*Operational Research in Engineering Sciences: Theory and Applications*
*Vol. 2, Issue 2, 2019, pp. 55-71*
*ISSN: 2620-1607*
*eISSN: 2620-1747*
*DOI:_ https://doi.org/10.31181/oresta1902039p*

# SELECTION OF A LOCATION FOR THE DEVELOPMENT OF MULTIMODAL LOGISTICS CENTER: APPLICATION OF SINGLE-VALUED NEUTROSOPHIC MABAC MODEL

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Received: 16 May 2019
Accepted: 05 August 2019
First online: 18 August 2019

Original scientific paper

***Abstract.*** *Logistics center (LC) is unique technological, spatial, organizational and economic unity that brings together different providers and users of logistics services. By selecting the optimal LC location, transport costs are reduced and business performance, competitiveness and profitability are improved. In order to achieve the overall optimum, it is necessary to perform adequate evaluation and selection of the optimal location for the construction of a LC. In this paper is performed the evaluation of potential locations based on new approach in the field of logistics. Weight coefficients of criteria are determined using objective model integrated in Single-Valued Neutrosophic (SVNN) Multi-Attributive Border Approximation Area Comparison (MABAC) model. In order to determine the stability of the model, the SVNN MABAC model is compared with other representative multi-criteria models. In the final part of the model validation, statistical correlation between the SVNN MABAC model and other MCDM approaches (SVNN WASPAS, SVNN VIKOR, SVNN TOPSIS and SVNN CODAS) is performed.*

**Key words**: *single-valued neutrosophic sets, MABAC, logistics center, multi-criteria decision making.*

## 1. Introduction

A logistics center (LC) location selection presents the process of selecting one of several possible solutions. A large number and heterogeneity of location factors clearly indicate that location issues are interdisciplinary and often require the application of complex procedures when searching for a solution. There are numerous methodologies and procedures that are available concerning this issue (Kaboli et al, 2007; Lai et al, 2010; Sun, 2012; Zare at al, 2013; Rahmaniani et al, 2013). The problem

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of location selection for the development of a logistics center can be considered as a special case within general facility location problem.

There are different studies associated with location selection decisions that have been commonly carried out by using multi-criteria decision-making (MCDM) techniques, such as distribution centre selection with weighted fuzzy factor rating system (Ou & Chou, 2009), selection of distribution centres with three-stage hierarchy of selection (Vinh & Devinder, 2005), distribution location problem with QFD (Chuang, 2002), location problem with fuzzy-AHP (Kaboli et al, 2007), location problem with MOORA and COPRAS method (Rezaeiniya et al, 2012), select distribution centers for a firm and location choice of distribution centers with PROMETHEE method (Fernández-Castro and Jiménez, 2005), logistic centre selection with dynamic dual-diamond model (Cao Yunzhong, 2009), logistics distribution location based on genetic algorithms and fuzzy comprehensive evolution (Shao et al, 2009), intermodal freight hub location decision with multi-objective evaluation model (Sirikijpanichkul & Ferreira, 2005; 2006), location selection of logistics centre based on fuzzy AHP and TOPSIS (Wang & Liu, 2007), selection of logistics centre location with fuzzy TOPSIS based on entropy weight (Chen & Liu, 2006), facility or plant location selection with multiple objective decision making (Farahani & Asgari, 2007), facility location selection with AHP and ELECTRE (Yang & Lee, 1997), convenience store location with fuzzy-AHP (Kuo et al, 2002), port selection with AHP and PROMETHEE (Ugboma et al, 2006), reverse logistics location selection with MOORA (Kannan et al, 2008), selecting a site for a logistical centre on factor and methods (Chen & Liu, 2006), logistic centre selection with fuzzy-AHP and ELECTRE Method (Ghoseiri & Lessan, 2008) and multi-modal hub location (Ashayeri & Kampstra, 2002).

The research shown in the previous section show that in the process of selecting a LC location, MOORA, COPRAS, TOPSIS, ELECTRE and PROMETHEA methods are often used in fuzzy or crisp environment. However, multi-criteria decision-making models that contain qualitative or quantitative attribute values can not always be expressed with crisp numbers. In traditional multi-criteria models (MCDM), the weight of every attribute and rank of alternatives are presented with crisp numbers. Though, in reality a decision maker may prefer attribute assessment using linguistic variables, instead of crisp values, due to partial knowledge of attributes or lack of information from the domain of the problem. A fuzzy set presented by Zadeh (1965) is one of the tools used to present such imprecision in mathematical form. Nevertheless, a fuzzy set can not present the degree of non-affiliation and the degree of imprecision of imprecise parameters.

In order to partially overcome the difficulties in defining imprecise parameters Atanassov (1986) introduced Intuitionistic fuzzy sets (IFS) characterized with the degree of affiliation and non-affiliation simultaneously. However, in the IFS, the sum of the degree of affiliation and the degree of non-affiliation of the imprecise parameter is less than a unity. That is why Smarandache (1999) presented the concept of neutrosophic sets (NS) in order to deal with unspecified or inconsistent information that usually exist in reality. The concept of neutrosophic set is a general platform that extends the concepts of classic sets, fuzzy sets (Zadeh, 1965), Intuitionistic fuzzy sets (Atanassov, 1986) and interval valued Intuitionistic fuzzy sets (Atanassov and Gargov, 1989).

Unlike Intuitionistic fuzzy sets and interval valued Intuitionistic fuzzy sets, in neutrosophic set uncertainty is explicitly characterized. The neutrosophic set (NS) has three basic components: (1) the truth function $T$, (2) the indeterminacy function $I$ and

(3) the falsity function *F*. Each of these components in the neutrosophic set is defined independently. However, so defined neutrosophic set hardly finds application in real scientific and engineering field. That is why Wang and others developed the concept of interval-valued neutrosophic sets (IVNS) (Wang et al, 2005) and the concept of single-valued neutrosophic sets (SVNS) (Wang et al, 2010). Due to the large presence of uncertainty, imprecision and inconsistency in subjective assessments, and due to simple application in practical problems, IVNS and SVNS have quickly become widely applied in reality (Ye, 2013).

In this paper, the LC location selection is performed by using Single-Valued Neutrophic Multi-Attributive Border Approximation Area Comparison (MABAC) method (SVNN MABAC). Within the SVN MABAC algorithm, objective approach has been implemented to determine weight coefficients of criteria based on single-valued neutrosophic numbers (SVNN). This paper has several goals. The first goal is to develop new multi-criteria model that integrates the SVNN concept with objective approach for determining weight coefficients and the MABAC method and improves the field of multi-criteria decision making. The second goal of the paper is to form completely new methodology to enable decision-makers to evaluate potential locations for a LC development in the case of partially known values and uncertain values of the decision attributes.

The paper is organized in the following way. After the introduction, in the second section is presented single-valued neutrosophic concept and basic arithmetic operations with the SVNN. The model for evaluating potential locations for LC development using the SVNN MABAC model is formed in the third section. The fourth section shows the application of the SVNN MABAC model and validation of the results obtained. Finally, the fifth section provides final conclusions.

## 2. Single-valued neutrosophic set

According to the definition of neutrosophic set, neutrosophic set *A* is universal set *X* characterized by membership function used to describe truth (truth-membership function) $T_A(x)$, membership function used to describe indeterminacy (indeterminacy-membership function) $I_A(x)$ and membership function used to describe falsity (falsity-membership function) $F_A(x)$, where $T_A(x)$, $I_A(x)$ and $F_A(x)$ are real standard or non standard subsets ranging in the interval $[^-0,1^+]$, so that each of the three neutrosophic components meets the condition where $T_A(x) \rightarrow [^-0,1^+]$, $I_A(x) \rightarrow [^-0,1^+]$ and $F_A(x) \rightarrow [^-0,1^+]$.

The set $I_A(x)$ can be used not only to present indeterminacy, but also to present uncertainty, inaccuracy, imprecision, error, contradiction, undefined, unknown, incomplete, redundancy, etc.. (Ghaderi et al, 2012; Biswas et al, 2016). In order to cover all the unclear information, indeterminacy-membership degree can be divided in subcomponets, such as "contradiction", "uncertainty" and ''unknown'' (Smarandache, 2005).

Sum of these three membership functions of the neutrosophic set $T_A(x)$, $I_A(x)$ and $F_A(x)$ should meet the following condition (Biswas et al, 2016) $^-0 \le T_A(x) + I_A(x) + F_A(x) \le 3^+$. The component of the neutrosophic set *A* for all the values of $x \in X$ is determined with $A^C$ so that $T_A^c(x) = 1^+ - T_A(x)$, $I_A^c(x) = 1^+ - I_A(x)$ and $F_A^c(x) = 1^+ - F_A(x)$. Neutrosophic set *A* is contained in another neutrosophic set B (respectively $A \subseteq B$ ) if and only if for every value $x \in X$ the following conditions are met: $\inf T_A(x) \le \inf T_B(x)$, $\sup T_A(x) \le \sup T_B(x)$, $\inf I_A(x) \ge \inf I_B(x)$, $\sup I_A(x) \ge \sup I_B(x)$, $\inf F_A(x) \ge \inf F_B(x)$ and $\sup F_A(x) \ge \sup F_B(x)$.

The SVNS are a special case of neutrophysic sets that can be successfully used in real scientific and engineering applications. The following section provides some basic definitions, operations and properties of the SVNS (Deli and Şubaş, 2017).

*Definition 1*. Let $X$ be universal point (objects) space with generic element $X$ marked with *x*. Then, single-valued neutrosophic set $\tilde{N} \subset X$ is presented with $T_{\tilde{N}}(x)$ truth membership function, $I_{\tilde{N}}(x)$ indeterminacy membership function and $F_{\tilde{N}}(x)$ falsity membership function with the condition $T_{\tilde{N}}(x),\ I_{\tilde{N}}(x),\ F_{\tilde{N}}(x) \in [0,1]$ for every $x \in X$.

Next we can mark SVNS in a simplified manner as

$$\tilde{N} = \{\langle x, T(x), I(x), F(x)\rangle \mid x \in X\} \tag{1}$$

In this paper, for the sake of simplicity the SVNS $\tilde{N} = \{\langle x, T(x), I(x), F(x)\rangle \mid x \in X\}$ will be presented with the simplified expression $\tilde{N} = \{\langle T(x), I(x), F(x)\rangle \mid x \in X\}$.

The sum of truth membership function $T_{\tilde{N}}(x)$, indeterminacy membership function $I_{\tilde{N}}(x)$ and falsity membership function $F_{\tilde{N}}(x)$ of SVNS meets the following relation

$$0 \le T_{\tilde{N}}(x) + I_{\tilde{N}}(x) + F_{\tilde{N}}(x) \le 3,\ \forall x \in X \tag{2}$$

When *X* is continuous object space, then single-valued neutrosophic set $\tilde{N}$ can be presented as

$$\tilde{N} = \int_x \left\langle T_{\tilde{N}}(x),\ I_{\tilde{N}}(x),\ F_{\tilde{N}}(x)\right\rangle \mid x,\ \forall x \in X \tag{3}$$

When *X* is discrete object space, then single-valued neutrosophic set $\tilde{N}$ can be presented as

$$\tilde{N} = \sum_x \left\langle T_{\tilde{N}}(x),\ I_{\tilde{N}}(x),\ F_{\tilde{N}}(x)\right\rangle \mid x,\ \forall x \in X \tag{4}$$

Therefore, final SVNC can be presented as follows

$$\tilde{N} = \left\{\left(\left\langle x_1, T_{\tilde{N}}(x_1), I_{\tilde{N}}(x_1), F_{\tilde{N}}(x_1)\right\rangle\right), \ldots, \left(\left\langle x_n, T_{\tilde{N}}(x_n), I_{\tilde{N}}(x_n), F_{\tilde{N}}(x_n)\right\rangle\right)\right\}; \\ \forall x_i \in X, i = 1,2,\ldots,n \tag{5}$$

*Definition 2*. Let $\tilde{A} = \left\{\left\langle T_{\tilde{A}}(x), I_{\tilde{A}}(x), F_{\tilde{A}}(x)\right\rangle\right\}$ and $\tilde{B} = \left\{\left\langle T_{\tilde{B}}(x), I_{\tilde{B}}(x), F_{\tilde{B}}(x)\right\rangle\right\}$ present two SVNS, and then the following operations can be defined on the mentioned SVNS (Wang et al, 2010):

(1) $\tilde{A} \subseteq \tilde{B}$ if and only if for every value of $x \in X$ are met the following conditions $T_{\tilde{A}}(x) \le T_{\tilde{B}}(x)$, $I_{\tilde{A}}(x) \ge I_{\tilde{B}}(x)$, $F_{\tilde{A}}(x) \ge F_{\tilde{B}}(x)$.

(2) $\tilde{A} = \tilde{B}$ if and only if for every value of $x \in X$ is met that $\tilde{A} \subseteq \tilde{B}$ and $\tilde{B} \subseteq \tilde{A}$.

(3) $\tilde{A}^c = \left\{x \mid \left\langle F_{\tilde{A}}(x), 1 - I_{\tilde{A}}(x), T_{\tilde{A}}(x), \right\rangle \mid x \in X\right\}, \forall x \in X$.

(4) $\tilde{A} \cup \tilde{B} = \left\langle \max\left(T_{\tilde{A}}(x), T_{\tilde{B}}(x)\right), \min\left(I_{\tilde{A}}(x), I_{\tilde{B}}(x)\right), \min\left(F_{\tilde{A}}(x), F_{\tilde{B}}(x)\right)\right\rangle, \forall x \in X$.

(5) $\tilde{A} \cap \tilde{B} = \left\langle \min\left(T_{\tilde{A}}(x), T_{\tilde{B}}(x)\right), \max\left(I_{\tilde{A}}(x), I_{\tilde{B}}(x)\right), \max\left(F_{\tilde{A}}(x), F_{\tilde{B}}(x)\right)\right\rangle, \forall x \in X$.

Let $\tilde{A} = \left\{\left\langle T_{\tilde{A}}(x), I_{\tilde{A}}(x), F_{\tilde{A}}(x)\right\rangle\right\}$ and $\tilde{B} = \left\{\left\langle T_{\tilde{B}}(x), I_{\tilde{B}}(x), F_{\tilde{B}}(x)\right\rangle\right\}$ present two SVNS, and then the operations with $\tilde{A}$ and $\tilde{B}$ are defined with the following expressions (Smarandache, 2016):

(1) Addition SVNS "+"

$$\tilde{A} + \tilde{B} = \left\langle \begin{array}{l} T_{\tilde{A}}(x) + T_{\tilde{B}}(x) - T_{\tilde{A}}(x) \cdot T_{\tilde{B}}(x), \\ I_{\tilde{A}}(x) + I_{\tilde{B}}(x) - I_{\tilde{A}}(x) \cdot I_{\tilde{B}}(x), \\ F_{\tilde{A}}(x) + F_{\tilde{B}}(x) - F_{\tilde{A}}(x) \cdot F_{\tilde{B}}(x) \end{array} \right\rangle \tag{6}$$

(2) Subtraction SVNS "−"

$$\tilde{A} - \tilde{B} = \left\langle \frac{T_{\tilde{A}}(x) - T_{\tilde{B}}(x)}{1 - T_{\tilde{B}}(x)}, \frac{I_{\tilde{A}}(x)}{I_{\tilde{B}}(x)}, \frac{F_{\tilde{A}}(x)}{F_{\tilde{B}}(x)} \right\rangle \tag{7}$$

where $T_{\tilde{A}}(x), I_{\tilde{A}}(x), F_{\tilde{A}}(x)$, $T_{\tilde{B}}(x), I_{\tilde{B}}(x), F_{\tilde{B}}(x) \in [0,1]$ with the limitation of $T_{\tilde{B}}(x) \neq 1$, $I_{\tilde{B}}(x) \neq 0$ and $F_{\tilde{B}}(x) \neq 0$.

(3) Multiplication SVNS "×"

$$\tilde{A} \times \tilde{B} = \left\langle T_{\tilde{A}}(x) \cdot T_{\tilde{B}}(x), I_{\tilde{A}}(x) \cdot I_{\tilde{B}}(x), F_{\tilde{A}}(x) \cdot F_{\tilde{B}}(x) \right\rangle \tag{8}$$

(4) Division SVNS "÷"

$$\tilde{A} \div \tilde{B} = \left\langle \frac{T_{\tilde{A}}(x)}{T_{\tilde{B}}(x)}, \frac{I_{\tilde{A}}(x) - I_{\tilde{B}}(x)}{1 - I_{\tilde{B}}(x)}, \frac{F_{\tilde{A}}(x) - F_{\tilde{B}}(x)}{1 - F_{\tilde{B}}(x)} \right\rangle \tag{9}$$

where $T_{\tilde{A}}(x), I_{\tilde{A}}(x), F_{\tilde{A}}(x)$, $T_{\tilde{B}}(x), I_{\tilde{B}}(x), F_{\tilde{B}}(x) \in [0,1]$ with the limitation of $T_{\tilde{B}}(x) \neq 0$, $I_{\tilde{B}}(x) \neq 1$ and $F_{\tilde{B}}(x) \neq 1$.

(5) Scalar multiplication SVNS where $k > 0$

$$k \times \tilde{A} = \left\langle 1 - \left(1 - T_{\tilde{A}}(x)\right)^k, \left(I_{\tilde{A}}(x)\right)^k, \left(F_{\tilde{A}}(x)\right)^k \right\rangle \tag{10}$$

(6) SVNS power, where $k > 0$

$$\tilde{A}^k = \left\langle \left(T_{\tilde{A}}(x)\right)^k, 1 - \left(1 - I_{\tilde{A}}(x)\right)^k, 1 - \left(1 - F_{\tilde{A}}(x)\right)^k \right\rangle \tag{11}$$

*Definition 3 (Euclidean distance).* Let

$\tilde{A} = \left\{\left(\left\langle x_1, T_{\tilde{A}}(x_1), I_{\tilde{A}}(x_1), F_{\tilde{A}}(x_1)\right\rangle\right), \ldots, \left(\left\langle x_n, T_{\tilde{A}}(x_n), I_{\tilde{A}}(x_n), F_{\tilde{A}}(x_n)\right\rangle\right)\right\}$ and

$\tilde{B} = \left\{\left(\left\langle x_1, T_{\tilde{B}}(x_1), I_{\tilde{B}}(x_1), F_{\tilde{B}}(x_1)\right\rangle\right), \ldots, \left(\left\langle x_n, T_{\tilde{B}}(x_n), I_{\tilde{B}}(x_n), F_{\tilde{B}}(x_n)\right\rangle\right)\right\}$ be two SVNS where

$\forall x_i \in X \ (i = 1, 2, \ldots, n)$. Then, Euclidean distance between the two SVNS $\tilde{A}$ and $\tilde{B}$ is defined as follows:

$$d_{Eu}(\tilde{A},\tilde{B}) = \sqrt{\sum_{i=1}^{n}\left\{\left(T_{\tilde{A}}(x_i) - T_{\tilde{B}}(x_i)\right)^2 + \left(I_{\tilde{A}}(x_i) - I_{\tilde{B}}(x_i)\right)^2 + \left(F_{\tilde{A}}(x_i) - F_{\tilde{B}}(x_i)\right)^2\right\}} \quad (12)$$

Normalized Euclidean distance between two SVNS $\tilde{A}$ and $\tilde{B}$ is obtained with the application of the following expression

$$d_{Eu}^{n}(\tilde{A},\tilde{B}) = \sqrt{\frac{1}{3n}\sum_{i=1}^{n}\left\{\left(T_{\tilde{A}}(x_i) - T_{\tilde{B}}(x_i)\right)^2 + \left(I_{\tilde{A}}(x_i) - I_{\tilde{B}}(x_i)\right)^2 + \left(F_{\tilde{A}}(x_i) - F_{\tilde{B}}(x_i)\right)^2\right\}} \quad (13)$$

*Definition 4*. Let $\tilde{A} = \left\{\left\langle T_{\tilde{A}}(x), I_{\tilde{A}}(x), F_{\tilde{A}}(x)\right\rangle\right\}$ be single valued neutrosophic number, and then the score function $S(\tilde{A})$ can be determined as crisp value by applying the following expression (Zavadskas et al, 2015)

$$S(\tilde{A}) = \frac{3 + T_{\tilde{A}}(x) - 2I_{\tilde{A}}(x) - F_{\tilde{A}}(x)}{4} \quad (14)$$

where the score function is defined in the interval $S(\tilde{A}) \in [0,1]$. Such defined score function allows obtaining crisp values ranging in the same interval as $\tilde{A}$ .

*Definition 5*. Let $\tilde{A} = \left\{\left\langle T_{\tilde{A}}(x), I_{\tilde{A}}(x), F_{\tilde{A}}(x)\right\rangle\right\}$ and $\tilde{B} = \left\{\left\langle T_{\tilde{B}}(x), I_{\tilde{B}}(x), F_{\tilde{B}}(x)\right\rangle\right\}$ be any of the SVNS. Then, if the condition $S(\tilde{A}) < S(\tilde{B})$ is valid, single valued neutrosophic number $\tilde{A}$ is smaller than single valued neutrosophic number $\tilde{B}$, respectively $\tilde{A} < \tilde{B}$.

*Definition 6*. The fuzzification of the SVNS $\tilde{N} = \left\{(x \mid \left\langle T_{\tilde{N}}(x), I_{\tilde{N}}(x), F_{\tilde{N}}(x)\right\rangle) \mid x \in X\right\}$ can be defined as the process of mapping $\tilde{N}$ in the fuzzy set $\tilde{F} = \left\{x \mid \mu_{\tilde{F}}(x) \mid x \in X\right\}$, respectively $f = \tilde{N} \to \tilde{F}$ for $x \in X$. Representative degree of membership to the fuzzy function $\mu_{\tilde{F}}(x) \in [0,1]$ of the vector $\left\{(x \mid \left\langle T_{\tilde{N}}(x), I_{\tilde{N}}(x), F_{\tilde{N}}(x)\right\rangle) \mid x \in X\right\}$ is defined as follows

$$\mu_{\tilde{F}}(x) = 1 - \sqrt{\left\{\left(1 - T_{\tilde{N}}(x)\right)^2 + \left(I_{\tilde{N}}(x)\right)^2 + \left(F_{\tilde{N}}(x)\right)^2\right\} \Big/ 3} \quad (15)$$

## 3. Single valued neutrosophic MABAC method

*Step 1.* Forming initial decision-making matrix (*N*). The evaluation of alternatives by criteria is performed by *m* experts $\{E_1, E_2, \ldots, E_m\}$ with the assigned weight coefficients $\{\varpi_1, \varpi_2, \ldots, \varpi_m\}$, $0 \le \varpi_e \le 1, \ (e = 1,2,\ldots,m)$, $\sum_{e=1}^{m}\varpi_e = 1$. With the aim of final ranking of alternatives $a_i \in A$ ($i = 1,2,..,b$), every expert $E_e$ ($e = 1,2,\ldots,m$) evaluates alternatives by the defined set of criteria $C = \{c_1, c_2, \ldots c_n\}$. Therefore, for every expert is formed related initial decision-making matrix

$$N^{(e)} = \left[\eta_{ij}^{(e)}\right]_{b\times n} = \begin{bmatrix} \eta_{11}^{(e)} & \eta_{12}^{(e)} & \cdots & \eta_{1n}^{(e)} \\ \eta_{21}^{(e)} & \eta_{22}^{(e)} & \cdots & \eta_{2n}^{(e)} \\ \vdots & \vdots & \ddots & \vdots \\ \eta_{b1}^{(e)} & \eta_{b2}^{(e)} & \cdots & \eta_{bn}^{(e)} \end{bmatrix}$$
$$= \begin{bmatrix} \left\langle T_{\eta 11}^{(e)}, I_{\eta 11}^{(e)}, F_{\eta 11}^{(e)} \right\rangle & \left\langle T_{\eta 12}^{(e)}, I_{\eta 12}^{(e)}, F_{\eta 12}^{(e)} \right\rangle & \cdots & \left\langle T_{\eta 1n}^{(e)}, I_{\eta 1n}^{(e)}, F_{\eta 1n}^{(e)} \right\rangle \\ \left\langle T_{\eta 11}^{(e)}, I_{\eta 11}^{(e)}, F_{\eta 11}^{(e)} \right\rangle & \left\langle T_{\eta 22}^{(e)}, I_{\eta 22}^{(e)}, F_{\eta 22}^{(e)} \right\rangle & \cdots & \left\langle T_{\eta 2n}^{(e)}, I_{\eta 2n}^{(e)}, F_{\eta 2n}^{(e)} \right\rangle \\ \vdots & \vdots & \ddots & \vdots \\ \left\langle T_{\eta b1}^{(e)}, I_{\eta b1}^{(e)}, F_{\eta b1}^{(e)} \right\rangle & \left\langle T_{\eta bn}^{(e)}, I_{\eta bn}^{(e)}, F_{\eta bn}^{(e)} \right\rangle & \cdots & \left\langle T_{\eta bn}^{(e)}, I_{\eta bn}^{(e)}, F_{\eta bn}^{(e)} \right\rangle \end{bmatrix} \tag{16}$$

where the elements of the matrix $N^{(e)}$ ($\eta_{ij}^{(e)}$) present SVN numbers from the predefined neutrosophic linguistic scale. Final aggregated decision-making matrix $N$ is obtained by averaging the elements $\eta_{ij}^{(e)} = \left\langle T_{\eta ij}^{(e)}, I_{\eta ij}^{(e)}, F_{\eta ij}^{(e)} \right\rangle$ of the matrix (16) by applying the expression (18).

$$N = \left[\eta_{ij}\right]_{b\times n} = \begin{bmatrix} \eta_{11} & \eta_{12} & \cdots & \eta_{1n} \\ \eta_{21} & \eta_{22} & \cdots & \eta_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \eta_{b1} & \eta_{b2} & \cdots & \eta_{bn} \end{bmatrix}$$
$$= \begin{bmatrix} \left\langle T_{\eta 11}, I_{\eta 11}, F_{\eta 11} \right\rangle & \left\langle T_{\eta 12}, I_{\eta 12}, F_{\eta 12} \right\rangle & \cdots & \left\langle T_{\eta 1n}, I_{\eta 1n}, F_{\eta 1n} \right\rangle \\ \left\langle T_{\eta 11}, I_{\eta 11}, F_{\eta 11} \right\rangle & \left\langle T_{\eta 22}, I_{\eta 22}, F_{\eta 22} \right\rangle & \cdots & \left\langle T_{\eta 2n}, I_{\eta 2n}, F_{\eta 2n} \right\rangle \\ \vdots & \vdots & \ddots & \vdots \\ \left\langle T_{\eta b1}, I_{\eta b1}, F_{\eta b1} \right\rangle & \left\langle T_{\eta bn}, I_{\eta bn}, F_{\eta bn} \right\rangle & \cdots & \left\langle T_{\eta bn}, I_{\eta bn}, F_{\eta bn} \right\rangle \end{bmatrix} \tag{17}$$

where the elements $\eta_{ij} = \left\langle T_{\eta ij}, I_{\eta ij}, F_{\eta ij} \right\rangle$ are obtained by applying the SVNN weighted average operator (SWNSWAA) , with the expression (18)

$$\eta_{ij} = SVNSWAA(\eta_{ij}^{(1)}, \eta_{ij}^{(2)}, .., \eta_{ij}^{(m)}) = \sum_{b=1}^{m} \varpi_e \eta_{ij}^{(1)}$$
$$= \left\langle 1 - \prod_{b=1}^{m} \left(1 - T_{\eta ij}^{(e)}\right)^{\varpi_e}, \prod_{b=1}^{m} \left(I_{\eta ij}^{(e)}\right)^{\varpi_e}, \prod_{b=1}^{m} \left(F_{\eta ij}^{(e)}\right)^{\varpi_e} \right\rangle \tag{18}$$

where $\varpi_e$ the weight coefficients, $0 \le \varpi_e \le 1,\ (e = 1, 2, ..., m)$, $\sum_{e=1}^{m} \varpi_e = 1$.

*Step 2.* Normalization of initial decision-making matrix ($N$). By normalization of the matrix elements (17), it is obtained the matrix $\hat{N} = \left[\hat{\eta}_{ij}\right]_{b\times n} = \left[\left\langle T_{\hat{\eta} ij}, I_{\hat{\eta} ij}, F_{\hat{\eta} ij} \right\rangle\right]_{b\times n}$ . The elements of the matrix $\hat{N}$ are obtained by applying the expression (19)

$$\eta_{ij} = \begin{cases} \left\langle T_{\eta ij}, I_{\eta ij}, F_{\eta ij} \right\rangle, & if \quad c_j \in B; \\ \left\langle F_{\eta ij}, 1 - I_{\eta ij}, T_{\eta ij} \right\rangle, & if \quad c_j \in C; \end{cases} \tag{19}$$

where $B$ and $C$, respectively, present the sets of criteria of benefit and cost type.

*Step 3. Determining weight coefficients' values.* Determining weight coefficients values is based on maximum deviation model (MDM). After the normalization of expert correspondent matrices, aggregated normalized decision-making matrix is obtained $\hat{N}=\left[\hat{\eta}_{ij}\right]_{b\times n}=\left[\left\langle T_{\hat{\eta}ij}, I_{\hat{\eta}ij}, F_{\hat{\eta}ij}\right\rangle\right]_{b\times n}$. Aggregated normalized decision-making matrix $\hat{N}$ is further transformed into the weighted matrix $N^{*}=\left[\eta_{ij}^{*}\right]_{b\times n}$, $\eta_{ij}^{*}=w_j\cdot\eta_{ij}$.

In the matrix $N$ can be calculated the degree of elements' deviation $\eta_{kj}$ ($1\leq k\leq b$) in relation to other elements $\eta_{ij}$ within the criteria $c_j$ ($j=1,2,\dots,n$)

$$\varphi_{ij}(w_j)=\sum_{k=1}^{b}d(\eta_{kj}^{*},\eta_{ij}^{*})=\sum_{k=1}^{b}d(\eta_{kj},\eta_{ij})w_j \tag{20}$$

Where $d(\eta_{kj},\eta_{ij})$ present the distance between $\eta_{kj}$ ($1\leq k\leq b$) and $\eta_{ij}$ ($j=1,2,\dots,n$). From the expression (19) it can be clearly noted that for higher values of $D_{ij}(w_j)$ the alternative $a_i$ ($i=1,2,\dots,b$) is better.

The MDM model is based on the following starting points: (1) In case there are small deviations between the value of $\eta_{kj}$ ($1\leq k\leq b$) and the value of $\eta_{ij}$ within the criterion $c_j$ ($j=1,2,\dots,n$), then the criterion has low influence to the rank of alternatives and small value of the weight coefficient $w_j$; (2) Contrary to the mentioned, if there are significant deviations between the value of $\eta_{kj}$ ($1\leq k\leq b$) and the value of $\eta_{ij}$ within the criterion $c_j$ ($j=1,2,\dots,n$), then the criterion has high influence to the rank of alternatives and large value of the weight coefficient $w_j$; (3) If all the values of $\eta_{ij}$ are identical within the criterion $c_j$ ($j=1,2,\dots,n$), then the criterion has no influence to the rank of alternatives and has the value of the weigh coefficient $w_j=0$. After that, it is calculated the degree of deviation between all the elements within the observed criterion $c_j$ ($j=1,2,\dots,n$).

*Step 3.1.* Calculation of the degree of deviation between all the elements within the observed criterion $c_j$ ($j=1,2,\dots,n$)

$$\varphi_{j}(w_j)=\sum_{i=1}^{b}\varphi_{ij}(w_j)=\sum_{i=1}^{b}\sum_{k=1}^{b}d(\eta_{kj},\eta_{ij})w_j \tag{21}$$

Respectively, calculation of total deviation of all alternatives by criteria

$$\varphi(w)=\sum_{j=1}^{n}\varphi_{j}(w_j)=\sum_{j=1}^{n}\sum_{i=1}^{b}\sum_{k=1}^{b}d(\eta_{kj},\eta_{ij})w_j \tag{22}$$

*Step 3.2.* The weight coefficients $w_j$ are obtained by solving optimization model which is based on maximum deviation

$$\begin{aligned}&\max D(w)=\sum_{j=1}^{n}\sum_{i=1}^{b}\sum_{u=1}^{b}d(\eta_{ij},\eta_{uj})w_j\\&s.t.\\&\begin{cases}\sum_{j=1}^{n}w_j^2=1;\\0\leq w_j\leq 1;\ \ j=1,2,\dots,n\end{cases}\end{aligned} \tag{23}$$

With the aim of solving the model (23), it is introduced the Lagrange function

$$L(w,p)=\sum_{j=1}^{n}\sum_{i=1}^{b}\sum_{u=1}^{b}d(\eta_{ij},\eta_{uj})w_j+\frac{\lambda}{2}\left(\sum_{j=1}^{n}w_j^2-1\right) \tag{24}$$

After partial deviation by $w$, and then by $p$ are obtained two equations $D(w)+pw_j=0$ i $\sum_{j=1}^{n}w_j^2=1$, where

$$w_j=\frac{\sum_{i=1}^{b}\sum_{u=1}^{b}\left\{\frac{1}{3}\left[\left|f\left(s_{pij}\right)-f\left(s_{p_{uj}}\right)\right|^{\varphi}+\left|f\left(s_{t-q_{ij}}\right)-f\left(s_{t-q_{uj}}\right)\right|^{\varphi}+\left|f\left(s_{t-r_{ij}}\right)-f\left(s_{t-r_{uj}}\right)\right|^{\varphi}\right]\right\}^{\frac{1}{\varphi}}}{\sqrt{\sum_{j=1}^{n}\left(\sum_{i=1}^{b}\sum_{u=1}^{b}\left\{\frac{1}{3}\left[\left|f\left(s_{pij}\right)-f\left(s_{p_{uj}}\right)\right|^{\varphi}+\left|f\left(s_{t-q_{ij}}\right)-f\left(s_{t-q_{uj}}\right)\right|^{\varphi}+\left|f\left(s_{t-r_{ij}}\right)-f\left(s_{t-r_{uj}}\right)\right|^{\varphi}\right]\right\}^{\frac{1}{\varphi}}\right)^2}} \tag{25}$$

*Step 3.3.* Calculation of final values of weight coefficients. By normalization of the values (25) are obtained final values of weight coefficients.

$$\omega_j=\frac{w_j}{\sum_{j=1}^{n}w_j} \tag{26}$$

where $\omega_j$ present optimal values of weight coefficients.

*Step 4.* Calculation of the elements of the border approximate area matrix ($G$). The elements of the matrix $G=\left[g_j\right]_{1\times n}$ are obtained by applying the expression (27)

$$g_j=\prod_{i=1}^{b}\left(d_{ij}\right)^{1/b}=\left\langle\prod_{i=1}^{b}\left(T_{dij}\right)^{1/b},1-\prod_{i=1}^{b}\left(1-I_{dij}\right)^{1/b},1-\prod_{i=1}^{b}\left(1-F_{dij}\right)^{1/b}\right\rangle \tag{27}$$

*Step 5.* Calculation of the matrix of the distance of alternatives from the border approximate area ($S$). The elements of the matrix $S=\left[s_{ij}\right]_{b\times n}$ are obtained by applying the expression (28)

$$s_{ij}=\begin{cases}d_{Eu}(d_{ij},g_j), & if\ d_{ij}>g_j;\\ 0, & if\ d_{ij}=g_j;\\ -d_{Eu}(d_{ij},g_j), & if\ d_{ij}<g_j.\end{cases} \tag{28}$$

where the distance $d_{Eu}$ is determined by applying the expression(13).

*Step 6.* Ranking alternatives. Based on the values of the criteria functions of alternatives $Q_i$ ($i=1,2,\ldots,b$), it is performed ranking of alternatives. Criteria functions are obtained by applying the expression (29),

$$Q_i=\sum_{j=1}^{n}s_j,\ \ i=1,2,\ldots,b;\ j=1,2,\ldots,n. \tag{29}$$

Rank of alternatives is determined based on the value $Q_i$, where it is more favorable for alternative to have as high as possible value of the criteria function $Q_i$.

## 4. Application of the SVNN MABAC model

In this paper, a case study of location selection for a multimodal LC is presented. As an example, eight potential locations for the development of a multimodal LC on the Danube River in the territory of Serbia are considered. Based on the recommendations of Zecevic (2006), nine criteria are identified based on which the selection of the location of a multimodal LC is done, as in the Table 1.

Table 1. Criteria for the evaluation of multimodal LC locations

| Mark | Criteria name | Criteria description |
|---|---|---|
| C1 | Connectivity to multimodal transport | The criterion presents traffic and logistic characteristics of the environment and the connection of the location with other modes of transport. This criterion expresses the possibility of approach, accepting and dispatching of the means of external transport. It belongs to the group of "benefit" criteria. |
| C2 | Assessment of infrastructure construction | This criterion shows the regulation of infrastructure to adequately serve the demands of goods flows in the LC. Every location has certain limitations, some of which can be eliminated by investing material resources, while some present limiting factors for the development and exploitation of the LC. The criterion belongs to the group of "benefit" criteria. |
| C3 | Influence to the environment | This criterion is descriptive and presents the impact of the location to environmental pollution through the emission of gases, noise and vibration. It belongs to the group of "cost" criteria. |
| C4 | Compliance with spatial plans and economic development strategy | The criterion shows the compliance of the LC development with spatial plans and the strategy of economic development. It belongs to the group of "benefit" criteria. |
| C5 | Existing intermodal transport units | This criterion is an estimate of the existing transport flows towards the LC. It is expressed through an estimate of the number of ITUs per year (ITU / year). It belongs to the group of "benefit" criteria. |
| C6 | Loading capacities of the LC | This criterion presents the loading capacities of the LC. The LC loading capacities express the maximum number of ITUs that can be unloaded within one hour (ITU / h). It belongs to the group of "benefit" criteria. |
| C7 | Available area for future development and LC capacity expansion | Based on the requirements of material flows and preliminary estimation of the required area for certain subsystems, it is determined the minimal required total area for the development of the LC. When designing, additional area is planned for the expansion and development of terminals in the future. The criterion belongs to the group of "benefit" criteria. |
| C8 | Distance of the users from the LC | The criterion is descriptive and presents an estimate of the distance of the LC location from the potential users of services. It belongs to the group of "cost" criteria. |
| C9 | Traffic safety | The criterion presents the regulation of the location of the LC from the aspect of traffic safety (regulation of traffic signalization, number of traffic accidents on access roads, regulation of road and rail crossings). The criterion is descriptive and belongs to the group of "benefit" criteria. |

In model testing participated four experts from the field of transport which are assigned weight coefficients $w_{e1}$=0.2864, $w_{e2}$=0.2741, $w_{e3}$=0.2170 and $w_{e4}$=0.1673.

Table 2. Aggregated initial decision-making matrix

| Crit | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 |
|---|---|---|---|---|---|---|---|---|
| C1 | (0.54,0.3,0.28) | (0.53,0.34,0.35) | (0.52,0.37,0.28) | (0.5,0.33,0.29) | (0.41,0.33,0.29) | (0.63,0.37,0.38) | (0.52,0.29,0.23) | (0.59,0.34,0.47) |
| C2 | (0.51,0.29,0.24) | (0.53,0.31,0.25) | (0.5,0.34,0.26) | (0.56,0.31,0.39) | (0.47,0.33,0.4) | (0.55,0.46,0.3) | (0.49,0.38,0.35) | (0.51,0.36,0.3) |
| C3 | (0.47,0.27,0.33) | (0.57,0.4,0.34) | (0.46,0.32,0.31) | (0.5,0.27,0.26) | (0.49,0.34,0.29) | (0.59,0.38,0.42) | (0.41,0.3,0.19) | (0.45,0.28,0.24) |
| C4 | (0.44,0.27,0.25) | (0.47,0.34,0.35) | (0.37,0.25,0.15) | (0.41,0.34,0.15) | (0.63,0.42,0.48) | (0.51,0.32,0.35) | (0.39,0.4,0.19) | (0.33,0.24,0.24) |
| C5 | (0.41,0.28,0.23) | (0.52,0.31,0.29) | (0.44,0.19,0.34) | (0.52,0.33,0.36) | (0.56,0.75,0.47) | (0.62,0.33,0.44) | (0.53,0.35,0.32) | (0.58,0.42,0.41) |
| C6 | (0.51,0.33,0.31) | (0.48,0.24,0.28) | (0.51,0.36,0.36) | (0.52,0.41,0.4) | (0.45,0.32,0.28) | (0.5,0.31,0.31) | (0.52,0.31,0.3) | (0.43,0.25,0.25) |
| C7 | (0.56,0.3,0.44) | (0.53,0.39,0.31) | (0.55,0.27,0.36) | (0.54,0.32,0.37) | (0.53,0.39,0.41) | (0.58,0.37,0.37) | (0.5,0.32,0.38) | (0.49,0.29,0.32) |
| C8 | (0.59,0.4,0.43) | (0.6,0.49,0.41) | (0.55,0.43,0.32) | (0.56,0.39,0.36) | (0.47,0.3,0.26) | (0.57,0.42,0.25) | (0.48,0.42,0.39) | (0.61,0.41,0.33) |
| C9 | (0.61,0.42,0.37) | (0.66,0.47,0.43) | (0.58,0.35,0.48) | (0.62,0.42,0.4) | (0.65,0.5,0.44) | (0.45,0.38,0.35) | (0.47,0.28,0.31) | (0.48,0.29,0.38) |

Experts evaluated the criteria by applying linguistic scale: Very important – VI (0.90,0.10,0.10); Important – I (0.75,0.25,0.20); Medium – M (0.50,0.50,0.50); Unimportant – UI (0.35,0.75,0.80); Very unimportant – VU (0.10,0.90,0.90).

Step 1: In the first step, the experts evaluated eight alternatives (locations) in relation to the nine evaluation criteria marked with C1 to C9. Thus, for every expert, one correspondent matrix is formed. Evaluation of the alternatives is made using predefined set of the SVN linguistic variables. Therefore, for every expert, a correspondent initial decision-making matrix is defined, which by using SWNSWAA (18) is aggregated into the initial decision-making matrix, as in the Table 2.

Table 3. Deviations between the criteria in the initial decision-making matrix

| Criteria | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 |
|---|---|---|---|---|---|---|---|---|
| C1 | 0.693161 | 0.729263 | 0.711873 | 0.673599 | 0.64468 | 0.854589 | 0.670868 | 0.873455 |
| C2 | 0.658016 | 0.678004 | 0.661235 | 0.7689 | 0.726337 | 0.80292 | 0.721386 | 0.691708 |
| C3 | 0.649877 | 0.812623 | 0.656083 | 0.646737 | 0.669801 | 0.866943 | 0.590643 | 0.604452 |
| C4 | 0.620961 | 0.728282 | 0.548415 | 0.614471 | 1.016261 | 0.743172 | 0.654049 | 0.545849 |
| C5 | 0.639613 | 0.718458 | 0.681562 | 0.750361 | 1.218171 | 0.889591 | 0.75045 | 0.872205 |
| C6 | 0.675299 | 0.623921 | 0.72922 | 0.80159 | 0.626706 | 0.658559 | 0.673925 | 0.589811 |
| C7 | 0.779089 | 0.738575 | 0.715328 | 0.717412 | 0.779176 | 0.777315 | 0.701796 | 0.665741 |
| C8 | 0.843699 | 0.894391 | 0.769733 | 0.772811 | 0.672498 | 0.770101 | 0.769027 | 0.818187 |
| C9 | 0.839894 | 0.942952 | 0.857972 | 0.860605 | 0.95581 | 0.731635 | 0.689946 | 0.725356 |
| Sum | 5.851 | 5.709 | 5.497 | 5.471 | 6.520 | 5.379 | 5.874 | 6.310 |

Step 2:

In the second step by applying the expression (19) it is normalized the aggregated matrix, which is further in the step three used for determining objective values of the weights of criteria.

Step 3:

After determining normalized initial decision-making matrix, by applying the expressions (20)-(24) are calculated the deviations between the elements of the aggregated matrix. Thus, for the criteria (C1-C9) are obtained the deviations presented in the Table 3.

By applying the expressions (25) and (26) are obtained optimal values of the weigh coefficients of criteria

$w_j = (0.1100,0.1073;0.1033;0.1028;0.1225;0.1011;0.1104;0.1186;0.1241)$ .

Step 5:

The calculation of the elements of border approximate area matrix (BAA). By applying the expression (27) are obtained the elements of border approximate area matrix, as in the Table 4.

Table 4. Border approximate area matrix

| Criteria | BAA |
|---|---|
| C1 | (0.10,0.11,0.12) |
| C2 | (0.11,0.11,0.13) |
| C3 | (0.13,0.12,0.10) |
| C4 | (0.17,0.12,0.12) |
| C5 | (0.08,0.13,0.15) |
| C6 | (0.14,0.10,0.10) |
| C7 | (0.08,0.11,0.08) |
| C8 | (0.06,0.09,0.08) |
| C9 | (0.07,0.09,0.11) |

Step 6:

The calculation of the matrix of alternatives distance from border approximate area. By applying the expression (28) is determined the distance of alternatives from the BAA, as in the Table 5.

Table 5. Distance of alternatives from border approximate area

| Criteria | A1 | A2 | A2 | A4 | A3 | A6 | A4 | A8 |
|---|---|---|---|---|---|---|---|---|
| C1 | 0.833 | -0.500 | -0.500 | 0.500 | -0.333 | -0.667 | 0.167 | 0.500 |
| C2 | 0.500 | 0.500 | -0.500 | 0.667 | -0.333 | 0.333 | -0.667 | 0.333 |
| C3 | 0.167 | -0.333 | 0.500 | 0.833 | 0.500 | 0.667 | 0.833 | 0.167 |
| C4 | 0.167 | -0.167 | 0.333 | -0.667 | 0.333 | -0.500 | 0.333 | 0.167 |
| C5 | -0.333 | -0.500 | 0.333 | 0.667 | -0.100 | -0.167 | 0.500 | 0.333 |
| C6 | 0.333 | 0.500 | 0.500 | 0.833 | -0.333 | 0.333 | -0.667 | 0.167 |
| C7 | -0.333 | -0.500 | -0.333 | -0.833 | -0.500 | 0.500 | -0.833 | 0.667 |
| C8 | 0.500 | -0.667 | 0.333 | 0.833 | 0.500 | 0.333 | -0.667 | 0.833 |
| C9 | -0.667 | 0.167 | 0.500 | -0.833 | -0.667 | 0.667 | 0.167 | 0.333 |

Step 7:

Ranking alternatives. Based on the distance of alternatives from border approximate area (Table 5), by applying the expression (29) are obtained final values of the criteria functions of alternatives and final rank of alternatives, as in the Table 6.

Table 6. Criteria functions and rank of alternatives

| Alternative | Qi | Rank |
|---|---|---|
| A1 | 1.167 | 4 |
| A2 | -1.500 | 8 |
| A3 | 1.160 | 5 |
| A4 | 2.000 | 2 |
| A5 | -0.933 | 7 |
| A6 | 1.499 | 3 |
| A7 | -0.834 | 6 |
| A8 | 3.500 | 1 |

The validation of the SVNN MABAC model is carried out in this part. The validation of the SVNN MABAC model is made by comparison with other multi-criteria SVNN models from bibliography. For these purposes, the following methods are used: SVNN WASPAS (Zavadskas et al, 2015), SVNN VIKOR (Pouresmaeil et al. 2017), SVNN TOPSIS (Pouresmaeil et al. 2017) i SVNN CODAS (Peng & Dai, 2018).

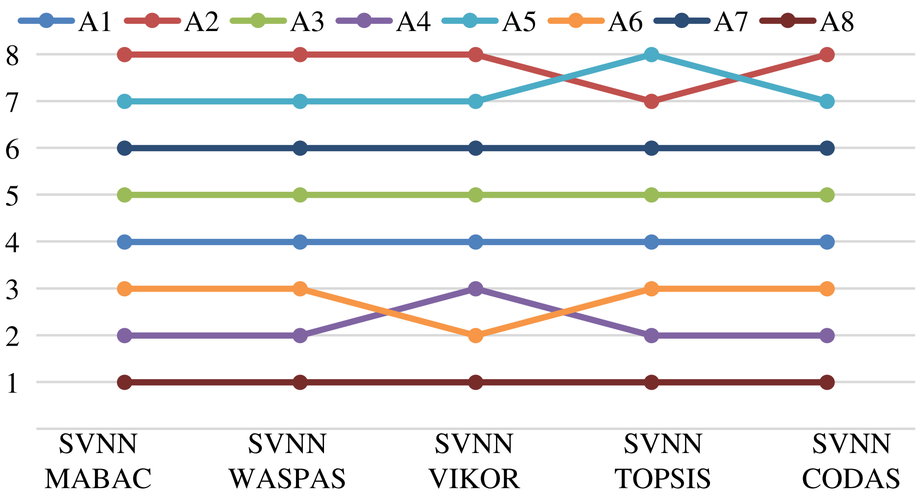


Figure 1. Comparison of the results of the SVNN MABAC model with other MCDM models

The Figure 1 shows that the eighth location is the best solution in all scenarios formed, respectively, in the application of all the other methods mentioned above. The location four in four models is in the second position, using SVNN MABAC, SVNN WASPAS, SVNN TOPSIS and SVNN CODAS, while using the SVNN VIKOR model it is in the third place. This is due to the significant differences between the SVNN VIKOR methodology and other MCDM models considered. The second location is on the eighth position four times, while in the SVNN TOPSIS model it is in the seventh position. Considering these are only the worst alternatives, these changes in ranks have no impact on the final decision. Since there is no complete consensus in the results between the models considered, statistical comparison of the ranks is performed in the following part and the correlation of the ranks is done using Spearman’s coefficient (Tian et al., 2018; Pamucar et al., 2019). In the table 7 it is presented Spearman's coefficient of rank correlation between the models observed.

Table 7. Spearman's coefficient of correlation for rank location using different methods

| Methods | SVNN MABAC | SVNN WASPAS | SVNN VIKOR | SVNN TOPSIS | SVNN CODAS |
|---|---|---|---|---|---|
| SVNN MABAC | 1.000 | 1.000 | 0.999 | 0.999 | 1.000 |
| SVNN WASPAS | - | 1.000 | 0.999 | 0.999 | 1.000 |
| SVNN VIKOR | - | - | 1.000 | 0.997 | 0.999 |
| SVNN TOPSIS | - | - | - | 1.000 | 0.999 |
| SVNN CODAS | - | - | - | - | 1.000 |

Based on the total calculated statistical coefficient of correlation (0.990), it can be concluded that the ranks are in high correlation in all formed scenarios. Observing the overall ranks and correlation coefficients, it can be concluded that the model obtained is very stable, and that the ranks are in high correlation. Since all the values are significantly greater than 0.90, according to Pamucar et al. (2018) these present very high correlation of ranks.

## 5. Conclusion

This paper presents the application of the SVNN MABAC model in the process of selecting the location of multimodal logistic center on the Danube River. The SVNN MABAC model additionally enriches the field of multi-criteria decision making. The model presented allows making more objective decisions through respecting subjectivity and uncertainty in the decision-making process. The third contribution of the paper is the improvement of the methodology for evaluating and selecting optimal location for the development of multimodal LC through new approach to dealing with imprecision, since the application of this or similar approach has not been observed in the literature that examines the subject area.

With the application of the developed approach, it is possible to consider the evaluation of a LC construction sites systematically, which have significant impact on the efficiency achievement of the entire supply chain. The SVNN MABAC model is also applicable for solving other logistic problems, such as supplier evaluation, selection of means of transport in other areas. The flexibility of the model is reflected in the fact that its upgrade can be carried out by integrating other methods of multi-criteria decision-making.

The results of the research shown in this paper indicate that the SVNN MABAC model presents a useful and reliable tool for rational decision-making. Basic recommendation for further use of this method is simple mathematical apparatus, stability (consistency) of the solution, as well as the possibility of combining it with other methods, especially concerning the determination of the weights of criteria.

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