Enhanced CoCoSo Method for Intuitionistic Fuzzy MAGDM and Application to Financial Risk Evaluation of High-Tech Enterprises

Huanwen Liu
School of Finance and Management, Changsha Social Work College, Changsha, 410004, Hunan, China
E-mail: csmz_huanwenliu@163.com

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The continuous innovation of science and technology is the foundation for the survival and development of high-tech enterprises. In order to gain a foothold in the fierce market competition, enterprises must seize market share by developing new high-tech products tailored to the market, and obtain economic benefits for maintaining survival and development. However, to ensure the smooth progress of the development and research process, sufficient financial support is required. Fundraising is particularly important, even if the required funds are raised, its own high-risk needs to be given special attention. The financial risk evaluation of high-tech enterprises is a multiple attribute group decision making (MAGDM). Recently, the Combined Compromise Solution (CoCoSo) method has been employed to manage MAGDM issues. The intuitionistic fuzzy sets (IFSs) are used as a tool for portraying uncertain information during the financial risk evaluation of high-tech enterprises. In this paper, the intuitionistic fuzzy CoCoSo (IF-CoCoSo) method is cultivated to manage the MAGDM based on the Hamming distance and Euclid distance under IFSs. In the end, a numerical case study for financial risk evaluation of high-tech enterprises is supplied to validate the proposed method. The main contributions of this paper are outlined: (1) the CoCoSo method has been extended to IFSs; (2) Information Entropy is used to derive weight based on the Hamming distance and Euclid distance under IFSs. (3) the IF-CoCoSo method is founded to manage the MAGDM based on the Hamming distance and Euclid distance under IFSs; (4) a numerical case study for financial risk evaluation of high-tech enterprises and some comparative analysis is supplied to validate the proposed method.

Povzetek: Predstavljena je metoda IF-CoCoSo za oceno finančnega tveganja visokotehnoloških podjetij, temelječ na intuicionističnih mehkih množicah in večatributnem skupinskem odločanju.

1 Introduction

In recent years, the role of science and technology in economic development has been continuously enhanced. The progress of technology has promoted the rapid development of high-tech industries, and the number of high-tech enterprises in China has increased from 49000 more than a decade ago to 330000 in 2021[1-3]. The business operations of high-tech enterprises mainly revolve around technological research and development and the transformation of technological achievements. The products and services they provide have high value due to their high technological content, which makes the economic benefits generated by high-tech enterprises crucial in China's total economic output[4-6]. In order to accelerate the transformation of China's industrial structure, the national level has attached increasing importance to high-tech industries and provided tax incentives and financial support in many aspects, providing certain guarantees for the development of high-tech enterprises[7-9]. However, due to various factors, high-tech enterprises still face high financial risks. Financial security is the key to the operation and development of high-tech enterprises, and effective prevention of financial risks is a challenge that high-tech enterprises must overcome[10, 11]. Only by establishing a sound risk management system can the development of high-tech enterprises be safeguarded. In order to enhance the ability of high-tech enterprises to resist financial risks, it is necessary to understand the existing financial problems of high-tech enterprises, conduct in-depth research on the reasons behind financial risks, propose prevention and control measures for various sources of financial risks, promote the stable development of high-tech enterprises, and thereby increase the contribution of high-tech industries to economic development[12-14]. Overall, the financial risks of high-tech enterprises are mainly caused by external and internal environmental factors. From the perspective of external factors of the enterprise, factors such as market acceptance, industry competition, and policy systems can bring a certain degree of financial risk to high-tech enterprises[15, 16]. The imperfect internal risk control system and risk prevention mechanism, insufficient human resources, and organizational management deficiencies of enterprises may also be the sources of financial risks. The development of high-tech enterprises relies on technological research results, followed by the commercialization of technology. In this process, the economic environment in which high-tech enterprises operate is highly uncertain. Firstly, the uncertainty of market factors can cause financial risks for high-tech

enterprises[17, 18]. At present, the updates and upgrades of technology are constantly accelerating, and people's quality of life is constantly improving. In this situation, consumers' consumption concepts and habits are changing rapidly. When a company's products are put into the market, there is a great deal of uncertainty in consumer reactions and purchasing situations, leading to the inability to guarantee the expected returns of the company. Secondly, the industry situation of high-tech enterprises also presents great uncertainty[19, 20]. In the field of high-tech, competition in the industry is becoming increasingly fierce. When some enterprises obtain more funding and talent support, accelerating the speed of technology development and transformation, it will make other high-tech enterprises very passive, bringing more financial risks and corporate crises. Thirdly, many policies and systems of the country may also increase the requirements for high-tech enterprises. Nowadays, the country not only has strict regulations on the recognition of high-tech enterprises, but also restricts and regulates their financial activities such as loans. There are also many factors that can lead to financial risks within high-tech enterprises[21, 22]. Firstly, many high-tech enterprises have not established sound financial risk management systems. In the process of preventing and controlling financial risks, the responsible department lacks clear guidance and cannot implement the financial risk management system. In the prevention of financial risks, many steps have not been taken properly, and in reality, early warning and emergency handling of financial risks have not been achieved. Secondly, high-tech enterprises have human resource deficiencies[23, 24]. Due to the nature of the enterprise, there is insufficient reserve of management personnel and managerial talents within the enterprise, and many employees do not understand the financial risk control system, making it difficult to promote and implement related work. Many management employees overlook financial risks and lack the ability to handle them, resulting in poor coordination and cooperation among staff[25, 26]. Thirdly, the corporate governance structure is incomplete. Financial risk management is a highly professional task, but many high-tech enterprises have governance issues and do not have independent and specialized responsible departments, resulting in loopholes in financial risk management at all levels[27, 28].

Decision making is one of the most common activities in daily life[29-32]. For example, an investment company needs to evaluate all possible alternative options and select the optimal investment plan to avoid investment risks and achieve maximum returns. A certain airline needs to evaluate the operational status of all routes in order to select the optimal route and promote successful experience to other routes, thereby improving the overall operational level of the airline. A manufacturing enterprise needs to select the best supplier from all raw material suppliers in order to obtain stable and reliable material sources. With the continuous development of the economy and society, decision-making issues have become increasingly complex[32-35]. Thus, in practical decision-making problems, it is often necessary to evaluate candidate methods from multiple perspectives, consider the overall performance of the candidate solutions, and then select the optimal solution[36-40]. In recent decades, multi-attribute decision-making (MADM), an important branch of management science and engineering, has received widespread attention from the academic community[41-44]. The so-called MADM refers to the evaluation of all decision plans by decision-makers from multiple dimensions, and then determining the optimal decision plan[45-49]. According to the experts' number of participating in decision evaluation, MADM is subdivided into multi-attribute group decision-making (MAGDM)[50-54]. The financial risk evaluation of high-tech enterprises is classical MAGDM. The IFSs [55-58] are used as a tool for portraying uncertain information during the financial risk evaluation of high-tech enterprises. Furthermore, many decision algorithms use the typical CoCoSo method [59] separately to obtain the most optimal decision choice. Until now, no or few algorithms have been studied on information entropy and CoCoSo method based on the Hamming distance and Euclid distance under IFSs. Therefore, an integrated intuitionistic fuzzy CoCoSo (IF-CoCoSo) method is constructed to manage MAGDM based on the Hamming distance and Euclid distance under IFSs. An illustrative example for financial risk evaluation of high-tech enterprises and some comparative analysis is constructed to demonstrate the validity and reliability of IF-CoCoSo method. The main research goal and motivation of this paper is outlined: (1) the CoCoSo method has been extended to IFSs based on the Hamming distance and Euclid distance; (2) Information Entropy is used to derive weight based on the Hamming distance and Euclid distance under IFSs. (3) the IF-CoCoSo method is founded to manage the MAGDM based on the Hamming distance and Euclid distance under IFSs; (4) a numerical case study for financial risk evaluation of high-tech enterprises and some comparative analysis is supplied to validate the proposed method.

The structure of this paper is listed below. In Section 2, the IFSs is introduced. In Section 3, IF-CoCoSo method is founded under IFSs with entropy based on the Hamming distance and Euclid distance. Section 4 gives an illustrative case for financial risk evaluation of high-tech enterprises and some comparative analysis. Some remarks are supplied in Section 5.

2 Preliminaries

Atanassov [60] constructed the IFSs.

Definition 1[60]. The IFSs on Θ is:

$$H = \left\{ \left\langle \theta, u_H(\theta), v_H(\theta) \right\rangle \middle| \theta \in \Theta \right\} \quad (1)$$

where $\mu_H(\theta) \in [0,1]$ is membership and $v_H(\theta) \in [0,1]$ is non-membership with information

condition: $0 \le \mu_H(\theta) + \nu_H(\theta) \le 1,\ \forall\ \theta \in \Theta$. Then, $h\theta = (hu, hv)$ is denoted as an IFN.

Definition 2[61, 62]. Let $h\theta_1 = (hu_1, hv_1)$ and $h\theta_2 = (hu_2, hv_2)$ be IFNs, the score functions (SF) and accuracy functions (AF) of $h\theta_1$ and $h\theta_2$ is constructed:

$$SF(h\theta_1) = hu_1 - hv_1, SF(h\theta_2) = hu_2 - hv_2 \tag{2}$$

$$AF(h\theta_1) = hu_1 + hv_1, AF(h\theta_2) = hu_2 + hv_2 \tag{3}$$

For two IFNs $h\theta_1 = (hu_1, hv_1)$ and $h\theta_2 = (hu_2, hv_2)$, then[63]

(1) *if* $SF(h\theta_1) < SF(h\theta_2),\ h\theta_1 < h\theta_2;$

(2) *if* $SF(h\theta_1) = SF(h\theta_2), AF(h\theta_1) < AF(h\theta_2),\ h\theta_1 < h\theta_2;$

(3) *if* $SF(h\theta_1) = SF(h\theta_2), AF(h\theta_1) = AF(h\theta_2),\ h\theta_1 = h\theta_2.$

Definition 3[64]. Let $h\theta_1 = (hu_1, hv_1)$ and $h\theta_2 = (hu_2, hv_2)$ be IFNs, the IFN distanced measure (IFNDM) is supplied:

$$IFNDM(h\theta_1, h\theta_2) = \frac{1}{2}\left[\left|\frac{2(hu_1 h\pi_2 - hu_2 h\pi_1 - 4(hu_1 - hu_2))}{4 - h\pi_1 h\pi_2}\right| + \left|\frac{4(hv_1 - hv_2) + 2(hv_1 h\pi_2 - hv_2 h\pi_1 + 2(h\pi_1 - h\pi_2))}{4 - h\pi_1 h\pi_2}\right|\right] \tag{4}$$

where $h\pi_1 = 1 - hu_1 - hv_1, h\pi_2 = 1 - hu_2 - hv_2$.

Definition 4[63]. Let $h\theta_1 = (hu_1, hv_1)$ and $h\theta_2 = (hu_2, hv_2)$ be two IFNs, the operation is constructed:

$$h\theta_1 \oplus h\theta_2 = (hu_1 + hu_2 - hu_1 hu_2, hv_1 hv_2) \tag{5}$$

$$h\theta_1 \otimes h\theta_2 = (hu_1 hu_2, hv_1 + hv_2 - hv_1 hv_2) \tag{6}$$

$$\lambda h\theta_1 = \left(1 - (1 - hu_1)^{\lambda}, (hv_1)^{\lambda}\right), \lambda > 0 \tag{7}$$

$$(h\theta_1)^{\lambda} = \left((hu_1)^{\lambda}, 1 - (1 - hv_1)^{\lambda}\right), \lambda > 0 \tag{8}$$

From the Definition 2, the useful operation laws are supplied.

(1) $h\theta_1 \oplus h\theta_2 = h\theta_2 \oplus h\theta_1, h\theta_1 \otimes h\theta_2 = h\theta_2 \otimes h\theta_1, \left((h\theta_1)^{\lambda_1}\right)^{\lambda_2} = (h\theta_1)^{\lambda_1\lambda_2}$;

(2) $\lambda(h\theta_1 \oplus h\theta_2) = \lambda h\theta_1 \oplus \lambda h\theta_2, (h\theta_1 \otimes h\theta_2)^{\lambda} = (h\theta_1)^{\lambda} \otimes (h\theta_2)^{\lambda}$;

(3) $\lambda_1 h\theta_1 \oplus \lambda_2 h\theta_1 = (\lambda_1 + \lambda_2) h\theta_1, (h\theta_1)^{\lambda_1} \otimes (h\theta_1)^{\lambda_2} = (h\theta_1)^{(\lambda_1 + \lambda_2)}$.

The IFWA and IFWG operator is introduced.

Definition 5[65]. Let $h\theta_j = (hu_j, hv_j)$ be a group of IFNs, the IFWA operator is:

$$\begin{aligned} &IFWA_{hw}(h\theta_1, h\theta_2, \ldots, h\theta_n) \\ &= \overset{n}{\underset{j=1}{\oplus}}(hw_j h\theta_j) \\ &= \left(1 - \prod_{j=1}^{n}(1 - hu_j)^{hw_j}, \prod_{j=1}^{n}(hv_j)^{hw_j}\right) \end{aligned} \tag{9}$$

where $hw = (hw_1, hw_2, ..., hw_n)^T$ be weight of $h\theta_j, hw_j > 0, \sum_{j=1}^{n} hw_j = 1.$

Definition 6[66]. Let $h\theta_j = (hu_j, hv_j)$ be a group of IFNs, the IFWG operator is:

$$\begin{aligned} &IFWG_{hw}(h\theta_1, h\theta_2, \ldots, h\theta_n) \\ &= \overset{n}{\underset{j=1}{\otimes}}(h\theta_j)^{hw_j} \\ &= \left(\prod_{j=1}^{n}(hu_j)^{hw_j}, 1 - \prod_{j=1}^{n}(1 - hv_j)^{hw_j}\right) \end{aligned} \tag{10}$$

where $hw = (hw_1, hw_2, ..., hw_n)^T$ be weight of $h\theta_j, hw_j > 0, \sum_{j=1}^{n} hw_j = 1.$

3 IF-CoCoSo method for MAGDM

Then, IF-CoCoSo method is constructed for MAGDM. Let $HA = \{HA_1, HA_2, \cdots, HA_m\}$ be alternative sets,

and attributes set $HG=\{HG_1, HG_2, \cdots, HG_n\}$ with weight $hw=(hw_1, hw_2, ..., hw_n)^T$, where $hw_j \in [0,1]$, $\sum_{j=1}^{n} hw_j = 1$ and a set of invited experts $HE=\{HE_1, HE_2, \cdots, HE_q\}$, let expert's weight be $h\omega=(h\omega_1, h\omega_2, ..., h\omega_n)^T$.

Then, IF-CoCoSo model is constructed for MAGDM.

Step 1. Build the intuitionistic fuzzy matrix $IFM^t=\left[IFM_{ij}^t\right]_{m\times n}=\left(hu_{ij}^{(t)},\ hv_{ij}^{(t)}\right)_{m\times n}$ and construct the average matrix $IFM=\left[IFM_{ij}\right]_{m\times n}$:

$$IFM^t=\left[IFM_{ij}^t\right]_{m\times n}$$

$$=\begin{array}{c} \\ HA_1 \\ HA_2 \\ \vdots \\ HA_m \end{array}\begin{array}{c} \begin{array}{cccc} HG_1 & HG_2 & \ldots & HG_n \end{array} \\ \begin{bmatrix} IFM_{11}^t & IFM_{12}^t & \ldots & IFM_{1n}^t \\ IFM_{21}^t & IFM_{22}^t & \ldots & IFM_{2n}^t \\ \vdots & \vdots & \vdots & \vdots \\ IFM_{m1}^t & IFM_{m2}^t & \ldots & IFM_{mn}^t \end{bmatrix} \end{array} \quad (11)$$

$$IFM=\left[IFM_{ij}\right]_{m\times n}$$

$$=\begin{array}{c} \\ HA_1 \\ HA_2 \\ \vdots \\ HA_m \end{array}\begin{array}{c} \begin{array}{cccc} HG_1 & HG_2 & \ldots & HG_n \end{array} \\ \begin{bmatrix} IFM_{11} & IFM_{12} & \ldots & IFM_{1n} \\ IFM_{21} & IFM_{22} & \ldots & IFM_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ IFM_{m1} & IFM_{m2} & \ldots & IFM_{mn} \end{bmatrix} \end{array} \quad (12)$$

Based on IFWA technique, the $IFM=\left[IFM_{ij}\right]_{m\times n}=\left(hu_{ij}, hv_{ij}\right)_{m\times n}$ is:

$$IFM_{ij}=h\omega_1 IFM_{ij}^1 \oplus h\omega_2 IFM_{ij}^2 \oplus \cdots \oplus h\omega_q IFM_{ij}^q$$

$$=\left(1-\prod_{t=1}^{q}(1-hu_{ij}^{(t)})^{h\omega_t}, \prod_{t=1}^{q}\left(hv_{ij}^{(t)}\right)^{h\omega_t}\right) \quad (13)$$

Step 2. Normalize the $IFM=\left[IFM_{ij}\right]_{m\times n}=\left(hu_{ij}, hv_{ij}\right)_{m\times n}$ into

$$NIFM=\left[NIFM_{ij}\right]_{m\times n}=\left(nhu_{ij}, nhv_{ij}\right)_{m\times n}.$$

For benefit attributes:

$$NIFM_{ij}=\left(nhu_{ij}, nhv_{ij}\right)=\left(hu_{ij}, hv_{ij}\right) \quad (14)$$

For cost attributes:

$$NIFM_{ij}=\left(nhu_{ij}, nhv_{ij}\right)=\left(hv_{ij}, hu_{ij}\right) \quad (15)$$

Step 3. Construct the intuitionistic fuzzy number negative ideal solution (IFNNIS):

$$IFNNIS_j=\left(nhu_j, nhv_j\right) \quad (16)$$

$$SF\left(IFNNIS_j\right)=\min_i SF\left(nhu_{ij}, nhv_{ij}\right) \quad (17)$$

Step 4. Construct the weight values with entropy.
The entropy[67] is used to define the weights. The calculating steps are defined.

$$IFNE_j=-\frac{1}{\ln n}\sum_{i=1}^{m}\left[\frac{HD\left(NIFM_{ij}, IFNNIS_j\right)+ED\left(NIFM_{ij}, IFNNIS_j\right)}{\sum_{i=1}^{m}\left(HD\left(NIFM_{ij}, IFNNIS_j\right)+ED\left(NIFM_{ij}, IFNNIS_j\right)\right)}\cdot \ln\left(\frac{HD\left(NIFM_{ij}, IFNNIS_j\right)+ED\left(NIFM_{ij}, IFNNIS_j\right)}{\sum_{i=1}^{m}\left(HD\left(NIFM_{ij}, IFNNIS_j\right)+ED\left(NIFM_{ij}, IFNNIS_j\right)\right)}\right)\right] \quad (18)$$

$$hw_j=\frac{1-IFNE_j}{\sum_{j=1}^{n}\left(1-IFNE_j\right)},\quad j=1,\mathrm{L}\ ,n \quad (19)$$

Step 5. Construct the IFN weighted arithmetic average (IFNWAA).

$$IFNWAA_i = \sum_{j=1}^{n} hw_j \times \left(\frac{HD\left(NIFM_{ij}, IFNNIS_j\right) + ED\left(NIFM_{ij}, IFNNIS_j\right)}{2} \right) \quad (20)$$

Step 6. Compute the IFN weighted geometric mean (IFNWGM).

$$IFNWGM_i = \sum_{j=1}^{n} \left(\frac{HD\left(NIFM_{ij}, IFNNIS_j\right) + ED\left(NIFM_{ij}, IFNNIS_j\right)}{2} \right)^{hw_j} \quad (21)$$

Step 7. The three designed strategies are employed to obtain the relative importance:

$$IFNKA_i = \frac{IFNWAA_i + IFNWGM_i}{\sum_{i=1}^{m}\left(IFNWAA_i + IFNWGM_i\right)} \quad (22)$$

$$IFNKB_i = \frac{IFNWAA_i}{\min\limits_i IFNWAA_i} + \frac{IFNWGM_i}{\min\limits_i IFNWGM_i} \quad (23)$$

$$IFNKC_i = \frac{\left(\begin{array}{l}\lambda IFNWAA_i \\ +(1-\lambda) IFNWGM_i\end{array}\right)}{\left(\begin{array}{l}\lambda \max\limits_i IFNWAA_i \\ +(1-\lambda)\max\limits_i IFNWGM_i\end{array}\right)}, 0 \le \lambda \le 1. \quad (24)$$

where $IFNKA_i$ is the arithmetic average of $IFNWAA_i, IFNWGM_i$, $IFNKB_i$ is the relative scores of $IFNWAA_i, IFNWGM_i$, and $IFNKC_i$ is the compromise values of $IFNWAA_i, IFNWGM_i$.

Step 8. Compute the decision value $IFNK_i$.

$$IFNK_i = \left(\begin{array}{l} \sqrt[3]{IFNKA_i \cdot IFNKB_i \cdot IFNKC_i} \\ + \dfrac{IFNKA_i + IFNKB_i + IFNKC_i}{3} \end{array} \right) \quad (25)$$

Step 9. Sort the alternatives with $IFNK_i \left(i = 1, 2, \cdots, m\right)$, and the higher the $IFNK_i$, the better the decision alternative is.

4 Numerical example and comparative analysis

4.1 Numerical example for financial risk evaluation of high-tech enterprises

In the 1970s, the concept of high-tech was born and widely spread, and its connotation continued to develop and derive in various countries around the world. With the development of economic globalization, high-tech enterprises play a crucial role in China's economic development. Technology is the internal driving force for the survival and development of an enterprise, especially high-tech enterprises. In the process of applying advanced technology or technological innovation, high-tech enterprises can obtain higher economic benefits by producing, selling, or providing innovative technology services through innovative products. However, compared with traditional enterprises, high-tech enterprises need to invest a lot of R&D funds and human and material resources, and this investment increases significantly with the increasing difficulty and complexity of R&D technology. Even when it comes to the development stage, the cost elasticity of investment increases, and there may be no gains. Sometimes, it requires repeated experimentation and continuous additional investment costs to succeed, while the cost level of the research and development process is very high. At the stage of product promotion, in order to increase market share and enable consumers to accept new products in a short period of time, it is inevitable to require a large amount of advertising investment. Overall, high-tech enterprises require high capital investment, with R&D investment intensity generally ranging from 5% to 15%. However, it may vary depending on the industry, with R&D investment intensity reaching up to 50%. In the later stage of the achievement transformation process, the investment will significantly increase, and the investment intensity in the process of transforming research and development achievements into goods or technologies is 5 to 10 times higher than that in the research and development process. This brings relatively high financial risks to high-tech enterprises. The continuous innovation of science and technology is the foundation for the survival and development of high-tech enterprises. In order to gain a foothold in the fierce

market competition, enterprises must seize market share by developing new high-tech products tailored to the market, and obtain economic benefits for maintaining survival and development. However, to ensure the smooth progress of the development and research process, sufficient financial support is required. Fundraising is particularly important, even if the required funds are raised, its own high-risk needs to be given special attention. The continuous innovation of science and technology is the foundation for the survival and development of high-tech enterprises. In order to gain a foothold in the fierce market competition, enterprises must seize market share by developing new high-tech products tailored to the market, and obtain economic benefits for maintaining survival and development. However, to ensure the smooth progress of the development and research process, sufficient financial support is required. Fundraising is particularly important, even if the required funds are raised, its own high-risk needs to be given special attention. The current world development pattern and economic environment have undergone significant changes, especially the development and innovation of science and technology, which have had a huge impact on the world economy and have had a certain impact on the development of enterprises. The establishment and growth of high-tech enterprises have their own characteristics. In the process of comparing the financial management work of high-tech enterprises with traditional enterprises, significant differences can also be found between the two. Therefore, high-tech enterprises should adopt financial management models that are more in line with the characteristics of the enterprise, use effective management methods to avoid various financial management risks, and actively respond to them based on a clear positioning of their own development. The financial risk evaluation of high-tech enterprises is a MAGDM. Therefore, the financial risk evaluation of high-tech enterprises is presented to show the developed approach in this paper. There are five high-tech enterprises $FA_i\left(i=1,2,3,4,5\right)$ to select. The experts choose four attributes to evaluate the five small and medium sized financial institutions in rural areas[68]: ① FG_1 is solvency for high-tech enterprises. ② FG_2 is financial risk management costs for high-tech enterprises. ③FG_3 is operational capacity for high-tech enterprises. ④FG_4 is profitability for high-tech enterprises. The five possible high-tech enterprises $FA_i\left(i=1,2,3,4,5\right)$ are to be evaluated with linguistic scales (See Table 1[69]) with four attributes through three experts $FE_t\left(t=1,2,3\right)$ (Suppose expert's weight is $\left(0.35,0.45,0.20\right)$.

The of the enterprise

Table 1: Linguistic scale and IFNs[69]

Linguistic Terms	IFNs
Exceedingly Terrible-HET	(0.10,0.80)
Very Terrible-HVT	(0.20,0.70)
Terrible-HT	(0.30,0.60)
Medium-HM	(0.50,0.50)
Well-HW	(0.65,0.30)
Very Well-HVW	(0.75,0.20)
Exceedingly Well-HEW	(1.0,0.0)

The IF-CoCoSo method is constructed to manage the financial risk evaluation of high-tech enterprises.

Step 1. Construct the IFN-matrix $IFM^t=\left[IFM_{ij}^t\right]_{5\times4}$ (See Table 2-4).

Table 2: Evaluation values by HE_1

	HG_1	HG_2	HG_3	HG_4
HA_1	HT	HW	HM	HVW
HA_2	HVW	HW	HVT	HM
HA_3	HM	HW	HVT	HVW
HA_4	HM	HT	HVW	HW
HA_5	HVT	HM	HVW	HT

Table 3: Evaluation values by HE_2

	HG_1	HG_2	HG_3	HG_4
HA_1	HM	HW	HVW	HVT
HA_2	HVT	HVT	HVW	HM
HA_3	HT	HVW	HVT	HM
HA_4	HVW	HW	HM	HVT
HA_5	HW	HM	HT	HVW

Table 4: Evaluation values by HE_3

	HG_1	HG_2	HG_3	HG_4
HA_1	HT	HVW	HW	HM
HA_2	HVW	HVT	HT	HW
HA_3	HW	HT	HM	HM
HA_4	HVW	HT	HM	HW
HA_5	HVT	HM	HW	HVT

Then through the IFWA, the $IFM = \left[IFM_{ij} \right]_{5\times4}$ is constructed (See Table 5).

Table 5: The $IFM = \left[IFM_{ij} \right]_{5\times4}$

	HG_1	HG_2	HG_3	HG_4
HA_1	(0.62，0.34)	(0.86，0.12)	(0.69，0.31)	(0.64，0.25)
HA_2	(0.73，0.27)	(0.67，0.24)	(0.47，0.52)	(0.49，0.51)
HA_3	(0.81，0.19)	(0.53，0.38)	(0.36，0.53)	(0.31，0.42)
HA_4	(0.78，0.14)	(0.52，0.46)	(0.25，0.49)	(0.54，0.38)
HA_5	(0.36，0.23)	(0.73，0.17)	(0.62，0.34)	(0.46，0.23)

Step 2. Normalize the $IFM = \left[IFM_{ij} \right]_{5\times4}$ into $NIFM = \left[NIFM_{ij} \right]_{5\times4}$ (See Table 6).

Table 6: The $NIFM = \left[NIFM_{ij} \right]_{5\times4}$

	HG_1	HG_2	HG_3	HG_4
HA_1	(0.62，0.34)	(0.12，0.86)	(0.69，0.31)	(0.64，0.25)
HA_2	(0.73，0.27)	(0.24，0.67)	(0.47，0.52)	(0.49，0.51)
HA_3	(0.81，0.19)	(0.38，0.53)	(0.36，0.53)	(0.31，0.42)
HA_4	(0.78，0.14)	(0.46，0.52)	(0.25，0.49)	(0.54，0.38)
HA_5	(0.36，0.23)	(0.17，0.73)	(0.62，0.34)	(0.46，0.23)

Step 3. Construct the IFNNIS (See Table 7).

Table 7: The IFNNIS

	HG_1	HG_2	HG_3	HG_4
IFNNIS	(0.36，0.23)	(0.12，0.86)	(0.25，0.49)	(0.31，0.42)

Step 4. Construct the weight values (See Table 8):

Table 8: The weight values

	HG_1	HG_2	HG_3	HG_4
weight	0.2333	0.3355	0.2177	0.2135

Step 5. Calculate the $IFNWAA_i$ (Table 9).

Table 9: The $IFNWAA_i$

	HA_1	HA_2	HA_3	HA_4	HA_5
IFNWAA	0.5914	0.6066	0.7978	0.4914	0.4044

Step 6. Calculate the $IFNWGM_i$ (Table 10).

Table 10: The $IFNWGM_i$

	HA_1	HA_2	HA_3	HA_4	HA_5
IFNWGM	0.4339	0.4073	0.6097	0.3355	0.2505

Step 7. Calculate the $IFNKA_i, IFNKB_i, IFNKC_i$ (See Table 11).

Table 11: Three designed strategies

	$IFNKA_i$	$IFNKB_i$	$IFNKC_i$
HA_1	0.2080	3.1948	0.7285

HA_2	0.2057	3.1259	0.7203
HA_4	0.2856	4.4069	1.0000
HA_4	0.1678	2.5548	0.5875
HA_5	0.1329	2.0000	0.4653

Step 8. Calculate the $IFNK_i$ (See Table 12).

Table 12: The $IFNK_i$

	HA_1	HA_2	HA_3	HA_4	HA_5
IFNK	2.1623	2.1244	2.9771	1.7349	1.3643

Step 9. According to $IFNK_i\left(i=1,2,3,4,5\right)$, the order is $HA_3 > HA_1 > HA_2 > HA_4 > HA_5$ and the best high-tech enterprise is HA_3.

4.2 Comparative analysis

Then, the IF-CoCoSo is compared with IFWA operator[70] and IFWG operator[63], intuitionistic fuzzy normalized weighted Bonferroni mean (IFNWBM) operator[71], dual generalized intuitionistic fuzzy weighted BM (DGIFWBM) operator[72], IF-Taxonomy method[73], IF-PROMETHEE method [74] and intuitionistic fuzzy FUCOM-WASPAS(IF-FUCOM-WASPAS) method[75]. The comparative information results are constructed in Table 13.

Table 13: Order of the different methods

	Order
IFWA operator[70]	$HA_3 > HA_1 > HA_2 > HA_4 > HA_5$
IFWG operator[63]	$HA_3 > HA_1 > HA_4 > HA_2 > HA_5$
IFNWBM operator[71]	$HA_3 > HA_1 > HA_2 > HA_4 > HA_5$
DGIFWBM operator[72]	$HA_3 > HA_1 > HA_4 > HA_2 > HA_5$
IF-Taxonomy method[73]	$HA_3 > HA_1 > HA_2 > HA_4 > HA_5$
IF- PROMETHEE method [74]	$HA_3 > HA_1 > HA_2 > HA_4 > HA_5$
IF-FUCOM-WASPAS method[75]	$HA_3 > HA_1 > HA_2 > HA_4 > HA_5$

From the above detailed analysis, it could be known that the order of these decision methods is slightly different, however, all these decision models have the same optimal high-tech enterprise and worst high-tech enterprise. This verifies the IF-CoCoSo model is reasonable and effective.

5 Conclusion

Under the new development situation, China has entered a new stage of economic development and is seeking a path of high-quality development. In recent years, the position of high-tech enterprises in the national economy and technological development has become increasingly prominent. Due to the high risk and high return characteristics of high-tech industries, more and more high-tech enterprises are paying attention to their own financial risk management. Financial risk management, as an important risk prevention measure for high-tech enterprises, helps to scientifically utilize and reasonably allocate the capital resources of high-tech enterprises, reduce operational risks, achieve overall strategic goals, and maximize value. Therefore, strengthening financial risk management is crucial for high-tech enterprises in China. The financial risk evaluation of high-tech enterprises is classical MAGDM. Recently, the CoCoSo method has been used to manage MAGDM. The IFSs are used as a tool for portraying uncertain information during the financial risk evaluation of high-tech enterprises. In this paper, the IF-CoCoSo method is founded to manage MAGDM under IFSs. Finally, a numerical case study for financial risk evaluation of high-tech enterprises is

supplied to validate the proposed method. The main contribution is outlined: (1) the CoCoSo method has been extended to IFSs; (2) Information Entropy is used to derive weight under IFSs. (3) the IF-CoCoSo method is founded to manage the MAGDM under IFSs; (4) a numerical case study for financial risk evaluation of high-tech enterprises and some comparative analysis is supplied to validate the proposed method.

There may be some possible limitations for financial risk evaluation of high-tech enterprises, which can be further explored in future research: (1) It is a worthwhile research topic to apply prospect theory to financial risk evaluation of high-tech enterprises under IFSs [76, 77]; (2) It is also worthwhile to apply regret theory to the study of MAGDM under IFSs [78, 79]; (3) In subsequent studies, the application of IFSs needs to be studied with consensus measures for financial risk evaluation of high-tech enterprises [80-82].

Compliance with ethical standards

Ethical approval

This article does not contain any studies with human participants or animals performed by any of the authors.

Conflict of interest

The authors declare that they have no conflict of interest.

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