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Interval fuzzy AHP method in risk assessment

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ABSTRACT

The Analytic Hierarchy Process (AHP) method is one of the oldest and mostly used multi-criteria decision-making methods. In addition to the development of a large number of other methods, the AHP method is still widely applied. More and more often, this method is being modified by the application of various mathematical tools dealing with the consideration of uncertainty and indeterminacy. This paper presents an approach to the modification of the AHP method using triangular interval fuzzy numbers. In this approach, the confidence interval of the fuzzy number describing the comparison of criteria differs from one comparison to another. It depends on the opinion of the decision makers/experts, respectively, on their certainty in the comparison they make. The modification of the method is presented on the problem of selecting the course of navigation of vessels in flooded areas, based on the risk assessment of each predicted course.

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1. INTRODUCTION[1]

A variety of methods were developed and are still being developed for the purposes of risk assessment. Due to the necessity of its quantification, multicriteria decision-making (MCDM) methods found its place in the risk assessment. The MCDM methods are applied in different areas. For example, these are applied in the supply chain management for the selection of suppliers (Durmić et al., 2020), in the field of logistics (Pamučar et al., 2021), in telecommunications for the selection of mobile network operator (Bošković et al., 2021), in the selection of different types of transport vehicles (Tešić et al., 2022a; Pamučar et al., 2022), in the military field for the selection of an aircraft (Milovanović et al., 2021), aircrafts (Djukić et al., 2022) and locations (Tešić et al., 2022), for the selection of different concepts (Bošković et al., 2023) and strategies (Badi et al., 2023), for the ranking of countries by the criterion of economic freedom (Puška et al., 2023), for the ranking of proofreaders during recruitment (Ali et al., 2023), as well as in other practical problems (Debnath & Ghosh, 2021; Granados et. al., 2022; Tešić et al., 2022b; Pamučar & Gorcun, 2022; Bitarafan et al., 2023).

[1] The initial version of the research was published at 2nd Security and Crisis Management - Theory and Practice (SeCMan), Obrenovac, Serbia (Božanić et al., 2016b).

Having in mind one of the most important characteristics of the risk - uncertainty, a fuzzy logic is becoming increasingly used in the risk assessment, as a very suitable mathematical support for the treatment of uncertainty (Božanić et al., 2015; Lyu et al., 2020; Iphar & Cukurluoz, 2020; Si & Ganguly, 2021; Koohathongsumrit & Meethom, 2021; Lin et al., 2021; Wang et al., 2021; Khodadadi-Karimvand & Shirouyehzad, 2021; Topal & Atasoylu, 2022; Kozhukhivskyi & Kozhukhivska, 2022; Zhou et al., 2022). In this regard, the paper presents a new approach to the fuzzification of the Analytic Hierarchy Process (AHP) method, by applying interval fuzzy numbers and the modified method (interval fuzzy AHP - IFAHP) in the risk assessment when selecting navigation vehicles directions of the Army of Serbia. The model is developed with the idea of using it for selection purposes, primarily in operations of providing assistance to civil authorities in case of floods or other disasters that cause flooding of certain areas.

The Army of Serbia very often takes a significant share in the assistance to civil authorities in cases of flooding. One of the ways of engagement refers to the use of navigation resources Serbian Army disposes with (scaffolding, amphibious transporters and boats). This assistance primarily relates to the transport of persons, animals, material and technical resources from the endangered area to safe places. However, the specificity of water surfaces resulting in flood can greatly affect the possibilities of navigation vehicles of the Army of Serbia. Namely, the primary purpose of scaffolding, amphibious transporters and boats Serbian Army disposes with is overcoming water barriers (rivers, canals, lakes and the like) in combat operations. Sailing through in flooded areas has a number of specific features which limit possibilities of the vehicles, such as uneven depth of water, large number of obstacles i.e. facilities and objects located below the water surface which usually cannot be seen, or visible objects among which is not possible to sail through (due to short distances), and the like. In that sense, the navigation imposes certain risks, while on the other hand it is necessary to provide assistance, *i.e.*, to carry out a transport from one location to another. In order to provide the necessary assistance, the selection of navigation routes would be made based on the degree of assessed risk. In particular, the direction of navigation or transportation from the flooded area with the smallest risk would be chosen.

Although risk forms an integral part of military operations, the risk assessment is still in the development phase (Božanić et al., 2015). Therefore, the development of the risk assessment models in military operations is directed towards the use of knowledge from other fields of human activity. Considering that there are many different approaches to the identification and evaluation in the risk assessment management, herein is adopted the method shown in (FM 5-19 Composite Risk Management, 2006). This method consists of the following steps: (1) Identify Hazard, (2) Assess Hazard (to define risk level), (3) Develop Controls and Make Decision, (4) Implement Controls, and (5) Supervise and Evaluate. The fuzzy AHP model, which has been developed in this paper, precedes the development of control measures and decision-making, and it is realized after the identification of hazards.

After the introduction, in the second section, an overview of earlier approaches to the AHP method fuzzification, as well as a new modification, is provided. In the third part, the application of the modified AHP method on a specific problem is presented, and the obtained results are compared with the classic AHP method.

2. DESCRIPTION OF THE METHODS APPLIED

In the following part of the paper it is described in detail a part of the methods applied. Another part of the methods is not described (the AHP and fuzzy logic), because these are considered relatively familiar areas.

2.1. Interval fuzzy numbers

The membership function to the fuzzy set type-2 occurs when the type-1 membership function, Figure 1a, is displayed in the fuzzy form, Figure 1b. Then it is obtained the type-2 membership function shown in the Figure 2. For certain values of the variable x' the membership function type-2 has different values of membership degree, *i.e.* different degree of membership for each of the points (x'). Repeating presented procedure for all the elements, it is obtained a three-dimension membership function (type-2 membership function), which describes type-2 fuzzy numbers (Mendoza et al., 2009; Castillo & Melin, 2008).

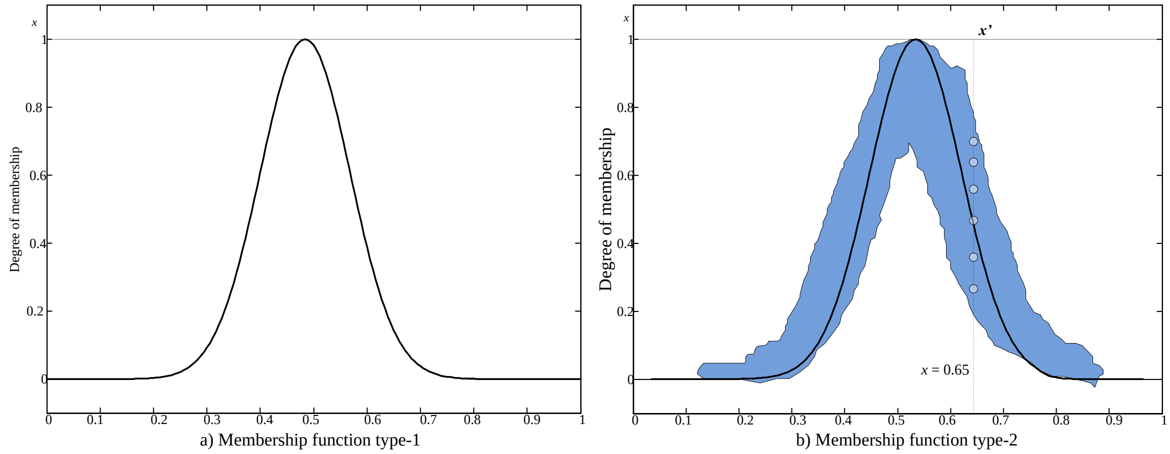

Figure 1. Fuzzy membership function type - 1 (a) and fuzzy membership function type - 2 (b) (Pamučar et al., 2015)

In the membership function of general fuzzy set type-2 ($\tilde{A}$), Figure 2, the value of the membership function in every point of the third dimension is described with two-dimension domain, so called, Footprint of Uncertainty - FOU. The footprint of certainty presents a blur of the membership function type-1. The type-2 membership function is described (bordered) with two membership functions type-1, $\overline{X}$ i $\underline{X}$, which are defined as Upper Membership Function - UMF and Lower Membership Function - LMF, respectively. Both functions, the UMF and the LMF are presented with the fuzzy set type-1. Therefore, it is possible to use arithmetic operations of the fuzzy set type-1 for characterization and operation with the fuzzy sets type-2 (Pamučar et al., 2015)

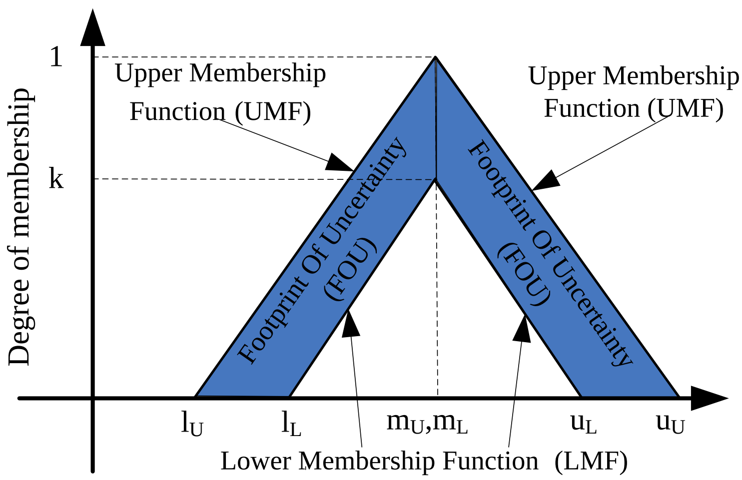

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Figure 2. Triangular membership function of the fuzzy number type-2

2.2. Fuzzification of the Saaty's scale

The analytic hierarchy process method was developed by Thomas Saaty (1980). For the purposes of this method he developed a special scale, so-called, Saaty's scale, which represents the standard of the Analytic Hierarchy Process (AHP). This method is well known and has been used for long in the practice of operational researches, more about which can be seen in (Saaty, 1980).

The improvement of the AHP method is mostly based on the improvement of the Saaty's scale and most of the examples in the research refer to its improvement by fuzzy theory. The application of this method in fuzzy environment is presented in many papers using different types of fuzzy numbers. Kahraman *et al.* (2020) present different method improvements by using hesitant, intuitionistic, and spherical fuzzy sets combined with other fuzzy MCDM methods. Yucesan & Gul (2020), Çalık (2021) and Ayyildiz & Taskin Gumus (2021) apply the AHP method improved with Pythagorean fuzzy numbers. The application of triangular fuzzy numbers, as the most widely used type of improvement of the Saaty's scale and most widely used form of fuzzy AHP method is presented in (Wang et al., 2020; Boral et al., 2020; Ban et al., 2020; Jumaryadi et al., 2020; Tripathi et al., 2021; Hossain & Thakur, 2021; Coffey & Claudio, 2021; Sivaprakasam & Angamuthu, 2023; Bhatt et al., 2021; Büyüközkan et al., 2021; Nazim et al., 2022), while Rajabpour et al. (2022) improve subject methodology using trapezoidal fuzzy numbers *etc*.

Based on everything previously mentioned and on other research can be concluded that fuzzification of the Saaty's scale can be roughly divided in two approaches. The first approach is a "strict fuzzification", in which the confidence interval of the fuzzy number is predetermined. Therefore, the expert opts in favor of a comparison in pairs, but it does not affect the values of the previously defined fuzzy number (Table 1, Column 2). The processes of defining fuzzy number and the degree of certainty present two separate researches. Another approach is a "soft fuzzification", in which in addition to the comparisons in pairs the expert performs, the values of fuzzy number also depend on the opinion of the expert (Table 1, Column 3).

Table 1. Presentation of different approaches to the fuzzification of the Saaty's scale

Classic Saaty's scale (Castilo & Melin, 2008)	Strict fuzzification (John et al., 2014)	Soft fuzzification (Božanić et al., 2016a)
1	(1,1,1)	(1, 1, 1)
3	(2,3,4)	$\left(3\gamma_{ji},3,\left(2-\gamma_{ji}\right)3\right)$
5	(4,5,6)	$\left(5\gamma_{ji},5,\left(2-\gamma_{ji}\right)5\right)$
7	(6,7,8)	$\left(7\gamma_{ji},7,\left(2-\gamma_{ji}\right)7\right)$
9	(8,9,9)	$\left(9\gamma_{ji},9,\left(2-\gamma_{ji}\right)9\right)$
2, 4, 6, 8	$\left(x-1,x,x+1\right)$	$\left(x\gamma_{ji},x,\left(2-\gamma_{ji}\right)x\right);\ x=2,4,6,8$

Based on the other "soft fuzzification" where the confidence interval of the number depends on the degree of certainty of the expert in comparison in pairs - γ (more detailed explanation can be found in (Božanić et al., 2016a)), a new fuzzification has been created by the application of interval fuzzy numbers (Table 2). The form of fuzzy numbers presented is the following:

$$\tilde{T}=\left(l_U,l_L,m,u_L,u_U\right) \tag{1}$$

Considering that m_U=m_L in the expression it is presented as *m*.

Table 2. Presentation of fuzzyficated values of the Saaty's scale by the application of interval fuzzy numbers

Value	Fuzzy number
1	(1,1,1,1,1)
3	$\left(3\gamma_{ji}^2,3\gamma_{ji},3,\left(2-\gamma_{ji}\right)3,\left(2-\gamma_{ji}^2\right)3\right)$
5	$\left(5\gamma_{ji}^2,5\gamma_{ji},5,\left(2-\gamma_{ji}\right)5,\left(2-\gamma_{ji}^2\right)5\right)$
7	$\left(7\gamma_{ji}^2,7\gamma_{ji},7,\left(2-\gamma_{ji}\right)7,\left(2-\gamma_{ji}^2\right)7\right)$
9	$\left(9\gamma_{ji}^2,9\gamma_{ji},9,\left(2-\gamma_{ji}\right)9,\left(2-\gamma_{ji}^2\right)9\right)$
2, 4, 6, 8	$\left(x\gamma_{ji}^2,x\gamma_{ji},x,\left(2-\gamma_{ji}\right)x,\left(2-\gamma_{ji}^2\right)x\right)$ $x=2,4,6,8$

The fuzzy number $\tilde{T}$, $x\in\left[1,9\right]$ must meet the following conditions also:

$$x\gamma^2=\begin{cases}x\gamma^2, & \forall\ 1\le x\gamma^2\le x\\ 1, & \forall\ x\gamma^2<1\end{cases} \tag{2}$$

$$x\gamma = \begin{cases} x\gamma, & \forall\ 1 \le x\gamma \le x \\ 1, & \forall\ x\gamma < 1 \end{cases} \qquad (3)$$

The value γ represents the degree of certainty of the expert in the comparison he performs. The value k (Figure 2) is the coefficient of the expert's competence. About the assessment of the expert's competence more can be read in (Milićević, 2014). Thus, in the case of expert's competence with k = 0.7 and in the comparison "3" - "low dominance," a fuzzy number would look like in Figure 3 (with varying degrees of certainty 1, 0.8 and 0.5).

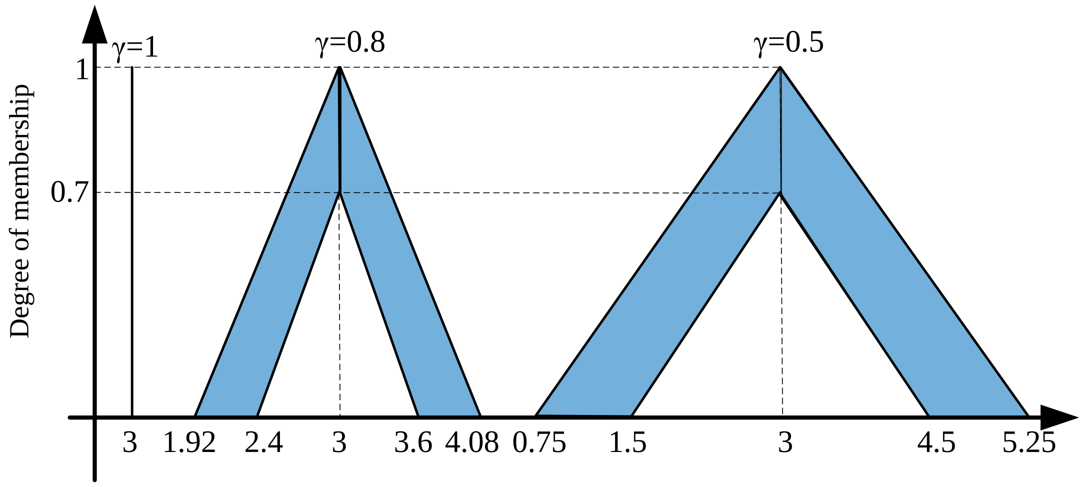

Figure 3. Presentation of the interval fuzzy number depending on the degree of certainty of the expert

Expressions for the calculation of the inverse interval fuzzy number $\tilde{T}^{-1}$ are shown in the Table 3.

Table 3. Presentation of the fuzzyficated inverse values of the Saaty's scale by applying interval fuzzy numbers

Value	Fuzzy number
1	(1,1,1,1,1)
1/3	$\left(1/(2-\gamma_{ji}^2)3, 1/(2-\gamma_{ji})3, 1/3, 1/3\gamma_{ji}, 1/3\gamma_{ji}^2\right)$
1/5	$\left(1/(2-\gamma_{ji}^2)5, 1/(2-\gamma_{ji})5, 1/5, 1/5\gamma_{ji}, 1/5\gamma_{ji}^2\right)$
1/7	$\left(1/(2-\gamma_{ji}^2)7, 1/(2-\gamma_{ji})7, 1/7, 1/7\gamma_{ji}, 1/7\gamma_{ji}^2\right)$
1/9	$\left(1/(2-\gamma_{ji}^2)9, 1/(2-\gamma_{ji})9, 1/9, 1/9\gamma_{ji}, 1/9\gamma_{ji}^2\right)$
1/2, 1/4, 1/6, 1/8	$\left(1/(2-\gamma_{ji}^2)x, 1/(2-\gamma_{ji})x, 1/x, 1/x\gamma_{ji}, 1/x\gamma_{ji}^2\right)$ $x = 2,4,6,8$

The inverse fuzzy number $\tilde{T}^{-1}$, $x \in [1/9, 1]$ must meet the following conditions also:

$$1/x\gamma^2 = \begin{cases} 1/x\gamma^2, & \forall\ \mathrm{x} \le x\gamma^2 \le 1 \\ 1, & \forall\ x\gamma^2 > 1 \end{cases} \qquad (4)$$

$$1/x\gamma = \begin{cases} 1/x\gamma, & \forall\ \mathrm{x} \le x\gamma \le 1 \\ 1, & \forall\ x\gamma > 1 \end{cases} \qquad (5)$$

3. PRESENTATION OF THE IFAHP METHOD APPLICATION

The basic idea of the IFAHP method is that it should be applied in group decision-making, although its application is also possible in individual decision-making. Basic steps in its application (regardless of whether it concerns defining weight coefficients of criteria or alternatives) are the following:

1) Data collection from the experts (comparisons are made in pairs by using classic Saaty's scale, stating the degree of certainty of every comparison made);

$$E = \begin{matrix} & C_1 & C_2 & \cdots & C_n \\ C_1 & a_{11};\gamma_{11} & a_{12};\gamma_{12} & \cdots & a_{1n};\gamma_{1n} \\ C_2 & a_{21};\gamma_{21} & a_{22};\gamma_{22} & \cdots & a_{2n};\gamma_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ C_n & a_{n1};\gamma_{n1} & a_{n2};\gamma_{n2} & \cdots & a_{nn};\gamma_{nn} \end{matrix} \tag{6}$$

2) Application of the AHP with the fuzzyficated Saaty's scale for each expert separately;

3) Aggregation of the obtained priority vectors.

Before starting the application of the method, basic criteria for performing the risk assessment should be defined. The criteria for risk assessment in this model are taken from (Božanić et al., 2015), and adapted to the specific problem. Basic criteria based on which shall be performed the risk assessment are the following (Božanić et al., 2015):

- Criterion 1 (C1) - *probability of hazard occurrence*. This criterion evaluates to what extent it is possible to occur the damage/adverse effect, *i.e.*, the manifestation of the hazard.
- Criterion 2 (C2) - *state of the system*. Under this criterion is meant the state of the system in relation to the potential hazard. In other words, it is considered the vulnerability of the system, as well as the assessment of possibilities for the defense of the system in case of emergency.
- Criterion 3 (C3) - *negative consequences*. This criterion includes human and material losses potential danger can cause.
- Criterion 4 (C4) - *ability to generate other hazards*. This criterion is defined because it is calculated the risk for each hazard, and there is no connecting component between hazards.

After defining the criteria, conditions are created for the application of the IFAHP method. The first step is to define the comparison matrix of criteria in pairs and degrees of certainty, according to the expression 6.

$$E_1 = \begin{matrix} & C_1 & C_2 & C_3 & C_4 \\ C_1 & 1;100 & 2;100 & 1/2;70 & 4;100 \\ C_2 & 1/2;100 & 1;100 & 1/3;60 & 2;80 \\ C_3 & 2;70 & 3;60 & 1;100 & 5;60 \\ C_4 & 1/4;100 & 1/2;80 & 1/5;60 & 1;100 \end{matrix}$$

In the second step it is performed the fuzzification of the previous matrix by applying the expressions provided in Tables 2 and 3.

$$E_1' = \begin{matrix} & C_1 & C_2 & C_3 & C_4 \\ C_1 & 1;1;1;1;1 & 2;2;2;2;2 & 0,33;0,38;0,5;0,71;1 & 4;4;4;4;4 \\ C_2 & 0,5;0,5;0,5;0,5;0,5 & 1;1;1;1;1 & 0,2;0,24;0,33;0,56;0,93 & 1,28;1,6;2;2,4;2,72 \\ C_3 & 1;1,4;2;2,6;3,02 & 1,08;1,8;3;4,2;4,92 & 1;1;1;1;1 & 1,8;3;5;7;8,2 \\ C_4 & 0,25;0,25;0,25;0,25;0,25 & 0,37;0,42;0,5;0,63;0,78 & 0,12;0,14;0,2;0,33;0,56 & 1;1;1;1;1 \end{matrix}$$

In further assessment standard steps of the AHP method are applied *i.e.*, weight vectors W are obtained. After obtaining weight vectors, it is performed the defuzzification of the obtained weight vectors W using the expression (Kahraman et al., 2014):

$$W = \frac{\frac{(u_U - l_U) + (m_U - l_U)}{3} + l_U + k\left[\frac{(u_L - l_L) + (m_L - l_L)}{3} + l_L\right]}{2} \tag{7}$$

The obtained weight coefficients of criteria are presented in the Table 4. For comparison purposes, the values obtained by classic AHP method are shown also.

Table 4. Weight coefficients of criteria obtained by the IFAHP and classic AHP method

Criterion	IFAHP	AHP
C_1	0.30	0.29
C_2	0.16	0.15
C_3	0.45	0.48
C_4	0.09	0.08

From the Table 4, it can be concluded that there are no changes in the rank of criteria, but there are differences in the obtained weight coefficient values.

The following step is to evaluate alternatives, *i.e.*, to select the most favorable one from the set of possible solutions. As well as in obtaining weight coefficients, the initial matrices are defined first, comparing each other for each criterion separately, and the degrees of certainty are defined for each comparison. Further is performed the fuzzification by the application of conventional steps of the AHP method and the defuzzification. In the abstract example of six alternatives are obtained the results shown in the Table 5. Also, in the table are shown the results that would be obtained by using classic AHP method.

Table 5. Rank of alternatives

Criterion	AHP	Rank	IFAHP	Rank
A_1	0,17	4.	0,19	4.
A_2	0,26	6.	0,23	6.
A_3	0,24	5.	0,21	5.
A_4	0,14	3.	0,13	3.
A_5	0,10	2.	0,10	1.
A_6	0,09	1.	0,12	2.

Analyzing the obtained results it is noticed that the rank of alternatives in case of using the IFAHP and classic AHP is uneven. The alternatives one and two have changed places. It is also noted that in case of the application of the IFAHP three alternatives are at the top, having very close values, which is not the case in the application of classic AHP method. Relying on the IFAHP method, the decision-makers would choose the alternative number five as the least risky, while by using classic AHP method, the decision-makers would choose the alternative six as a solution. In this specific case, it can be considered more logical to select the sixth alternative, because within the IFAHP method the level of certainty of the decision makers/experts was considered, while this was not the case with the classic AHP method. In other words, the persons who make comparisons using classic AHP method, even when they know for sure that they are not sure about something, do not have the opportunity to declare it, but have to decide on one of the possibilities. On the other hand, observing the three first-ranked alternatives, it can be seen that the difference in the obtained values is small. Unfortunately, the AHP method does not provide a special mathematical tool to establish whether the first-ranked alternative is sufficiently dominant in relation to the others, as is the case with some other methods (for example, with the VIKOR method).

4. CONCLUSION

In the paper has successfully been presented the application of the modified AHP method on the example of individual decision-making, based on the risk assessment performed. In a similar way, the application would be conducted in group decision-making. The displayed fuzzification may affect the output values, but also the rank of alternatives. The impact on the rank of alternatives is possible in close values, based on what the comparison in pairs remains the most important element of the method. The degree of certainty is only an additional element that has the capacity to reduce the output result or increase it for a relatively small value.

Practical importance of the paper is reflected in successful decision-making on the basis of the risk assessment of possible navigation vehicles directions of the Army of Serbia in the flooded areas. In this paper it is ignored the decision-making on the basis of the length a particular vehicle should cross over in the course of navigation, the fuel consumption and the like, because differences are small from one to the other alternative. Also, the urgency of actions taken during floods affects to ignore a large number of parameters, which in other situations would be of great importance.

Further research should be directed towards the application of the presented modification to solving other problems. Also, the development of a mathematical tool for determining the degree of dominance of the first-ranked alternative would be an important subject of the authors' research in case of the AHP method.

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