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Selection of Ice Crossing Point location using hybrid MCDM model Fuzzy AHP-EWAA-Fuzzy CoCoSo

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ABSTRACT

This paper investigates the selection of locations for tank crossings over frozen water obstacles using a hybrid Fuzzy Analytic Hierarchy Process (AHP)–Einstein Weighted Arithmetic Average (EWAA)–Fuzzy Combined Compromise Solution (CoCoSo) model. The analysis includes key criteria relevant to the selection process. The Fuzzy AHP method enables precise determination of criterion weights based on expert opinions, aggregated using the EWAA operator, while Fuzzy CoCoSo provides a comprehensive analysis of alternatives to identify the optimal location. The results show that the combination of these methods offers a reliable framework for decision-making under complex conditions. Sensitivity analysis confirms the stability of the results, and comparative analysis supports the validity of the Fuzzy CoCoSo method. The model proves to be efficient and reliable for selecting locations for tank crossings over frozen water surfaces, providing a foundation for future research and practical application.

1. Introduction

Making the right decisions is a fundamental aspect of any process. Decision makers in the Serbian Armed Forces often encounter scenarios that require them to make critical decisions under time constraints, relying heavily on logical reasoning [1]. This requires a comprehensive examination of all relevant information, with the application of intuition and expertise relevant to the specific decision context. The key question is how to guarantee the selection of optimal decisions, especially considering that wrong choices during combat can lead to catastrophic consequences, including loss of life, damage to equipment and resources, or failure to achieve set goals. This paper presents a hybrid Fuzzy Analytic Hierarchy Process (AHP)-Einstein weighted arithmetic average (EWAA)-Fuzzy Combined Compromise Solution (CoCoSo) model designed to improve the decision-making process and improve the quality of decisions regarding the crossing of tanks over ice-covered water obstacles. The effectiveness of this multi-criteria decision-making model (MCDM) has been confirmed in various studies addressing different decision-making challenges. In this study, the Fuzzy AHP method is used

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to determine the criterion weight coefficients, while the Fuzzy CoCoSo method is used to identify the most suitable alternative. The combination of these two methods, using triangular fuzzy numbers, in the MCDM model has been demonstrated in not a large number of studies in different areas. Choudhary and Mishra [2] using this model, look for critical points of success for the implementation of Industry 4.0. Authors in [3] use methods in risk management, and so on, while their joint application, in different models with different theories, is shown in many papers [4-7]

Effectively overcoming water obstacles is a key factor in unit maneuvers and directly affects the course and outcome of modern combat operations. This task is considered one of the most demanding combat operations for armies worldwide [8]. Various MCDM models were used for the selection of locations on the water obstacle: Fuzzy Defining Interrelationships Between Ranked criteria (DIBR)-Fuzzy DIBR II-EWAA- Bonferroni mean (BM)-DEXi-Fuzzy Logarithm Methodology of Additive Weights (LMAW) [9], Fuzzy Logical System [10-11], DIBR-Fuzzy Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS) [12], etc.

In some regions of Serbia, water obstacles freeze over during the winter. Although climatic conditions, especially sudden temperature changes, often make crossing frozen water obstacles uncertain, knowing and using this method can be crucial when circumstances permit.

An ice crossing point (ICP) is a location on a river or lake where units of all types can cross, provided that the natural or reinforced thickness of the ice can withstand the load. The ICP includes a starting line, approaches to the shore, descents onto the ice from the shore, exits from the ice to the shore, and a prepared ice road for movement. ICP widths generally range from 300 to 600 meters, with a minimum distance of 150 meters between roads.

The carrying capacity of the ice cover primarily depends on its thickness, structure, air temperature and load distribution during the transition [13]. Modern combat operations require continuous mobility of ground forces, especially tank units, which provide significant firepower and achieve superiority on the battlefield. The Serbian Army is equipped with the M-84 tank, a tracked combat vehicle characterized by powerful armament, strong armor protection and exceptional maneuverability, weighing about 42 tons [14].

This paper presents an MCDM model that improves the decision-making process for the selection of locations for tank crossings of frozen obstacles. While the literature mostly describes the criteria that such locations must meet, this approach allows for a more detailed and precise definition of these criteria. As a result, decision-making relies on the experience and knowledge of decision-makers in such situations. When decision-makers have limited knowledge or experience, the application of MCDM methods significantly facilitates the making of quality and accurate decisions. The decision-making process involves ranking the available locations and choosing the most suitable ones for the transition.

2. Methodology

For the purpose of selecting the location for the ICP, a hybrid Fuzzy AHP-EWAA-Fuzzy CoCoSo model was created, and the algorithm of the methodology is shown in Figure 1.

2.1. Fuzzy AHP method

The AHP method, developed by Thomas Saaty in 1980 [15], is a well-known approach that has been widely applied in operational practice over a long period. It is based on the decomposition of a complex problem into a hierarchy, with the goal positioned at the top, followed by criteria, sub-criteria, and alternatives structured across various levels and sublevels of the hierarchy.

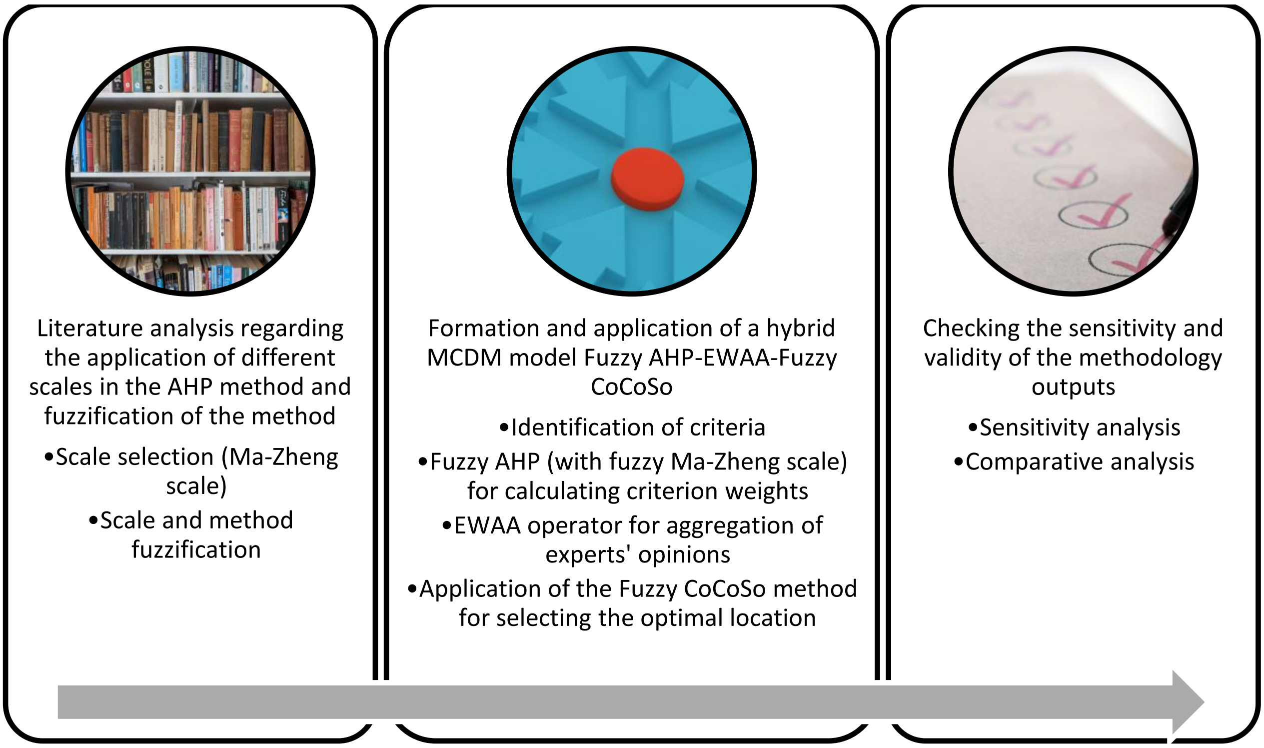

Fig. 1. Algorithm of application of MCDM model Fuzzy AHP-EWAA-Fuzzy CoCoSo

The pairwise comparison matrix is transformed into an eigenvalue problem—the normalized and unique eigenvectors. This process provides weights for all attributes at all levels of the hierarchy. The solution to the problem is then determined by computing the normalized vector for each of the considered alternatives and ranking them accordingly. More details about AHP and its application can be found in [15-18] and other studies. In order to better deal with uncertainty and imprecision when making decisions using this method, it is necessary to modify the method with one of the theories that treat this area well. One of the theories is Fuzzy theory.

Unlike traditional sets, in the fuzzy logic, the membership of an element within a set is not strictly or precisely determined, allowing an element to belong to the set to varying degrees [19]. This characteristic of fuzzy logic enables the quantification of information that cannot be addressed using classical logic. The foundational principles of fuzzy logic were introduced by Zadeh [20, 21], providing a sufficient basis for the field's development and its increasing practical applications. The Fuzzy AHP method has been applied in various researches so far [22-25].

One of the first fuzzifications of AHP methods was presented in [26]. Since then, various authors have fuzzified this method in various ways and applied it in various fields [27].

One of the approaches to fuzzification is given in [28], which is based on the degree of conviction of the decision-makers (κ). The stated conviction is expressed by the experts as a percentage of conviction, i.e. if the expert is 90% convinced of his claims, then $\kappa = 0.9$.

By introducing different values of degree of conviction, the elements of the fuzzy number (left and right distributions) change, i.e. the elements of the fuzzy number $\tilde{G}$ are formed as follows, Eq. 1 [28]:

$$\tilde{G} = (g_1, g_2, g_3) = (y\kappa, y, (2-\kappa)y), \ y \in [1,9] \tag{1}$$

where *y* represents the standard elements of the Saaty's scales [29], which represents the basic scale for assessing the relationship in the AHP method. In addition to Saaty's linear scale, others were developed, such as quadratic and a root square scale [30], geometric scale [31], Ma-Zheng scale [32], logarithmic [33], etc.

Ma and Zheng [32] introduced inverse linear scale 9/9-9/1 (Table 1), where the qualitative-verbal indicators are shown in the range of 9/9 to 9/1, and the scale values are obtained using next expression:

$$s = \frac{9}{(10 - y)} \tag{2}$$

Table 1
Ma-Zheng's scale compared to Saaty's scale

Standard values – *y* of the *Saaty's scale*	Linguistic descriptor	Values of the *Ma-Zheng's scale - s*
1	The same significance (TSD)	1
3	Poor dominance (PD)	9/7
5	Strong dominance (SD)	9/5
7	Very strong dominance (VSD)	9/3
9	Absolute dominance (AD)	9
2; 4; 6; 8	Intermediate values (IMV-8, IMV-6, IMV-4, IMV-2)	9/8; 9/6;9/4; 9/2

Applying the approach of Božanić et al. [28], that is, by forming triangular fuzzy numbers using Eq. (1), where y now represents the elements of the Ma-Zheng scale, the values presented in Table 2 are obtained (if for example $\kappa = 0.9$). By implementing this fuzzified scale in the AHP method, it is fuzzified and the Fuzzy AHP method is obtained. It is important to note here, and due to the specificity of the AHP method, that if the left distribution of the fuzzy number, after applying equation (1), is less than 1, then the value 1 is assigned. This rule does not apply to inverse scale values. Also, if the criteria are considered to be equal in importance, then all elements of the triangular fuzzy number have the value 1, i.e. it is equal to (1,1,1).

Table 2
Values of the fuzzificated Ma-Zheng's scale ($\kappa = 0.9$)

Values of the Ma-Zheng's scale	Definition	Values of the fuzzificated Ma-Zheng's scale	Inverse values of the fuzzificated Ma-Zheng's scale
1	The same significance (TSD)	(1,1,1)	(1,1,1)
9/8	Intermediate value 8 (IMV-8)	(1.01,1.13,1.24)	(0.8,0.89,0.98)
9/7	Poor dominance (PD)	(1.16,1.29,1.41)	(0.7,0.78,0.86)
9/6	Intermediate value 6 (IMV-6)	(1.35,1.5,1.65)	(0.6,0.67,0.73)
9/5	Strong dominance (SD)	(1.62,1.8,1.98)	(0.5,0.56,0.61)
9/4	Intermediate value 4 (IMV-4)	(2.03,2.25,2.48)	(0.4,0.44,0.49)
9/3	Very strong dominance (VSD)	(2.7,3,3.3)	(0.3,0.33,0.37)
9/2	Intermediate values 2 (IMV-2)	(4.05,4.5,4.95)	(0.2,0.22,0.24)
9	Absolute dominance (AD)	(8.1,9,9.9)	(0.1,0.11,0.12)

The steps of the fuzzy AHP method are the same as for the classical AHP method, using the above-mentioned scale (Table 2). Defuzzification of triangular fuzzy numbers $\tilde{G}$ is performed using Eq. 3.

$$G = ((g_3 - g_1) + (g_2 - g_1)) / 3 + g_1 \tag{3}$$

2.3. Fuzzy CoCoSo method

The CoCoSo (Combined Compromise Solution) method is a MCDM technique, which combines different aggregation methods to reach a compromise solution. Basically, the CoCoSo method uses simple additive weighting and a compromise exponentially weighted production model [34]. The CoCoSo method is useful because it allows flexibility and precision in decision-making, especially in situations with multiple criteria. The advantage of this method is that it offers a balanced approach, combining multiple perspectives into one decision and providing more robust results. The approach is based on three interrelated hypotheses:

1) Each criterion in the decision matrix is categorized as either a "benefit" or a "cost" criterion.
2) The weights of the criteria are determined by using established methods, which can be either subjective or objective.
3) Qualitative criteria are quantified through techniques and methods designed to translate linguistic expressions into numerical values, using Fuzzy theory (triangular fuzzy numbers).

The application of the CoCoSo method has been demonstrated in numerous studies [35-37], etc.

Like other methods, this method is also enhanced with triangular fuzzy numbers [38-40]. The Fuzzy CoCoSo method consists of five steps, presented in Figure 2.

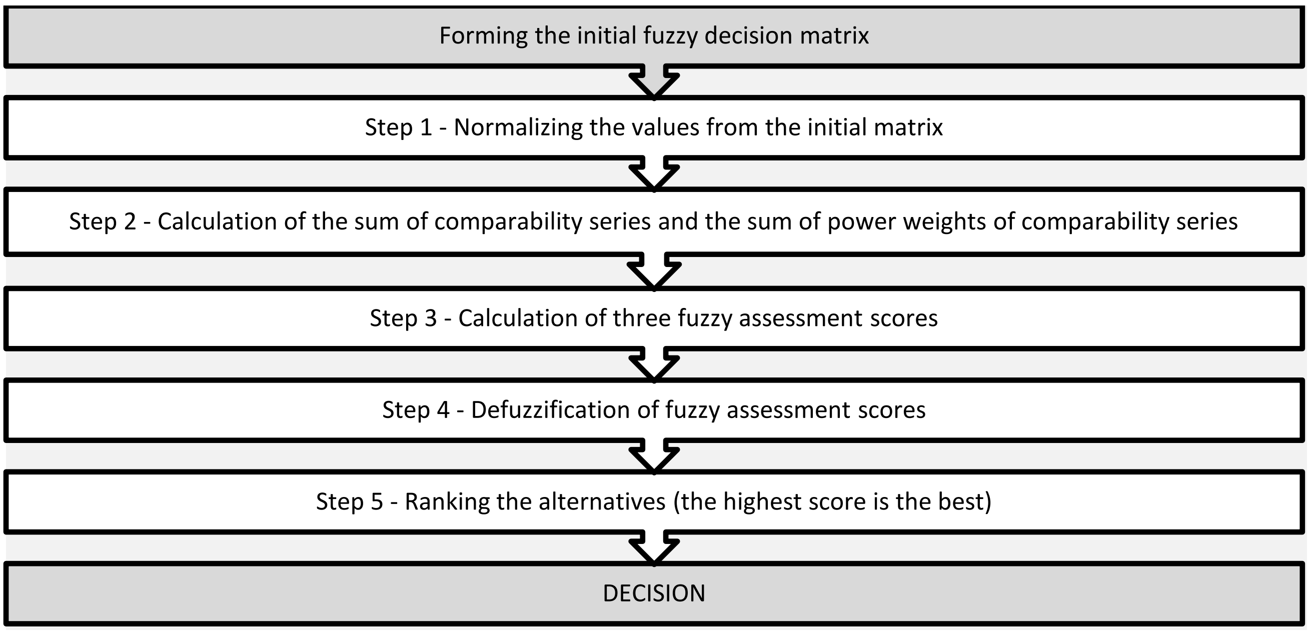

Fig. 2. Fuzzy CoCoSo method algorithm

3. Results

Following the methodological algorithm (Figure 1), it is first necessary to identify the criteria. By analyzing the available literature, the criteria for selecting the most suitable locations of ICP were defined. The conditions that must be met by the location for the crossing by tanks are described in [13] and presented in Table 3. All criteria are of the Benefit type and are stacked according to importance. All criteria are of qualitative type.

Table 3
Criteria determining the choice of location

Criteria	Description
C1-Ice Thickness	The minimum ice thickness required for a crossing depends on the load. For pedestrians, it should be at least 4 cm; for vehicles and transporters, between 16–35 cm, depending on their weight; and for tanks and heavy engineering machinery between 40–64 cm, depending on their weight. The average air temperature over the past three days significantly affects the required ice thickness for a crossing. For temperatures of -10°C or below, the minimum required tank thickness is 64 cm; at temperatures between -9°C and -1°C it is 71 cm; and at 0°C it is 80 cm. To measure the ice thickness, holes of approximately 15 cm in diameter are drilled every 5–10 meters along the axis of the crossing location. The required ice thickness can also be calculated using the equation: $t = 9 \cdot \sqrt{c}$, where: t is the thickness of the ice (cm), and c is the weight of the cargo (tons) [14]. It is also important to note that ice is usually thinner near the coast, in areas where water flow is faster and snow cover is thicker. In contrast, ice tends to be thicker in deeper river sections, slow-moving lowland rivers, and areas with minimal snow cover. Lower air temperatures make ice harder. An air temperature of -10°C is assumed for this analysis.
C2-Ice Composition (Ice Crust)	This refers to the condition of the ice crust at the crossing point. River ice usually has two layers: an upper, opaque layer and a lower, more transparent layer. The upper layer is porous, contains various impurities deposited from the ground, and is not very thick. The lower layer, bluish or greenish in color, is much stronger. Cracks and cavities in the ice significantly reduce its carrying capacity.
C3-Condition of Ice at the Water-Land Transition	Particular attention must be paid to areas of frozen water barriers where the ice meets the shore, as fluctuations in water level can create gaps under the ice, causing its underside to lose contact with the water. In addition, the impacts of vehicles on the ice are most significant in these areas. Such locations should be avoided or strengthened by additional freezing or the construction of ramps. If the water from the drilled holes rises to 0.8–0.9 ice thickness, the ice is stable and suitable for crossing at that location.
C4-Snow Cover	The presence and condition of the snow cover, as well as the effort required to remove it, are critical to enabling the crossing. To prepare the crossing site, snow is removed from the route manually or mechanically, leaving about 10 cm to prevent slipping.
C5-Access Roads and Shore Composition at the Crossing Site	This criterion involves assessing the availability and condition of access roads leading to and from the crossing point on both sides of the water obstacle, as well as the geological and soil composition of the banks in terms of terrain navigability and bearing capacity.
C6-Availability of Local Construction Materials Near the Crossing Site	The criterion includes the presence, quantity and quality of local construction materials in the vicinity of the crossing. If the ice load-bearing capacity is insufficient, it can be strengthened in various ways, such as additional freezing by pouring water or constructing a roadway of beams, fascias or other materials. It is necessary to determine the availability and volume of materials in the vicinity of the crossing for reinforcement purposes.

First, it is necessary to define the comparison values between the criteria, based on the scale presented in Table 2. For the purposes of this research, the evaluation of the relationships between the criteria was carried out by five experts $E = \{E1, E2, ..., E5\}$ with competence weights $E^{\varpi} = \{0.21, 0.22, 0.19, 0.18, 0.2\}$. The comparison values for experts are presented in Table 4.

Table 4
The comparison values for Fuzzy AHP method given by experts

	C1	C2	C3	C4	C5	C6
E1						
C1	TSD	IMV-8	PD	SD	VSD	AD
C2	1/IMV-8	TSD	IMV-8	PD	SD	VSD
C3	1/PD	1/IMV-8	TSD	IMV-8	PD	SD
C4	1/SD	1/PD	1/IMV-8	TSD	IMV-8	PD
C5	1/VSD	1/SD	1/PD	1/IMV-8	TSD	IMV-8
C6	1/AD	1/VSD	1/SD	1/PD	1/IMV-8	TSD
E2						
C1	TSD	PD	PD	SD	IMV-4	IMV-2
C2	1/PD	TSD	PD	PD	SD	IMV-4
C3	1/PD	1/PD	TSD	PD	PD	SD
C4	1/SD	1/PD	1/PD	TSD	PD	PD
C5	1/IMV-4	1/SD	1/PD	1/PD	TSD	PD
C6	1/IMV-2	1/IMV-4	1/SD	1/PD	1/PD	TSD
E3						
C1	TSD	IMV-8	IMV-8	PD	IMV-4	AD
C2	1/IMV-8	TSD	IMV-8	IMV-8	PD	IMV-4
C3	1/IMV-8	1/IMV-8	TSD	IMV-8	IMV-8	PD
C4	1/PD	1/IMV-8	1/IMV-8	TSD	IMV-8	IMV-8
C5	1/IMV-4	1/PD	1/IMV-8	1/IMV-8	TSD	IMV-8
C6	1/AD	1/IMV-4	1/PD	1/IMV-8	1/IMV-8	TSD
E4						
C1	TSD	PD	IMV-8	IMV-6	VSD	IMV-2
C2	1/PD	TSD	PD	IMV-8	IMV-6	VSD
C3	1/IMV-8	1/PD	TSD	PD	IMV-8	IMV-6
C4	1/IMV-6	1/IMV-8	1/PD	TSD	PD	IMV-8
C5	1/VSD	1/IMV-6	1/IMV-8	1/PD	TSD	PD
C6	1/IMV-2	1/VSD	1/IMV-6	1/IMV-8	1/PD	TSD
E5						
C1	TSD	IMV-8	PD	SD	IMV-4	AD
C2	1/IMV-8	TSD	IMV-8	PD	SD	IMV-4
C3	1/PD	1/IMV-8	TSD	IMV-8	PD	SD
C4	1/SD	1/PD	1/IMV-8	TSD	IMV-8	PD
C5	1/IMV-4	1/SD	1/PD	1/IMV-8	TSD	IMV-8
C6	1/AD	1/IMV-4	1/SD	1/PD	1/IMV-8	TSD

The experts were confident in their claims $E^{\kappa} = \{0.8, 0.9, 0.8, 0.7, 1\}$. Applying Eq. (1), the values from Table 2 and the specified levels of experts' confidence, the following fuzzy comparison values are obtained for each of the experts (Table 5):

Table 5
The fuzzy comparison values for Fuzzy AHP method given by experts

	E1					
	C1	C2	C3	C4	C5	C6
C1	(1,1,1)	(0.9,1.13,1.35)	(1.03,1.29,1.54)	(1.44,1.8,2.16)	V(1.44,1.8,2.16)	(7.2,9,10.8)
C2	(0.71,0.89,1.07)	(1,1,1)	(0.9,1.13,1.35)	(1.03,1.29,1.54)	(1.44,1.8,2.16)	V(1.44,1.8,2.16)
C3	(0.62,0.78,0.93)	(0.71,0.89,1.07)	(1,1,1)	(0.9,1.13,1.35)	(1.03,1.29,1.54)	(1.44,1.8,2.16)
C4	(0.44,0.56,0.67)	(0.62,0.78,0.93)	(0.71,0.89,1.07)	(1,1,1)	(0.9,1.13,1.35)	(1.03,1.29,1.54)
C5	(0.27,0.33,0.4)	(0.44,0.56,0.67)	(0.62,0.78,0.93)	(0.71,0.89,1.07)	(1,1,1)	(0.9,1.13,1.35)
C6	(0.09,0.11,0.13)	(0.27,0.33,0.4)	(0.44,0.56,0.67)	(0.62,0.78,0.93)	(0.71,0.89,1.07)	(1,1,1)
	E2					
	C1	C2	C3	C4	C5	C6
C1	(1,1,1)	(1.03,1.29,1.54)	(1.03,1.29,1.54)	(1.44,1.8,2.16)	(1.8,2.25,2.7)	(3.6,4.5,5.4)
C2	(0.62,0.78,0.93)	(1,1,1)	(1.03,1.29,1.54)	(1.03,1.29,1.54)	(1.44,1.8,2.16)	(1.8,2.25,2.7)
C3	(0.62,0.78,0.93)	(0.62,0.78,0.93)	(1,1,1)	(1.03,1.29,1.54)	(1.03,1.29,1.54)	(1.44,1.8,2.16)
C4	(0.44,0.56,0.67)	(0.62,0.78,0.93)	(0.62,0.78,0.93)	(1,1,1)	(1.03,1.29,1.54)	(1.03,1.29,1.54)
C5	(0.36,0.44,0.53)	(0.44,0.56,0.67)	(0.62,0.78,0.93)	(0.62,0.78,0.93)	(1,1,1)	(1.03,1.29,1.54)
C6	(0.18,0.22,0.27)	(0.36,0.44,0.53)	(0.44,0.56,0.67)	(0.62,0.78,0.93)	(0.62,0.78,0.93)	(1,1,1)
	E3					
	C1	C2	C3	C4	C5	C6
C1	(1,1,1)	(0.9,1.13,1.35)	(0.9,1.13,1.35)	(1.03,1.29,1.54)	(1.8,2.25,2.7)	(7.2,9,10.8)
C2	(0.71,0.89,1.07)	(1,1,1)	(0.9,1.13,1.35)	(0.9,1.13,1.35)	(1.03,1.29,1.54)	(1.8,2.25,2.7)
C3	(0.71,0.89,1.07)	(0.71,0.89,1.07)	(1,1,1)	(0.9,1.13,1.35)	(0.9,1.13,1.35)	(1.03,1.29,1.54)
C4	(0.62,0.78,0.93)	(0.71,0.89,1.07)	(0.71,0.89,1.07)	(1,1,1)	(0.9,1.13,1.35)	(0.9,1.13,1.35)
C5	(0.36,0.44,0.53)	(0.62,0.78,0.93)	(0.71,0.89,1.07)	(0.71,0.89,1.07)	(1,1,1)	(0.9,1.13,1.35)
C6	(0.09,0.11,0.13)	(0.36,0.44,0.53)	(0.62,0.78,0.93)	(0.71,0.89,1.07)	(0.71,0.89,1.07)	(1,1,1)
	E4					
	C1	C2	C3	C4	C5	C6
C1	(1,1,1)	(1.03,1.29,1.54)	(0.9,1.13,1.35)	(1.2,1.5,1.8)	V(1.44,1.8,2.16)	(3.6,4.5,5.4)
C2	(0.62,0.78,0.93)	(1,1,1)	(1.03,1.29,1.54)	(0.9,1.13,1.35)	(1.2,1.5,1.8)	V(1.44,1.8,2.16)
C3	(0.71,0.89,1.07)	(0.62,0.78,0.93)	(1,1,1)	(1.03,1.29,1.54)	(0.9,1.13,1.35)	(1.2,1.5,1.8)
C4	(0.53,0.67,0.8)	(0.71,0.89,1.07)	(0.62,0.78,0.93)	(1,1,1)	(1.03,1.29,1.54)	(0.9,1.13,1.35)
C5	(0.27,0.33,0.4)	(0.53,0.67,0.8)	(0.71,0.89,1.07)	(0.62,0.78,0.93)	(1,1,1)	(1.03,1.29,1.54)
C6	(0.18,0.22,0.27)	(0.27,0.33,0.4)	(0.53,0.67,0.8)	(0.71,0.89,1.07)	(0.62,0.78,0.93)	(1,1,1)
	E5					
	C1	C2	C3	C4	C5	C6
C1	(1,1,1)	(0.9,1.13,1.35)	(1.03,1.29,1.54)	(1.44,1.8,2.16)	(1.8,2.25,2.7)	(7.2,9,10.8)
C2	(0.71,0.89,1.07)	(1,1,1)	(0.9,1.13,1.35)	(1.03,1.29,1.54)	(1.44,1.8,2.16)	(1.8,2.25,2.7)
C3	(0.62,0.78,0.93)	(0.71,0.89,1.07)	(1,1,1)	(0.9,1.13,1.35)	(1.03,1.29,1.54)	(1.44,1.8,2.16)
C4	(0.44,0.56,0.67)	(0.62,0.78,0.93)	(0.71,0.89,1.07)	(1,1,1)	(0.9,1.13,1.35)	(1.03,1.29,1.54)
C5	(0.36,0.44,0.53)	(0.44,0.56,0.67)	(0.62,0.78,0.93)	(0.71,0.89,1.07)	(1,1,1)	(0.9,1.13,1.35)
C6	(0.09,0.11,0.13)	(0.36,0.44,0.53)	(0.44,0.56,0.67)	(0.62,0.78,0.93)	(0.71,0.89,1.07)	(1,1,1)

After applying the steps of the Fuzzy AHP method, the values of the weight coefficients of the criteria are obtained for each of the experts (Table 6).

Table 6
Weight Coefficients of Criteria for experts

Expert/Criteria	C1	C2	C3	C4	C5	C6
E1	0.309616	0.20124	0.164467	0.13675	0.109173	0.078753
E2	0.275638	0.203892	0.171572	0.141462	0.117946	0.08949
E3	0.289024	0.182329	0.160586	0.148388	0.12547	0.094204
E4	0.275619	0.202466	0.165525	0.146092	0.118856	0.091442
E5	0.301222	0.197246	0.165945	0.137515	0.114717	0.083355

In order to obtain the final values of the weights of the criteria, it is necessary to aggregate the values obtained for each individual criterion by each expert, considering the weights of the experts' competencies. The above was performed using the EWAA operator [41, 42], Eq. 4:

$$EWAA\left\{Z_1, Z_2, ..., Z_j\right\} = \sum_{j=1}^{e} Z_j^e \frac{\prod_{j=1}^{e}\left(1+f\left(Z_j^e\right)\right)^{\varpi} - \prod_{j=1}^{e}\left(1-f\left(Z_j^e\right)\right)^{\varpi}}{\prod_{j=1}^{e}\left(1+f\left(Z_j^e\right)\right)^{\varpi} + \prod_{j=1}^{e}\left(1-f\left(Z_j^e\right)\right)^{\varpi}} \tag{4}$$

where Z represents the values that are aggregated, e the total number of experts, and ϖ the coefficients of expert competence.

By applying Eq. (4), the values of the criterion weights are aggregated, and the final values are calculated (Table 7).

Table 7
The Final Value of the Weight Coefficients of Criteria

Criteria	Final weight of criteria
C1	0.290
C2	0.198
C3	0.166
C4	0.142
C5	0.117
C6	0.087

Given that the criteria are of a qualitative type, a scale was created for evaluating alternatives according to the criteria (Table 8). Although criterion C1 can be expressed in centimeters, it is also of a qualitative type, since there is generally a range of values, which must be scaled. Each of the experts has a certain percentage of conviction in their claims, so Eq. (1) and degree of conviction were also used to form triangular fuzzy numbers (κ). The values of the experts' degree of conviction are the same as when determining the weights of the criteria.

Table 8
Fuzzy Linguistic Rating Scale

Linguistic expression	Fuzzy values
Less favorable (LF)	$(1,1,1)$
Partially favorable (PF)	$(2\kappa,2,2(2-\kappa))$
Favorable (F)	$(3\kappa,3,3(2-\kappa))$
Very favorable (VF)	$(4\kappa,4,4(2-\kappa))$
Excellent (E)	$(5\kappa,5,5(2-\kappa))$

Given that the weight coefficients of the criteria have been obtained and the influence of each criterion on the final decision is now known, it is necessary to form an initial decision matrix. For the alternatives, seven different ICPs have been defined $A=\{A1, A2, ..., A7\}$. Then, each of the experts evaluated the alternatives according to each criterion, using the Fuzzy linguistic scale (Table 8). In order not to burden the content of the text, below only the initial decision matrix for expert E1 will be presented (Table 9). Expert E1 is 80% convinced of his claims, i.e. the value of degree of conviction is 0.8.

Table 9
Initial Decision Matrix for E1

Expert/Criteria	C1	C2	C3	C4	C5	C6
A1	E	F	PF	PF	F	F
A2	VF	F	F	E	LF	E
A3	F	VF	E	F	PF	PF
A4	E	E	VF	VF	E	LF
A5	F	PF	PF	PF	F	F
A6	E	F	VF	E	PF	F
A7	VF	E	VF	VF	PF	F

Applying the values from Table 8 and the degree of conviction values, the following Fuzzy initial decision matrix for expert E1 is obtained (Table 10).

Table 10
Fuzzy Initial Decision Matrix for E1

Expert/Criteria	C1	C2	C3	C4	C5	C6
A1	(4,5,6)	(2.4,3,3.6)	(1.6,2,2.4)	(1.6,2,2.4)	(2.4,3,3.6)	(2.4,3,3.6)
A2	(3.2,4,4.8)	(2.4,3,3.6)	(2.4,3,3.6)	(4,5,6)	(1,1,1)	(4,5,6)
A3	(2.4,3,3.6)	(3.2,4,4.8)	(4,5,6)	(2.4,3,3.6)	(1.6,2,2.4)	(1.6,2,2.4)
A4	(4,5,6)	(4,5,6)	(3.2,4,4.8)	(3.2,4,4.8)	(4,5,6)	(1,1,1)
A5	(2.4,3,3.6)	(1.6,2,2.4)	(1.6,2,2.4)	(1.6,2,2.4)	(2.4,3,3.6)	(2.4,3,3.6)
A6	(4,5,6)	(2.4,3,3.6)	(3.2,4,4.8)	(4,5,6)	(1.6,2,2.4)	(2.4,3,3.6)
A7	(3.2,4,4.8)	(4,5,6)	(3.2,4,4.8)	(3.2,4,4.8)	(1.6,2,2.4)	(2.4,3,3.6)

By implementing the weights of the criteria from Table 7 and the initial decision matrix into the mathematical apparatus of the Fuzzy CoCoSo method, the ranking of alternatives is reached (Figure 3).

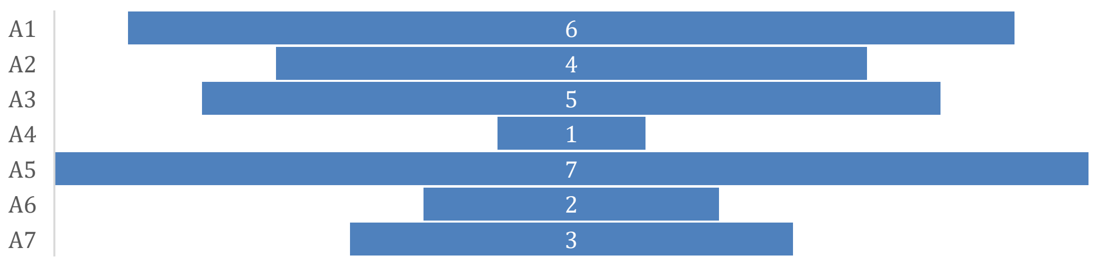

Fig. 3. The rank of alternatives

Based on the results shown in Figure 3, the optimal alternative is A7, that is, this alternative is the closest to the ideal solution, while the alternative A5 is the worst ranked and the furthest from the ideal solution.

3. Sensitivity and comparative analysis

3.1. Sensitivity analysis

There are different ways of conducting sensitivity analysis of the output results of MCDM methods [43-45]. One of the ways is by defining different scenarios of changing the weights of the criteria, implementing them in the method and observing possible changes in the output results [46]. For the purposes of this research, 25 scenarios of changing the weights of the criteria were formed (Figure 4).

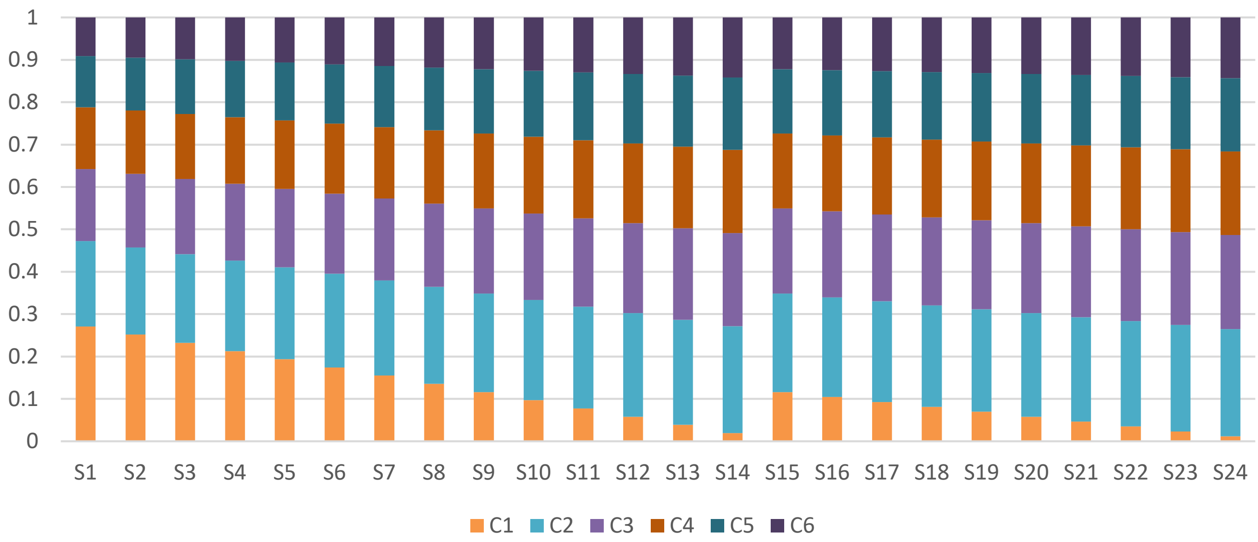

Fig. 4. Scenarios of changes in criteria weights

By applying the defined scenarios (Figure 4) in the Fuzzy CoCoSo method, the following ranks of alternatives are obtained (Figure 5):

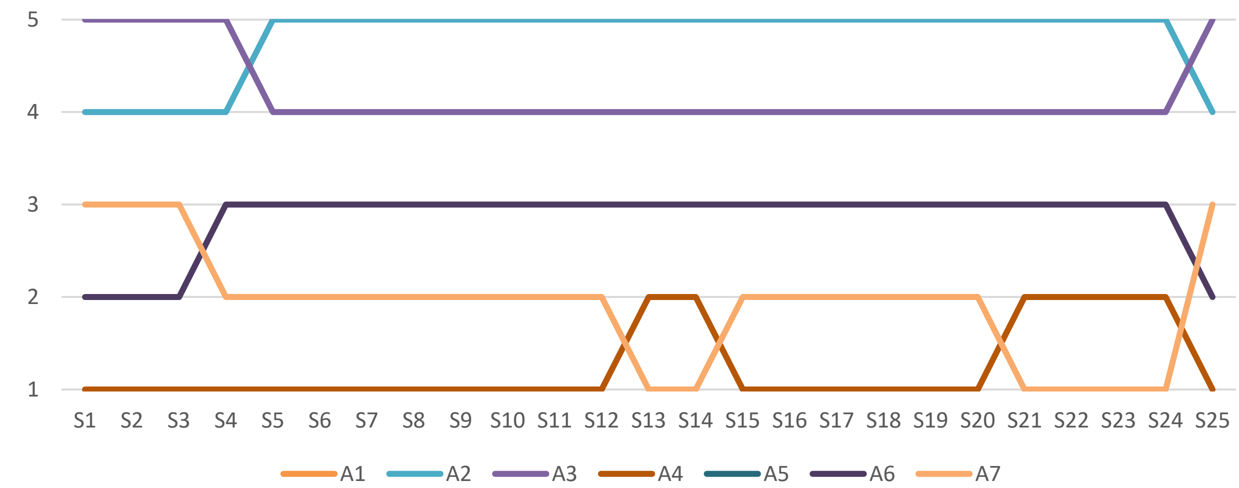

Fig. 5. Alternative rankings after applying the weight change scenario

As can be concluded from the results of the Sensitivity Analysis (Figure 5), the method is sensitive to changes in the weight coefficients of the criteria, and special attention should be paid when determining them. But despite the mentioned sensitivity, the first-ranked alternative A4 is at the very top of the ranking, while the last-ranked alternative A5 is at the very bottom of the ranking, so it cannot be optimal under any circumstances.

3.2. Comparative analysis

In addition to sensitivity analysis, a key component of validating the results is comparative analysis [47-49]. To check the validity of the output results of the proposed methodology, the output results of the Fuzzy CoCoSo method were compared with the results of the other four methods, which implemented the same input data (Figure 6). Methods were used for subject comparison: Fuzzy COPRAS [50], Fuzzy MABAC [51], Fuzzy WASPAS [52], and Fuzzy SAW [53].

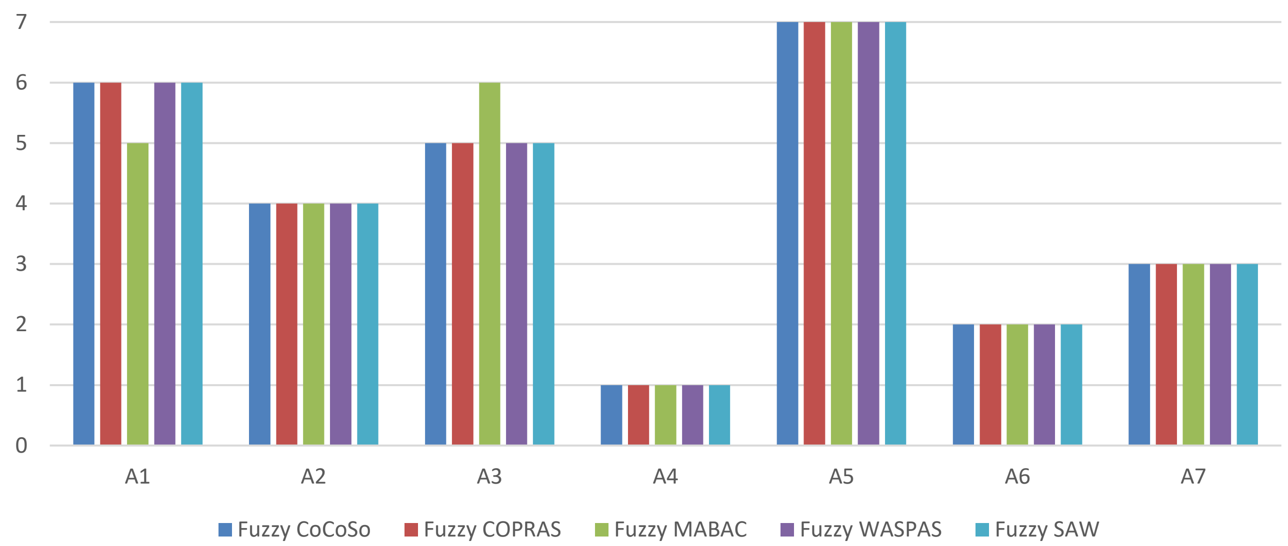

Fig. 6. Comparison of results obtained by different methods

As can be seen from Figure 6, the results of the Fuzzy CoCoSo method give identical results to the Fuzzy SAW, Fuzzy COPRAS, and Fuzzy WASPAS methods, while with the Fuzzy MABAC method, there are minor deviations in the ranking of alternatives, mostly in the fifth-ranked and sixth-ranked alternatives, which does not affect the final decision on the optimal alternative. It can be concluded that the proposed methodology gives reliable and valid results.

4. Conclusions

This paper presents the selection of ICP for tanks using the Fuzzy AHP and Fuzzy CoCoSo methods, as well as the EWAA operator. The research included an assessment of various criteria that influence the choice of the optimal location, such as the characteristics of ice, snow cover, access roads and the existence of construction materials in the immediate vicinity of the crossing point.

The application of the Fuzzy AHP method enabled the precise determination of criteria weights based on expert opinions aggregated using the EWAA operator, while the Fuzzy CoCoSo method provided a comprehensive evaluation of alternatives. The results showed that the combination of these methods provides a robust framework for decision-making in complex conditions.

The conducted sensitivity analysis to changes in weight criteria confirmed the stability and reliability of the obtained results, indicating that small changes in weights do not significantly affect the final ranking of alternatives. Comparative analysis showed that the Fuzzy CoCoSo method provides valid results.

Finally, the application of this model for choosing the place of tank crossing over the frozen water obstacle proved to be effective and reliable, providing a solid basis for future research and practical application in this or similar situations. Based on the results of this research, it is possible to identify several directions for future research: 1) Expanding the list of criteria, through the inclusion of additional ones, such as weather conditions, enemy influence, masking conditions, etc.; 2) Application of other MCDM methods and approaches, which can help in comparing results and evaluating the effectiveness of different approaches; 3) Integration with GIS technologies, which would improve the decision-making process by providing visual and spatially relevant data; 4) Carrying out case studies in different and concrete geographical and climatic conditions, thus creating conditions for additional validation and adaptation of the MCDM model to specific situations.

Author Contributions

Conceptualization and methodology D.T., D.B., A.M., and A.P.; software, D.T., and D.B.,; validation, D.B., A.M., and A.P.; formal analysis, investigation, resources, A.P.; writing—original draft preparation, writing—review and editing, visualization, D.T., D.B., A.M., and A.P.; supervision, D.B. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement

All data are included in the manuscript. However, the reader may contact the corresponding author for more details on the data.

Conflicts of Interest

The authors declare no conflicts of interest.

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