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# A Hybrid Quadripartitioned Single-Valued Neutrosophic Method and its Application for the Selection of Emergency Logistics Outsourcing Suppliers

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**ABSTRACT**

The selection of an emergency logistics outsourcing supplier (ELOS) is critical for enhancing disaster response efficiency, reducing operational costs, and strengthening supply chain resilience. A scientifically robust supplier evaluation framework optimizes resource allocation, mitigates risks, and ensures timely material distribution, serving as a cornerstone of effective emergency management systems. This study introduces a novel hybrid quadripartitioned single-valued neutrosophic (QSVN) multi-criteria decision-making (MCDM) approach, integrating the coefficient of variation method (CVM) and complex proportional assessment (COPRAS) to address ambiguity and uncertainty in decision-making. Key contributions include (1) establishing QSVN Aczel-Alsina operational rules based on Aczel-Alsina norms, (2) developing weighted averaging and geometric Aczel-Alsina aggregation operators for QSVN numbers (QSVNNs), and (3) proposing a hybrid CVM-COPRAS framework for criteria weighting and alternative ranking. A case study on ELOS selection validates the method's efficacy, supported by sensitivity and comparative analyses demonstrating its robustness and superiority over existing techniques. The results confirm the model's stability and improved performance in complex decision-making under uncertainty.

## 1. Introduction

In recent years, with the increasing frequency of various types of natural disasters, emergency response departments often delegate the transportation, procurement, and related tasks of emergency supplies to logistics outsourcing suppliers to ensure rapid, efficient, and scientifically sound mitigation of human casualties and losses [1, 2]. The objective is to leverage the expertise of specialized ELOS, which can utilize their extensive organizational experience and infrastructure to expedite the delivery and distribution of relief supplies, thereby maximizing the preservation of human life. ELOS are enterprises or organizations dedicated to providing logistics services in response

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to natural disasters, public health crises, and unforeseen accidents. Their competitive advantage lies in their core capabilities, including rapid response, resource allocation, and multimodal transportation, as well as their strengths in inventory management, transportation network coverage, and digitalization. A scientifically rigorous selection process for ELOS holds significant implications: (1) Timely delivery of relief supplies mitigates secondary disasters, such as social instability caused by shortages of food and water among affected populations. (2) Optimized resource allocation through intelligent algorithms minimizes redundant transportation and resource wastage. (3) Economies of scale achieved via long-term collaboration with professional suppliers reduce per-unit logistics costs. Given the inherent uncertainty and ambiguity in supplier selection, as well as the cognitive limitations of decision-makers, this process constitutes a classic multi-criteria decision-making (MCDM) problem. Consequently, this study aims to develop a MCDM model under fuzzy conditions to address the selection of ELOS.

Multi-attribute decision-making (MADM), as a pivotal branch of decision science, refers to the systematic process of determining priority relationships among alternative solutions through multi-dimensional evaluation theories and methods under specified assessment criteria. In increasingly complex and dynamic evaluation environments, decision-making experts often encounter challenges in providing precise evaluation information, leading them to employ fuzzy sets characterized by uncertainty to articulate their preferences [3]. Subsequent theoretical advancements have witnessed the emergence of intuitionistic fuzzy sets [4], Pythagorean fuzzy sets [5], and q-rung orthopair fuzzy sets as extended frameworks to better capture uncertain cognitive preferences in decision analysis, achieving remarkable progress in practical applications [6-11]. While conventional fuzzy sets and their extensions effectively address most real-world uncertainties, inherent limitations persist when handling discontinuous and inconsistent information. To bridge this gap, Smarandache [12] pioneered neutrosophic set theory from a philosophical perspective, which quantifies uncertain and inconsistent preference information through three independent membership functions: truth-membership, falsity-membership, and indeterminacy-membership. To operationalize neutrosophic sets in practical problem-solving, Wang et al., [13] rigorously redefined these tripartite membership functions and established formal operational rules for single-valued neutrosophic sets (SVNSs). Capitalizing on SVNS's superior capability in uncertainty handling, extensive theoretical explorations and practical implementations have been conducted in decision analysis, encompassing aggregation operators [14, 15], information measures [16-18], and decision model construction [19-21]. Moreover, SVNS has demonstrated significant utility across diverse domains, providing robust decision support for policymakers and administrators [22-24]. Nevertheless, SVNS maintains independence between its indeterminacy membership function and other components, retaining inherent fuzziness in uncertainty characterization. Addressing this limitation, Chatterjee et al., [25] proposed the innovative concept of QSVNS (QSVNS) and some information measures, which decomposes the indeterminacy membership into "contradictory membership degree" and "ignorant membership degree". This theoretical refinement substantially enhances SVNS's capacity for uncertainty representation, enabling more sophisticated modeling of inconsistent information and thereby establishing QSVNS as a comprehensive framework for uncertainty quantification in complex decision scenarios. Chatterjee et al., [26] proposed a group decision method based on quadripartitioned neutrosophic weighted aggregation operators. Mohanasundari and Mohana [27] proposed some novel Dombi operators to build up MCDM framework with QSVN environment. Hussain et al., [28] constructed the QSVN graph to do with practical problems. Goyal and Rani [29] proffered novel Weighted aggregated sum product assessment (WASPAS) method on the basis of QSVN Einstein operators for dealing with QSVN decision problems. After that, some novel extensions based on QSVN are propounded, such as, quadripartitioned single valued bipolar neutrosophic sets

[30], bipolar qsvn sets [31], QSVN Z-numbers and quadripartitioned single-valued trapezoidal neutrosophic sets [32]. To our best knowledge, there is no research to combine the QSVNS and COPRAS approach.

The complex proportional assessment (COPRAS) method [33], as a prominent tool in MCDM, distinguishes itself by efficiently and transparently addressing complex decision-making problems. In contrast to methods such as technique for order of preference by similarity to ideal solution (TOPSIS) method [34], WASPAS method [35], and Elimination and Choice Translating Reality (ELECTRE) method [36], COPRAS method directly handles both beneficial (maximization) and non-beneficial (minimization) criteria by independently calculating their weighted sums, thereby preserving data integrity and avoiding distortions. In recent years, scholarly attention has increasingly focused on advancing COPRAS in decision analysis, with research primarily concentrated in the following directions: (1) extending the COPRAS method to diverse fuzzy and uncertain environments to construct more robust decision-making models; (2) enhancing the classical COPRAS approach through novel aggregation operators to broaden its applicability; (3) applying COPRAS to practical problems across various domains to validate its effectiveness; and (4) integrating COPRAS with other methodologies to develop hybrid decision-making models for real-world analytical applications. Further, Saraji et al., [37] proposed a hybrid decision framework based on CRiteria Importance Through Intercriteria Correlation (CRITIC)and COPRAS methods to assess the challenges to industry 4.0 adoption for a sustainable digital transformation. Liu et al., [38] first propounded the conception of interval-valued hesitant Fermatean fuzzy set and then proposed improved COPRAS methodology to choose the optimal desalination technology. Gao et al., [39] first defined the novel spherical aggregation operators and entropy measures, and then constructed a novel group decision method based on best and worst method and COPRAS method to determine the best digital supply chain partner. In addition, more researches on COPRAS method can be studied references [40-44]. However, the existing research shows that the combination of QSVNS, Aczel-alsin operators and COPRAS method has not been investigated.

Based on the discussions of the mentioned references, the aim of this research is to construct a hybrid MCDM approach to determine the best ELOS from a set of suppliers. Therefore, the key novelties of this study are illustrated as follows:

i. In order to aggregate the QSVNNs, we define novel Aczel-Alsina operations on QSVNNs. Then we propose the weight averaging, weighted geometric and their ordered weight operators, which can overcome the shortcomings of aggregation operators-based algebraic norms.
ii. To deal with the MCDM problem with unknown weight information in the context of QSVN, we propose novel CVM approach based on QSVN score function.
iii. To strength the flexibility of classical COPRAS method, we propose the enhanced COPRAS method based on the proposed QSVNAAWA operator or QSVNAAWG operator.
iv. A hybrid MCDM framework is proposed for selecting the best ELOS.

The organizational framework of this study is structured as follows: Section 2 revisits fundamental theoretical constructs pertaining to QSVNSs. Section 3 formalizes innovative operational mechanisms and advances novel aggregation operators through mathematical derivation. Section 4 develops an integrated decision-making paradigm, designated as the QSVN-CVM-COPRAS methodology. Section 5 implements an empirical investigation evaluating ELOSs, demonstrating the proposed method's operational applicability. Subsequent sections conduct comprehensive sensitivity assessments and comparative evaluations to rigorously examine the framework's stability and implementation viability. The concluding section synthesizes critical research insights and delineates substantive contributions to the field.

## 2. Fundamental conceptions of QSVN

The current part recalls several fundamental notions of QSVNSs including definition, operations and aggregation operators.

Definition 1 [25]. Let $\Phi = \{y_1, y_2, \cdots, y_t\}$ be a fix universal set. A QSVNS $M$ on $\Phi$ is depicted using the following mathematical expression:

$$M = \left\{ \left\langle y, \overline{T}_M(y_j), \overline{C}_M(y_j), \overline{I}_M(y_j), \overline{F}_M(y_j) \right\rangle \middle| y \in \Theta \right\}, \tag{1}$$

Where $\overline{T}_M(y_j): \Theta \to [0,1]$, $\overline{C}_M(y_j): \Theta \to [0,1]$, $\overline{I}_M(y_j): \Theta \to [0,1]$ and $\overline{F}_M(y_j): \Theta \to [0,1]$ denote the truth, contradiction, ignorance and falsity membership functions, severally, meeting $0 \le \overline{T}_M(y_j) + \overline{C}_M(y_j) + \overline{I}_M(y_j) + \overline{F}_M(y_j) \le 1$, $\forall y_i \in \Theta$. For simplicity, $(\overline{T}_M, \overline{C}_M, \overline{I}_M, \overline{F}_M)$ is signified as a QSVN number (QSVNN), expressed via $\chi = (\overline{T}_\chi, \overline{C}_\chi, \overline{I}_\chi, \overline{F}_\chi)$.

Definition 2 [25]. For two QSVNNs $\chi_1 = (\overline{T}_{\chi_1}, \overline{C}_{\chi_1}, \overline{I}_{\chi_1}, \overline{F}_{\chi_1})$ and $\chi_2 = (\overline{T}_{\chi_2}, \overline{C}_{\chi_2}, \overline{I}_{\chi_2}, \overline{F}_{\chi_2})$, and a real number $\lambda > 0$, then several operations of QSVNNs are presented as:

(1) $\chi_1 \oplus \chi_2 = (\overline{T}_{\chi_1} + \overline{T}_{\chi_2} - \overline{T}_{\chi_1}\overline{T}_{\chi_2}, \overline{C}_{\chi_1} + \overline{C}_{\chi_2} - \overline{C}_{\chi_1}\overline{C}_{\chi_2}, \overline{I}_{\chi_1}\overline{I}_{\chi_2}, \overline{F}_{\chi_1}\overline{F}_{\chi_2})$,

(2) $\chi_1 \otimes \chi_2 = (\overline{T}_{\chi_1}\overline{T}_{\chi_2}, \overline{C}_{\chi_1}\overline{C}_{\chi_2}, \overline{I}_{\chi_1} + \overline{I}_{\chi_2} - \overline{I}_{\chi_1}\overline{I}_{\chi_2}, \overline{F}_{\chi_1} + \overline{F}_{\chi_2} - \overline{F}_{\chi_1}\overline{F}_{\chi_2})$,

(3) $\lambda\chi_1 = \left(1 - (1 - \overline{T}_{\chi_1})^\lambda, 1 - (1 - \overline{C}_{\chi_1})^\lambda, (\overline{I}_{\chi_1})^\lambda, (\overline{F}_{\chi_1})^\lambda\right)$,

(4) $(\chi_1)^\lambda = \left((\overline{T}_{\chi_1})^\lambda, (\overline{C}_{\chi_1})^\lambda, 1 - (1 - \overline{I}_{\chi_1})^\lambda, 1 - (1 - \overline{F}_{\chi_1})^\lambda\right)$,

(5) $\chi_1 \cup \chi_2 = \left(\max\{\overline{T}_{\chi_1}, \overline{T}_{\chi_2}\}, \max\{\overline{C}_{\chi_1}, \overline{C}_{\chi_2}\}, \min\{\overline{I}_{\chi_1}, \overline{I}_{\chi_2}\}, \min\{\overline{F}_{\chi_1}, \overline{F}_{\chi_2}\}\right)$,

(6) $\chi_1 \cap \chi_2 = \left(\min\{\overline{T}_{\chi_1}, \overline{T}_{\chi_2}\}, \min\{\overline{C}_{\chi_1}, \overline{C}_{\chi_2}\}, \max\{\overline{I}_{\chi_1}, \overline{I}_{\chi_2}\}, \max\{\overline{F}_{\chi_1}, \overline{F}_{\chi_2}\}\right)$,

(7) $(\chi_1)^c = (\overline{F}_{\chi_1}, \overline{I}_{\chi_1}, \overline{C}_{\chi_1}, \overline{T}_{\chi_1})$,

(8) $\chi_1 \subseteq \chi_2$ if $\overline{T}_{\chi_1} \le \overline{T}_{\chi_2}$, $\overline{C}_{\chi_1} \le \overline{C}_{\chi_2}$, $\overline{I}_{\chi_1} \le \overline{I}_{\chi_2}$, and $\overline{F}_{\chi_1} \le \overline{F}_{\chi_2}$.

(9) $\chi_1 = \chi_2 \Leftrightarrow \chi_1 \subseteq \chi_2$ and $\chi_2 \subseteq \chi_1$.

Definition 3 [27]. For a QSVNN $\chi = (\overline{T}_\chi, \overline{C}_\chi, \overline{I}_\chi, \overline{F}_\chi)$, the score and accuracy functions are defined as below:

$$S(\chi) = \frac{1}{4}\left(3 + \overline{T}_\chi - \overline{C}_\chi - \overline{I}_\chi - \overline{F}_\chi\right), S(\chi) \in [0,1], \tag{2}$$

$$A(\chi) = \overline{T}_\chi - \overline{F}_\chi, A(\chi) \in [-1,1]. \tag{3}$$

Definition 4 [27]. For two QSVNNs $\chi_1 = (\overline{T}_{\chi_1}, \overline{C}_{\chi_1}, \overline{I}_{\chi_1}, \overline{F}_{\chi_1})$ and $\chi_2 = (\overline{T}_{\chi_2}, \overline{C}_{\chi_2}, \overline{I}_{\chi_2}, \overline{F}_{\chi_2})$, the comparison laws are given as:

If $S(\chi_1) > S(\chi_2)$, then $\chi_1 \succ \chi_2$;

If $S(\chi_1) < S(\chi_2)$, then $\chi_1 \prec \chi_2$;

If $S(\chi_1) = S(\chi_2)$, then

If $A(\chi_1) > A(\chi_2)$, then $\chi_1 \succ \chi_2$;

If $A(\chi_1) < A(\chi_2)$, then $\chi_1 \prec \chi_2$;

If $A(\chi_1)=A(\chi_2)$, then $\chi_1 \sim \chi_2$.

Definition 5 [25]. Let $\chi_j=\left(\overline{T}_{\chi_j},\overline{C}_{\chi_j},\overline{I}_{\chi_j},\overline{F}_{\chi_j}\right)(j=1,2,\cdots,t)$ be a set of QSVNNs. where $\varpi_j$ is the weight of QSVNN $\chi_j$ with $\sum_{j=1}^{n}\varpi_j=1,\ \varpi_j\in[0,1]$. Then QSVN weighted averaging (QSVNWA) operator and QSVN weighted geometric (QSVNWG) operator are depicted as:

$$\begin{aligned}
&QSVNWA(\chi_1,\chi_2,\dots,\chi_t)=\overset{t}{\underset{j=1}{\oplus}}\varpi_j\chi_j \\
&=\left(1-\prod_{j=1}^{t}\left(1-\overline{T}_j\right)^{\varpi_j},1-\prod_{j=1}^{t}\left(1-\overline{C}_j\right)^{\varpi_j},\prod_{j=1}^{t}\left(\overline{I}_j\right)^{\varpi_j},\prod_{j=1}^{t}\left(\overline{F}_j\right)^{\varpi_j}\right),
\end{aligned} \tag{4}$$

$$\begin{aligned}
&QSVNWG(\chi_1,\chi_2,\dots,\chi_t)=\overset{t}{\underset{j=1}{\otimes}}\left(\chi_j\right)^{\varpi_j} \\
&=\left(\prod_{j=1}^{t}\left(\overline{T}_j\right)^{\varpi_j},\prod_{j=1}^{t}\left(\overline{C}_j\right)^{\varpi_j},1-\prod_{j=1}^{t}\left(1-\overline{I}_j\right)^{\varpi_j},1-\prod_{j=1}^{t}\left(1-\overline{F}_j\right)^{\varpi_j}\right).
\end{aligned} \tag{5}$$

## 3. Fundamental conceptions of QSVN

This part presents the definition of QSVN Aczel-Alsina operations and then develops several novel Aczel-Alsina operators to fuse multiple QSVNNs.

Definition 6 [45]. Let $a$ and $b$ are two arbitrary, non-negative real numbers $(a,b>0)$, then the definition of Aczel–Alsina norms can be described as:

$$T_{AA}^{\Im}(a,b)=\exp\left\{-\left(\left(-\ln a\right)^{\Im}+\left(-\ln b\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},\ \Im>0, \tag{6}$$

$$S_{AA}^{\Im}(a,b)=1-\exp\left\{-\left(\left(-\ln(1-a)\right)^{\Im}+\left(-\ln(1-b)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},\ \Im>0. \tag{7}$$

Definition 7. For three QSVNNs $\chi=\left(\overline{T}_{\chi},\overline{C}_{\chi},\overline{I}_{\chi},\overline{F}_{\chi}\right)$, $\chi_1=\left(\overline{T}_{\chi_1},\overline{C}_{\chi_1},\overline{I}_{\chi_1},\overline{F}_{\chi_1}\right)$ and $\chi_2=\left(\overline{T}_{\chi_2},\overline{C}_{\chi_2},\overline{I}_{\chi_2},\overline{F}_{\chi_2}\right)$. And a real number $\lambda$, the QSVN Aczel-Alsina operations are defined as:

$$\chi_1\oplus\chi_2=\left(\begin{array}{l}
1-\exp\left\{-\left(\left(-\ln\left(1-\overline{T}_1\right)\right)^{\Im}+\left(-\ln\left(1-\overline{T}_2\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},1-\exp\left\{-\left(\left(-\ln\left(1-\overline{C}_1\right)\right)^{\Im}+\left(-\ln\left(1-\overline{C}_2\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}, \\
\exp\left\{-\left(\left(-\ln\left(\overline{I}_1\right)\right)^{\Im}+\left(-\ln\left(\overline{I}_2\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},\exp\left\{-\left(\left(-\ln\left(\left(\overline{F}_1\right)^2\right)\right)^{\Im}+\left(-\ln\left(\overline{F}_2\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}
\end{array}\right);$$

$$\chi_1\otimes\chi_2=\left(\begin{array}{l}
\exp\left\{-\left(\left(-\ln\left(\overline{T}_1\right)\right)^{\Im}+\left(-\ln\left(\overline{T}_2\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},\exp\left\{-\left(\left(-\ln\left(\overline{C}_1\right)\right)^{\Im}+\left(-\ln\left(\overline{C}_2\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}, \\
1-\exp\left\{-\left(\left(-\ln\left(1-\overline{I}_1\right)\right)^{\Im}+\left(-\ln\left(1-\overline{I}_2\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},1-\exp\left\{-\left(\left(-\ln\left(1-\overline{F}_1\right)\right)^{\Im}+\left(-\ln\left(1-\overline{F}_2\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}
\end{array}\right)$$

$$\lambda\chi_1 = \begin{pmatrix} 1-\exp\left\{-\left(\lambda\left(-\ln\left(1-\overline{T}_{\chi_1}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}, 1-\exp\left\{-\left(\lambda\left(-\ln\left(1-\overline{C}_{\chi_1}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}, \\ \exp\left\{-\left(\lambda\left(-\ln\left(\overline{I}_{\chi_1}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}, 1-\exp\left\{-\left(\lambda\left(-\ln\left(\overline{F}_{\chi_1}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\} \end{pmatrix};$$

$$\left(\chi_1\right)^{\lambda} = \begin{pmatrix} \exp\left\{-\left(\lambda\left(-\ln\left(\overline{T}_{\chi_1}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}, 1-\exp\left\{-\left(\lambda\left(-\ln\left(\overline{C}_{\chi_1}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}, \\ 1-\exp\left\{-\left(\lambda\left(-\ln\left(1-\overline{I}_{\chi_1}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}, 1-\exp\left\{-\left(\lambda\left(-\ln\left(1-\overline{F}_{\chi_1}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\} \end{pmatrix}$$

Theorem 1. Let $\chi = \left(\overline{T}_{\chi}, \overline{C}_{\chi}, \overline{I}_{\chi}, \overline{F}_{\chi}\right)$, $\chi_1 = \left(\overline{T}_{\chi_1}, \overline{C}_{\chi_1}, \overline{I}_{\chi_1}, \overline{F}_{\chi_1}\right)$ and $\chi_2 = \left(\overline{T}_{\chi_2}, \overline{C}_{\chi_2}, \overline{I}_{\chi_2}, \overline{F}_{\chi_2}\right)$ be two QSVNNs, and $\lambda, \lambda_1, \lambda_2 \geq 0.$ Then, the following properties can be obtained:

(1) $\chi_1 \oplus \chi_2 = \chi_2 \oplus \chi_1.$

(2) $\chi_1 \otimes \chi_2 = \chi_2 \otimes \chi_1.$

(3) $\lambda\left(\chi_1 \oplus \chi_2\right) = \lambda\chi_1 \oplus \lambda\chi_2.$

(4) $\lambda_1\chi_1 \oplus \lambda_2\chi_1 = \left(\lambda_1 + \lambda_2\right)\chi_1.$

(5) $\left(\chi_1 \otimes \chi_2\right)^{\lambda} = \left(\chi_1\right)^{\lambda} \otimes \left(\chi_2\right)^{\lambda}.$

(6) $\left(\chi_1\right)^{\lambda_1} \otimes \left(\chi_1\right)^{\lambda_2} = \left(\chi_1\right)^{\lambda_1+\lambda_2}.$

Proof. It is trivial via Definition 3.1.

### *2.2 SVN Aczel-Alsina averaging operator*

Definition 8. Let $\chi_j = \left(\overline{T}_{\chi_j}, \overline{C}_{\chi_j}, \overline{I}_{\chi_j}, \overline{F}_{\chi_j}\right)\left(j = 1, 2, \cdots, t\right)$ be a set of QSVNNs. The QSVN Aczel-Alsina weighted averaging (QSVNAAWA) operator is a mapping: $\Delta^t \rightarrow \Delta$ and defined as

$$QSVNAAWA\left(\chi_1, \chi_2, ..., \chi_t\right) = \varpi_1\chi_1 \oplus \varpi_2\chi_2 \oplus \cdots \oplus \varpi_t\chi_t, \tag{8}$$

wherein $\Delta$ denotes the set of QSVNN. $\varpi_j$ is the weight of QSVNN $\chi_j$ with condition $\sum_{j=1}^{t}\varpi_j = 1,$ $\varpi_j \in [0, 1].$

Theorem 2. The integration outcome of the set of QSVNNs using QSVNAAWA is a QSVNN and represented as:

$$QSVNAAWA\left(\chi_1, \chi_2, ..., \chi_t\right) = \begin{pmatrix} 1-\exp\left\{-\left(\sum_{j=1}^{t}\varpi_j\left(-\ln\left(1-\overline{T}_{\chi_j}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}, 1-\exp\left\{-\left(\sum_{j=1}^{t}\varpi_j\left(-\ln\left(1-\overline{C}_{\chi_j}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}, \\ \exp\left\{-\left(\sum_{j=1}^{t}\varpi_j\left(-\ln\left(\overline{I}_{\chi_j}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}, \exp\left\{-\left(\sum_{j=1}^{t}\varpi_j\left(-\ln\left(\overline{F}_{\chi_j}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\} \end{pmatrix}. \tag{9}$$

Proof. This theorem can be proved with the aid of mathematical induction principle. Obviously, the Eq. (8) holds for $t = 1$. When $t = 2$, one has

$$\varpi_1\chi_1=\left(\begin{array}{l}1-\exp\left\{-\left(\varpi_1\left(-\ln\left(1-\overline{T}_{\chi_1}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},1-\exp\left\{-\left(\varpi_1\left(-\ln\left(1-\overline{C}_{\chi_1}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},\\ \exp\left\{-\left(\varpi_1\left(-\ln\left(\overline{I}_{\chi_1}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},1-\exp\left\{-\left(\varpi_1\left(-\ln\left(\overline{F}_{\chi_1}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}\end{array}\right)$$

$$\varpi_2\chi_2=\left(\begin{array}{l}1-\exp\left\{-\left(\varpi_2\left(-\ln\left(1-\overline{T}_{\chi_2}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},1-\exp\left\{-\left(\varpi_2\left(-\ln\left(1-\overline{C}_{\chi_2}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},\\ \exp\left\{-\left(\varpi_2\left(-\ln\left(\overline{I}_{\chi_2}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},1-\exp\left\{-\left(\varpi_2\left(-\ln\left(\overline{F}_{\chi_2}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}\end{array}\right)$$

Therefore, we can acquire

$$QSVNAAWA\left(\chi_1,\chi_2\right)=\left(\begin{array}{l}1-\exp\left\{-\left(\sum_{j=1}^{2}\varpi_j\left(-\ln\left(1-\overline{T}_{\chi_j}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},1-\exp\left\{-\left(\sum_{j=1}^{2}\varpi_j\left(-\ln\left(1-\overline{C}_{\chi_j}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},\\ \exp\left\{-\left(\sum_{j=1}^{2}\varpi_j\left(-\ln\left(\overline{I}_{\chi_j}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},\exp\left\{-\left(\sum_{j=1}^{2}\varpi_j\left(-\ln\left(\overline{F}_{\chi_j}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}\end{array}\right).$$

Thus, Eq. (8) keeps for $t=2$. It is supposed that Eq.(8) keeps for $t=\hat{t}$, then

$$QSVNAAWA\left(\chi_1,\chi_2,...,\chi_{\hat{t}}\right)=\left(\begin{array}{l}1-\exp\left\{-\left(\sum_{j=1}^{\hat{t}}\varpi_j\left(-\ln\left(1-\overline{T}_{\chi_j}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},1-\exp\left\{-\left(\sum_{j=1}^{\hat{t}}\varpi_j\left(-\ln\left(1-\overline{C}_{\chi_j}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},\\ \exp\left\{-\left(\sum_{j=1}^{\hat{t}}\varpi_j\left(-\ln\left(\overline{I}_{\chi_j}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},\exp\left\{-\left(\sum_{j=1}^{\hat{t}}\varpi_j\left(-\ln\left(\overline{F}_{\chi_j}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}\end{array}\right).$$

Now, for $t=\hat{t}+1$, we have

$$QSVNAAWA\left(\chi_1,\chi_2,...,\chi_{\hat{t}+1}\right)=QSVNAAWA\left(\chi_1,\chi_2,...,\chi_t\right)\oplus\varpi_{\hat{t}+1}\chi_{\hat{t}+1}$$

$$=\begin{pmatrix}1-\exp\left\{-\left(\sum_{j=1}^{\hat{t}}\varpi_j\left(-\ln\left(1-\overline{T}_{\chi_j}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},1-\exp\left\{-\left(\sum_{j=1}^{\hat{t}}\varpi_j\left(-\ln\left(1-\overline{C}_{\chi_j}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},\\ \exp\left\{-\left(\sum_{j=1}^{\hat{t}}\varpi_j\left(-\ln\left(\overline{I}_{\chi_j}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},\exp\left\{-\left(\sum_{j=1}^{\hat{t}}\varpi_j\left(-\ln\left(\overline{F}_{\chi_j}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}\end{pmatrix}$$

$$\oplus\begin{pmatrix}1-\exp\left\{-\left(\varpi_{\hat{t}+1}\left(-\ln\left(1-\overline{T}_{\chi_2}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},1-\exp\left\{-\left(\varpi_{\hat{t}+1}\left(-\ln\left(1-\overline{C}_{\chi_{\hat{t}+1}}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},\\ \exp\left\{-\left(\varpi_{\hat{t}+1}\left(-\ln\left(\overline{I}_{\chi_2}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},1-\exp\left\{-\left(\varpi_{\hat{t}+1}\left(-\ln\left(\overline{F}_{\chi_{\hat{t}+1}}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}\end{pmatrix}$$

$$=\begin{pmatrix}1-\exp\left\{-\left(\sum_{j=1}^{\hat{t}+1}\varpi_j\left(-\ln\left(1-\overline{T}_{\chi_j}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},1-\exp\left\{-\left(\sum_{j=1}^{\hat{t}+1}\varpi_j\left(-\ln\left(1-\overline{C}_{\chi_j}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},\\ \exp\left\{-\left(\sum_{j=1}^{\hat{t}+1}\varpi_j\left(-\ln\left(\overline{I}_{\chi_j}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},\exp\left\{-\left(\sum_{j=1}^{\hat{t}+1}\varpi_j\left(-\ln\left(\overline{F}_{\chi_j}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}\end{pmatrix}$$

Hence, Eq. (8) keeps for $t=\hat{t}+1$. Correspondingly, Eq.8() maintains for all $t$.

Definition 9. Let $\chi_j=\left(\overline{T}_{\chi_j},\overline{C}_{\chi_j},\overline{I}_{\chi_j},\overline{F}_{\chi_j}\right)(j=1,2,\cdots,t)$ be a set of QSVNNs. The QSVN Aczel-Alsina ordered weighted averaging (QSVNAAOWA) operator is a mapping: $\Delta^t\to\Delta$ and defined as

$$QSVNAAOWA\left(\chi_1,\chi_2,...,\chi_t\right)=\varpi_1\chi_{o(1)}\oplus\varpi_2\chi_{o(2)}\oplus\cdots\oplus\varpi_t\chi_{o(t)},\tag{10}$$

wherein $\varpi_j$ is the weight of QSVNN. $\chi_j$ with condition $\sum_{j=1}^{t}\varpi_j=1,\ \varpi_j\in[0,1]$. $\Delta$ denotes the set of QSVNN. $\left(o(1),o(2),\cdots,o(t)\right)$ stands for the permutation of $(j=1,2,\cdots,t)$ with $\chi_{o(j-1)}\geq\chi_{o(j)}$, $\forall j=2,3,\cdots,t$.

Theorem 3. The integration outcome of the set of QSVNNs using QSVNAAOWA is a QSVNN and represented as:

$$QSVNAAOWA\left(\chi_1,\chi_2,...,\chi_t\right)=\begin{pmatrix}1-\exp\left\{-\left(\sum_{j=1}^{t}\varpi_j\left(-\ln\left(1-\overline{T}_{o(j)}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},1-\exp\left\{-\left(\sum_{j=1}^{t}\varpi_j\left(-\ln\left(1-\overline{C}_{o(j)}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},\\ \exp\left\{-\left(\sum_{j=1}^{t}\varpi_j\left(-\ln\left(\overline{I}_{o(j)}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},\exp\left\{-\left(\sum_{j=1}^{t}\varpi_j\left(-\ln\left(\overline{F}_{o(j)}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}\end{pmatrix}.\tag{11}$$

Proof. It is similar to Theorem 2.

Proposition 1. Let $\chi_j=\left(\overline{T}_{\chi_j},\overline{C}_{\chi_j},\overline{I}_{\chi_j},\overline{F}_{\chi_j}\right)(j=1,2,\cdots,t)$ be a set of QSVNNs. $\varpi_j$ is the weight of QSVNN. $\chi_j$ with condition $\sum_{j=1}^{t}\varpi_j=1,\ \varpi_j\in[0,1]$. Then QSVNAAWA and QSVNAAOWA operators meet the following properties:

(1) *Idempotency:* If all SCFNs are equal, i.e., $\chi_j = \chi$, $\forall j$, then one has

$$QSVNAAWA(\chi_1, \chi_2, ..., \chi_t) = \chi,$$
$$QSVNAAOWA(\chi_1, \chi_2, ..., \chi_t) = \chi.$$

(2) *Boundedness:* if $\chi^- = \min\{\chi_1, \chi_2, \cdots, \chi_t\}$ and $\chi^+ = \max\{\chi_1, \chi_2, \cdots, \chi_t\}$, then we have

$$\chi^- \le QSVNAAWA(\chi_1, \chi_2, ..., \chi_t) \le \chi^+,$$
$$\chi^- \le QSVNAAOWA(\chi_1, \chi_2, ..., \chi_t) \le \chi^+.$$

(3) *Monotonicity:* For the set of SCFNs, $\chi_j$ and $\chi_j \, (j = 1, 2, \cdots, t)$. If $\chi_j \le \chi_j$, then we have

$$QSVNAAWA(\chi_1, \chi_2, ..., \chi_t) \le QSVNAAWA(\chi_1, \chi_2, ..., \chi_t),$$
$$QSVNAAOWA(\chi_1, \chi_2, ..., \chi_t) \le QSVNAAOWA(\chi_1, \chi_2, ..., \chi_t).$$

*3.2 Spherical cubic fuzzy Aczel-Alsina geometric operator*

Definition 10. Let $\chi_j = \left(\overline{T}_{\chi_j}, \overline{C}_{\chi_j}, \overline{I}_{\chi_j}, \overline{F}_{\chi_j}\right)(j = 1, 2, \cdots, t)$ be a set of QSVNNs. The QSVN Aczel-Alsina weighted geometric (QSVNAAWG) operator is a mapping: $\Delta^t \to \Delta$ and defined as

$$QSVNAAWG(\chi_1, \chi_2, ..., \chi_t) = (\chi_1)^{\varpi_1} \otimes (\chi_2)^{\varpi_2} \otimes \cdots \otimes (\chi_t)^{\varpi_t}, \tag{12}$$

wherein $\Delta$ denotes the set of QSVNNs. $\varpi_j$ is the weight of QSVNN $\chi_j$ with condition $\sum_{j=1}^{t} \varpi_j = 1,\ \varpi_j \in [0, 1]$.

Theorem 4. The integration outcome of the set of QSVNNs using QSVNAAWG is a QSVNN and represented as:

$$QSVNAAWG(\chi_1, \chi_2, ..., \chi_t) = \begin{pmatrix} \exp\left\{-\left(\sum_{j=1}^{t} \varpi_j \left(-\ln\left(\overline{T}_{\chi_j}\right)\right)^{\mho}\right)^{\frac{1}{\mho}}\right\}, \exp\left\{-\left(\sum_{j=1}^{t} \varpi_j \left(-\ln\left(\overline{T}_{\chi_j}\right)\right)^{\mho}\right)^{\frac{1}{\mho}}\right\}, \\ 1 - \exp\left\{-\left(\sum_{j=1}^{t} \varpi_j \left(-\ln\left(1 - \overline{I}_{\chi_j}\right)\right)^{\mho}\right)^{\frac{1}{\mho}}\right\}, 1 - \exp\left\{-\left(\sum_{j=1}^{t} \varpi_j \left(-\ln\left(1 - \overline{F}_{\chi_j}\right)\right)^{\mho}\right)^{\frac{1}{\mho}}\right\} \end{pmatrix}. \tag{13}$$

Proof. It is similar to Theorem 2.

Definition 11. Let $\chi_j = \left(\overline{T}_{\chi_j}, \overline{C}_{\chi_j}, \overline{I}_{\chi_j}, \overline{F}_{\chi_j}\right)(j = 1, 2, \cdots, t)$ be a set of QSVNNs. The QSVN Aczel-Alsina ordered weighted geometric (QSVNAAOWG) operator is a mapping: $\Delta^t \to \Delta$ and defined as

$$QSVNAAOWG(\chi_1, \chi_2, ..., \chi_t) = \left(\chi_{o(1)}\right)^{\varpi_1} \otimes \left(\chi_{o(2)}\right)^{\varpi_2} \otimes \cdots \otimes \left(\chi_{o(t)}\right)^{\varpi_t}, \tag{14}$$

wherein $\varpi_j$ is the weight of QSVNN $\chi_j$ with condition $\sum_{j=1}^{t} \varpi_j = 1,\ \varpi_j \in [0, 1]$. $\Delta$ denotes the set of QSVNNs. $\left(o(1), o(2), \cdots, o(t)\right)$ stands for the permutation of $(j = 1, 2, \cdots, t)$ with $\chi_{o(j-1)} \ge \chi_{o(j)}$, $\forall j = 2, 3, \cdots, t$.

Theorem 12. The integration outcome of the set of QSVNNs using QSVNAAOWA is a QSVNN and represented as:

$$QSVNAAOWG(\chi_1,\chi_2,...,\chi_t)=\left(\begin{array}{l}\exp\left\{-\left(\sum_{j=1}^{t}\varpi_j\left(-\ln\left(\overline{T}_{o(j)}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},\exp\left\{-\left(\sum_{j=1}^{t}\varpi_j\left(-\ln\left(\overline{CC}_{o(j)}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},\\ 1-\exp\left\{-\left(\sum_{j=1}^{t}\varpi_j\left(-\ln\left(1-\overline{I}_{o(j)}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},1-\exp\left\{-\left(\sum_{j=1}^{t}\varpi_j\left(-\ln\left(1-\overline{F}_{o(j)}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}\end{array}\right). \quad (15)$$

Proof. It is similar to Theorem 2.

Proposition 2. Let $\chi_j=\left(\overline{T}_{\chi_j},\overline{C}_{\chi_j},\overline{I}_{\chi_j},\overline{F}_{\chi_j}\right)(j=1,2,\cdots,t)$ be a set of QSVNNs. $\varpi_j$ is the weight of QSVNN. $\chi_j$ with condition $\sum_{j=1}^{t}\varpi_j=1,\ \varpi_j\in[0,1]$. Then QSVNAAWA and QSVNAAOWA operators meet the following properties:

(1) *Idempotency:* If all QSVNNs are equal, i.e., $\chi_j=\chi$, $\forall j$, then one has

$$QSVNAAWG(\chi_1,\chi_2,...,\chi_t)=\chi,$$
$$QSVNAAOWG(\chi_1,\chi_2,...,\chi_t)=\chi.$$

(2) *Boundedness:* if $\chi^-=\min\{\chi_1,\chi_2,\cdots,\chi_t\}$ and $\chi^+=\max\{\chi_1,\chi_2,\cdots,\chi_t\}$, then we have

$$\chi^-\le QSVNAAWG(\chi_1,\chi_2,...,\chi_t)\le\chi^+,$$
$$\chi^-\le QSVNAAOWG(\chi_1,\chi_2,...,\chi_t)\le\chi^+.$$

(3) *Monotonicity:* For the set of SCFNs, $\chi_j$ and $\chi_j\ (j=1,2,\cdots,t)$. If $\chi_j\le\chi_j$, then we have

$$QSVNAAWG(\chi_1,\chi_2,...,\chi_t)\le QSVNAAWG(\chi_1,\chi_2,...,\chi_t),$$
$$QSVNAAOWG(\chi_1,\chi_2,...,\chi_t)\le QSVNAAOWG(\chi_1,\chi_2,...,\chi_t)$$

## 4. An enhanced COPRAS decision approach under QSVN setting.

In this section, we propose a novel MCDM approach based on the combination of QSVNAAWA operator, QSVNAAWG operator, coefficient of variation method (CVM) method and COPRAS method under QSVN setting. In the proposed MCDM method, the QSVN- CVM method-based score function is utilized for the computing of weight of criteria. The QSVN-COPRAS method is propounded based on the developed QSVNAAWA and QSVNAAWG operators to acquire the ranking the set of alternatives.

In order to deal with the MCDM problem under QSVN environment, we first give several necessary notions and further construct the enhanced COPRAS method. A classical MCDM problem consists of a group of alternatives denoted as $P=\{P_i\,|i=1,2,\cdots,q\}$ and a set of criteria indicated as $\mathbb{C}=\{\mathbb{C}_j\,|j=1,2,\cdots,t\}$. It is supposed the QSVN decision matrix is signified as $H=(\chi_{ij})_{q\times t}$, wherein $\chi_{ij}=\left(\overline{T}_{\chi_{ij}},\overline{C}_{\chi_{ij}},\overline{I}_{\chi_{ij}},\overline{F}_{\chi_{ij}}\right)$ is a QSVNN and represents the preference of decision alternative $P_i$ with respect to attribute $\mathbb{C}_j$. Based on the mentioned notions, the proposed enhanced COPRAS decision approach with QSVN information is illustrated as below:

Step 1：Generating the QSVN decision-making matrix $H=(\chi_{ij})_{q\times t}\left(i=1,2,\cdots q;j=1,2,\cdots t\right)$.

$$H=(\chi_{ij})_{q\times t}=\begin{pmatrix} \left(\overline{T}_{\chi_{11}},\overline{C}_{\chi_{11}},\overline{I}_{\chi_{11}},\overline{F}_{\chi_{11}}\right) & \left(\overline{T}_{\chi_{12}},\overline{C}_{\chi_{12}},\overline{I}_{\chi_{12}},\overline{F}_{\chi_{12}}\right) & \cdots & \left(\overline{T}_{\chi_{1n}},\overline{C}_{\chi_{1n}},\overline{I}_{\chi_{1n}},\overline{F}_{\chi_{1n}}\right) \\ \left(\overline{T}_{\chi_{21}},\overline{C}_{\chi_{21}},\overline{I}_{\chi_{21}},\overline{F}_{\chi_{21}}\right) & \left(\overline{T}_{\chi_{22}},\overline{C}_{\chi_{22}},\overline{I}_{\chi_{22}},\overline{F}_{\chi_{22}}\right) & \cdots & \left(\overline{T}_{\chi_{2n}},\overline{C}_{\chi_{2n}},\overline{I}_{\chi_{2n}},\overline{F}_{\chi_{2n}}\right) \\ \vdots & \vdots & \ddots & \vdots \\ \left(\overline{T}_{\chi_{m1}},\overline{C}_{\chi_{m1}},\overline{I}_{\chi_{m1}},\overline{F}_{\chi_{m1}}\right) & \left(\overline{T}_{\chi_{m2}},\overline{C}_{\chi_{m2}},\overline{I}_{\chi_{m2}},\overline{F}_{\chi_{m2}}\right) & \cdots & \left(\overline{T}_{\chi_{mn}},\overline{C}_{\chi_{mn}},\overline{I}_{\chi_{mn}},\overline{F}_{\chi_{mn}}\right) \end{pmatrix}. \tag{16}$$

Step 2: Obtaining the normalized QSVN decision-making matrix.

In order to unify the type of criteria, the decision matrix $H=(\chi_{ij})_{q\times t}$ should be shifted into as $G=(g_{ij})_{q\times t}\left(i=1,2,\cdots q; j=1,2,\cdots t\right)$, where

$$g_{ij}=\begin{cases}\chi_{ij}=\left(\overline{T}_{\chi_{ij}},\overline{C}_{\chi_{ij}},\overline{I}_{\chi_{ij}},\overline{F}_{\chi_{ij}}\right),\text{for benefit criteria}\\ \left(\chi_{ij}\right)^{c}=\left(\overline{F}_{\chi_{ij}},\overline{I}_{\chi_{ij}},\overline{C}_{\chi_{ij}},\overline{T}_{\chi_{ij}}\right),\text{for cost criteria}\end{cases} \tag{17}$$

Step 3: Compute the importance of criteria.

Step 3.1: Determine the score matrix $S=(s_{ij})_{q\times t}$ of the normalized QSVN decision-making matrix by Eq.(18):

$$s_{ij}=\frac{1}{4}\left(3+\overline{T}_{g_{ij}}-\overline{C}_{g_{ij}}-\overline{I}_{g_{ij}}-\overline{F}_{g_{ij}}\right). \tag{18}$$

Step 3.2: To compute the mean value of the $j$ th criteria with the aid of Eq.(19):

$$s_{j}=\frac{1}{q}\sum_{i=1}^{q}s_{ij},\ j=1,2,\cdots t. \tag{19}$$

Step 3.3: To compute the standard deviation of the $j$ th criteria with the aid of Eq.(20):

$$L_{j}=\sqrt{\frac{1}{q-1}\sum_{i=1}^{q}\left(s_{ij}-\overline{s}_{j}\right)^{2}},\ j=1,2,\cdots,t. \tag{20}$$

Step 3.4: To compute the coefficient of variation of the $j$ th criteria by

$$V_{j}=\frac{L_{j}}{\overline{s}_{j}},\ j=1,2,\cdots,t. \tag{21}$$

Step 3.5: Based on the normalization process of the coefficient of variation, the weight of criteria can be determined by

$$\varpi_{j}=\frac{V_{j}}{\sum_{j=1}^{t}V_{j}}. \tag{22}$$

Step 4. Computing the maximizing and minimizing indexes of each alternative.

First, we compute the aggregation value of alternative $P_i$ under benefit criteria by QSVNAAWA operator, displayed in Eq.(23)

$$R_{i}^{+}=\overset{d}{\underset{j=1}{\oplus}}\varpi_{j}g_{ij}=\begin{pmatrix}1-\exp\left\{-\left(\sum_{j=1}^{d}\varpi_{j}\left(-\ln\left(1-\overline{T}_{g_{ij}}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},1-\exp\left\{-\left(\sum_{j=1}^{d}\varpi_{j}\left(-\ln\left(1-\overline{C}_{g_{ij}}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},\\ \exp\left\{-\left(\sum_{j=1}^{d}\varpi_{j}\left(-\ln\left(\overline{I}_{g_{ij}}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\},\exp\left\{-\left(\sum_{j=1}^{d}\varpi_{j}\left(-\ln\left(\overline{F}_{g_{ij}}\right)\right)^{\Im}\right)^{\frac{1}{\Im}}\right\}\end{pmatrix}. \tag{23}$$

If we utilize QSVNAAWG operator, the integration value of alternative $P_i$ under benefit criteria can be attained by Eq.(24):

$$R_i^+ = \underset{j=1}{\overset{d}{\otimes}} \left(g_{ij}\right)^{\varpi_j} = \left( \begin{array}{l} \exp\left\{ -\left( \sum_{j=1}^{d} \varpi_j \left( -\ln\left( \overline{T}_{g_{ij}} \right) \right)^{\Im} \right)^{\frac{1}{\Im}} \right\}, \exp\left\{ -\left( \sum_{j=1}^{d} \varpi_j \left( -\ln\left( \overline{C}_{g_{ij}} \right) \right)^{\Im} \right)^{\frac{1}{\Im}} \right\}, \\ 1-\exp\left\{ -\left( \sum_{j=1}^{d} \varpi_j \left( -\ln\left( 1-\overline{I}_{g_{ij}} \right) \right)^{\Im} \right)^{\frac{1}{\Im}} \right\}, 1-\exp\left\{ -\left( \sum_{j=1}^{d} \varpi_j \left( -\ln\left( 1-\overline{F}_{g_{ij}} \right) \right)^{\Im} \right)^{\frac{1}{\Im}} \right\} \end{array} \right). \tag{24}$$

In a similar way, we compute the fusion value of alternative $P_i$ under cost criteria by QSVNAAWA operator, the result is presented by Eq.(25):

$$R_i^- = \underset{j=1}{\overset{t-d}{\oplus}} \varpi_j g_{ij} = \left( \begin{array}{l} 1-\exp\left\{ -\left( \sum_{j=1}^{t-d} \varpi_j \left( -\ln\left( 1-\overline{T}_{g_{ij}} \right) \right)^{\Im} \right)^{\frac{1}{\Im}} \right\}, 1-\exp\left\{ -\left( \sum_{j=1}^{t-d} \varpi_j \left( -\ln\left( 1-\overline{C}_{g_{ij}} \right) \right)^{\Im} \right)^{\frac{1}{\Im}} \right\}, \\ \exp\left\{ -\left( \sum_{j=1}^{t-d} \varpi_j \left( -\ln\left( \overline{I}_{g_{ij}} \right) \right)^{\Im} \right)^{\frac{1}{\Im}} \right\}, \exp\left\{ -\left( \sum_{j=1}^{t-d} \varpi_j \left( -\ln\left( \overline{F}_{g_{ij}} \right) \right)^{\Im} \right)^{\frac{1}{\Im}} \right\} \end{array} \right). \tag{25}$$

Likewise, If we utilize QSVNAAWG operator, the integration value of alternative $P_i$ under cost criteria can be attained by Eq.(26):

$$R_i^- = \underset{j=1}{\overset{t-d}{\otimes}} \left(g_{ij}\right)^{\varpi_j} = \left( \begin{array}{l} \exp\left\{ -\left( \sum_{j=1}^{t-d} \varpi_j \left( -\ln\left( \overline{T}_{g_{ij}} \right) \right)^{\Im} \right)^{\frac{1}{\Im}} \right\}, \exp\left\{ -\left( \sum_{j=1}^{t-d} \varpi_j \left( -\ln\left( \overline{C}_{g_{ij}} \right) \right)^{\Im} \right)^{\frac{1}{\Im}} \right\}, \\ 1-\exp\left\{ -\left( \sum_{j=1}^{t-d} \varpi_j \left( -\ln\left( 1-\overline{I}_{g_{ij}} \right) \right)^{\Im} \right)^{\frac{1}{\Im}} \right\}, 1-\exp\left\{ -\left( \sum_{j=1}^{t-d} \varpi_j \left( -\ln\left( 1-\overline{F}_{g_{ij}} \right) \right)^{\Im} \right)^{\frac{1}{\Im}} \right\} \end{array} \right). \tag{26}$$

where $d$ indicates the number of positive attributes and $t-d$ represents the number of negative criteria.

Step 4: The relative significance $\Gamma_i$ value of each alternative is computed as:

$$\Gamma_i = S\left(R_i^+\right) + \frac{\sum_{i=1}^{q} S\left(R_i^-\right)}{S\left(R_i^-\right) \sum_{i=1}^{q} \frac{1}{S\left(R_i^-\right)}}. \tag{27}$$

Step 6: Ranking the alternative based the relative significance $U_i$

$$U_i = \left( \frac{\Gamma_i}{\max_{1 \le i \le q} \Gamma_i} \right) \times 100\%. \tag{28}$$

Accordingly, the bigger the value $U_i$, the better the alternative $P_i$.

## 5. Outcomes and discussion

This section will utilize the proposed QSVN-CVM-COPRAS approach to deal with the optimal ELOS selection problem. The detailed decision processes are conducted to validate the applicability of the proposed method. We also discuss the stability of the proposed QSVN-CVM-COPRAS approach via utilizing diverse parameters.

*5.1 Case study*

In this section, we execute the presented method for the selection of ELOS with QSVN information. In emergency response to sudden public events such as natural disasters, outbreaks of epidemics, or accidents, the rapid response capability and service quality of logistics outsourcing suppliers directly affect rescue efficiency. Due to the characteristics of sudden changes in demand, time urgency, and environmental uncertainty in emergency logistics, traditional supplier evaluation methods are difficult to effectively handle uncertain and imprecise evaluation information in the decision-making process. This article takes the selection of outsourcing suppliers for an emergency supplies transfer station in a disaster area as an example. The transfer station needs to complete the tasks of receiving, sorting, and distributing medical supplies and life support supplies within 72 hours. Decision makers need to comprehensively consider the five evaluation indicators of suppliers' rapid response capability ($\mathbb{C}_1$), service quality level ($\mathbb{C}_2$), resource allocation capability($\mathbb{C}_3$), corporate integrity and qualification level($\mathbb{C}_4$), and operating costs($\mathbb{C}_5$). Based on the above indicators, the optimal supplier should be determined among the four candidate logistics outsourcing suppliers $P_i\left(i=1,2,3,4\right)$ to provide corresponding emergency service.

The decision implementation steps of the proposed QSVN-CVM-COPRAS approach to determine the optimal ELOS are displayed as below:

Step 1 : Based on the cognition of experts, the decision matrix $H=(\chi_{ij})_{q\times t}\left(i=1,2,\cdots q;j=1,2,\cdots t\right)$ is provided in the form of QSVN information and listed in Table 1.

**Table 1**
The initial QSVN decision matrix $H=(\chi_{ij})_{q\times t}$

| | $\mathbb{C}_1$ | $\mathbb{C}_2$ | $\mathbb{C}_3$ |
|---|---|---|---|
| $P_1$ | (0.21,0.28,0.32,0.26) | (0.22,0.21,0.35,0.63) | (0.11,0.22,0.33,0.55) |
| $P_2$ | (0.6, 0.7, 0.05, 0.08) | (0.25,0.32,0.26,0.15) | (0.25,0.26,0.33,0.36) |
| $P_3$ | (0.35,0.22,0.36,0.45) | (0.53,0.10,0.22,0.52) | (0.45,0.3,0.2,0.2) |
| $P_4$ | (0.33,0.12,0.26,0.52) | (0.23,0.21,0.19,0.42) | (0.15,0.11,0.28,0.35) |

| | $\mathbb{C}_4$ | $\mathbb{C}_5$ |
|---|---|---|
| $P_1$ | (0.15,0.02,0.45,0.15) | (0.05,0.28,0.39,0.65) |
| $P_2$ | (0.05,0.52,0.15,0.34) | (0.5,0.3,0.4,0.4 ) |
| $P_3$ | (0.45,0.32,0.35,0.25) | (0.4,0.4,0.3,0.5) |
| $P_4$ | (0.13,0.22,0.29,0.32) | (0.05,0.11,0.03,0.35) |

Step 2: Obtaining the normalized QSVN decision-making matrix.

To unify the type of criteria, the normalized QSVN decision-making matrix. $G=(g_{ij})_{q\times t}\left(i=1,2,\cdots q;j=1,2,\cdots t\right)$ is attained by Eq.(17) and shown in Table 2.

**Table 2**
The normalized QSVN decision matrix $G=(g_{ij})_{q\times t}$

| | $\mathbb{C}_1$ | $\mathbb{C}_2$ | $\mathbb{C}_3$ |
|---|---|---|---|
| $P_1$ | (0.21,0.28,0.32,0.26) | (0.22,0.21,0.35,0.63) | (0.11,0.22,0.33,0.55) |
| $P_2$ | (0.6, 0.7, 0.05, 0.08) | (0.25,0.32,0.26,0.15) | (0.25,0.26,0.33,0.36) |
| $P_3$ | (0.35,0.22,0.36,0.45) | (0.53,0.10,0.22,0.52) | (0.45,0.3,0.2,0.2) |
| $P_4$ | (0.33,0.12,0.26,0.52) | (0.23,0.21,0.19,0.42) | (0.15,0.11,0.28,0.35) |

| | $\mathbb{C}_4$ | $\mathbb{C}_5$ |
|---|---|---|
| $P_1$ | (0.15,0.02,0.45,0.15) | (0.65,0.39,0.28, 0.05) |
| $P_2$ | (0.05,0.52,0.15,0.34) | (0.4,0.4,0.3,0.5 ) |
| $P_3$ | (0.45,0.32,0.35,0.25) | (0.5,0.3,0.4,0.4) |
| $P_4$ | (0.13,0.22,0.29,0.32) | (0.35,0.03,0.11,0.05) |

Step 3: Compute the importance of criteria. First, we determine the score matrix $S=(s_{ij})_{q\times t}$ of the normalized QSVN decision-making matrix by Eq.(18) and show in Table 3. Then the mean value of the $j$ th criteria is computed with the aid of Eq.(19): $\bar{s}_1=0.6169$, $\bar{s}_2=0.6031$, $\bar{s}_3=0.5919$, $\bar{s}_4=0.5875$, $\bar{s}_5=0.6681$. Further, the standard deviation of the $j$ th criteria is figured out with the aid of Eq.(20) and listed as $L_1=0.0517$, $L_2=0.0700$, $L_3=0.0764$, $L_4=0.0583$, $L_5=0.1119$. After that, we compute the coefficient of variation of the $j$ th criteria by Eq.(21) and show as $V_1=0.0839$, $V_2=0.1160$, $V_3=0.1292$, $V_4=0.0993$, $V_5=0.1675$,. Lastly, the weight of criteria can be determined by Eq.(22) and show as $\varpi_1=0.1408$, $\varpi_2=0.1946$, $\varpi_3=0.2167$, $\varpi_4=0.1667$, $\varpi_5=0.2812$.

**Table 3**
The QSVN score matrix $S=(s_{ij})_{q\times t}$

| | $\mathbb{C}_1$ | $\mathbb{C}_2$ | $\mathbb{C}_3$ | $\mathbb{C}_4$ | $\mathbb{C}_5$ |
|---|---|---|---|---|---|
| $P_1$ | 0.5875 | 0.5075 | 0.5025 | 0.6325 | 0.7325 |
| $P_2$ | 0.6925 | 0.6300 | 0.5750 | 0.5100 | 0.5500 |
| $P_3$ | 0.5800 | 0.6725 | 0.6875 | 0.6325 | 0.6000 |
| $P_4$ | 0.6075 | 0.6025 | 0.6025 | 0.5750 | 0.7900 |

Step 4. Computing the maximizing and minimizing indexes of each alternative. The maximizing and minimizing indexes of each alternative with respect of benefit-type criteria and cost-type criteria are computed by Eq. (23) and Eq. (25), the outcomes are listed as
$R_1^+=(0.1043,0.2178,0.4780,0.4842)$, $R_2^+=(0.3090,0.2860,0.2893,0.3243)$,
$R_3^+=(0.3307,0.1850,0.3820,0.4406)$, $R_4^+=(0.1680,0.1360,0.3697,0.5075)$;
$R_1^-=(0.2556,0.1298,0.6991,0.4307)$, $R_2^-=(0.1338,0.1338,0.7128,0.8229)$,
$R_3^-=(0.1771,0.0954,0.7729,0.7729)$, $R_4^-=(0.1141,0.0085,0.5376,0.4307)$.

Step 5: The relative significance $\Gamma_i$ value of each alternative is computed based on Eq.(27) and listed as $\Gamma_1=0.8691$, $\Gamma_2=1.1312$, $\Gamma_3=1.0850$, $\Gamma_4=0.9010$.

Step 6: The relative significance $U_i$ can be computed by Eq.(28) and listed as: $U_1=76.82\%$, $U_2=100\%$, $U_3=95.91\%$, $U_4=79.65\%$. Hence, ranking of candidate suppliers is $P_2\succ P_3\succ P_4\succ P_1$ and the second supplier ($P_2$) is the best option.

Further, when we use the QSVNAAWG operator in the step 4, the maximizing and minimizing indexes of each alternative with respect of benefit-type criteria and cost-type criteria are computed by Eq.(24) and Eq.(26), we can also attain the relative significance $U_i$ can be computed by Eq.() and listed as: $U_1 = 89.56\%$, $U_2 = 100\%$, $U_3 = 98.27\%$, $U_4 = 88.26\%$. Hence, ranking of candidate suppliers is $P_2 \succ P_3 \succ P_4 \succ P_1$ and the second supplier ( $P_2$ ) is the best option.

### *5.2 Sensitivity analysis*

In this subsection, we discuss the sensitivity analysis of the proposed QSVN-CVM-COPRAS approach by parameter analysis. In the proposed method, the parameter $\Im$ in QSVNAAWA and QSVNAAWG operators stands for the decision preference of decision maker. Hence, we conduct the sensitivity analysis based on diverse parameter values of $\Im$. The decision outcomes are attained by using the proposed method and listed in Table 4 and Figure 1. From, Figure 1, we can find that the best option by using diverse parameters are all the second supplier ( $P_2$ ), which indicates the proposed QSVN-CVM-COPRAS has stronger stability.

**Table 4**
The decision outcomes and ranking attained by diverse parameter values of $\Im$

| | $P_1$ | $P_2$ | $P_3$ | $P_4$ | Ranking |
|---|---|---|---|---|---|
| 1 | 0.7682 | 1.0000 | 0.9591 | 0.7965 | $P_2 \succ P_3 \succ P_4 \succ P_1$ |
| 3 | 0.7735 | 1.0000 | 0.9547 | 0.7792 | $P_2 \succ P_3 \succ P_4 \succ P_1$ |
| 5 | 0.7797 | 1.0000 | 0.9551 | 0.7817 | $P_2 \succ P_3 \succ P_4 \succ P_1$ |
| 7 | 0.7818 | 1.0000 | 0.9552 | 0.7836 | $P_2 \succ P_3 \succ P_4 \succ P_1$ |
| 9 | 0.7827 | 1.0000 | 0.9554 | 0.7852 | $P_2 \succ P_3 \succ P_4 \succ P_1$ |
| 11 | 0.7833 | 1.0000 | 0.9555 | 0.7866 | $P_2 \succ P_3 \succ P_4 \succ P_1$ |

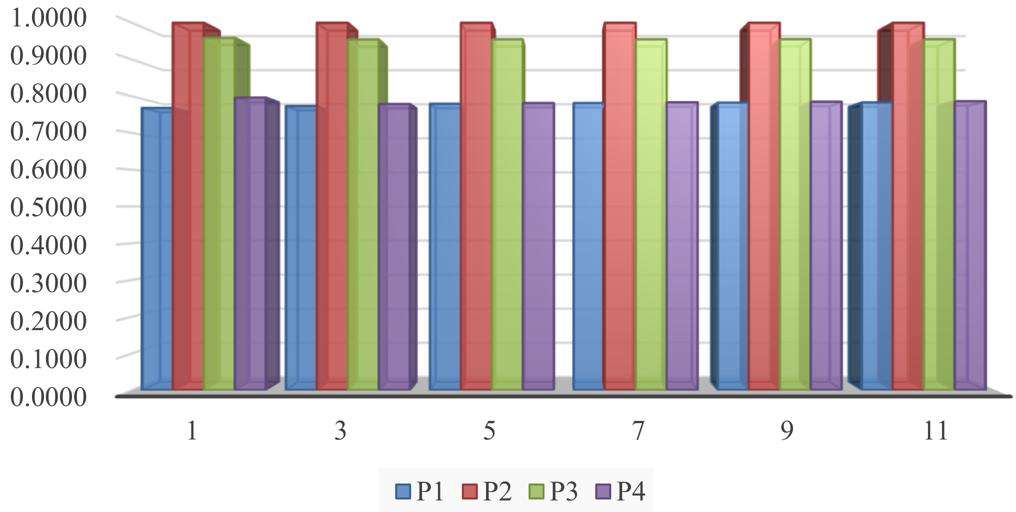


**Fig. 1.** The decision outcomes and ranking attained by diverse parameter values of $\Im$

### *5.3 Comparison analysis*

In order to validate the effectiveness of the proposed QSVN-CVM-COPRAS methodology, we carry out comparison analysis by comparing the proposed method with other prior QSVN decision approaches including QSVNWA operator-based method and QSVN-WASPAS method. In order to ensure the reasonability of the comparison, we use the normalized decision matrix as assessment information and the weight information determined in this paper. The corresponding comparison outcomes are displayed in Table 5.

**Table 5**
The decision outcomes based on different QSVN methods

| Method | Ranking of the suppliers | Best option |
|---|---|---|
| Method based on QSVNWA operator[25] | $P_2 \succ P_3 \succ P_4 \succ P_1$ | $P_2$ |
| QSVN-WASPAS method[29] | $P_2 \succ P_3 \succ P_4 \succ P_1$ | $P_2$ |
| QSVN-CVM-COPRAS method | $P_2 \succ P_3 \succ P_4 \succ P_1$ | $P_2$ |

Based on the comparison results, we can find that the best option attained by different QSVN decision approaches are all same, the rankings attained from the existing method are $P_2 \succ P_3 \succ P_4 \succ P_1$. Thus, the proposed QSVN-CVM-COPRAS methodology is an effective approach to resolve uncertain decision problem. The merits of the proposed approach can be summarized as follows: (1) it has stronger flexibility because of the improved COPRAS method based on Aczel-alsina operators. (2) it can deal with the problem without weight information with the QSVN information.

## 6. Conclusion

In this paper, we propose a hybrid decision methodology to determine the prioritization of a group of ELOSs with an uncertain perspective. In order to enhance the flexibility of information fusion process in QSVN setting, we define the Aczel-Alsina operations on QSVNNs and the proposed for novel QSVN Aczel-Alsina operators. The related properties are also discussed. Next, we propose QSVN-CVM method based on score function to determine the weight of criteria. Further, we improve the classical COPRAS method based on the proposed novel QSVNAAWA operator and QSVNAAWG operator to attain the prioritization of candidate schemes. After that, the applicability of the QSVN-CVM-COPRAS methodology is proved by an ELOS problem. Some results discussions including sensitivity and comparison analysis are conducted to highlight the superiority of the proposed approach. Aiming at the future research, we can investigate the decision methodologies with other decision models and consensus reaching process in the environment of QSVN. In addition, some novel aggregation operators can be studied based on generalized Dombi norms, softmax function, Muhiread mean and so forth.

### Author Contributions

For research articles with several authors, a short paragraph specifying their individual contributions must be provided. The following statements should be used "Conceptualization, D.Li and Y.R.; methodology, D.Li; software, D.Li and Y.R.; validation, D.Li and Y.R.; formal analysis, D.Li and Y.R.; investigation, D.Li writing—original draft preparation, D.Li and Y.R.; writing—review and editing. Authorship must be limited to those who have contributed substantially to the work reported.

### Data Availability Statement

The datasets generated during and/or analyzed during the current study is available from the corresponding author on reasonable request.

### Conflicts of Interest

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

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