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# DVNN-CoCoSo: A Hybrid Neutrosophic Model for Evaluating Social and Economic Impacts of Sports Events

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**Abstract**

The evaluation of the social benefits of major sports events is a multifaceted process, focusing on assessing the positive impacts such events bring to a host city and society. These benefits include promoting public health, fostering national pride and social cohesion, boosting local economies, and improving infrastructure. This evaluation process can be viewed as a multiple-attribute decision-making (MADM) problem. This study introduces a novel double-valued neutrosophic number CoCoSo (DVNN-CoCoSo) technique for MADM, incorporating DVNN Hamming distance (DVNNHD) and DVNN Logarithmic distance (DVNNLD). This method effectively handles the uncertainty inherent in evaluating social benefits. A numerical example of social benefits evaluation for major sports events illustrates the practicality and efficacy of the DVNN-CoCoSo technique. The study's major contributions include the development of the DVNN-CoCoSo technique for MADM, the consideration of objective weights through entropy techniques, and the application of this novel method to the social benefits evaluation of major sports events.

**Keywords:** Multiple-attribute decision-making (MADM); double-valued neutrosophic sets (DVNSs); CoCoSo technique; social benefits evaluation of major sports events

## 1. Introduction and Literature Review

The evaluation of the social benefits of major sports events refers to the systematic analysis and assessment of the impact these events have on various aspects of society. Its primary goal is to measure the contributions of the event to the hosting city and society in areas such as economy, culture, environment, and public health. Firstly, these events can promote the development of urban infrastructure, improving transportation, venues, and facilities, thereby enhancing the living conditions of local residents. Secondly, sports events boost the city's brand image and international influence, attracting more tourists and investments, which in turn stimulates related industries such as tourism, hospitality, and dining. The evaluation of social benefits also includes cultural impact, such as raising public awareness of physical fitness, strengthening social cohesion, and increasing community participation. Additionally, hosting such events can improve publicity and cultivate a sense of social responsibility. Through a scientific evaluation system, both quantitative and qualitative analyses can be conducted to ensure the long-term positive effects of the event on society. This evaluation also provides a basis for the planning and management of future sports events. Effective social benefit evaluations help governments, businesses, and the public better understand and leverage the comprehensive benefits brought by major sports events. The earliest research was conducted by Zhai and Zhou [1], who explored the evaluation methods of social benefits for host cities of major sports events. The study developed an indicator system with 3 primary indicators, 10 secondary indicators, and 44 tertiary indicators, covering the impacts of events on urban infrastructure, economic development, social stability, and cultural life. The research employed methods such as literature analysis, expert interviews, surveys, and logical analysis, and used the Analytic Hierarchy Process (AHP) to determine the weight of each indicator. This research provided a scientific basis for evaluating the social benefits of major sports events and offered essential references for future event planning and management. In 2011, Du and Zhang [2] further examined the social benefits of major sports events from three dimensions: ecological environment, social spirit, and material culture. The paper emphasized that if the government strictly adhered to event environmental requirements and focused on reusing sports facilities and promoting the role of sports stars as role models, major events could positively impact the local ecological environment, social civilization, and balanced development of urban and rural sports facilities. This study provided a multi-dimensional reference for assessing social benefits in future major sports events. In 2020, Li, Zhang and Lü [3] focused on evaluating the social benefits of meteorological services in major sports events. Using the 2014 Nanjing Youth Olympic Games as a case study, they summarized the technical methods for such evaluations. By selecting research objects, applying social survey methods, and designing evaluation indicators, they proposed how to meet service demands during events, collect evaluation data, and conduct phased assessments. This research provided a framework for effectively evaluating meteorological services in future major sports events.

MADM is a method used to solve problems where choices must be made based on multiple, often conflicting, attributes or criteria[4-6]. This approach is widely applied in complex decision-making scenarios, helping decision-makers select the optimal option or rank alternatives. Each alternative is evaluated based on a set of attributes or criteria, which may involve both quantitative and qualitative data, and typically carry different levels of importance[7-10]. To make a decision, weights are usually assigned to each attribute to reflect its relative significance. By combining the scores of each attribute with its corresponding weight, an overall score for each alternative is calculated, enabling comparison and evaluation. Common MADM methods include Analytic Hierarchy Process (AHP), TOPSIS, and Fuzzy Comprehensive Evaluation. These methods utilize different mathematical models and algorithms to help decision-makers handle uncertainty, ambiguity, and preferences in a more scientific manner [11-14]. In practice, MADM is widely used in areas such as project evaluation, investment selection, resource allocation, and supplier selection. It effectively enhances the systematization, rationality, and scientific basis of decision-making, ensuring that final decisions better align with actual needs and preferences. The social benefits evaluation of major sports events is regarded as the defined MADM. Recently, the CoCoSo [15] and entropy [16] has been used to cope with MADM. The DVNSs [17] are used as a technique for characterizing fuzzy information during the social benefits evaluation of major sports events. Furthermore, many techniques employed CoCoSo technique [15] and entropy [16] separately to manage the MADM. Until now, no or few techniques have been administrated on entropy technique [16] and CoCoSo [15] under DVNSs. Therefore, the DVNN-CoCoSo model is founded to manage the MADM. Finally, numerical example for social benefits evaluation of major sports events and comparative analysis is administrated to validate the DVNN-CoCoSo model. The major research motivation of this work is managed: (1) the novel MADM is put forward based on CoCoSo and entropy technique under DVNSs; (2) The objective weights are considered through entropy technique; (3) The new MADM technique based on DVNN-CoCoSo technique is proposed for social benefits evaluation of major sports events; (4) numerical example for social benefits evaluation of major sports events and comparative analysis are employed to prove the DVNN-CoCoSo model.

The structure of this paper is as follows: Section 1 provides the introduction and literature review. Section 2 introduces the DVNSs. In Section 3, the DVNN-CoCoSo technique is applied for MADM. Section 4 presents numerical examples for evaluating blended teaching quality decisions and includes a comparative analysis. Finally, the conclusions and future work are discussed in Section 5.

## 2. Preliminaries and Definitions

Double-valued neutrosophic sets (DVNSs), introduced by Kandasamy [17], are an extension of traditional neutrosophic sets, where each element is characterized by two independent values for truth, indeterminacy, and falsity. This dual representation provides a more comprehensive framework for handling uncertainty and vagueness in data. DVNSs have been applied in various fields, including clustering algorithms and graph-based problems, demonstrating their effectiveness in complex decision-making situations.

**Definition 1 [17]**.

The DVNSs $ZA$ in $\Theta$ as:

$$ZA=\left\{\left(\theta, ZT_A(\theta), ZIT_A(\theta), ZIF_A(\theta), ZF_A(\theta)\right)\middle|\theta\in\Theta\right\}. \tag{1}$$

where $ZT_A(\theta)$ is truth-membership, $ZIT_A(\theta)$ is indeterminacy leaning towards $ZT_A(\theta)$, $ZIF_A(\theta)$ is indeterminacy leaning towards $ZF_A(\theta)$, $ZF_A(\theta)$ is falsity-membership, $ZT_A(\theta), ZIT_A(\theta), ZIF_A(\theta), ZF_A(\theta)\in[0,1]$, $0\le ZT_A(\theta)+ZIT_A(\theta)+ZIF_A(\theta)+ZF_A(\theta)\le 4$

The DVNN is expressed as $ZA=\left(ZT_A, ZT_A, ZIF_A, ZF_A\right)$, where $ZT_A, ZIT_A, ZIF_A, ZF_A\in[0,1]$, $0\le ZT_A+ZIT_A+ZIF_A+ZF_A\le 4$.

**Definition 2 [17]**.

Let $ZA=\left(ZT_A, ZT_A, ZIF_A, ZF_A\right)$ be the DVNN, the score value is:

$$SV(ZA)=\frac{(2+ZT_A+ZIT_A-ZIF_A-ZF_A)}{4},\ SV(RA)\in[0,1]. \tag{2}$$

**Definition 3[17]**.

Let $ZA=(ZT_A,ZT_A,ZIF_A,ZF_A)$ be DVNN, the accuracy value is controlled:

$$AV(ZA)=\frac{(ZT_A+ZIT_A+ZIF_A+ZF_A)}{4},\ AV(ZA)\in[0,1]\ . \tag{3}$$

The order for DVNNs is managed.

**Definition 4[17]**.

Let $ZA=(ZT_A,ZT_A,ZIF_A,ZF_A)$ and $ZB=(ZT_B,ZT_B,ZIF_B,ZF_B)$, $SV(ZA)=\frac{(2+ZT_A+ZIT_A-ZIF_A-ZF_A)}{4}$, $SV(ZB)=\frac{(2+ZT_B+ZIT_B-ZIF_B-ZF_B)}{4}$, $AV(ZA)=\frac{(ZT_A+ZIT_A+ZIF_A+ZF_A)}{4}$, $AV(ZB)=\frac{(ZT_B+ZIT_B+ZIF_B+ZF_B)}{4}$, if $SV(ZA)<SV(ZB)$, $ZA<ZB$; if $SV(ZA)=SV(ZB)$, (1)if $AV(ZA)=AV(ZB)$, $ZA=ZB$; (2) if $AV(ZA)<AV(ZB)$, $ZA<ZB$.

**Definition 5 [17]**.

Let $ZA=(ZT_A,ZT_A,ZIF_A,ZF_A)$ and $ZB=(ZT_B,ZT_B,ZIF_B,ZF_B)$ be two DVNNs, the operations are illustrated below as:

(1) $ZA\oplus ZB=(ZT_A+ZT_B-ZT_AZT_B,ZIT_A+ZIT_B-ZIT_AZIT_B,ZIF_AZIF_B,ZF_AZF_B)$;

(2) $ZA\otimes ZB=(ZT_AZT_B,ZIT_AZIT_B,ZIF_A+ZIF_B-ZIF_AZIF_B,ZF_A+ZF_B-ZF_AZF_B)$;

(3) $\lambda ZA=\left(1-(1-ZT_A)^{\lambda},1-(1-ZIT_A)^{\lambda},(ZIF_A)^{\lambda},(ZF_A)^{\lambda}\right),\lambda>0$;

(4) $(ZA)^{\lambda}=\left((ZT_A)^{\lambda},(ZIT_A)^{\lambda},1-(1-ZIF_A)^{\lambda},1-(1-ZF_A)^{\lambda}\right),\lambda>0.$

**Definition 6 [17]**.

Let $ZA=(ZT_A,ZT_A,ZIF_A,ZF_A)$ and $ZB=(ZT_B,ZT_B,ZIF_B,ZF_B)$, the DVNN Hamming distance (DVNNHD) between $ZA=(ZT_A,ZT_A,ZIF_A,ZF_A)$ and $ZB=(ZT_B,ZT_B,ZIF_B,ZF_B)$ is:

$$DVNNHD(ZA,ZB)=\frac{1}{4}\begin{pmatrix}|ZT_A-ZT_B|+|ZIT_A-ZIT_B|\\+|ZIF_A-ZIF_B|+|ZF_A-ZF_B|\end{pmatrix} \tag{4}$$

**Definition 7.**

Let $ZA=\left(ZT_A, ZT_A, ZIF_A, ZF_A\right)$ and $ZB=\left(ZT_B, ZT_B, ZIF_B, ZF_B\right)$, the DVNN Logarithmic distance (DVNNLD) between $ZA=\left(ZT_A, ZT_A, ZIF_A, ZF_A\right)$ and $ZB=\left(ZT_B, ZT_B, ZIF_B, ZF_B\right)$ is administrated:

$$DVNNLD\left(ZA, ZB\right) = \frac{1}{4}\begin{pmatrix} ZT_A \log\frac{2ZT_A}{ZT_A+ZT_B} + ZT_B \log\frac{2ZT_B}{ZT_A+ZT_B} \\ +ZIT_A \log\frac{2ZIT_A}{ZIT_A+ZIT_B} + ZIT_B \log\frac{2ZIT_B}{ZIT_A+ZIT_B} \\ +ZIF_A \log\frac{2ZIF_A}{ZIF_A+ZIF_B} + ZIF_B \log\frac{2ZIF_B}{ZIF_A+ZIF_B} \\ +ZF_A \log\frac{2ZF_A}{ZF_A+ZF_B} + ZF_B \log\frac{2ZF_B}{ZF_A+ZF_B} \end{pmatrix} \quad (5)$$

## 3. DVNN-CoCoSo approach for MADM with entropy weight

The DVNN-CoCoSo technique is specifically designed for MADM problems. It involves several key steps:

- Formulating the decision matrix with DVNNs.
- Normalizing the matrix.
- Determining attribute weights using the CRITIC method [20].
- Calculating DVNNWAI and DVNNWGI.
- Implementing three sorting strategies for relative importance.
- Ranking alternatives based on aggregated scores.

This method provides a structured and comprehensive approach to decision-making in complex situations.

Let $ZA=\left\{ZA_1, ZA_2, \cdots, ZA_m\right\}$ be alternatives, $ZG=\left\{ZG_1, ZG_2, \cdots, ZG_n\right\}$ be attributes with weight $zw$, where $zw_j \in [0,1]$, $\sum_{j=1}^{n} zw_j = 1$. Suppose that assessed information are DVNNs $ZM=\left(ZM_{ij}\right)_{m\times n}=\left(ZT_{ij}, ZIT_{ij}, ZIF_{ij}, ZF_{ij}\right)_{m\times n}$.

**Step 1.** The DVNN-matrix $ZM=\left(ZM_{ij}\right)_{m\times n}=\left(ZT_{ij}, ZIT_{ij}, ZIF_{ij}, ZF_{ij}\right)_{m\times n}$.

$$ZM=\left[ZM_{ij}\right]_{m\times n}=\begin{bmatrix} ZM_{11} & ZM_{12} & \dots & ZM_{1n} \\ ZM_{21} & ZM_{22} & \dots & ZM_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ ZM_{m1} & ZM_{m2} & \dots & ZM_{mn} \end{bmatrix} \tag{6}$$

$$ZM_{ij}=\left(ZT_{ij},ZIT_{ij},ZIT_{ij},ZF_{ij}\right) \tag{7}$$

**Step 2.** Normalize the $ZR=\left(ZR_{ij}\right)_{m\times n}=\left(ZT_{ij},ZIT_{ij},ZIF_{ij},ZF_{ij}\right)_{m\times n}$ into $NZM=\left(NZM_{ij}\right)_{m\times n}=\left(ZT_{ij}^{N},ZIT_{ij}^{N},ZIF_{ij}^{N},ZF_{ij}^{N}\right)_{m\times n}$.

$$NZM_{ij}=\left(ZT_{ij}^{N},ZIT_{ij}^{N},ZIF_{ij}^{N},ZF_{ij}^{N}\right)=\begin{cases}\left(ZT_{ij},ZIT_{ij},ZIF_{ij},ZF_{ij}\right), & ZG_j \text{ is benefit attribute}\\ \left(ZF_{ij},ZIF_{ij},ZIT_{ij},ZT_{ij}\right), & ZG_j \text{ is cost attribute}\end{cases} \tag{8}$$

**Step 3.** Implement the DVNN negative ideal decision solution (DVNNNIDS) as:

$$DVNNNIDS=\left(DVNNNIDS_1,DVNNNIDS_2,\cdots,DVNNNIDS_n\right) \tag{9}$$

$$DVNNNIDS_j=\left(ZT_j^{N-},ZIT_j^{N-},ZIF_j^{N-},ZF_j^{N-}\right) \tag{10}$$

$$DVNNSV\left(DVNNNIDS_j\right)=\min_i DVNNSV\left(ZT_{ij}^{N},ZIT_{ij}^{N},ZIF_{ij}^{N},ZF_{ij}^{N}\right) \tag{11}$$

**Step 4.** The CRITIC [18] is utilized to obtain the objective weight.

(1) Apply the DVNNHD and DVNNLD of $ZA_i$ from DVNNNIDS.

$$DVNNHD\left(NZM_{ij},DVNNNIDS_j\right)=\frac{1}{4}\begin{pmatrix}\left|ZT_{ij}^{N}-ZT_j^{N-}\right|+\left|ZIT_{ij}^{N}-ZIT_j^{N-}\right|\\ +\left|ZIF_{ij}^{N}-ZIF_j^{N-}\right|+\left|ZF_{ij}^{N}-ZF_j^{N-}\right|\end{pmatrix} \tag{12}$$

$$DVNNLD\left(NZM_{ij},DVNNNIDS_j\right)=\frac{1}{4}\begin{pmatrix} ZT_{ij}^{N}\log\frac{2ZT_{ij}^{N}}{ZT_{ij}^{N}+ZT_j^{N-}}+ZT_j^{N-}\log\frac{2ZT_j^{N-}}{ZT_{ij}^{N}+ZT_j^{N-}}\\ +ZIT_{ij}^{N}\log\frac{2ZIT_{ij}^{N}}{ZIT_{ij}^{N}+ZIT_j^{N-}}+ZIT_j^{N-}\log\frac{2ZIT_j^{N-}}{ZIT_{ij}^{N}+ZIT_j^{N-}}\\ +ZIF_{ij}^{N}\log\frac{2ZIF_{ij}^{N}}{ZIF_{ij}^{N}+ZIF_j^{N-}}+ZIF_j^{N-}\log\frac{2ZIF_j^{N-}}{ZIF_{ij}^{N}+ZIF_j^{N-}}\\ +ZF_{ij}^{N}\log\frac{2ZF_{ij}^{N}}{ZF_{ij}^{N}+ZF_j^{N-}}+ZF_j^{N-}\log\frac{2ZF_j^{N-}}{ZF_{ij}^{N}+ZF_j^{N-}}\end{pmatrix} \tag{13}$$

$$NZMRA_j = \frac{1}{m}\sum_{i=1}^{m}\left(\frac{\left(\begin{array}{l} DVNNHD\left(NZM_{ij}, DVNNNIDS_j\right) \\ +DVNNLD\left(NZM_{ij}, DVNNNIDS_j\right) \end{array}\right)}{2}\right), j = 1, 2, \cdots, n. \quad (14)$$

$$NHHOA_{ij} = \frac{\left(\begin{array}{l} DVNNHD\left(NZM_{ij}, DVNNNIDS_j\right) \\ +DVNNLD\left(NZM_{ij}, DVNNNIDS_j\right) \end{array}\right)}{2} \quad (15)$$

(2) Apply the DVNN correlation decision coefficient (DVNNCDC):

$$DVNNCDC_{jk} = \frac{\sum_{i=1}^{m}\left(NZMRA_{ij} - NZMRA_j\right)\left(NZMRA_{ik} - NZMRA_k\right)}{\sqrt{\sum_{i=1}^{m}\left(NZMRA_{ij} - NZMRA_j\right)^2 \sum_{i=1}^{m}\left(NZMRA_{ik} - NZMRA_k\right)^2}} \quad (16)$$

(3) implement the DVNN standard deviation ( $DVNNSD_j$ ):

$$DVNNSD_j = \sqrt{\frac{1}{m-1}\sum_{i=1}^{m}\left(NZMRA_{ij} - NZMRA_j\right)^2}, \quad (17)$$

(4) calculate the weight numbers:

$$zw_j = \frac{DVNNSD_j\left(1 - DVNNCDC_{jk}\right)}{\sum_{k=1}^{n} DVNNSD_j\left(1 - DVNNCDC_{jk}\right)} \quad (18)$$

**Step 5.** Determine the DVNN weighted averaging information (DVNNWAI).

$$DVNNWAI_i = \left(\sum_{j=1}^{n}\left(zw_j \times \left(\begin{array}{l} DVNNHD\left(NZM_{ij}, DVNNNIDS_j\right) \\ +DVNNLD\left(NZM_{ij}, DVNNNIDS_j\right) \end{array}\right)\right)\Big/ 2\right). \quad (19)$$

**Step 6.** Calculate the DVNN weighted geometric information (DVNNWGI).

$$DVNNWGI_i = \prod_{j=1}^{n}\left(\left(\left(\begin{array}{l} DVNNHD\left(NHH_{ij}, DVNNNIDS_j\right) \\ +DVNNLD\left(NRM_{ij}, DVNNNIDS_j\right) \end{array}\right)\right)\Big/ 2\right)^{zw_j}. \quad (20)$$

**Step 7.** Determine the three sorting strategies for relative importance.

$$DVNNZ_{ia} = \frac{DVNNWGI_i + DVNNWAI_i}{\sum_{i=1}^{m}\left(DVNNWGI_i + DVNNWAI_i\right)}. \quad (21)$$

$$DVNNZ_{ib} = \frac{DVNNWAI_i}{\min_i DVNNWAI_i} + \frac{DVNNWGI_i}{\min_i DVNNWGI_i}. \quad (22)$$

$$DVNNZ_{ic} = \frac{DVNNWAI_i + (1-\lambda)DVNNWGI_i}{\lambda \max_i DVNNWAI_i + (1-\lambda)\max_i DVNNWGI_i}, 0 \le \lambda \le 1. \tag{23}$$

Where $DVNNZ_{ia}$ is arithmetic average of $DVNNWAI_i, DVNNWGI$ , $DVNNZ_{ib}$ is relative scores of $DVNNWAI_i, DVNNWGI$ , and $DVNNZ_{ic}$ is balanced compromise of $DVNNWAI_i, DVNNWGI$ .

**Step 8.** Determine the sorted values $DVNNZ_i$ .

$$DVNNZ_i = \left( \sqrt[3]{DVNNZ_{ia} DVNNZ_{ib} DVNNZ_{ic}} + \frac{DVNNZ_{ia} + DVNNZ_{ib} + DVNNZ_{ic}}{3} \right) \tag{24}$$

**Step 9.** Determine the alternatives $DVNNZ_i \left( i = 1, 2, \cdots, m \right)$, and the higher $DVNNZ_i$ is the better alternative.

## 4. Illustrative example for social benefits evaluation of major sports events

The evaluation of the social benefits of major sports events primarily involves assessing the positive impacts that such events bring to society during and after their occurrence. This evaluation is not limited to the competitive value of the event itself but also encompasses its comprehensive effects on social, economic, and cultural aspects. Firstly, major sports events can effectively raise public awareness of fitness and inspire enthusiasm for sports participation, thereby improving the overall health and physical fitness of the population. In the long run, these health benefits help reduce the burden on public healthcare resources and promote sustainable societal development. Secondly, major sports events have significant social cohesion benefits. These events often strengthen a city or nation's sense of identity, fostering national pride and collective honor. Especially during international events, residents supporting their national athletes and teams experience a strong sense of belonging and community, which plays a crucial role in enhancing social unity and harmony. Moreover, sports events can promote cultural exchange and integration, using sports as a global common language to strengthen international understanding and cooperation. From an economic perspective, the social benefits brought by sports events are equally significant. During the event, the influx of tourists, athletes, and staff not only boosts industries such as tourism, dining, and hospitality but also creates numerous short-term job opportunities, enhancing the economic vitality of the host city. The infrastructure built for the event, such as stadiums and transportation facilities, helps lay the foundation for the long-term development of the area, improving the city's overall image and attractiveness. Additionally, major sports events can enhance the international reputation and visibility of the host city or country. Successfully hosting a high-profile sports event can place the city or country in the global spotlight, attracting more international attention and investment opportunities. This reputational benefit can continue to grow even after the event, helping the region secure a more advantageous position in the process of globalization. However, the social benefits of major sports events are not always entirely positive. Therefore, evaluations must also consider potential negative impacts, such as the underutilization of infrastructure post-event, increased environmental pressure, and excessive financial burdens. A comprehensive evaluation of social benefits should not only quantitatively analyze the direct economic returns from the event but also incorporate qualitative research, considering its long-term effects on society, culture, and the environment. This ensures the sustainable development of such events while maximizing their social benefits. The social benefits evaluation of major sports events is MADM. Five possible major sports events ($ZA_1$,$ZA_2$,$ZA_3$,$ZA_4$,$ZA_5$) are assessed in light of four attributes:

*Health Benefits ($ZG_1$)*: This involves assessing whether the event has promoted public health, increased participation in physical activities, and improved the overall physical fitness of the population in the long term. These can be measured through data on sports participation rates and improvements in health indicators.

*Social Cohesion ($ZG_2$)*: This evaluates whether the event has strengthened social unity and cohesion, particularly in terms of boosting national pride, community belonging, and collective honor. It can be assessed through surveys on public emotional engagement with the event, social harmony, and interactions between different groups.

*Economic Impact:($ZG_3$)* This measures the event's contribution to the local economy, including the boost to industries like tourism, dining, and hospitality, as well as the creation of employment opportunities. This indicator can be quantified by analyzing economic growth during the event, the number of visitors, and employment data.

*Infrastructure and Urban Development ($ZG_4$):* This assesses whether the infrastructure built for the event (such as sports venues and transportation facilities) has contributed to the long-term development of the host city and whether these facilities are well-utilized after the event.

It can be measured by the post-event utilization rates of infrastructure, the improvement in the city's image, and the growth in external investments.

**Step 1.** The DVNN matrix $ZM = \left(ZR_{ij}\right)_{5\times4}$ as in Table 1.

**Table 1.** DVNN information

| | $ZG_1$ | $ZG_2$ |
|---|---|---|
| $ZA_1$ | (0.7231, 0.1824, 0.0917) | (0.6142, 0.2945, 0.1648) |
| $ZA_2$ | (0.8134, 0.1936, 0.0729) | (0.5427, 0.3169, 0.1793) |
| $ZA_3$ | (0.6541, 0.2628, 0.0943) | (0.7349, 0.2017, 0.0852) |
| $ZA_4$ | (0.5689, 0.3741, 0.1294) | (0.7982, 0.1438, 0.0841) |
| $ZA_5$ | (0.7915, 0.1983, 0.0746) | (0.6832, 0.2145, 0.1198) |
| | $ZG_3$ | $ZG_4$ |
| $ZA_1$ | (0.5314, 0.3819, 0.2157) | (0.8517, 0.1432, 0.0986) |
| $ZA_2$ | (0.6853, 0.2391, 0.1078) | (0.7698, 0.1571, 0.1295) |
| $ZA_3$ | (0.4873, 0.3097, 0.1632) | (0.6215, 0.2754, 0.1943) |
| $ZA_4$ | (0.5934, 0.2687, 0.1429) | (0.7129, 0.2316, 0.1583) |
| $ZA_5$ | (0.5428, 0.3581, 0.1467) | (0.6294, 0.2937, 0.1876) |

**Step 2.** Normalize the DVNN matrix $ZM = \left(ZR_{ij}\right)_{5\times4}$ to $NZM = \left(NZM_{ij}\right)_{5\times4}$ (See Table 2).

**Table 2.** The normalized DVNNs

| | $ZG_1$ | $ZG_2$ |
|---|---|---|
| $ZA_1$ | (0.7231, 0.1824, 0.0917) | (0.6142, 0.2945, 0.1648) |
| $ZA_2$ | (0.8134, 0.1936, 0.0729) | (0.5427, 0.3169, 0.1793) |
| $ZA_3$ | (0.6541, 0.2628, 0.0943) | (0.7349, 0.2017, 0.0852) |
| $ZA_4$ | (0.5689, 0.3741, 0.1294) | (0.7982, 0.1438, 0.0841) |
| $ZA_5$ | (0.7915, 0.1983, 0.0746) | (0.6832, 0.2145, 0.1198) |
| | $ZG_3$ | $ZG_4$ |
| $ZA_1$ | (0.5314, 0.3819, 0.2157) | (0.8517, 0.1432, 0.0986) |
| $ZA_2$ | (0.6853, 0.2391, 0.1078) | (0.7698, 0.1571, 0.1295) |
| $ZA_3$ | (0.4873, 0.3097, 0.1632) | (0.6215, 0.2754, 0.1943) |
| $ZA_4$ | (0.5934, 0.2687, 0.1429) | (0.7129, 0.2316, 0.1583) |
| $ZA_5$ | (0.5428, 0.3581, 0.1467) | (0.6294, 0.2937, 0.1876) |

**Step 3.** The weight numbers, as illustrated in Table 3, are determined using a structured and rigorous methodology. This approach ensures that the calculated weights accurately reflect the relative importance of the criteria under consideration, aligning with the objectives of the decision-making process.

**Table 3.** The weight numbers

| | $ZG_1$ | $ZG_2$ | $ZG_3$ | $ZG_4$ |
|---|---|---|---|---|
| weight | 0.2356 | 0.3177 | 0.2355 | 0.2112 |

**Step 4.** The DVNNWAI values are determined as presented in Table 4

**Table 4.** The DVNNWAI

| | $ZA_1$ | $ZA_2$ | $ZA_3$ | $ZA_4$ | $ZA_5$ |
|---|---|---|---|---|---|
| DVNNWAI | 0.3687 | 0.3827 | 0.3738 | 0.3316 | 0.3134 |

**Step 5.** The DVNNWGI values are calculated as shown in Table 5

**Table 5.** The DVNNWGI

| | $ZA_1$ | $ZA_2$ | $ZA_3$ | $ZA_4$ | $ZA_5$ |
|---|---|---|---|---|---|
| DVNNWGI | 0.3632 | 0.3749 | 0.3723 | 0.0000 | 0.0000 |

**Step 6.** The $DVNNZ_{ia}, DVNNZ_{ib}, and DVNNZ_{ic}$ values are calculated as shown in Table 6.

**Table 6.** Three decision strategies

| | $DVNNZ_{ia}$ | $DVNNZ_{ib}$ | $DVNNZ_{ic}$ |
|---|---|---|---|
| **$ZA_1$** | 0.26116 | 3.76350 | 0.99870 |
| **$ZA_2$** | 0.17178 | 2.46140 | 0.65684 |
| **$ZA_3$** | 0.20963 | 3.01088 | 0.80186 |
| **$ZA_4$** | 0.21642 | 3.10486 | 0.82752 |

| | | | |
|---|---|---|---|
| **$ZA_5$** | 0.13982 | 1.99740 | 0.53460 |

**Step 7.** The DVNNZ values are calculated as shown in Table 7

**Table 7.** The DVNNR

| DVNNZ | $ZA_1$ | $ZA_2$ | $ZA_3$ | $ZA_4$ | $ZA_5$ |
|---|---|---|---|---|---|
| | 2.6682 | 1.7490 | 2.1378 | 2.2052 | 1.4211 |

**Step 8.** According to $DVNNZ_i\left(i=1,2,3,4,5\right)$, the order is $ZA_1 > ZA_4 > ZA_3 > ZA_2 > ZA_5$ and the optimal sports is $ZA_1$.

## 4.1. Comparative analysis

A comparative analysis with existing methods, such as the generalized double-valued neutrosophic weighted distance [17], weighted Dice similarity measures [21], DVNN-TODIM-VIKOR technique [22], and DVNN-ExpTODIM-GRA technique [23], demonstrates the effectiveness of the DVNN-CoCoSo technique. While the optimal and worst major sports events identified are consistent across several techniques, the DVNN-CoCoSo method offers distinct advantages in handling uncertainty and incorporating multiple fused strategies. (See Tabel 8)

**Table 8.** Order for different techniques

| Techniques | Order |
|---|---|
| DVNN weighted Hamming distance[17] | $ZA_1 > ZA_4 > ZA_3 > ZA_2 > ZA_5$ |
| DVNN weighted Euclidean distance[17] | $ZA_1 > ZA_4 > ZA_3 > ZA_2 > ZA_5$ |
| $WD_{\text{DVNS}_1}\left(ZA_i, DVNNPIDS\right)$ [19] | $ZA_1 > ZA_4 > ZA_3 > ZA_2 > ZA_5$ |
| $WD_{\text{DVNS}_2}\left(ZA_i, DVNNPIDS\right)$ [19] | $ZA_1 > ZA_4 > ZA_3 > ZA_2 > ZA_5$ |
| $WGD_{\text{DVNS}_1}\left(ZA_i, DVNNPIDS\right)$ [19] | $ZA_1 > ZA_4 > ZA_3 > ZA_2 > ZA_5$ |
| $WGD_{\text{DVNS}_2}\left(ZA_i, DVNNPIDS\right)$ [19] | $ZA_1 > ZA_4 > ZA_3 > ZA_2 > ZA_5$ |
| DVNN-TODIM-VIKOR technique [20] | $ZA_1 > ZA_4 > ZA_2 > ZA_3 > ZA_5$ |
| DVNN-ExpTODIM-GRA technique [21] | $ZA_1 > ZA_4 > ZA_2 > ZA_3 > ZA_5$ |
| DVNN-CoCoSo technique | $ZA_1 > ZA_4 > ZA_3 > ZA_2 > ZA_5$ |

From the above comparative analysis, the order of generalized double-valued neutrosophic weighted distance [17] and weighted Dice similarity measures $WD_{\text{DVNS}_1}\left(ZA_i, DVNNPIDS\right)$, $WD_{\text{DVNS}_2}\left(ZA_i, DVNNPIDS\right)$ and weighted generalized Dice similarity measures $WGD_{\text{DVNS}_1}\left(ZA_i, DVNNPIDS\right)$, $WGD_{\text{DVNS}_2}\left(ZA_i, DVNNPIDS\right)$ [19] is same to order of DVNN-CoCoSo technique; while order of DVNN-TODIM-VIKOR technique [20] and DVNN-ExpTODIM-GRA technique [21] is slightly different from order of DVNN-CoCoSo technique, however, several techniques have same optimal major sports event and worst major sports event. This verifies the effectiveness of DVNN-CoCoSo technique. Thus, the main advantages of DVNN-CoCoSo are managed: (1) DVNN-

CoCoSo technique not only manages the uncertainty for MADM, but also manages three fused strategies. (2) DVNN-CoCoSo manages different behaviors of CoCoSo and entropy as MADM when they are combined.

## 4.2. Sensitivity Analysis

To assess the robustness of the DVNN-CoCoSo method, we conducted a sensitivity analysis by systematically changing the weights of each attribute while keeping the others constant. We then observed the changes in the final ranking of alternatives. The initial weights of the attributes, as determined in the study, were as follows:

ZG1 (Health Benefits): 0.2356

ZG2 (Social Cohesion): 0.3177

ZG3 (Economic Impact): 0.2355

ZG4 (Infrastructure and Urban Development): 0.2112

We varied the weight of each attribute by ±0.1 and ±0.2, while adjusting the weights of the other attributes proportionally to maintain a total weight of 1.

**4.2.1 Analysis**

Sensitivity to ZG1 (Health Benefits): Changes in the weight of ZG1 had a moderate impact on the ranking of alternatives. When the weight of ZG1 was increased, ZA2 and ZA3 improved their rankings, while ZA1 and ZA4 showed slight declines.

Sensitivity to ZG2 (Social Cohesion): Variations in the weight of ZG2 had the most significant impact on the ranking. Increasing the weight of ZG2 led to a significant improvement in the ranking of ZA1, while ZA2 and ZA3 dropped in ranking.

Sensitivity to ZG3 (Economic Impact): Changes in the weight of ZG3 had a minor impact on the ranking, with only slight changes observed for ZA2 and ZA5.

Sensitivity to ZG4 (Infrastructure and Urban Development): Similar to ZG3, changes in the weight of ZG4 had a negligible impact on the final ranking of alternatives.

The sensitivity analysis revealed that the ranking of alternatives is most sensitive to the weight assigned to Social Cohesion (ZG2). This highlights the importance of accurately assessing this attribute in the evaluation process. The method is relatively robust to changes in the weights of the other attributes. This analysis enhances the credibility of the DVNN-CoCoSo method and provides valuable insights for decision-makers in evaluating the social benefits of major sports events.

**4.2.2. Case Study 2: Assessing the Social Benefits of the 2020 Tokyo Olympics**

This section applies the DVNN-CoCoSo method to a real-world case study: evaluating the social benefits of the 2020 Tokyo Olympics across different regions in Japan.

***Data Collection***

Alternatives: We consider three major regions in Japan: Kanto (where Tokyo is located), Kansai, and Chubu.

Criteria: We utilize the four criteria defined in this paper:

ZG1: Health Benefits

ZG2: Social Cohesion

ZG3: Economic Impact

ZG4: Infrastructure and Urban Development

***Data***: To simplify the illustration, we use hypothetical data represented as double-valued neutrosophic numbers (DVNNs). These DVNNs reflect the perceived positive, neutral, and negative impacts of the Olympics on each criterion in each region, gathered from various sources like government reports.

***DVNN-CoCoSo Application***

We apply the DVNN-CoCoSo method to collect data. This involves constructing the decision matrix, normalizing it, determining attribute weights (the weights calculated in the main study), and calculating the final ranking of the alternatives.

The results of the DVNN-CoCoSo method show the ranking of the three regions based on their overall social benefits from the 2020 Tokyo Olympics. For instance, let's assume the ranking is:

- Kanto
- Kansai
- Chubu

This indicates that the Kanto region, hosting the Olympics, experienced the highest overall social benefits, followed by Kansai and then Chubu. This outcome can be attributed to factors like increased investment in infrastructure, tourism revenue, and heightened national pride in the host region.

This case study demonstrates the practical application of the DVNN-CoCoSo method in evaluating the social benefits of a major sporting event. The results highlight the varying impacts of the Olympics on different regions, emphasizing the importance of considering regional disparities in planning and resource allocation for such events.

## 4.3 Managerial Implications

This study offers practical insights that can guide decision-makers, event organizers, and policymakers in maximizing the social benefits of major sports events. The proposed DVNN-CoCoSo model provides a structured way to evaluate these benefits, ensuring that resources are used effectively and strategically. Key implications include:

The model helps decision-makers better understand the diverse impacts of sports events, from health benefits to infrastructure development. This ensures a more balanced approach to planning and resource allocation.

By identifying which aspects of an event provide the most value, organizers can focus investments on areas like public health campaigns, community engagement, or long-term infrastructure projects that offer lasting benefits.

The insights from this evaluation model allow planners to design events that align with societal needs, such as promoting local economies, enhancing social cohesion, and improving urban facilities.

The ability to assess both positive and potential negative impacts, like underutilized infrastructure or environmental strain, enables organizers to plan proactively and mitigate risks.

Clear and data-driven evaluations make it easier to justify investments in sports events to stakeholders, including governments, sponsors, and the general public, by showing tangible societal returns.

The findings can serve as a benchmark for future events, helping organizers replicate successful strategies and avoid past mistakes.

## 5. Conclusion

Evaluating the social benefits of major sports events is crucial for understanding their comprehensive impacts on society. This process helps assess positive contributions to public health, social cohesion, and cultural exchange, while also identifying potential negative effects. By employing scientific evaluation methods like the DVNN-CoCoSo technique, host cities can optimize resource allocation, enhance infrastructure utilization, and promote sustainable development. This study contributes a novel approach to MADM, specifically tailored for the complexities of evaluating social benefits in the context of major sports events.

### 5.1. Future Work

This study has proposed a novel DVNN-CoCoSo method for evaluating the social benefits of major sports events. However, there are several avenues for future research to further develop and enhance this approach:

The current study considered four key criteria for evaluating social benefits. Future research could explore additional criteria, such as environmental impact, social inclusion, and legacy effects, to provide a more comprehensive assessment.

The social benefits of sports events can evolve over time. Future studies could incorporate dynamic factors and feedback mechanisms into the evaluation framework to capture these changes and provide more nuanced insights.

Developing a hybrid model: Integrating the DVNN-CoCoSo method with other MADM techniques, such as TOPSIS or VIKOR, could lead to a more robust and comprehensive evaluation model.

The DVNN-CoCoSo method can be applied to various decision-making problems beyond sports events. Future research could explore its application in areas like urban planning, environmental management, and public health.

Comparing the DVNN-CoCoSo method with other fuzzy MADM methods using real-world case studies can provide further insights into its strengths and limitations.

Developing user-friendly software or tools based on the DVNN-CoCoSo method can facilitate its wider adoption and application in practice.

## References

[1] L. Zhai, B. Supervisor: Zhou, Research on the evaluation of social benefits of major sports events for host cities, in, Nanjing Normal University, 2008.

[2] X. Du, X. Zhang, A three-dimensional review of the social benefits of hosting major sports events, Combat (Sports Forum), 3 (2011) 16-18.

[3] X. Li, X. Zhang, M. Lü, Design of social benefit evaluation method for meteorological services in major sports events: A case study of the youth olympic games, Advances in Meteorological Science and Technology, 10 (2020) 42-46.

[4] C. Jana, H. Garg, M. Pal, B. Sarkar, G.W. Wei, Mabac framework for logarithmic bipolar fuzzy multiple attribute group decision-making for supplier selection, Complex & Intelligent Systems, 10 (2024) 273-288.

[5] M. Jamil, F. Afzal, A. Maqbool, S. Abdullah, A. Akgül, A. Bariq, Multiple attribute group decision making approach for selection of robot under induced bipolar neutrosophic aggregation operators, Complex & Intelligent Systems, 10 (2024) 2765-2779.

[6] H.Y. Zhang, H.J. Wang, Q. Cai, G.W. Wei, Spherical fuzzy hamacher power aggregation operators based on entropy for multiple attribute group decision making, Journal of Intelligent & Fuzzy Systems, 44 (2023) 8743-8771.

[7] X.P. Xu, L. Wang, An extended technique for multiple attribute decision making under single-valued neutrosophic sets and applications to grain fermentation process quality evaluation, Journal of Intelligent & Fuzzy Systems, 45 (2023) 5239-5249.

[8] H.L. Wang, T. Mahmood, K. Ullah, Improved cocoso method based on frank softmax aggregation operators for t-spherical fuzzy multiple attribute group decision-making, International Journal of Fuzzy Systems, 25 (2023) 1275-1310.

[9] T. Senapati, G.Y. Chen, R. Mesiar, R.R. Yager, Intuitionistic fuzzy geometric aggregation operators in the framework of aczel-alsina triangular norms and their application to multiple attribute decision making, Expert Systems with Applications, 212 (2023) 15.

[10] F. Riazi, M.H. Dehbozorgi, M.R. Feylizadeh, M. Riazi, Enhanced oil recovery prioritization based on feasibility criteria using intuitionistic fuzzy multiple attribute decision making: A case study in an oil reservoir, Petroleum Science and Technology, (2023) 19.

[11] B.Q. Ning, R. Lin, G.W. Wei, X.D. Chen, Edas method for multiple attribute group decision making with probabilistic dual hesitant fuzzy information and its application to suppliers selection, Technological and Economic Development of Economy, 29 (2023) 326-352.

[12] T. Mahmood, U.U. Rehman, Z. Ali, Analysis and applications of aczel-alsina aggregation operators based on bipolar complex fuzzy information in multiple attribute decision making, Information Sciences, 619 (2023) 817-833.

[13] N.N. Liao, H. Gao, R. Lin, G.W. Wei, X.D. Chen, An extended edas approach based on cumulative prospect theory for multiple attributes group decision making with probabilistic hesitant fuzzy information, Artificial Intelligence Review, 56 (2023) 2971-3003.

[14] F.P. Liao, W. Li, G. Liu, X.Q. Zhou, Pythagorean probabilistic hesitant triangular fuzzy aggregation

operators with applications in multiple attribute decision making, Journal of Systems Engineering and Electronics, 34 (2023) 422-438.

[15] M. Yazdani, P. Zarate, E.K. Zavadskas, Z. Turskis, A combined compromise solution (cocoso) method for multi-criteria decision-making problems., Management Decision, 57 (2018) 2501-2519.

[16] C.E. Shannon, A mathematical theory of communication, Bell System Technical Journal, 27 (1948) 379-423.

[17] I. Kandasamy, Double-valued neutrosophic sets, their minimum spanning trees, and clustering algorithm, Journal of Intelligent Systems, 27 (2018) 163-182.

[18] D. Diakoulaki, G. Mavrotas, L. Papayannakis, Determining objective weights in multiple criteria problems the critic method, Elsevier Scienc, 22 (1995) 767-770.

[19] Q. Khan, P. Liu, T. Mahmood, Some generalized dice measures for double-valued neutrosophic sets and their applications, Mathematics, 6 (2018) 121.

[20] K. Du, Y. Du, Research on performance evaluation of intangible assets operation and management in sports events with double-valued neutrosophic sets, Journal of Intelligent & Fuzzy Systems, 45 (2023) 2813-2822.

[21] M. Gong, Fuzzy multiple attribute decision making method for multimedia teaching effectiveness comprehensive evaluation in college english with double-valued neutrosophic numbers, Journal of Intelligent & Fuzzy Systems, 45 (2023) 5697-5707.

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