{Ex_i}\right)^{q}\right)^{\eta}\right)^{\frac{1}{q}}\right)^{q}\right)\left(1-\left(\left(1-\left(1-\left(o^{nw_j}_{Ex_j}\right)^{q}\right)^{\gamma}\right)^{\frac{1}{q}}\right)^{q}\right)\right)^{\frac{1}{q}}, (o_{En_i}nw_i)^{\eta}\left(o_{En_j}nw_j\right)^{\gamma}, (o_{He_i}nw_i)^{\eta}\left(o_{He_j}nw_j\right)^{\gamma}\right) \end{pmatrix}$$

$$= \begin{pmatrix} \left(\left(1-\left(1-f^{q}_{Ex_i}\right)^{nw_i}\right)^{\frac{\eta}{q}}\left(1-\left(1-f^{q}_{Ex_j}\right)^{nw_j}\right)^{\frac{\gamma}{q}}, (f_{En_i}nw_i)^{\eta}\left(f_{En_j}nw_j\right)^{\gamma}, (f_{He_i}nw_i)^{\eta}\left(f_{He_j}nw_j\right)^{\gamma}\right); \\ \left(\left(1-\left(1-\left(g^{nw_i}_{Ex_i}\right)^{q}\right)^{\eta}\left(1-\left(g^{nw_j}_{Ex_j}\right)^{q}\right)^{\gamma}\right)^{\frac{1}{q}}, (g_{En_i}nw_i)^{\eta}\left(g_{En_j}nw_j\right)^{\gamma}, (g_{He_i}nw_i)^{\eta}\left(g_{He_j}nw_j\right)^{\gamma}\right); \\ \left(\left(1-\left(1-\left(o^{nw_i}_{Ex_i}\right)^{q}\right)^{\eta}\left(1-\left(o^{nw_j}_{Ex_j}\right)^{q}\right)^{\gamma}\right)^{\frac{1}{q}}, (o_{En_i}nw_i)^{\eta}\left(o_{En_j}nw_j\right)^{\gamma}, (o_{He_i}nw_i)^{\eta}\left(o_{He_j}nw_j\right)^{\gamma}\right) \end{pmatrix}$$

Meanwhile, the mathematical induction is used to obtain

$$\sum_{\substack{i,j=1\\ i\neq j}}^{n}(C_i nw_i)^{\eta}\otimes\left(C_j nw_j\right)^{\gamma}$$

$$=\left(\begin{array}{l}\left(\left(1-\prod_{\substack{i,j=1\\ i\neq j}}^{n}\left(1-\left(1-\left(1-f_{Ex_i}^{q}\right)^{nw_i}\right)^{\eta}\left(1-\left(1-f_{Ex_j}^{q}\right)^{nw_j}\right)^{\gamma}\right)\right)^{\frac{1}{q}},\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(f_{En_i}nw_i\right)^{\eta}\left(f_{En_j}nw_j\right)^{\gamma},\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(f_{He_i}nw_i\right)^{\eta}\left(f_{He_j}nw_j\right)^{\gamma}\right);\\ \left(\prod_{\substack{i,j=1\\ i\neq j}}^{n}\left(1-\left(1-\left(g_{Ex_i}^{nw_i}\right)^{q}\right)^{\eta}\right)^{\frac{1}{q}}\left(1-\left(1-\left(g_{Ex_j}^{nw_j}\right)^{q}\right)^{\gamma}\right)^{\frac{1}{q}},\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(g_{En_i}nw_i\right)^{\eta}\left(g_{En_j}nw_j\right)^{\gamma},\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(g_{He_i}nw_i\right)^{\eta}\left(g_{He_j}nw_j\right)^{\gamma}\right);\\ \left(\prod_{\substack{i,j=1\\ i\neq j}}^{n}\left(1-\left(1-\left(o_{Ex_i}^{nw_i}\right)^{q}\right)^{\eta}\right)^{\frac{1}{q}}\left(1-\left(1-\left(o_{Ex_j}^{nw_j}\right)^{q}\right)^{\gamma}\right)^{\frac{1}{q}},\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(o_{En_i}nw_i\right)^{\eta}\left(o_{En_j}nw_j\right)^{\gamma},\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(o_{He_i}nw_i\right)^{\eta}\left(o_{He_j}nw_j\right)^{\gamma}\right)\end{array}\right)$$

Further, the scalar multiplication rule on T-SFCs in Definition 4 is used to multiply $\frac{2}{n(n+1)}$ times $\sum_{\substack{i,j=1\\ i\neq j}}^{n}(a_i nw_i)^{\eta}\otimes(a_j nw_j)^{\gamma}$ as follows

$$\frac{2}{n(n+1)}\sum_{\substack{i,j=1\\ i\neq j}}^{n}(C_i nw_i)^{\eta}\otimes\left(C_j nw_j\right)^{\gamma}$$

$$=\left(\begin{array}{l}\left(\begin{array}{l}\left(1-\left(\prod_{\substack{i,j=1\\ i\neq j}}^{n}\left(1-\left(1-\left(1-f_{Ex_i}^{q}\right)^{nw_i}\right)^{\eta}\left(1-\left(1-f_{Ex_j}^{q}\right)^{nw_j}\right)^{\gamma}\right)\right)^{\frac{2}{n(n+1)}}\right)^{\frac{1}{q}},\\ \frac{2}{n(n+1)}\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(f_{En_i} nw_i\right)^{\eta}\left(f_{En_j} nw_j\right)^{\gamma},\frac{2}{n(n+1)}\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(f_{He_i} nw_i\right)^{\eta}\left(f_{He_j} nw_j\right)^{\gamma}\end{array}\right);\\ \left(\begin{array}{l}\left(\prod_{\substack{i,j=1\\ i\neq j}}^{n}\left(1-\left(1-\left(g_{Ex_i}^{nw_i}\right)^{q}\right)^{\eta}\right)^{\frac{1}{q}}\left(1-\left(1-\left(g_{Ex_j}^{nw_j}\right)^{q}\right)^{\gamma}\right)^{\frac{1}{q}}\right)^{\frac{2}{n(n+1)}},\\ \frac{2}{n(n+1)}\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(g_{En_i} nw_i\right)^{\eta}\left(g_{En_j} nw_j\right)^{\gamma},\frac{2}{n(n+1)}\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(g_{He_i} nw_i\right)^{\eta}\left(g_{He_j} nw_j\right)^{\gamma}\end{array}\right);\\ \left(\begin{array}{l}\left(\prod_{\substack{i,j=1\\ i\neq j}}^{n}\left(1-\left(1-\left(o_{Ex_i}^{nw_i}\right)^{q}\right)^{\eta}\right)^{\frac{1}{q}}\left(1-\left(1-\left(o_{Ex_j}^{nw_j}\right)^{q}\right)^{\gamma}\right)^{\frac{1}{q}}\right)^{\frac{2}{n(n+1)}},\\ \frac{2}{n(n+1)}\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(o_{En_i} nw_i\right)^{\eta}\left(o_{En_j} nw_j\right)^{\gamma},\frac{2}{n(n+1)}\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(o_{He_i} nw_i\right)^{\eta}\left(o_{He_j} nw_j\right)^{\gamma}\end{array}\right)\end{array}\right)$$

Finally, the exponential operation rule in Definition 4 is used to compute the $\frac{1}{\eta+\gamma}^{th}$ power of $\frac{2}{n(n+1)}\sum_{\substack{i,j=1\\ i\neq j}}^{n}(C_i nw_i)^{\eta}\otimes(C_j nw_j)^{\gamma}$ as follows.

$$\left(\frac{2}{n(n+1)}\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(C_i nw_i\right)^{\eta}\otimes\left(C_j nw_j\right)^{\gamma}\right)^{\frac{1}{\eta+\gamma}}$$

$$=\left(\begin{array}{l}
\left(\begin{array}{l}
\left(1-\left(\prod_{\substack{i,j=1\\ i\neq j}}^{n}\left(1-\left(1-\left(1-f_{Ex_i}^{q}\right)^{nw_i}\right)^{\eta}\left(1-\left(1-f_{Ex_j}^{q}\right)^{nw_j}\right)^{\gamma}\right)\right)^{\frac{2}{n(n+1)}}\right)^{\frac{1}{(\eta+\gamma)q}}, \\
\left(\frac{2}{n(n+1)}\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(f_{En_i}nw_i\right)^{\eta}\left(f_{En_j}nw_j\right)^{\gamma}\right)^{\frac{1}{\eta+\gamma}}, \left(\frac{2}{n(n+1)}\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(f_{He_i}nw_i\right)^{\eta}\left(f_{He_j}nw_j\right)^{\gamma}\right)^{\frac{1}{\eta+\gamma}}
\end{array}\right); \\
\left(\begin{array}{l}
\left(1-\left(1-\left(\prod_{\substack{i,j=1\\ i\neq j}}^{n}\left(1-\left(1-\left(g_{Ex_i}^{nw_i}\right)^{q}\right)^{\eta}\right)\left(1-\left(1-\left(g_{Ex_j}^{nw_j}\right)^{q}\right)^{\gamma}\right)\right)^{\frac{2}{n(n+1)}}\right)^{\frac{1}{\eta+\gamma}}\right)^{\frac{1}{q}}, \\
\left(\frac{2}{n(n+1)}\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(g_{En_i}nw_i\right)^{\eta}\left(g_{En_j}nw_j\right)^{\gamma}\right)^{\frac{1}{\eta+\gamma}}, \left(\frac{2}{n(n+1)}\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(g_{He_i}nw_i\right)^{\eta}\left(g_{He_j}nw_j\right)^{\gamma}\right)^{\frac{1}{\eta+\gamma}}
\end{array}\right); \\
\left(\begin{array}{l}
\left(1-\left(1-\left(\prod_{\substack{i,j=1\\ i\neq j}}^{n}\left(1-\left(1-\left(o_{Ex_i}^{nw_i}\right)^{q}\right)^{\eta}\right)\left(1-\left(1-\left(o_{Ex_j}^{nw_j}\right)^{q}\right)^{\gamma}\right)\right)^{\frac{2}{n(n+1)}}\right)^{\frac{1}{\eta+\gamma}}\right)^{\frac{1}{q}}, \\
\left(\frac{2}{n(n+1)}\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(o_{En_i}nw_i\right)^{\eta}\left(o_{En_j}nw_j\right)^{\gamma}\right)^{\frac{1}{\eta+\gamma}}, \left(\frac{2}{n(n+1)}\sum_{\substack{i,j=1\\ i\neq j}}^{n}\left(o_{He_i}nw_i\right)^{\eta}\left(o_{He_j}nw_j\right)^{\gamma}\right)^{\frac{1}{\eta+\gamma}}
\end{array}\right)
\end{array}\right)$$

Subsequently, based on the result of proof, we can infer that Theorem 1 is true.

Appendix B

The Proof of the Theorem 2.

Set $w_i = \frac{1}{n}$, Since $C_i = \langle (f_{Ex_i}, f_{En_i}, f_{He_i}), (g_{Ex_i}, g_{En_i}, g_{He_i}), (o_{Ex_i}, o_{En_i}, o_{He_i}) \rangle = C$, then we get

$$S - TFCWHM(C_1, C_2, \cdots, C_n)$$

$$= \left(\frac{2}{n(n+1)} \sum_{i=1}^{n} \sum_{\substack{j=1, \\ i \neq j}}^{n} \left(C_i n \frac{1}{n} \right)^{\eta} \otimes \left(C_j n \frac{1}{n} \right)^{\gamma} \right)^{\frac{1}{\eta+\gamma}}$$

$$= \left(\frac{2}{n(n+1)} \frac{n(n+1)}{2} (C_i)^{\eta+\gamma} \right)^{\frac{1}{\eta+\gamma}}$$

$$= C_i$$

Therefore, the T-SFCWHM operator meets the properties of idempotency.

The Proof of the Theorem 3.

Since $C^- = \min_{\leq i \leq n} \{C_i\}$, and $C^+ = \max_{\leq i \leq n} \{C_i\}$, according to the Theorem 2, we obtain.

$$S - TFCWHM(C_1, C_2, \ldots, C_n)$$

$$= \left(\frac{2}{n(n+1)} \sum_{i=1}^{n} \sum_{j=1}^{n} (C_i n w_i)^{\eta} \otimes (C_j n w_j)^{\gamma} \right)^{\frac{1}{\eta+\gamma}}$$

$$\leq \left(\frac{2}{n(n+1)} \sum_{i=1}^{n} \sum_{j=1}^{n} (C^+)^{\eta} \otimes (C^+)^{\gamma} \right)^{\frac{1}{\eta+\gamma}}$$

$$\leq \left(\frac{2}{n(n+1)} \sum_{i=1}^{n} \sum_{j=1}^{n} (C^+)^{\eta+\gamma} \right)^{\frac{1}{\eta+\gamma}} = C^+$$

In a similar way, we obtain $C^- \leq S - TFCWHM(C_1, C_2, \ldots, C_n)$,

Subsequently, we get $C^- \leq S - TFCWHM(C_1, C_2, \ldots, C_n) \leq C^+$, and the T-SFCWHM operator meets the properties of boundedness.

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