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Modeling Uncertainties Associated with Single-Valued Neutrosophic Multi-Attribute Decision-Making for Performance Evaluation of Risk Investment in Small and Medium-Sized High-Technology Venture Enterprises

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Abstract: In recent years, a group of rapidly growing technology-based entrepreneurial enterprises have emerged in China, playing an increasingly important role in the national economy. However, small and medium-sized technology startups have low profitability and high risk, making it difficult to obtain sufficient funds from traditional financing channels. At present, research on venture capital evaluation mainly focuses on the evaluation of projects before venture capital, and empirical methods are mostly used to study the promoting effect of venture capital on performance after investment, ignoring the issue of continuous evaluation after investment. The performance evaluation of risk investment in small and medium-sized high-technology venture enterprises is MADM. In such study, the generalized weighted geometric Bonferroni mean (GWGBM) technique is illustrated for MADM under single-valued neutrosophic sets (SVNSs). We begin by constructing the single-valued neutrosophic number GWGBM (SVNNGWGBM) operator, followed by the introduction of the MADM based on this technique. Subsequently, we provide an illustrative example that evaluates the performance of risk investment in small and medium-sized high-technology venture enterprises, supplemented by some comparative analyses to demonstrate the SVNNGWGBM technique. The principal contributions of this research are highlighted: (1) The maximizing deviation method is employed to derive the weight; (2)The GSVNNWBM technique is developed, setting the stage for the introduction of MADM methods based on GSVNNWBM technique; (3) Numerical example is presented that focuses on the performance evaluation of risk investment in small and medium-sized high-technology venture enterprises, along with a comparative decision analysis.

Keywords: Multiple-attribute decision-making (MADM); SVNSs; GWGBM operator; medium-sized high-technology venture enterprises

1. Introduction

In the era of knowledge economy, science and technology have become the decisive force for economic and social development[1]. To remain invincible in fierce international competition, a country must possess strong technological innovation capabilities. To this end, various countries have introduced various policies to support the development of science and technology[2]. China has also pointed out that China should improve its independent innovation capacity, build an innovative country, actively encourage and guide innovation, and make science and technology a strong support for economic development. In this context, technology startups have become a bridge for transforming science and technology into real productivity, driving continuous technology development, promoting the continuous optimization and upgrading of industrial structure, and creating a large number of employment opportunities, becoming the important driving force for social development. In 2012, Global Entrepreneurship Watch released the "Global Entrepreneurship Watch China Report", which showed that compared to 2010, China's entrepreneurial activity index significantly increased in 2011, ranking first among 54 member states. In recent years, a group of rapidly growing technology-based entrepreneurial enterprises have emerged in China, which have rapidly grown in the short term and become industry leaders[3, 4]. For example, the fourth-generation laser typesetting system of Founder Group directly leapfrogged the second and third-generation technologies, bidding farewell to the era of type printing in China's typesetting and printing industry; Dalian Luming Group has broken the monopoly of the international lighting industry and driven the development of China's semiconductor lighting industry by utilizing its pioneering rare earth light storage self-luminescent materials and luminescent chip technology. The application of flash memory technology by Shenzhen Langke Company gives it an unparalleled competitive advantage in this field. From this, it can be seen that China's technology-based entrepreneurial enterprises are very active in technological innovation activities, which can effectively promote the transformation of scientific and technological achievements [5]. Therefore, the development of technology-based entrepreneurial enterprises has obtained widespread attention from the theoretical community and the government[6]. Technology-based startups are in the entrepreneurial stage, where their main task is to develop new products with low profitability and high technological and market risks, which can easily lead to business failure. Studies conducted abroad reveal that in the United States, a significant 68% of small and medium-sized technology enterprises fail within their first five years of operation. Only 19% manage to survive between 6 to 10 years, and a mere 13% endure beyond the 10-year mark. In contrast, data from China indicate that 44.31% of small and medium-sized enterprises fail within the first 3 years, 25.66% survive for 3 to 5 years, 23.08% persist for 5 to 10 years, and just 6.95% manage to survive longer than a decade [7, 8]. The high-risk characteristics of small and medium-sized technology startups make it difficult for them to raise the necessary funds from traditional financing channels[9, 10]. In addition to the high-risk characteristics mentioned above, small and medium-sized technology startups also have the characteristic of high returns: once the developed technology is completed and successfully enters the market, they will obtain high profits. This high-risk and high return characteristic precisely meets the requirements of venture capital, and the intervention of venture capital can solve the financial problems in its development [11, 12]. Venture capital, as a new financing method, provides an effective financing channel for small and medium-sized technology startups.

Since the 1950s, with rapid development of science and technology, scientific decision-making has gradually replaced traditional empirical decision-making and played a crucial role in the development of world politics, military, economy, and science and technology[13-16]. Therefore, the difficulty of making scientific decisions gradually increases, and the decision-making results often deviate from expectations. To reduce decision-making bias and improve decision-making level, scientific and effective quantitative decision-making methods are indispensable[17-21]. Decision-making challenges involving the expression of uncertain information have garnered widespread attention globally, as highlighted in numerous studies [22, 23]. The field of uncertain MADM has particularly drawn significant interest from international scholars in recent years [24-26]. Key contributions to this field include Zadeh's introduction of fuzzy sets (FSs) [27], Atanassov's development of intuitionistic fuzzy sets (IFSs) [28], and Ye's proposal of SVNSs [29]. Further advancements were made by Liu and Wang [30] who illustrated the SVNNWBM, and Yager [31] illustrated the GBM specifically for MADM. Zhu et al. [32] illustrated geometric BM (GBM) operator. Xia, Xu and Zhu [33] Illustrated the generalized WBM operator. Despite these theoretical advancements, real-world MADM applications often encounter complex interdependencies among input variables, which are not adequately addressed by previously studied operators [34, 35]. To mitigate this limitation, the GWGBM operator was adopted, noted for its capability to reflect the nuances of data interrelationships [33]. This operator was further tailored to SVNSs, resulting in the development of the GSVNNWBM operator. Based on this new operator, innovative MADM methods were formulated. The practical application of these methods was demonstrated through a case study focused on the performance evaluation of risk investment in small and medium-sized high-technology venture enterprises, supplemented by comparative decision analysis. The primary objectives of this research were clearly illustrated: (1) Utilizing the maximizing deviation method (MDM) to derive weight information; (2) Developing the GSVNNWBE technique and subsequently proposing MADM based on this enhanced technique; (3) Illustrating these methodologies through a detailed case study on risk investment in high-tech ventures, including some comparative decision analysis to highlight the effectiveness of GSVNNWBE technique.

The remainder of this study is illustrated: Section 2 provides a concise review of SVNSs. Section 3 details the construction of GSVNNWBM operator. In Section 4, we develop the MADM that utilize the GSVNNWBM operator. Section 5 presents a practical application, showcasing the performance evaluation of risk investment in small and medium-sized high-technology venture enterprises. Finally, the conclusions are summarized in Section 6.

2. **Preliminaries**

Wang et al. [36] illustrated the SVNSs

Definition 1 [36]. The SVNSs PA in Θ is illustrated:

$$PA=\left\{\left(\theta, PT_A(\theta), PI_A(\theta), PF_A(\theta)\right) \mid \theta \in \Theta\right\} \tag{1}$$

where $PT_A(\theta), PI_A(\theta), PF_A(\theta)$ is truth-membership, indeterminacy-membership and falsity-membership, $PT_A(\theta), PI_A(\theta), PF_A(\theta) \in [0,1]$, $0 \le PT_A(\theta)+PI_A(\theta)+PF_A(\theta) \le 3$.

The SVNN is illustrated as $PA=\left(PT_A, PI_A, PF_A\right)$, where $PT_A, PI_A, PF_A \in [0,1]$, and $0 \le PT_A + PI_A + PF_A \le 3$.

Definition 2 [37]. Let $PA=\left(PT_A, PI_A, PF_A\right)$, the score function is illustrated:

$$SF(PA)=\frac{\left(2+PT_A-PI_A-PF_A\right)}{3},\ SF(PA)\in[0,1]. \tag{2}$$

Definition 3[37]. Let $PA=\left(PT_A, PI_A, PF_A\right)$, the accuracy function is illustrated:

$$AF(PA)=\frac{PT_A-PF_A+1}{2},\ AF(PA)\in[0,1]\ . \tag{3}$$

Peng et al.[37] illustrated the order structure.

Definition 4[37]. Let $PA=\left(PT_A,PI_A,PF_A\right)$, $PB=\left(PT_B,PI_B,PF_B\right)$, let $SF\left(PA\right)=\frac{\left(2+PT_A-PI_A-PF_A\right)}{3}$ and $SF\left(PB\right)=\frac{\left(2+PT_B-PI_B-PF_B\right)}{3}$, and let $AF\left(PA\right)=\frac{PT_A-PF_A+1}{2}$ and $AF\left(PB\right)=\frac{PT_B-PF_B+1}{2}$, if $SF\left(PA\right)<SF\left(PB\right)$, $PA<PB$; if $SF\left(PA\right)=SF\left(PB\right)$, (1)if $AF\left(PA\right)=AF\left(PB\right)$, $PA=PB$; (2) if $AF\left(PA\right)<AF\left(PB\right)$, $PA<PB$.

Definition 5[36]. Let $PA=\left(PT_A,PI_A,PF_A\right)$ and $PB=\left(PT_B,PI_B,PF_B\right)$, the illustrated operations are:

(1) $PA\oplus PB=\left(PT_A+PT_B-PT_APT_B,PI_API_B,PF_APF_B\right)$;
(2) $PA\otimes PB=\left(PT_APT_B,PI_A+PI_B-PI_API_B,PF_A+PF_B-PF_APF_B\right)$;
(3) $\lambda PA=\left(1-\left(1-PT_A\right)^{\lambda},\left(PI_A\right)^{\lambda},\left(PF_A\right)^{\lambda}\right),\lambda>0$;
(4) $\left(PA\right)^{\lambda}=\left(\left(PT_A\right)^{\lambda},\left(PI_A\right)^{\lambda},1-\left(1-PF_A\right)^{\lambda}\right),\lambda>0.$

Definition 6[33]. Let $ps,pt,pr>0$, $\beta_i (i=1,2,3,\ldots,n)$ be positive values along with weight $pw=(pw_1,pw_2,\ldots,pw_n)^T$, $pw_i\in\left[0,1\right],\sum_{i=1}^{n}pw_i=1$. The GWGBM technique is illustrated:

$$\begin{aligned}&\text{GWGBM}^{ps,pt,pr>0}(\beta_1,\beta_2,\ldots,\beta_n)\\&=\frac{1}{ps+pt+pr}\prod_{i,j,k=1}^{n}(ps\beta_i+pt\beta_j+pr\beta_k)^{pw_ipw_jpw_k}\end{aligned}\tag{4}$$

3. SVNNGWGBM operator

The SVNNGWGBM technique is illustrated on the GWGBM technique.

Definition 7. Let $ps,pt,pr>0$, $PA_i=(PT_i,PI_i,PF_i)$ be SVNNs with weight $pw_i=(pw_1,pw_2,\ldots,pw_n)^T$, $\sum_{i=1}^{n}pw_i=1$. If

$$\begin{aligned}&SVNNGWGBM_{pw}^{ps,pt,pr}(PA_1,PA_2,\cdots,PA_n)\\&=\frac{1}{ps+pt+pr}\mathop{\otimes}_{i,j,k=1}^{n}(psPA_i\oplus ptPA_j\oplus prPA_k)^{pw_ipw_jpw_k}\end{aligned}\tag{5}$$

then $\text{SVNNGWGBM}_{pw}^{ps,pt,pr}$ is called SVNNGWGBM operator.

The Theorem 1 is illustrated.

Theorem 1. Let $ps, pt, pr > 0$ and $PA_i = (PT_i, PI_i, PF_i)(i = 1, 2, \ldots, n)$ be SVNNs. The fused result of SVNNGWGBM is SVNN and

$$\begin{aligned} & SVNNGWGBM_{pw}^{ps,pt,pr}(PA_1, PA_2, \cdots, PA_n) \\ & = \frac{1}{ps+pt+pr} \mathop{\otimes}_{i,j,k=1}^{n} (psPA_i \oplus ptPA_j \oplus prPA_k)^{pw_i pw_j pw_k} \\ & = \begin{pmatrix} 1-(1-\prod_{i,j,k=1}^{n}(1-(1-PT_i)^{ps}(1-PT_j)^{pt}(1-PT_k)^{pr})^{pw_i pw_j pw_k})^{1/(ps+pt+pr)}, \\ (1-\prod_{i,j,k=1}^{n}(1-PI_i^{ps}PI_j^{pt}PI_k^{pr})^{pw_i pw_j pw_k})^{1/(ps+pt+pr)}, \\ (1-\prod_{i,j,k=1}^{n}(1-PF_i^{ps}PF_j^{pt}PF_k^{pr})^{pw_i pw_j pw_k})^{1/(ps+pt+pr)}. \end{pmatrix} \end{aligned} \tag{6}$$

Proof: From Definition 5, it could be obtained:

$$\begin{aligned} psPA_i &= (1-(1-PT_i)^{ps}, PI_i^{ps}, PF_i^{ps}), \\ ptPA_j &= (1-(1-PT_j)^{pt}, PI_j^{pt}, PF_j^{pt}), \\ prPA_k &= (1-(1-PT_k)^{pr}, PI_k^{pr}, PF_k^{pr}). \end{aligned} \tag{7}$$

$$\begin{aligned} & psPA_i \oplus ptPA_j \oplus prPA_k \\ & = \begin{pmatrix} 1-(1-PT_i)^{ps}(1-PT_j)^{pt}(1-PT_k)^{pr}, \\ PI_i^{ps}PI_j^{pt}PI_k^{pr}, PF_i^{ps}PF_j^{pt}PF_k^{pr} \end{pmatrix} \end{aligned} \tag{8}$$

Thereafter,

$$\begin{aligned} & \left(psPA_i \oplus ptPA_j \oplus prPA_k\right)^{pw_i pw_j pw_k} \\ & = \begin{pmatrix} (1-(1-PT_i)^{ps}(1-PT_j)^{pt}(1-PT_k)^{pr})^{pw_i pw_j pw_k}, \\ 1-(1-PI_i^{ps}PI_j^{pt}PI_k^{pr})^{pw_i pw_j pw_k}, \\ 1-(1-PF_i^{ps}PF_j^{pt}PF_k^{pr})^{pw_i pw_j pw_k}. \end{pmatrix} \end{aligned} \tag{9}$$

Therefore,

$$\begin{aligned} & \mathop{\otimes}_{i,j,k=1}^{n} \left(psPA_i \oplus ptPA_j \oplus prPA_k\right)^{pw_i pw_j pw_k} \\ & = \begin{pmatrix} \prod_{i,j,k=1}^{n}(1-(1-PT_i)^{ps}(1-PT_j)^{pt}(1-PT_k)^{pr})^{pw_i pw_j pw_k}, \\ 1-\prod_{i,j,k=1}^{n}(1-PI_i^{ps}PI_j^{pt}PI_k^{pr})^{pw_i pw_j pw_k}, \\ 1-\prod_{i,j,k=1}^{n}(1-PF_i^{ps}PF_j^{pt}PF_k^{pr})^{pw_i pw_j pw_k}. \end{pmatrix} \end{aligned} \tag{10}$$

Thus,

$$\frac{1}{ps+pt+pr}\underset{i,j,k=1}{\overset{n}{\otimes}}\left(psPA_i \oplus ptPA_j \oplus prPA_k\right)^{pw_i pw_j pw_k}$$
$$=\begin{pmatrix} 1-(1-\prod_{i,j,k=1}^{n}(1-(1-PT_i)^{ps}(1-PT_j)^{pt}(1-PT_k)^{pr})^{pw_i pw_j pw_k})^{1/(ps+pt+pr)}, \\ (1-\prod_{i,j,k=1}^{n}(1-PI_i^{ps}PI_j^{pt}PI_k^{pr})^{pw_i pw_j pw_k})^{1/(ps+pt+pr)}, \\ (1-\prod_{i,j,k=1}^{n}(1-PF_i^{ps}PF_j^{pt}PF_k^{pr})^{pw_i pw_j pw_k})^{1/(ps+pt+pr)}. \end{pmatrix} \quad (11)$$

Thus, (6) is obtained.

Then,

$$\begin{aligned} &0 \le 1-(1-\prod_{i,j,k=1}^{n}(1-(1-PT_i)^{ps}(1-PT_j)^{pt}(1-PT_k)^{pr})^{pw_i pw_j pw_k})^{1/(ps+pt+pr)} \le 1, \\ &0 \le (1-\prod_{i,j,k=1}^{n}(1-PI_i^{ps}PI_j^{pt}PI_k^{pr})^{pw_i pw_j pw_k})^{1/(ps+pt+pr)} \le 1, \\ &0 \le (1-\prod_{i,j,k=1}^{n}(1-PF_i^{ps}PF_j^{pt}PF_k^{pr})^{pw_i pw_j pw_k})^{1/(ps+pt+pr)} \le 1. \end{aligned} \quad (12)$$

Therefore,

$$\begin{aligned} 0 \le 1-&(1-\prod_{i,j,k=1}^{n}(1-(1-PT_i)^{ps}(1-PT_j)^{pt}(1-PT_k)^{pr})^{pw_i pw_j pw_k})^{1/(ps+pt+pr)} \\ &+(1-\prod_{i,j,k=1}^{n}(1-PI_i^{ps}PI_j^{pt}PI_k^{pr})^{pw_i pw_j pw_k})^{1/(ps+pt+pr)} \\ &+(1-\prod_{i,j,k=1}^{n}(1-PF_i^{ps}PF_j^{pt}PF_k^{pr})^{pw_i pw_j pw_k})^{1/(ps+pt+pr)} \le 3. \end{aligned} \quad (13)$$

Thereby finishing the proof.

The SVNNGWGBM technique has some properties.

Property 4. Let $ps, pt, pr > 0$ and $PA_i = (PT_i, PI_i, PF_i)(i = 1, 2, \ldots, n)$ be a set of SVNNs.

(1) (Idempotency). If $PA_i = (PT_i, PI_i, PF_i)(i = 1, 2, \ldots, n)$ are equal, that is, $PA_i = PA = (PT, PI, PF)$, then

$$SVNNGWGBM_{pw}^{ps,pt,pr}(PA_1, PA_2, \cdots, PA_n) = PA \quad (14)$$

(2) (Monotonicity). Let $PA_i = (PT_{A_i}, PI_{A_i}, PF_{A_i})(i = 1, 2, 3, \ldots, n)$ and $PB_i = (PT_{B_i}, PI_{B_i}, PF_{B_i})$ $(i = 1, 2, 3, \ldots, n)$ be two sets of SVNNs. If $PT_{A_i} \le PT_{B_i}$, $PI_{A_i} \ge PI_{B_i}$, $PF_{A_i} \ge PF_{B_i}$ holds for

all i, then

$$SVNNGWGBM_{pw}^{ps,pt,pr}(PA_1, PA_2, \cdots, PA_n) \\ \leq SVNNGWGBM_{pw}^{ps,pt,pr}(PB_1, PB_2, \cdots, PB_n) \tag{15}$$

(3) (Boundedness). Let $PA_i = (PT_{A_i}, PI_{A_i}, PF_{A_i})(i = 1,2,3,\ldots,n)$ be SVNNS. If

$PA^{+} = (\max_i(PT_i), \min_i(PI_i), \min_i(PF_i))$ and $PA^{-} = (\min_i(PT_i), \max_i(PI_i), \max_i(PF_i))$ then

$$PA^{-} \leq SVNNGWGBM_{pw}^{ps,pt,pr}(PA_1, PA_2, \cdots, PA_n) \leq PA^{+}. \tag{16}$$

4. MADM technique based on SVNNGWGBM technique under SVNNs

The SVNNGWGBM technique is illustrated for MADM for SVNSs. Let $PX = \{PX_1, PX_2, \ldots, PX_n\}$ be attributes, $pw = \{pw_1, pw_2, \ldots, pw_n\}$ be weight of PX_j. Let $PA = \{PA_1, PA_2, \ldots, PA_m\}$ be alternatives. $PP = (pp_{ij})_{m \times n} = (PT_{ij}, PI_{ij}, PF_{ij})_{m \times n}$ is SVNN-matrix.

The SVNNGWGBM technique for MADM is illustrated (See Figure 1).

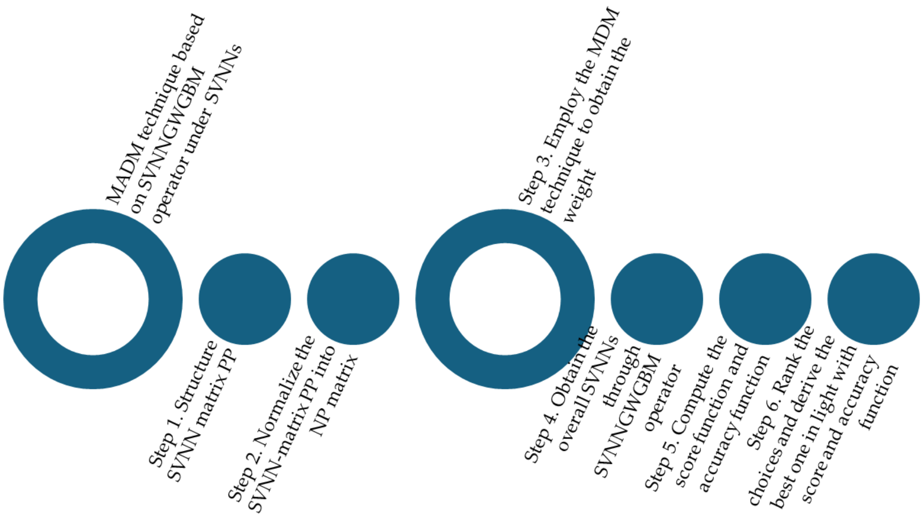

Figure 1. MADM technique based on SVNNGWGBM operator under SVNNs

Step 1. Illustrate SVNN matrix $PP = (pp_{ij})_{m \times n} = (PT_{ij}, PI_{ij}, PF_{ij})_{m \times n}$.

$$PP = \left(PP_{ij}\right)_{m\times n} = \begin{bmatrix} PP_{11} & PP_{12} & \dots & PP_{1n} \\ PP_{21} & PP_{22} & \dots & PP_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ PP_{m1} & PP_{m2} & \dots & PP_{mn} \end{bmatrix}$$

$$PP = \left(PP_{ij}\right)_{m\times n} = \left(PT_{ij}, PI_{ij}, PF_{ij}\right)_{m\times n} \tag{17}$$

$$= \begin{bmatrix} \left(PT_{11}, PI_{11}, PF_{11}\right) & \left(PT_{12}, PI_{1}, PF_{12}\right) & \dots & \left(PT_{1n}, PI_{1n}, PF_{1n}\right) \\ \left(PT_{21}, PI_{21}, PF_{21}\right) & \left(PT_{22}, PI_{22}, PF_{22}\right) & \dots & \left(PT_{2n}, PI_{2n}, PF_{2n}\right) \\ \vdots & \vdots & \vdots & \vdots \\ \left(PT_{m1}, PI_{m1}, PF_{m1}\right) & \left(PT_{m2}, PI_{m2}, PF_{m2}\right) & \dots & \left(PT_{mn}, PI_{mn}, PF_{mn}\right) \end{bmatrix}$$

Step 2. Normalize the $PP = \left[PP_{ij}\right]_{m\times n}$ to $NP = \left[NP_{ij}\right]_{m\times n}$.

$$NP_{ij} = \left(NPT_{ij}, NPI_{ij}, NPF_{ij}\right) = \begin{cases} \left(PT_{ij}, PI_{ij}, PF_{ij}\right), & PX_j \text{ is benefit attribute} \\ \left(PF_{ij}, 1-PI_{ij}, PT_{ij}\right), & PX_j \text{ is benefit attribute} \end{cases} \tag{18}$$

Step 3. Employ the maximizing deviation method (MDM) to ascertain the weights.

The MDM [38] under SVNSs to ascertain the weight.

(1) Depending on $NP = \left[NP_{ij}\right]_{m\times n}$, the deviation degree PA_i to others is illustrated.

$$SVNNDD_{ij} = \sum_{t=1}^{m} pw_j \cdot \left| AF\left(NP_{ij}\right) - AF\left(NP_{tj}\right) \right| \tag{19}$$

(2) Illustrate the total weighted deviation.

$$SVNNDD_j\left(pw\right) = \sum_{i=1}^{m} SVNNDD_{ij}\left(pw\right) = \sum_{i=1}^{m}\sum_{t=1}^{m} pw_j \left| AF\left(NP_{ij}\right) - AF\left(NP_{tj}\right) \right| \tag{20}$$

(3) Illustrate non-linear programming technique.

$$\left(M-1\right)\begin{cases} \max SVNNDD\left(pw\right) = \sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{t=1}^{m} pw_j \left| AF\left(NP_{ij}\right) - AF\left(NP_{tj}\right) \right| \\ s.t.\ \mathrm{pw}_j \ge 0,\ \sum_{j=1}^{n} pw_j^2 = 1 \end{cases} \tag{21}$$

The Lagrange decision function is illustrated for this model.

$$LF\left(pw, \xi\right) = \sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{t=1}^{m} pw_j \left| AF\left(NP_{ij}\right) - AF\left(NP_{tj}\right) \right| + \frac{\xi}{2}\left(\sum_{j=1}^{n} pw_j^2 - 1\right)$$

where ξ is Lagrange multiplier. The given partial derivatives are illustrated.

$$\begin{cases} \dfrac{\partial LF}{\partial pw_j} = \sum_{i=1}^{m}\sum_{t=1}^{m}\left|AF\left(NP_{ij}\right) - AF\left(NP_{tj}\right)\right| + \xi pw_j = 0 \\ \dfrac{\partial LF}{\partial \xi} = \dfrac{1}{2}\left(\sum_{j=1}^{n} pw_j^2 - 1\right) = 0 \end{cases}$$

The weight is illustrated: $pw_j^* = \dfrac{\sum_{i=1}^{m}\sum_{t=1}^{m}\left|AF\left(NP_{ij}\right) - AF\left(NP_{tj}\right)\right|}{\sqrt{\sum_{j=1}^{n}\left(\sum_{i=1}^{m}\sum_{t=1}^{m}\left|AF\left(NP_{ij}\right) - AF\left(NP_{tj}\right)\right|\right)^2}}$

Finally, the normalized weights are:

$$pw_j = \frac{\sum_{i=1}^{m}\sum_{t=1}^{m} AF\left(NP_{ij}\right) - AF\left(NP_{tj}\right)}{\sum_{j=1}^{n}\sum_{i=1}^{m}\sum_{t=1}^{m} AF\left(NP_{ij}\right) - AF\left(NP_{tj}\right)} \tag{22}$$

Step 4. In light with $NP = \left[NP_{ij}\right]_{m\times n}$, we could fuse the $NP = \left[NP_{ij}\right]_{m\times n}$ through SVNNGWGBM technique to obtain the SVNN $NP_i = \left(NPT_i, NPI_i, NPF_i\right)$:

$$\begin{aligned} NP_i &= \left(NPT_i, NPI_i, NPF_i\right) \\ &= SVNNGWGBM_{pw}^{ps,pt,pr}(NP_{i1}, NP_{i2}, \cdots, NP_{in}) \\ &= \frac{1}{ps+pt+pr} \underset{i,j,k=1}{\overset{n}{\otimes}} (psNP_{if} \oplus ptNP_{ij} \oplus prNP_{ik})^{pw_i pw_j pw_k} \\ &= \begin{pmatrix} 1-(1-\prod_{i,j,k=1}^{n}(1-(1-NPT_{if})^{ps}(1-NPT_{ij})^{pt}(1-NPT_{ik})^{pr})^{pw_i pw_j pw_k})^{1/(ps+pt+pr)}, \\ (1-\prod_{i,j,k=1}^{n}(1-NPI_{if}^{ps} NPI_{ij}^{pt} NPI_{ik}^{pr})^{pw_i pw_j pw_k})^{1/(ps+pt+pr)}, \\ (1-\prod_{i,j,k=1}^{n}(1-NPF_{if}^{ps} NPF_{ij}^{pt} NPF_{ik}^{pr})^{pw_i pw_j pw_k})^{1/(ps+pt+pr)}. \end{pmatrix} \end{aligned} \tag{23}$$

Step 5. Illustrate the $SF\left(NP_i\right), AF\left(NP_i\right)\left(i=1,2,\cdots,m\right)$.

$$SF\left(nq_i\right) = \frac{\left(2 + NPT_i - NPI_i - NPF_i\right)}{3}, AF\left(NP_i\right) = \frac{NPT_i - NPF_i + 1}{2} \tag{24}$$

Step 6. Rank the $PA_i\left(i=1,2,\cdots,m\right)$ through $SF\left(NP_i\right), AF\left(NP_i\right)\left(i=1,2,\cdots,m\right)$.

5. Case Study and Comparative Evaluation

In this section, we will present a case study followed by a comparative evaluation to explore the key findings and implications of our research. By analyzing specific examples, we aim to highlight differences and similarities that can inform us of our understanding of the subject matter.

5.1 **Case Study**

In recent years, scholars have believed that the sustained growth of enterprises is related to their entrepreneurial behavior, such as innovation, initiative, and risk-taking. That is to say, enterprises should support new concepts, actively take action, and create competitive advantages. With the foresight of the enterprise, proactive enterprises can develop emerging opportunities. However, not all small and medium-sized enterprises can quickly identify opportunities and take immediate action under high market uncertainty, which means that the process of entrepreneurs discovering opportunities has costs and is not an "epiphany". Therefore, whether start-up small and medium-sized enterprises can overcome the danger period or achieve sustained and stable growth, and truly transform into growth performance, the identification and development of opportunities are key. The proposal of entrepreneurial orientation precisely solves this problem. Entrepreneurship orientation is a fusion of innovation, initiative, and risk-taking, which is more reflected in the entrepreneurial attitude and willingness of entrepreneurs. It is a mechanism for entrepreneurship and innovation, so the foresight or entrepreneurial spirit of entrepreneurs plays a greater guiding role throughout the entire process. Entrepreneurial orientation is not simply equivalent to behavioral orientation with the fundamental goal of creating a new enterprise. It also encompasses the understanding of new entry opportunities and the attitude and behavioral tendencies towards taking action that enterprises exhibit during their successful entrepreneurial process in complex and uncertain environments. It is a strategy of achieving success through targeted actions. Therefore, from the perspective of entrepreneurial orientation, resource pooling can enable small and medium-sized enterprises to demonstrate stronger risk resistance and achieve sustained growth. Firstly, entrepreneurship utilizes the resources at hand rather than the resources illustrated through search. Secondly, individuals or organizations that adopt entrepreneurial patchwork do not wait for the "right" resources. They use the resources at hand, take positive actions to address problems, seize opportunities, and do not hesitate about whether the resources at hand are feasible. They believe that "can" is more important than "should", and this process includes the experimental process of restructuring, restructuring, and resource acquisition. Finally, entrepreneurial patchwork requires examining the resources at hand from different perspectives and perspectives and reconsidering the way resources are utilized, which is a "creative reengineering" behavior. Organizations that are good at entrepreneurial patchwork can identify new attributes of the resources at hand and use them to implement innovation, generating differentiated value from homogeneous resources. Entrepreneurship patchwork is an ability for organizations to achieve sustained competitive advantages. The performance evaluation of risk investment in small and medium-sized high-technology venture enterprises is MADM. In this study, an empirical application of performance evaluation of risk investment in small and medium-sized high-technology venture enterprises is given through SVNNGWGBM method. There are five medium-sized high-technology venture enterprises are evaluated their performance evaluation of risk investment. Five medium-sized high-technology venture enterprises are assessed fairly under four attributes:

PX_1 is the personnel input. The forefront of technology is a crucial driver for the growth and continuous innovation of high-tech enterprises. Yet, advancing technologically not only demands substantial capital but also a significant investment in top-notch personnel. When high-tech enterprises secure funding from entrepreneurial venture capital, the venture capitalists often leverage their extensive experience and networks to assist in recruiting key talents essential for the enterprise's development. These key talents include not only scientists and engineers directly involved in technological innovation but also managerial talents who foster an environment conducive to innovation. Additionally, similar to the role investment banks play in underwriting corporate IPOs, entrepreneurial venture capital can act as a "reputation medium" for high-tech enterprises. Before these enterprises receive investment, a significant information asymmetry exists between them and potential employees due to the lack of publicly available information. The news of an investment signals to top talents that the enterprise likely has better success prospects and a more promising future than those without such backing, thus attracting high-quality candidates. This helps mitigate the initial information gaps and positions the enterprise more favorably in the competitive market.

PX_2 is the capital investment. Technological innovation is the cornerstone of growth for high-tech enterprises, which, unlike traditional enterprises, require significantly more funding for research and development. Despite this need, securing funding is often more challenging for high-tech enterprises than for their traditional counterparts. A pervasive shortage of funds acts as a critical barrier to technological innovation across the globe, including in China. This is primarily due to the high-risk nature and lack of sufficient collateral assets typical of high-tech enterprises, making traditional financing avenues like bank loans less viable. However, entrepreneurial venture capital, which inherently seeks out high-risk, high-return opportunities, aligns well with the financial needs of high-tech enterprises. This type of funding not only addresses the difficulties these enterprises face in accessing traditional financial support but also becomes a principal mode of financing for their technological innovations. Moreover, venture capital does more than just supply direct financial assistance; it also facilitates access to additional external funds. Venture capitalists are well-informed and experienced, and their investment in a company often serves as a testament to the company's quality. Consequently, the reputational capital of venture capitalists sends a strong, positive signal to other potential investors. In essence, entrepreneurial venture capital helps high-tech enterprises overcome traditional financing barriers and expand their funding avenues, playing a crucial role in their ongoing innovation and development.

PX_3 is the sales revenue and profit. The primary objective of high-tech enterprises in technological innovation is to commercialize and industrialize their innovations, while also enabling entrepreneurial venture capitalists to achieve substantial capital returns through these commercial activities. Consequently, the sales revenue and profits generated by high-tech enterprises serve as critical indicators for assessing the impact of entrepreneurial venture capital on their technological advancements. Entrepreneurial venture capitalists bring invaluable experience gained from investing in various enterprises, offering crucial insights and guidance that are often lacking within high-tech enterprises. For instance, these investors leverage their extensive industry-specific investment experience to preemptively address potential challenges, thereby reducing the likelihood of market failures for new products. Moreover, venture capitalists facilitate connections between high-tech companies and potential customers and suppliers through their extensive social networks and portfolio companies. Additionally, the enhanced reputation that comes with association with entrepreneurial venture capital can broaden a high-tech company's network of potential customers and suppliers, further boosting its market presence.

PX_4 is the innovation capability. Technology forms the bedrock of small and medium-sized technology startups. Venture capital plays a crucial role in supporting and enhancing their capacity for technological innovation. Consequently, when evaluating the performance of these startups, it is essential to specifically assess their capabilities in technological innovation.

Clearly, PX_2 represents the cost, while the other elements are considered benefits. Subsequently, the SVNNGWGBM method is utilized in MADM to assess the performance of risk investment in small and medium-sized high-technology venture enterprises using SVNNs. The decision-making process using the SVNNGWGBM method includes the following steps:

Step 1. Illustrate the SVNN-matrix $PP = \left(PP_{ij}\right)_{5\times4}$ (Table 1).

Table 1. SVNN matrix

	PX_1	PX_2	PX_3	PX_4
PA_1	(0.39, 0.28, 0.37)	(0.29, 0.27, 0.28)	(0.32, 0.55, 0.34)	(0.25, 0.32, 0.43)
PA_2	(0.36, 0.24, 0.51)	(0.54, 0.26, 0.24)	(0.39, 0.34, 0.63)	(0.37, 0.43, 0.38)
PA_3	(0.59, 0.36, 0.53)	(0.54, 0.27, 0.68)	(0.32, 0.28, 0.56)	(0.56, 0.27, 0.46)
PA_4	(0.52, 0.23, 0.59)	(0.58, 0.37, 0.35)	(0.53, 0.45, 0.36)	(0.58, 0.36, 0.61)
PA_5	(0.51, 0.26, 0.53)	(0.56, 0.29, 0.54)	(0.57, 0.24, 0.53)	(0.39, 0.43, 0.56)

Step 2. Normalize $PP = \left(PP_{ij}\right)_{5\times4}$ to $NP = \left(NP_{ij}\right)_{5\times4}$ (See the Table 2).

Table 2. The NP matrix

	PX_1	PX_2	PX_3	PX_4
PA_1	(0.39, 0.28, 0.37)	(0.28, 0.73, 0.29)	(0.32, 0.55, 0.34)	(0.25, 0.32, 0.43)
PA_2	(0.36, 0.24, 0.51)	(0.24, 0.74, 0.54)	(0.39, 0.34, 0.63)	(0.37, 0.43, 0.38)
PA_3	(0.59, 0.36, 0.53)	(0.68, 0.73, 0.54)	(0.32, 0.28, 0.56)	(0.56, 0.27, 0.46)
PA_4	(0.52, 0.23, 0.59)	(0.35, 0.63, 0.58)	(0.53, 0.45, 0.36)	(0.58, 0.36, 0.61)

PA_5	(0.51, 0.26, 0.53)	(0.54, 0.71, 0.56)	(0.57, 0.24, 0.53)	(0.39, 0.43, 0.56)

Step 3. Illustrate the weights (Table 3).

Table 3. The weight information

	PX_1	PX_2	PX_3	PX_4
pw_j	0.2477	0.1796	0.2548	0.3179

Step 4. Obtain the $NP_i\left(i=1,2,\cdots,5\right)$ through utilizing SVNNGWGBM technique (Table 4).

Table 4. The $NP_i\left(i=1,2,3,\cdots,5\right)$ by SVNNGWGBM technique ($s=t=r=1$)

Techniques	$NP_i\left(i=1,2,\cdots,5\right)$
PA_1	(0.5223,0.4796,0.3453)
PA_2	(0.6976,0.2957,0.3889)
PA_3	(0.5637,0.6493,0.3199)
PA_4	(0.5865,0.5728,0.3326)
PA_5	(0.5875,0.6457,0.1847)

Step 5. Obtain the $SV\left(NP_i\right)\left(i=1,2,3,\cdots,5\right)$ (Table 5).

Table 5. $SV\left(NP_i\right)\left(i=1,2,3,\cdots,5\right)$

Techniques	$SV\left(NP_i\right)\left(i=1,2,\cdots,5\right)$	Order
PA_1	0.5850	5
PA_2	0.7374	1

PA_3	0.6170	4
PA_4	0.6293	3
PA_5	0.6441	2

Step 6. From Table 5, the order is illustrated: $PA_2 > PA_5 > PA_4 > PA_3 > PA_1$, and the optimal small and medium-sized high-technology venture enterprise is PA_2.

5.2. Influence analysis

To demonstrate how varying decision parameters of the SVNNGWGBM method influence the ranking outcomes, the results are presented in Tables 6 and 7.

Table 6. Different parameters for SVNNGWGBM

(s,t,r)	$SF(PA_1)$	$SF(PA_2)$	$SF(PA_3)$	$SF(PA_4)$	$SF(PA_5)$
$(1,1,1)$	0.5850	0.7374	0.6170	0.6293	0.6441
$(2,2,2)$	0.8287	0.9320	0.8595	0.8551	0.8600
$(3,3,3)$	0.8957	0.9677	0.9213	0.9022	0.9245
$(4,4,4)$	0.9213	0.9775	0.9447	0.9165	0.9523
$(5,5,5)$	0.9337	0.9813	0.9567	0.9224	0.9674
$(6,6,6)$	0.9410	0.9833	0.9644	0.9256	0.9766
$(7,7,7)$	0.9457	0.9847	0.9697	0.9277	0.9828
$(8,8,8)$	0.9492	0.9859	0.9739	0.9295	0.9873
$(9,9,9)$	0.9517	0.9870	0.9773	0.9309	0.9907
$(10,10,10)$	0.9539	0.9881	0.9801	0.9321	0.9934

Table 7. Order for SVNNGWGBM

(s,t,r)	Order
$(1,1,1)$	$PA_2 > PA_5 > PA_4 > PA_3 > PA_1$
$(2,2,2)$	$PA_2 > PA_5 > PA_3 > PA_4 > PA_1$
$(3,3,3)$	$PA_2 > PA_5 > PA_3 > PA_4 > PA_1$
$(4,4,4)$	$PA_2 > PA_5 > PA_3 > PA_1 > PA_4$
$(5,5,5)$	$PA_2 > PA_5 > PA_3 > PA_1 > PA_4$
$(6,6,6)$	$PA_2 > PA_5 > PA_3 > PA_1 > PA_4$
$(7,7,7)$	$PA_2 > PA_5 > PA_3 > PA_1 > PA_4$
$(8,8,8)$	$PA_2 > PA_5 > PA_3 > PA_1 > PA_4$
$(9,9,9)$	$PA_2 > PA_5 > PA_3 > PA_1 > PA_4$
$(10,10,10)$	$PA_2 > PA_5 > PA_3 > PA_1 > PA_4$

The information presented in Tables 6 and 7 illustrates that the prioritization of advantages and disadvantages shifts slightly when different parameter values are applied in the SVNNGWGBM process. This variability underscores the flexibility of parameter selection, which can be adjusted to align with the decision-maker's subjective perspective. On one hand, DMs can manipulate these parameter values to generate varying decision outcomes. This ability to modify results based on parameter adjustments allows decision-makers to explore different scenarios and their potential impacts thoroughly. On the other hand, the choice of parameter also serves as an indicator of the decision-maker’s risk tolerance. By selecting specific parameters, decision-makers can express their propensity for risk, whether they are risk-averse, risk-neutral, or risk-seeking. This aspect of parameter selection not only influences the decision outcome but also provides insight into the decision-maker's strategic approach and risk management preferences.

5.3 Comparative analysis

The SVNNGWGBM approach is compared with SVNNWA [37] , SVNNWG [37], SVNN-CODAS [39], SVNN-WASPAS [40], SVNN-TOPSIS [41] and SVNN-EDAS [42]. The final results are recorded in Table 8.

Table 8. Results of different techniques

Techniques	Order
SVNNWA technique [37]	$PA_2 > PA_5 > PA_4 > PA_3 > PA_1$
SVNNWG technique [37]	$PA_2 > PA_5 > PA_3 > PA_4 > PA_1$
SVNN-CODAS technique [39]	$PA_2 > PA_5 > PA_4 > PA_3 > PA_1$
SVNN-WASPAS technique [40]	$PA_2 > PA_5 > PA_4 > PA_3 > PA_1$
SVNN-TOPSIS technique [41]	$PA_2 > PA_5 > PA_4 > PA_3 > PA_1$
SVNN-EDAS technique [42]	$PA_2 > PA_5 > PA_3 > PA_4 > PA_1$
The proposed SVNNGWGBM technique	$PA_2 > PA_5 > PA_4 > PA_3 > PA_1$

The above analysis indicates that the ranking outcomes derived from the proposed SVNNGWGBM technique are consistent with those obtained using the SVNNWA technique [37] , SVNN-CODAS technique [39], SVNN-WASPAS [40] and SVNN-TOPSIS [41]. However, there are subtle differences when compared to the results from the SVNNWG technique [37]. The major reason for these differences is that the SVNNWG technique [37] emphasizes the influence of individual criteria, whereas the SVNN-EDAS technique [42] focuses on measuring distances from the average solution. Upon comparing the decision results of SVNNGWGBM technique [42] with those from the SVNNWA, SVNNWG, SVNN-CODAS, SVNN-WASPAS, SVNN-TOPSIS and SVNN-EDAS, it is observed that although there are minor variations, the identification of the best and worst small and medium-sized high-technology venture enterprises remains consistent across methods. This consistency validates the effectiveness of the SVNNGWGBM technique as a relatively straightforward and reliable option for MADM.

6. Conclusion

In the era of "innovation and entrepreneurship," technology-based small and medium-sized entrepreneurial enterprises are encountering extraordinary opportunities. However, the high degree of market uncertainty also presents formidable challenges for their sustained growth. Particularly for these entrepreneurial ventures, the rapid shifts in market conditions and environmental uncertainties pose significant risks. Additionally, technological innovation demands frequent product updates, and the ever-changing customer demands further escalate the market's unpredictability and risk. Confronting this dynamic and complex market environment requires these enterprises to swiftly identify opportunities, creatively overcome resource limitations, proactively establish lasting competitive advantages, enhance resilience, and secure sustainable growth. These challenges are particularly acute for startup technology-based small and medium-sized enterprises. The performance evaluation of risk investment in such enterprises is a classic issue in MADM. In this context, the WBM technique is adapted for addressing MADM challenges with SVNSs. The SVNNGWGBM technique is detailed, and MADM methodologies based on this operator are subsequently introduced. An illustrative example concerning the performance evaluation of risk investment in small and medium-sized high-technology venture enterprises, along with comparative analysis, are provided to verify the efficacy of SVNNGWGBM technique.

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