A Multi-Attribute Decision-Making Approach for International Shipping Operator Selection Based on Single-Valued Neutrosophic Power Hamy Mean Operators

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Abstract: Maritime shipping is a crucial method of transporting goods internationally and is vital in supporting global trade. However, due to its global scope, the international shipping market is susceptible to political and economic disturbances. The recent escalation in the Israeli–Palestinian conflict has severely impacted the international shipping market, particularly in the tense Red Sea region. Previous research has neglected the significance of evaluating international shipping companies, particularly their origins, within their evaluation frameworks. A fuzzy multi-attribute decision-making (MADM) approach is necessary to address the complexity of evaluating shipping companies with unclear criteria and uncertain expert opinions. Symmetry is crucial in various mathematical fields, with recent applications in hesitant fuzzy sets (HFSs) and neutrosophic sets (NSs), which are frequently employed to solve complex MADM problems. The consideration of symmetry in decision-making processes can enhance the robustness and fairness of evaluations, ensuring a balanced and unbiased approach. The neutrosophic–hesitant fuzzy set (NHFS) considers both the uncertainty of membership degrees of elements (hesitancy in HFSs) and the performance of membership degrees in the true, false, and neutral aspects (the ternary relation in NSs). NHFSs can be seen as a generalization of HFSs and NSs, providing a flexible mathematical framework to more effectively describe and analyze the uncertainties, hesitancies, and fuzziness involved in MADM problems. This study presents single-valued neutrosophic power Hamy mean (SVNPHM) operators and single-valued neutrosophic weighted power Hamy mean operators, which are derived from power aggregation operators (AOs) and the Hamy mean (HM), within the framework of single-valued neutrosophic sets (SVNS). Some properties were investigated via these operators. Furthermore, SVNPHM operators were employed to address single-valued neutrosophic MADM issues. The proposed methodology was validated by conducting a case study on international shipping provider selection, showcasing the methodology’s relevance and efficiency.

Keywords: optimization; decision-making; single-valued neutrosophic power Hamy mean; single-valued neutrosophic weighted power Hamy mean; shipping operator selection

1. Introduction

Maritime transportation moves large quantities of goods in international trade and is one of the most important modes of transportation in international commodity exchange, with the volume of transported goods accounting for approximately 80 percent or more of all international transported goods. With advantages such as a large capacity and low freight rates, maritime transportation has become the lifeline of global trade. However, the international shipping market is inherently susceptible to worldwide political and economic events due to its global nature. Premiums and freight rates for the Red
Sea–Suez route have significantly increased due to ongoing attacks by the Houthis on merchant ships in the Red Sea. To mitigate risk, many shipping companies opt to use older cargo ships for this route, despite their increased vulnerability to attacks and the higher likelihood of issues such as ship sinking or cargo leakage. Many international shipping companies have suspended the Red Sea route to avoid these hazardous waters, rerouting via the distant Cape of Good Hope in Africa. This has resulted in increased navigation costs and extended transport times. The ongoing obstruction of this significant sea passage will affect the worldwide supply network and could potentially hinder global economic recovery. Nevertheless, maritime transportation remains irreplaceable in the international transportation of goods. International maritime transportation has received increasing attention in recent years from scholars in various fields. Exploring the concept of symmetry in MADM frameworks can enhance the fairness and effectiveness of evaluations, ensuring a balanced and structured approach that considers all relevant factors. Although studies on maritime transportation have significantly contributed to international shipping services, they have neglected the selection of international shipping operators.

Choosing a delivery service requires an MADM technique that includes evaluating various qualitative and quantitative aspects. Multi-attribute evaluation is a vital component of modern decision-making studies, alongside symmetry studies, economic impact assessments, supplier selection, and evaluating an enterprise’s technological capabilities. Its practical importance extends across mathematics, economics, culture, management, science, and technology. Organizing and ranking limited options based on different attributes requires specifically gathering choice data via MADM. Aggregating decision information is a key aspect of research on MADM. However, in many situations, it is challenging to convey the decision-making information provided by decision-makers (DMs) using precise figures because people’s judgment is frequently hazy, and objective things are complex. Meanwhile, excessive redundant data may result in decision-making environmental uncertainty and complexity. These factors make it challenging for DMs to reach reasonable decisions [1]. (The summary of all abbreviations used in this article is provided in Table A1).

Unfortunately, there is a lack of studies on the evaluation of shipping operators, even though it is a significant scientific matter that impacts stakeholders. This study introduces SVNPHM and SVNWPHM operators, which were created using PA operators and the HM. The SVNWPHM operator is utilized to address single-valued neutrosophic MADM issues and create an assessment criteria framework for global maritime service providers.

The remainder of this paper is structured as follows: Section 2 provides an overview of the pertinent literature and Section 3 explores the basic principles of SVNNSs and HM and PA operators. The SVNPHM and SVNWPHM operators are introduced by combining the PA and HM operators in Section 4. Furthermore, this research examined certain characteristics of the suggested AOs. An MADM approach based on these AOs is developed in Section 5. In Section 6, an assessment and a comparison of shipping operators are carried out to support the proposed plan. Section 7 provides the conclusions.

2. Literature Review

2.1. The Literature Related to Research Methodologies

The decision-making process is often uncertain and ambiguous, and expert judgment is often hesitant and hazy. Decision-makers frequently depend on a variety of precise data and information to make decisions; however, abundant irrelevant data can lead to confusion and complexity in the decision-making process. This complicates the ability of decision-makers to make well-informed choices [2].

The common goal of multi-attribute decision-making (MADM) and multi-criteria decision-making (MCDM) is to assist decision-makers in making optimal decisions when considering multiple attributes or criteria to achieve a more scientific and rational decision
outcome. Multi-criteria decision-making (MCDM) has demonstrated an outstanding performance in many fields. For example, Talib et al. [3] and Albahri et al. [4] used MCDM to assist healthcare professionals in enhancing the quality of care for autistic patients. Albahri et al. [5] employed MCDM to link mobile healthcare with distributed hospital servers [6]. Multi-attribute decision-making (MADM) methods represent reliable ways to solve real-world problems for various applications by providing rational and logical solutions [7]. Many authors widely apply MADM to ranking [8] and sorting problems [9], and this method is also applicable to the selection of international shipping operators discussed in this paper.

In order to introduce a sense of symmetry into the decision-making process, the primary objective is to effectively articulate the decision data and minimize information loss [10]. Based on this, many scholars have developed methods to express fuzzy information, such as fuzzy sets [11], intuitionistic fuzzy sets [12], and interval-valued intuitionistic fuzzy sets [13]. Despite the extensive application of IFSs and IVIFSs to the MADM dilemma, the uncertain and conflicting data in numerous scenarios remain unresolved. Smarandache proposed neutrosophic sets (NSs) to address these issues. An NS assigns each element degrees of truth (T), indeterminacy (I), and falsity (F) membership, each lying within the nonstandard unit interval [0−, 1+] [14]. Several original concepts such as SVNSs [15], SNSs [16], and INSs [17] have also been proposed. SVNSs are used in many areas. For example, Li et al. [18] created SVNN Heronian mean operators to solve MADM problems. Ye proposed similarity-based SVN clustering techniques in [19] and created SVNS bidirectional projection and measures for decision-making in [20].

Information aggregation operators (AOs) have been successfully used as MADM tools by aggregating a sequence of input arguments into one [21]. Zhang [22] developed the notion of a power average (PA) operator to counteract the effects of DMs’ subjective preferences for inappropriate evaluation values. Many scholars have since extended PA operators to handle more problems. For instance, Xu [21] proposed intuitionistic fuzzy power aggregation (IFPA) operators, He et al. introduced generalized PA operators for interval-valued IFSs [23], Zhang et al. created Frank IFPA operators [24], and so on.

Li et al. [25] were the first to design Hamy mean (HM) operators, which modify the parameter values to account for the interactions between various parameters. The HM operator was then widely applied and extended for MADM. Singh [26] extended HM operators for interval type-2 fuzzy information. Liu and You [27] and Wu et al. [28] enhanced HM operators to handle linguistic neutrosophic and two-tuple linguistic neutrosophic information, respectively. Liu et al. [29] incorporated the standard PA operator within the HM operator to allow the better management of INSs, considering the interactions between multiple arguments and offering increased flexibility via parameter value adjustments.

2.2. Assessment of the Shipping Industry

With 70% of the earth’s surface covered by oceans, maritime transport is an important link connecting the globe, carrying global trade, creating global value, and promoting a global society. In this section, we will review previous studies to obtain valuable information in four areas, namely, shipping quality, sustainability, risk assessments and shipping bunker selection.

Regarding shipping quality assessment, Chen [30] used a fuzzy MCDM approach to evaluate operational services. This evaluation can help shipping companies to improve their service levels. Moreover, Lo et al. [31] developed and utilized a model to plan a ferry network service in a specific area in China. Regarding shipping sustainability assessments, Wu et al. [32] examined the ecological impacts of international shipping and developed a methodology for assessing the sustainability of international shipping companies. This methodology employs information assessment and expert participation. In addition, Moldanová et al. [33] used the case of shipping activities in the Baltic Sea as an assessment framework to analyze the impacts of shipping scenarios on ecosystems and
the marine environment. Regarding shipping risk assessment, Liu et al. [34] discussed the use of the analytical network process (ANP) in risk assessment and constructed a risk assessment framework for shipping companies’ logistics. They aimed to maximize shipping providers’ ability to improve the quality of their logistics management and quickly avoid risks. Chuah et al. [35] investigated the key risk factors affecting safety at sea and made management recommendations. Studies on fuel selection for shipping vessels have focused on the use of alternative energy sources as energy shortages become more problematic [36]. Tan et al. [37] showed that the fuel choice significantly influences the fuel consumption of maritime vessels. Fuel costs account for a substantial amount of the expenses associated with shipping operations, typically falling between 20 and 60 percent. Xing et al. [38] utilized a multidimensional decision-making framework to determine the most viable alternative fuel for transportation. Their research showed that methanol was the most viable choice, whereas zero-emission synthetic fuels such as hydrogen and ammonia were not considered cost-effective.

3. Preliminaries

The flowchart of this section is shown in Figure 1.

![Flowchart](image)

Figure 1. Flowchart.

3.1. SVNSs

**Definition 1** [39]. Given a universe of discourse $C$, $u$ represents a generic element in $C$. The single-valued neutrosophic set (SVNS) can be defined as

$$P = \left\{ u \left( T_p (u), I_p (u), F_p (u) \right) \mid u \in C \right\},$$  

(1)
where \( T_p(u), I_p(u) \) and \( F_p(u) \) denote the truth membership function, the indeterminacy membership function, and the falsity membership function of the element \( u \in C \) to the set \( P \), respectively. For each point \( u \) in \( C \), we obtain \( T_p(u), I_p(u), F_p(u) \in [0,1] \) and \( 0 \leq T_p(u) + I_p(u) + F_p(u) \leq 3 \).

For convenience, \( u = (T_u, I_u, F_u) \) can be used to represent an element \( u \) in the SVNS, and the element \( u \) is viewed as a single-valued neutrosophic number, which can be shortened to SVNN.

**Example 1.** Let \( Q = (0.7, 0.1, 0.1) \) and \( P = (0.5, 0.2, 0.3) \) be two SVNNs. By following the procedures outlined in Definition 1, we can generate the following Figure 2.

![Figure 2. SVNS example diagram.](image)

**Definition 2** [40]. Given two SVNNs \( Q = (T_Q, I_Q, F_Q) \) and \( P = (T_P, I_P, F_P) \), the operational laws are described as follows:

The complement of \( P \) is \( \bar{P} = (F_p, 1 - I_p, T_p) \),

\[
P \oplus Q = \left( T_p + T_Q - T_pT_Q, I_pI_Q, F_pF_Q \right),
\]

\[
P \odot Q = \left( T_pT_Q, I_p + I_Q - I_pI_Q, F_p + F_Q - F_pF_Q \right),
\]

\[
\lambda P = \left( 1 - (1 - T_p)^\lambda, (I_p)^\lambda, (F_p)^\lambda \right), \lambda > 0,
\]

\[
P^\lambda = \left( (T_p)^\lambda, 1 - (1 - I_p)^\lambda, 1 - (1 - F_p)^\lambda \right), \lambda > 0.
\]

**Example 2.** Assume \( Q = (0.7, 0.1, 0.1) \) and \( P = (0.5, 0.2, 0.3) \) are two SVNNs, with \( \lambda = 2 \). By applying the operations described in Definition 2, we obtain the following outcomes.

1. The complement of \( P \) is \( \bar{P} = (0.5, 0.1, 0.3) \);
(3) \[ P \oplus Q = (0.7 + 0.5 - 0.7 \times 0.5, 0.1 \times 0.2, 0.1 \times 0.3) = (0.85, 0.02, 0.03); \]
(4) \[ P \otimes Q = (0.7 \times 0.5, 0.1 + 0.2 - 0.1 \times 0.2, 0.1 + 0.3 - 0.1 \times 0.3) = (0.35, 0.28, 0.37); \]
(5) \[ \lambda P = (1 - (1 - 0.5)^2, 0.1^2, 0.3^2) = (0.75, 0.01, 0.09); \]
(6) \[ P^\lambda = (0.5^2, 1 - (1 - 0.1)^2, 1 - (1 - 0.3)^2) = (0.025, 0.19, 0.51). \]

**Definition 3** [40]. Here, we let \( P = (T_p, I_p, F_p) \) be an SVNN and we define a scoring function \( R \) for an SVNN in the following manner:

\[
R(P) = \frac{2 + T_p - I_p - F_p}{3}, R(P) \in [0, 1]
\]

As a result, the following definition of an SVNN accuracy function \( \Lambda \) can be used:

\[
\Lambda(P) = T_p - F_p, \Lambda(P) \in [-1, 1]
\]

**Definition 4** [40]. Let \( Q = (T_Q, I_Q, F_Q) \) and \( P = (T_p, I_p, F_p) \) be any two SVNNs. The comparison rules are defined in Table 1.

<table>
<thead>
<tr>
<th>Rules</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>( R(P) &lt; R(Q) )</td>
<td>( \Lambda(P) &lt; \Lambda(Q) ) ( P &lt; Q )</td>
</tr>
<tr>
<td>( R(P) = R(Q) )</td>
<td>( \Lambda(P) = \Lambda(Q) ) ( P = Q )</td>
</tr>
</tbody>
</table>

**Definition 5** [15]. Let \( Q = (T_Q, I_Q, F_Q) \) and \( P = (T_p, I_p, F_p) \) be two SVNNs. Then, the Hamming–Hausdorff distance between \( P \) and \( Q \) can be defined as follows:

\[
d(P, Q) = \frac{1}{3} \left( |T_p - T_Q| + |I_p - I_Q| + |F_p - F_Q| \right)
\]

3.2. Power Average Operator

**Definition 6** [22]. The PowerA operator is the mapping of PowerA: \( R^* \rightarrow R \), which can be described as

\[
\text{PowerA}(\beta_1, \beta_2, \ldots, \beta_n) = \frac{\sum_{i=1}^{n} (1 + Y(\beta_i)) \beta_i}{\sum_{i=1}^{n} (1 + Y(\beta_i))}
\]

Next, certain characteristics are outlined as follows:

1. \( \text{STP}(\beta_i, \beta_j) \in [0, 1]; \)
2. \( \text{STP}(\beta_i, \beta_j) = \text{STP}(\beta_j, \beta_i); \)
3. \( \text{STP}(\beta_i, \beta_j) \geq \text{STP}(\beta_i, \beta_j) \text{ if } |\beta_i - \beta_j| < |\beta_p - \beta_q|. \)
3.3. Hamy Mean Operator

**Definition 7** [41]. The Hamy mean operator is defined as follows:

\[
HM^{(k)}(a_1, a_2, \ldots, a_n) = \frac{\sum_{1 \leq i_1 < \ldots < i_k \leq n} \left( \prod_{j=1}^{k} a_{i_j} \right)^{1/k}}{C^k_n}
\]  

(12)

where

\[
C^k_n = \frac{n!}{k!(n-k)!}.
\]

4. Single-Valued Neutrosophic Power Hamy Mean Operators

This section will combine the classical PowerA operators with HM operators to solve complex decision situation problems in an SVN environment. Then, the SVNPHM and SVNWPHM operators will be developed and some properties will be discussed.

4.1. The SVNPHM Operator

**Definition 8.** Here, we let \( P_j = (T_j, I_j, F_j) \) \((j = 1, 2, \ldots, n)\) be a collection of SVNNs, and the SVNPHM operator is defined as follows:

\[
SVNPHM^{(k)}(P_1, P_2, \ldots, P_n) = \frac{1}{C^k_n} \left\{ \sum_{1 \leq i_1 < \ldots < i_k \leq n} \left( \prod_{j=1}^{k} \left( 1 + T(P_{i_j}) \right) P_{i_j} \right)^{1/k} \right\}
\]

(13)

\[
T(P_j) = \sum_{i=1 \atop i \neq j}^{n} STP(P_j, P_i)
\]

where

\[
\sigma_i = \frac{\left( 1 + T(P_i) \right)}{\sum_{i=1}^{n} \left( 1 + T(P) \right)}.
\]

To simplify Equation (13), we can define

\[
SVNPHM^{(k)}(P_1, P_2, \ldots, P_n) = \frac{1}{C^k_n} \left\{ \sum_{1 \leq i_1 < \ldots < i_k \leq n} \left( \prod_{j=1}^{k} n\sigma_{i_j} P_{i_j} \right)^{1/k} \right\}
\]  

(14)

The outcomes based on Definition 8 are as follows.

**Theorem 1.** An SVNN also exists in the aggregate value produced by the SVNPHM operator.
Proof. According to the operational rules for SVNNs, we obtain

\[ n\sigma_j P_j = \left\{ 1 - \left( 1 - T_{ij} \right)^{n\sigma_j}, \left( I_{ij} \right)^{n\sigma_j}, \left( F_{ij} \right)^{n\sigma_j} \right\} ; \]

and

\[ \prod_{j=1}^{k} n\sigma_j P_j = \left\{ \prod_{j=1}^{k} \left( 1 - \left( 1 - T_{ij} \right)^{n\sigma_j} \right), 1 - \prod_{j=1}^{k} \left( 1 - \left( I_{ij} \right)^{n\sigma_j} \right), 1 - \prod_{j=1}^{k} \left( 1 - \left( F_{ij} \right)^{n\sigma_j} \right) \right\} ; \]

Then,

\[ \left( \prod_{j=1}^{k} n\sigma_j P_j \right)^\lambda = \left\{ \left( \prod_{j=1}^{k} \left( 1 - \left( 1 - T_{ij} \right)^{n\sigma_j} \right) \right)^\lambda, 1 - \left( \prod_{j=1}^{k} \left( 1 - \left( I_{ij} \right)^{n\sigma_j} \right) \right)^\lambda, 1 - \left( \prod_{j=1}^{k} \left( 1 - \left( F_{ij} \right)^{n\sigma_j} \right) \right)^\lambda \right\} ; \]

and so

\[ \sum_{\lambda \in C \cdot Q \cdot \lambda} \left( \prod_{j=1}^{k} n\sigma_j P_j \right)^\lambda = \left\{ \prod_{\lambda \in C \cdot Q \cdot \lambda} \left( 1 - \left( 1 - T_{ij} \right)^{n\sigma_j} \right)^\lambda, \prod_{\lambda \in C \cdot Q \cdot \lambda} \left( 1 - \left( I_{ij} \right)^{n\sigma_j} \right)^\lambda, \prod_{\lambda \in C \cdot Q \cdot \lambda} \left( 1 - \left( F_{ij} \right)^{n\sigma_j} \right)^\lambda \right\} ; \]

Therefore,
\[ SVNPHM^{(k)}(P_1, P_2, \ldots, P_n) \]
\[ = \frac{1}{C_n^k} \left( \prod_{i=1}^{k} n \sigma_{j} \right) \frac{1}{C_n^k} \]
\[ = \left\{ 1 - \left( \prod_{i=1}^{k} (1 - (1 - T_{ij})^{n \sigma_{j}}) \right) \right\} \frac{1}{C_n^k} \]
\[ = \left\{ 1 - \left( \prod_{i=1}^{k} (1 - (1 - I_{ij})^{n \sigma_{j}}) \right) \right\} \frac{1}{C_n^k} \]

SVNPHM’s basic properties will be discussed next.

**Property 1 (Idempotency).** If \( P_e = P(e = 1, 2, \ldots, n) \) for all \( j \), then
\[ SVNPHM^{(k)}(P_1, P_2, \ldots, P_n) = P \].

**Proof.** Since \( P_e = P(e = 1, 2, \ldots, n) \), then
\[ n \sigma_{j} = \frac{n(1 + T(P_e))}{\sum_{i=1}^{n}(1 + T(P_i))} = 1 \]. Therefore, according to Theorem 1, we obtain
\[ SVNPHM^{(k)}(P_1, P_2, \ldots, P_n) \]
\[ = 1 - \left( \prod_{i=1}^{n} (1 - (T_i)^{1/l_i}) \right) \left( \prod_{i=1}^{n} (1 - (1 - I_i)^{1/l_i}) \right) \left( \prod_{i=1}^{n} (1 - (1 - F_i)^{1/l_i}) \right) \left( \prod_{i=1}^{n} (1 - (1 - T_i)^{1/l_i}) \right) \]
\[ = \{ T, I, F \} = P \].

**Property 2 (Commutativity).** Here, we let \( P_e'(e = 1, 2, \ldots, n) \) be a set of SVNNs and \( P_e' \) be any permutation of \( P_e \). Next,
\[ SVNPHM^{(k)}(P_1, P_2, \ldots, P_n) = SVNPHM^{(k)}(P_1', P_2', \ldots, P_n') \].
Proof. Since \( (P'_1, P'_2, \ldots, P'_n) \) is any permutation of \( (P_1, P_2, \ldots, P_n) \). Therefore,

\[
SVNPHM^{(k)}(P'_1, P'_2, \ldots, P'_n) = \frac{1}{C_n^k} \sum_{1 \leq i_1 < i_2 \leq n} \left( \prod_{i=1}^{k} \left( \frac{n \left[ 1 + T \left( P'_i \right) \right]}{\sum_{i=1}^{n} \left[ 1 + T \left( P'_i \right) \right]} \right) \right) ^{\frac{1}{k}}
\]

\[
SVNPHM^{(k)}(P_1, P_2, \ldots, P_n).
\]

\( \Box \)

Property 3 (Boundedness). The SVNPHM operator is located between the max and min operators.

\[
P^- \leq SVNPHM^{(k)}(P_1, P_2, \ldots, P_n) \leq P^+
\]

where

\[
P^- = \min \left( P_1, P_2, \ldots, P_n \right) = \left( T^-, I^-, F^- \right)
\]

and

\[
P^+ = \max \left( P_1, P_2, \ldots, P_n \right) = \left( T^+, I^+, F^+ \right).
\]

Proof. Since

\[
n \sigma_{ij} P_{ij} = \left\{ 1 - \left( 1 - T_{ij} \right)^{\sigma_{ij}}, \left( I_{ij} \right)^{\sigma_{ij}}, \left( F_{ij} \right)^{\sigma_{ij}} \right\} \geq \left\{ 1 - \left( 1 - T^- \right)^{\sigma_{ij}}, \left( I^- \right)^{\sigma_{ij}}, \left( F^- \right)^{\sigma_{ij}} \right\}
\]

and

\[
\prod_{j=1}^{k} n \sigma_{ij} P_{ij} = \left\{ \prod_{j=1}^{k} \left( 1 - \left( 1 - T_{ij} \right)^{\sigma_{ij}} \right), 1 - \prod_{j=1}^{k} \left( 1 - \left( I_{ij} \right)^{\sigma_{ij}} \right), 1 - \prod_{j=1}^{k} \left( 1 - \left( F_{ij} \right)^{\sigma_{ij}} \right) \right\}
\]

\[
\geq \left\{ \prod_{j=1}^{k} \left( 1 - \left( 1 - T^- \right)^{\sigma_{ij}} \right), 1 - \prod_{j=1}^{k} \left( 1 - \left( I^- \right)^{\sigma_{ij}} \right), 1 - \prod_{j=1}^{k} \left( 1 - \left( F^- \right)^{\sigma_{ij}} \right) \right\}
\]

then

\[
\left( \prod_{j=1}^{k} n \sigma_{ij} P_{ij} \right)^{\frac{1}{k}} \geq \left( \prod_{j=1}^{k} \left( 1 - \left( 1 - T^- \right)^{\sigma_{ij}} \right) \right)^{\frac{1}{k}}, 1 - \left( \prod_{j=1}^{k} \left( 1 - \left( I^- \right)^{\sigma_{ij}} \right) \right)^{\frac{1}{k}}, 1 - \left( \prod_{j=1}^{k} \left( 1 - \left( F^- \right)^{\sigma_{ij}} \right) \right)^{\frac{1}{k}}
\]

Then,
\[ \sum_{i_1 < \cdots < i_k} \left[ \prod_{j=1}^k \left( 1 - \prod_{i_j} \left( 1 - (1 - T_{i_j}) \omega_{i_j}^T \right) \right) \right]^\frac{1}{C_k} \sum_{j=1}^n \left[ \prod_{i_j} \left( 1 - (1 - F_{i_j}) \sigma_{i_j} \right) \right]^\frac{1}{C_k} \]

\[ SVNHM^{(k)}(P_1, P_2, ..., P_n) = \frac{1}{C_k} \sum_{i_1 < \cdots < i_k} \left[ \prod_{j=1}^k \left( 1 - \prod_{i_j} \left( 1 - (1 - T_{i_j}) \omega_{i_j}^T \right) \right) \right]^\frac{1}{C_k} \]

Hence,

\[ SVNHM^{(k)}(P_1, P_2, ..., P_n) \leq P^s. \]

Similarly, it can be proven that

\[ SVNHM^{(k)}(P_1, P_2, ..., P_n) \leq P^s. \]

\[ = P \]

4.2. The SVNWPHM Operator

Definition 9. Here, let us set \( P_j = (T_j, I_j, F_j) (j = 1, 2, ..., n) \) as a collection of SVNNs. \( \omega = (\omega_1, \omega_2, ..., \omega_n)^T \) is the weight vector of \( P_j (j = 1, 2, ..., n) \), and \( \sum_{j=1}^n \omega_j = 1 \).

The SVNWPHM operator is defined as follows:

\[ SVNWPHM_{\omega}^{(k)}(P_1, P_2, ..., P_n) = \frac{1}{C_k} \sum_{1 \leq i_1 < \cdots < i_k \leq n} \left( \prod_{i=1}^{\min(k, n)} \omega_{i} \left( 1 + T \left( P_{i_j} \right) \right) P_{i_j} \right)^{\frac{1}{k}} \]

(19)

\[ T(P_j) = \sum_{i=1}^{n} \omega_i \text{Supp}(P_j, P_i) \]

where

\[ \rho_i = \frac{\omega_{i} \left( 1 + T \left( P_{i_j} \right) \right)}{\sum_{j=1}^{n} \omega_i \left( 1 + T \left( P_i \right) \right)} \]

To simplify Equation (19), it can be defined that the simplified form of Equation (19) is expressed as
We can obtain the following results based on Definition 9.

**Theorem 2.** The combined result obtained from applying the SVNWPHM operator is also an SVNN.

\[
SVNWPHM^{(k)}_{\omega}(P_1, P_2, \ldots, P_n) = \frac{1}{C_n^k} \left( \sum_{1 \leq i_1 < \ldots < i_k \leq n} \left( \prod_{j=1}^{k} P_{i_j}^{n \rho_{i_j}} \right)^{\frac{1}{k}} \right)
\]

(20)

Proof. This theorem can be proven as in Theorem 1. □

Next, we will examine some fundamental characteristics of the SVNWPHM operator.

**Property 4 (Idempotency).** If \( P_j = P(j = 1, 2, \ldots, n) \) for all \( j \), then

\[
SVNWPHM^{(k)}_{\omega}(P_1, P_2, \ldots, P_n) = P
\]

(22)

**Property 5 (Commutativity).** Here, we let \( P_j(j = 1, 2, \ldots, n) \) be a set of SVNNs and \( P'_j \) be any permutation of \( P_j \). Thus,

\[
SVNWPHM^{(k)}_{\omega}(P_1, P_2, \ldots, P_n) = SVNWPHM^{(k)}_{\omega}(P'_1, P'_2, \ldots, P'_n)
\]

(23)

**Property 6 (Boundedness).** The SVNWPHM operator is located between the max and min operators:

\[
P^- \leq SVNWPHM^{(k)}_{\omega}(P_1, P_2, \ldots, P_n) \leq P^+
\]

(24)
where
\[
P^- = \min\left( P_1, P_2, \ldots, P_n \right) = \left( T^-, I^-, F^- \right)
\]
and
\[
P^+ = \max\left( P_1, P_2, \ldots, P_n \right) = \left( T^+, I^+, F^+ \right).
\]

The proofs for the aforementioned properties are identical to those for the SVNPHM operator; hence, they are omitted here.

The properties of the SVNPHM/SVNWPHM operator are summarized as shown in Figure 3.

---

**Figure 3.** The properties of the SVNPHM/SVNWPHM operator.

---

**5. MADM Approach**

In this part, we will use the SVNWPHM operator for MADM with SVNNs and the following notations to describe the MADM problems. The set of attributes can be shown as
\[
C = \{ C_1, C_2, \ldots, C_n \},
\]
and a set of alternatives can be shown as
\[
X = \{ X_1, X_2, \ldots, X_m \}.
\]
\[
\omega = (\omega_1, \omega_2, \ldots, \omega_n)
\]
can be used as the weight vector of the criteria, where
\[
\omega_j \geq 0, \ j = 1, 2, \ldots, n, \sum_{j=1}^{n} \omega_j = 1.
\]

Following this, we proceed with the necessary steps to address this problem.

**Step 1.** The supports are calculated as:
\[
S_T (P, P) = \mu - \nu\]

Here, \(d(P, P)\) is the Hamming–Hausdorff distance between \(P\) and \(P\) as in Definition 5.

**Step 2.** The weighted support
\[
T(P, \omega)\]

of the SVNN \(P\) by the other SVNN \(P\) is determined using the weights \(\omega\) of the criteria
\[
C_v (v = 1, 2, \ldots, n).
\]
Then, the SVNN’s corresponding weight $\gamma_{\mu\nu} (\nu = 1, 2, \ldots, n)$ is determined.

$$
T\left(P_{\mu\nu}\right) = \sum_{\kappa=1}^{n} \alpha_{\kappa} \text{STP}\left(P_{\mu\nu}, P_{\mu\kappa}\right)
$$

(26)

Step 3. The overall values $P_{\mu} (\mu = 1, 2, \ldots, m)$ of the alternative $X_\mu$ are derived from Equation (21) using the SVNWPHM operator.

Step 4. The score function $S\left(P_{\mu}\right) (\mu = 1, 2, \ldots, m)$ is calculated for all SVNNs according to Equation (7).

Step 5. All the alternatives $X_\mu (\mu = 1, 2, \ldots, m)$ are ranked, and the best one(s) are chosen.

Step 6. End.

The flowchart of this process is shown in Figure 4.

Figure 4. Flowchart.
6. Shipping Supplier Evaluation Cases

Determining scientific and reasonable assessment indexes is crucial for the rational selection of international shipping suppliers. While many supplier assessment systems are available, few studies have focused on assessing international shipping operators, especially in the context of regional armed conflicts. To fill this void, this study introduces a new evaluation model that considers the distinct obstacles encountered by maritime companies operating in conflict areas. The situation in the Red Sea region has been tense since the outbreak of the recent Israeli–Palestinian conflict. Although the conflict has not expanded to a regional level, it has significantly impacted the international shipping market. Several international shipping companies have suspended the Red Sea route and diverted to the distant African Cape of Good Hope to avoid these dangerous waters.

Incorporating the concept of symmetry into the assessment framework, we have included the country of the shipping provider as one of the assessment indicators. A shipping provider may be unable to access some routes if the shipping operator’s country has an interest in military conflicts, which results in poor route stability and timeliness and affects the shipping cargo’s safety.

In addition, economic standard indicators can reflect the inputs and profits in terms of economic costs for shipping company operation. Understanding a company’s economic situation can help decision-makers determine the business situations and future trends of alternative companies. Shipping companies with larger load capacities may have a competitive edge regarding financial expenses.

The social reputation indicator reflects a company’s standing derived from long-term customer satisfaction, a critical competitive advantage. A good social reputation can provide the enterprise with more development space and increase the employees’ sense of belonging, which will continuously promote the enterprise’s development.

The management level indicator can reflect the management and control of personnel, services, equipment, and so on in the operation process of shipping operators. Management is one of the most important productive forces of modern enterprises. Enterprises with higher management levels have an advantage regarding the fierce market competition, which is conducive to these enterprises’ long-term development.

Thus, the evaluation indicator system of the shipping operator herein should include the country, economic standard, social reputation, and management level, as shown in Figure 5.

![shipping operator evaluation indicator system](image)

**Figure 5.** Shipping operator evaluation indicator system.

This section will demonstrate the application of SVNWPHM operators to MADM problems using international shipping suppliers as a case study. There are five possible shipping suppliers to choose from: \( X_\mu (\mu = 1, 2, 3, 4, 5) \). The four expert-chosen criteria to assess the five potential shipping suppliers are as follows: \( C_1 \) represents the country to which the shipping supplier belongs, \( C_2 \) represents the economic standard, \( C_3 \) represents social reputation, and \( C_4 \) represents the management level.
The decision-maker uses the SVNNs to evaluate the five potential shipping suppliers, \( X_\mu (\mu = 1, 2, 3, 4, 5) \), based on the four criteria (whose weighting vector is \( \omega = (0.2, 0.1, 0.3, 0.4)^T \)) listed in the following matrix:

\[
\tilde{R} = \begin{bmatrix}
(0.5, 0.8, 0.1) & (0.6, 0.3, 0.3) & (0.3, 0.6, 0.1) & (0.5, 0.7, 0.2) \\
(0.7, 0.2, 0.1) & (0.7, 0.2, 0.2) & (0.7, 0.2, 0.4) & (0.8, 0.2, 0.1) \\
(0.6, 0.7, 0.2) & (0.5, 0.7, 0.3) & (0.5, 0.3, 0.1) & (0.6, 0.3, 0.2) \\
(0.8, 0.1, 0.3) & (0.6, 0.3, 0.4) & (0.3, 0.4, 0.2) & (0.5, 0.6, 0.1) \\
(0.6, 0.4, 0.4) & (0.4, 0.8, 0.1) & (0.7, 0.6, 0.1) & (0.5, 0.8, 0.2)
\end{bmatrix}
\]

6.1. Decision-Making Procedure

The proposed method is adapted to select the best shipping supplier.

Step 1. The supports are calculated:

\[
\begin{align*}
STP_{12} &= STP_{21} = \begin{bmatrix} 0.7333 \\ 0.9667 \\ 0.3000 \end{bmatrix}; \\
STP_{13} &= STP_{31} = \begin{bmatrix} 0.8667 \\ 0.9000 \\ 0.8000 \end{bmatrix}; \\
STP_{14} &= STP_{41} = \begin{bmatrix} 0.9333 \\ 0.0333 \\ 0.2333 \end{bmatrix}; \\
STP_{23} &= STP_{32} = \begin{bmatrix} 0.7333 \\ 0.9333 \\ 0.8333 \end{bmatrix}; \\
STP_{24} &= STP_{42} = \begin{bmatrix} 0.8000 \\ 0.9333 \\ 0.8333 \end{bmatrix}; \\
STP_{34} &= STP_{43} = \begin{bmatrix} 0.8667 \\ 0.8667 \\ 0.8333 \end{bmatrix}
\end{align*}
\]

Step 2. The weights \( \omega_\nu (\nu = 1, 2, \ldots, n) \) of the attribute \( C_\nu (\nu = 1, 2, \ldots, n) \) are then adopted to calculate the weighted support \( L(P_{\mu \nu}) \) of SVNN \( P_{\mu \nu} \) by the other SVNN:

\[
L(P_{\mu \nu}) = \begin{bmatrix} 0.7067 & 0.6867 & 0.5934 & 0.5267 \\ 0.7534 & 0.8467 & 0.6200 & 0.5467 \\ 0.5600 & 0.7133 & 0.5533 & 0.4600 \end{bmatrix}
\]

\[
P_{\mu \kappa} (\kappa = 1, 2, \ldots, n, \kappa \neq j) = \begin{bmatrix} 0.6167 & 0.7633 & 0.5767 & 0.4967 \\ 0.6800 & 0.7467 & 0.6133 & 0.5333 \\ 0.5600 & 0.7133 & 0.5533 & 0.4600 \end{bmatrix}
\]

Then, the weight \( \gamma_{\mu \nu} (j = 1, 2, \ldots, n) \) associated with the SVNNs \( P_{\mu \nu} (\mu = 1, 2, \ldots, m, \nu = 1, 2, \ldots, n) \) is calculated:
\[(\gamma_{\mu\nu})_{5\times4} = \begin{bmatrix} 0.2135 & 0.1055 & 0.2990 & 0.3820 \\ 0.2138 & 0.1126 & 0.2963 & 0.3772 \\ 0.2090 & 0.1086 & 0.3010 & 0.3814 \\ 0.2035 & 0.1117 & 0.3039 & 0.3809 \\ 0.2058 & 0.1122 & 0.3010 & 0.3810 \end{bmatrix}.\]

Step 3. The overall values \( P_{\mu}(\mu = 1, 2, \ldots, m) \) of the alternative \( X_{\mu} \) (supposing \( k = 3 \)) are derived from Equation (21) using the SVNWPHM operator:

\[ P_1 = (0.4276, 0.6557, 0.2332); P_2 = (0.6672, 0.2512, 0.2597); P_3 = (0.5029, 0.5857, 0.2661); P_4 = (0.4936, 0.3961, 0.3319); P_5 = (0.4990, 0.7025, 0.2551). \]

Step 4. Here, we attempt to calculate the score function \( R(P_{\mu})(\mu = 1, 2, \ldots, m) \) of the overall SVNNs according to Equation (7).

\[ R_1 = 0.5129; R_2 = 0.7173; R_3 = 0.5504; R_4 = 0.5885; R_5 = 0.5138. \]

Step 5. All the alternatives \( X_{\mu}(\mu = 1, 2, \ldots, m) \) are ranked, and the best one(s) is chosen.

According to Definition 4 and the results in Step 4, we obtain \( R_2 > R_4 > R_3 < R_5 > R_1 \). Therefore, the final ranking is \( X_2 > X_4 > X_3 > X_5 > X_1 \).

Step 6. End.

6.2. Effect of Parameter \( \vartheta \)

In this part, the SVNWPHM operator’s parameter \( \vartheta \) is set to various values to observe the ranking results. The ranking results are shown in Table 2.

<table>
<thead>
<tr>
<th>( \vartheta )</th>
<th>Score Values</th>
<th>Ranking Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \vartheta = 1 )</td>
<td>( VS_1 = 0.5615; VS_3 = 0.7931; ) ( VS_5 = 0.5909 )</td>
<td>( X_2 &gt; X_4 &gt; X_3 &gt; X_5 &gt; X_1 )</td>
</tr>
<tr>
<td>( \vartheta = 2 )</td>
<td>( R_1 = 0.5306; R_2 = 0.7386; ) ( R_3 = 0.5885; R_4 = 0.6128; ) ( R_5 = 0.5385 )</td>
<td>( X_2 &gt; X_4 &gt; X_3 &gt; X_5 &gt; X_1 )</td>
</tr>
<tr>
<td>( \vartheta = 3 )</td>
<td>( R_1 = 0.5129; R_2 = 0.7173; ) ( R_3 = 0.5504; R_4 = 0.5885; ) ( R_5 = 0.5138 )</td>
<td>( X_2 &gt; X_4 &gt; X_3 &gt; X_5 &gt; X_1 )</td>
</tr>
<tr>
<td>( \vartheta = 4 )</td>
<td>( R_1 = 0.5000; R_2 = 0.7091; ) ( R_3 = 0.5330; R_4 = 0.5773; ) ( R_5 = 0.5012 )</td>
<td>( X_2 &gt; X_4 &gt; X_3 &gt; X_5 &gt; X_1 )</td>
</tr>
</tbody>
</table>
6.3. Comparative Analysis

The following part compares our proposed method with the SVNWA operator proposed by Sahin [42] and the SVNWBPM operator proposed by Wei [43]. Table 3 shows the score functions and lists the final rankings.

Table 3. Scores and ranking of the alternatives for different operators.

<table>
<thead>
<tr>
<th>Score Values</th>
<th>Ranking Order</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVNWA</td>
<td>$R_1 = 0.5604; R_2 = 0.7942; R_3 = 0.6689; R_4 = 0.6757; R_5 = 0.5898$</td>
</tr>
<tr>
<td>SVNWBPM</td>
<td>$R_1 = 0.5394; R_2 = 0.7436; R_3 = 0.6253; R_4 = 0.6269; R_5 = 0.5601$</td>
</tr>
<tr>
<td>SVNWPHM</td>
<td>$R_1 = 0.5129; R_2 = 0.7173; R_3 = 0.5504; R_4 = 0.5885; R_5 = 0.5138$</td>
</tr>
</tbody>
</table>

Three operators have the same ranking order in Table 3, demonstrating the logic and efficiency of our suggested approach. The proposed operator considered the link between the attribute values and weight simultaneously; however, the SVNWA operator failed. Unlike the Bonferroni operator, the Hamy operator is considered an aggregation tool, which considers the interrelationship between multiple input parameters.

The factors contributing to the differences in the ultimate standings of each analyzed method and the recommended procedure are outlined in Table 4. Our approach considers the interrelationships between any two qualities, numerous arguments, and membership versus non-membership, while flexibly expressing preferences and describing uncertainty. Therefore, we infer that SVNWPHM is more practical and efficient.

Table 4. The outcomes of comparing various analyzed methodologies.

<table>
<thead>
<tr>
<th>Aggregation Operators</th>
<th>Interrelationship Between Arguments</th>
<th>The Effect of Model Uncertainty is Greater.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algebraic</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>BM</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>HM</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>MSM</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>SVNWPHM</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

7. Conclusions

The ongoing Red Sea crisis has major implications for the region’s political economy and increases the risks for international shipping, creating a vicious cycle. The Houthis’ attacks on Red Sea merchant ships have greatly affected the Red Sea–Suez route. The stagnation of this vital maritime route not only threatens the international shipping industry’s growth but also dampens the prospects for global economic recovery. Given this context, it is crucial to incorporate shipping providers’ countries of origin in assessment indicators and evaluate international shipping operators in the context of regional armed conflicts, an aspect that has been overlooked in previous studies. Assessing a shipping provider’s origin country can help avoid or reduce the risk of travel restrictions or armed attacks that
may result in the sinking of a ship due to the shipping operator’s interests in a military conflict zone.

Evaluating shipping operators is complex, including many variables ranging from the operator’s origin country and economic performance to its management quality and social reputation. In addition, experts experience difficulties and are hesitant when describing ambiguities and uncertainties. Inspired by the topic of symmetry, we proposed the SVNPHM operator by combining the HM operator with SVNNs and the conventional PA operator. The score function was then expanded upon and used to rank all the alternatives after investigating some desirable features. Additionally, we developed a new method based on the SVNPHM operator and applied it to MADM problems, giving the specific steps. Furthermore, we demonstrated the new method’s effectiveness and viability by comparing it with current methods. The SVNPHM operators can aggregate fuzzy information and partitioned parameters simultaneously to address complex decision-making situations, serving as a useful tool to efficiently overcome MADM challenges.

The research outcomes of this study are poised to have a profound impact on the maritime industry. Firstly, the establishment of an assessment indicator system for international shipping operators in this paper provides a valuable reference for decision-makers in the shipping industry. It offers insights that can aid in making informed choices when selecting a suitable operator and improving the overall operational efficiency. Secondly, by utilizing the SVNPHM operator to address MCDM problems, its successful extension into the maritime sector enhances decision-making efficiency and accuracy. This not only offers a new perspective and method for the management and development of the shipping industry but also brings important value to enhancing competitiveness, addressing challenges, and driving the growth of the industry and the global maritime market.

The following innovations have been made based on the results of this paper: AOs and HM operators provide excellent alternative solutions, so they are widely used in practice [16,17]. This study aimed to select the best international shipping operator and expand the application field of the SVNPHM approach. Additionally, inspired by the concept of symmetry, the SVNPHM operator was developed by combining the HM operator with SVNNs and the conventional PA operator, enhancing the symmetry in the decision-making process. Secondly, influenced by the Red Sea shipping crisis, assessment indicators have become critical in selecting international shipping operators. A system was constructed using a logical structure with causal connections between statements. This paper presented the first assessment indicator system for international shipping operators, focusing on shipping suppliers’ countries from the perspective of regional armed conflicts. This study provides suggestions and references for decision-makers to select shipping suppliers, thereby improving their competitiveness.

Considering the complexity of the real situation, our future research will focus on creating other approaches that can handle various types of fuzzy information and expand the use of the improved operators. In the future, NHFS and SVNPHM, as useful tools for handling complex real-world problems, can be applied in various fields and decision problems to help people better deal with complex uncertainty and fuzzy information, such as in the financial investment sector for stock market prediction and in the healthcare sector for medical diagnosis. Moreover, other fuzzy sets, such as the interval-valued intuitionistic fuzzy hypersoft set and q-rung orthopair fuzzy two-tuple linguistic sets, can be coupled to address practical issues. Further enhancing the symmetry aspect in decision-making, future research will also consider the complexity and instability of the global shipping industry to develop advanced modeling methods for selecting shipping companies.

Author Contributions: Conceptualization, methodology, formal analysis, writing paper, software, original draft preparation, Y.W.; reviewing and editing, supervision, project administration, K.Z.;
visualization, data curation, investigation, validation, Z.C. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A. Abbreviations Format

Here is a summary of all the abbreviations used in this article:

Table A1. Summary of abbreviations.

<table>
<thead>
<tr>
<th>Full Name</th>
<th>Abbreviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multi-Attribute Decision-Making</td>
<td>MADM</td>
</tr>
<tr>
<td>Hesitant Fuzzy Set</td>
<td>HFS</td>
</tr>
<tr>
<td>Neutrosophic Set</td>
<td>NS</td>
</tr>
<tr>
<td>Neutrosophic Hesitant Fuzzy Set</td>
<td>NHFS</td>
</tr>
<tr>
<td>Single-Valued Neutrosophic Power Hamy Mean</td>
<td>SVNPHM</td>
</tr>
<tr>
<td>Single-Valued Neutrosophic Weighted Power Hamy Mean</td>
<td>SVNWPHM</td>
</tr>
<tr>
<td>Single-Valued Neutrosophic Set</td>
<td>SVN</td>
</tr>
<tr>
<td>Hamy Mean</td>
<td>HM</td>
</tr>
<tr>
<td>Power Average</td>
<td>PA</td>
</tr>
<tr>
<td>Aggregation Operator</td>
<td>AO</td>
</tr>
<tr>
<td>Decision-Maker</td>
<td>DM</td>
</tr>
<tr>
<td>Simplified Neutrosophic Set</td>
<td>SNS</td>
</tr>
<tr>
<td>Interval Neutrosophic Set</td>
<td>INS</td>
</tr>
<tr>
<td>Intuitionistic Fuzzy Power Aggregation</td>
<td>IFPA</td>
</tr>
<tr>
<td>Intuitionistic Fuzzy Set</td>
<td>IFS</td>
</tr>
<tr>
<td>Interval-Valued Intuitionistic Fuzzy Set</td>
<td>IVIFS</td>
</tr>
<tr>
<td>Multi-Criteria Decision-Making</td>
<td>MCDM</td>
</tr>
<tr>
<td>Analytical Network Process</td>
<td>ANP</td>
</tr>
<tr>
<td>Single-Valued Neutrosophic Number</td>
<td>SVNN</td>
</tr>
<tr>
<td>Single-Valued Neutrosophic Weighted Averaging</td>
<td>SVNWA</td>
</tr>
<tr>
<td>Single-Valued Neutrosophic Weighted Bonferroni Power Mean</td>
<td>SVNWBPM</td>
</tr>
<tr>
<td>Bonferroni Mean</td>
<td>BM</td>
</tr>
<tr>
<td>Maclaurin Symmetric Mean</td>
<td>MSM</td>
</tr>
</tbody>
</table>

References

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