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Full Length Research Paper

Modelling of the fuzzy logical system for offering support in making decisions within the engineering units of the Serbian Army

Dragan Pamučar*, Darko Božanić, Boban Đorović and Aleksandar Milić

Military Academy, Serbia, Generala Pavla Jurisica Sturma 33, 11000 Belgrade, Serbia.

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The paper presents a decision making process when choosing the location for the establishment of bridge crossing point in order to overcome water obstacles. Since the decision making process is followed by a bigger or smaller degree of undefined criteria that are necessary for making relevant decision, the fuzzy logic was used for the exploitation of those uncertainties and ambiguities. The paper presents the modelling of fuzzy logical system that presents support to decision making process in military organization. In the final part of the paper, testing of the model was done and the best location for the bridge crossing point of the river was selected.

Key words: Multicriteria decision making, fuzzy logic, water obstacles, bridge crossing point.

INTRODUCTION

Management process in every organization is carried out by making appropriate decisions and turning them into actions. This means that the management process is often equated with the process of decision making which indicates the great importance of decision making in the process of managing organizations. The efficiency of management, as well as functioning and development of each organization depend on the correctness of decision making, that is, the correctness of actions taken. In most cases, the decision making process in the military organization is in terms of not having relevant information, which is characterized by a high degree of uncertainty, subjectivity and ambiguity. Fuzzy logic proves to be an appropriate tool to address the described uncertainties and ambiguities. In that way, fuzzy logic enables the exploitation of tolerance that exists in imprecision, ambiguity and partial truth of the results obtained through research.

All the armies of the world give great importance to overcoming water obstacles, as a very important combat action. In order to overcome water obstacles in a faster and safer way, means specifically intended for this type of activity are improved and developed. However, in order to overcome the water obstacle successfully, it is necessary to make the proper choice of location for setting means needed for its overcoming. These actions require the application of specific procedures, detailed planning, control measures and very strong logistical support.

These conclusions impose the need to act carefully and systematically in the process of location selection for overcoming water obstacles, because any wrong decision can lead to weakening combat capabilities of units while performing the task. Persons who make decision sometimes are in a position to discuss only one location and then the decision is about accepting or rejecting the location. However, they often find themselves in a situation where they conclude, after ranking the offered locations, the best location to be chosen.

Throughout this paper the fuzzy logic system which selects bridge crossing point across the river on the basis of defined criteria is presented. In the complex environmental conditions many problems in decision making exist, and alternative solutions are followed by various types of uncertainty and imprecision. The

*Corresponding author. E-mail: dpamucar@gmail.com.

proposed solutions can be described by linguistic expressions and modeled by uncertain numbers. In the classical approach, modelling uncertainty is based on the application of the probability theory, where the uncertainties are modeled by random variables which have different distribution. Treatment of uncertainty in this way has certain limitations. One of the limitations is that the calculation of the probability of each random variable requires a large number of records data, as well as the fact that the combination of different uncertainties leads to a complex probability distribution which requires complex mathematical expressions, that is, it increases the complexity and volume of calculation. Development of new fields in mathematics made it possible to describe the uncertainties and imprecision in a more realistic way. In other words, soft computing methods are alternatives to the classical approach of treating uncertainties. One of the methods of soft computing is fuzzy set theory.

Starting from the characteristics of some multiple criteria methods decision making fuzzy logic system for valuing locations for the establishment of bridge crossing point across water obstacles has been developed. In the next part of the paper phases of the mentioned model will be presented, as well as its application.

PROBLEM SETUP

The Serbian Army is organized at the strategic, operational and tactical level in commands, units and institutions. It is generally composed of branches, arms and services. The engineers serve as an arm within the Serbian Army whose units give combat support creating necessary conditions for engagement of combat and manoeuvering units. One of the tasks of the engineers is to provide successful overcoming of water obstacles during offensive and defensive operations. In addition, the engineers of the Serbian Army are very often engaged in overcoming water obstacles in peacetime.

From the military standpoint the concept of water obstacle includes all water surfaces that must be overcome by vessels, while the concept of overcoming water obstacles includes a set of measures, actions and procedures undertaken for the purpose of crossing water obstacle in order to perform the given task. The engineers of the Serbian Army, who intended to overcome the water obstacles, are organized into two pontoon battalions within the River Flotilla of the Army forces and equipped by sets of pontoon bridge PM-M-71. Similar to the American Improved Ribbon Bridge (IRB) and the Russian PMP - M and PP - 91 so the ferry and pontoon bridges can be made from the sets of PM-M-71 pontoon bridge. Depending on the way of engaging means ferries and bridges crossing points can be arranged.

Ferry crossing point (FCP) of the water obstacle includes part of the river, bank and hinterland which was arranged for the transport of combat and noncombat means by ferries, from one bank to another (Pifat, 1980). The term bridge crossing point (BCP) of the water obstacle means the place where the river overcoming was done, together with the bank and hinterland where a smooth transition of combat and noncombat means from one to the other bank of the water obstacle was enabled. Out of sets of the pontoon bridge PM-M-71 bridges of class capacity 20 and 60 tons are made (Figure 1).

The choice of location for BCP is a complex activity that depends on a number of criteria. Defining criteria is complicated by the fact that it is a combat situation that occurs under the following circumstances:

In the case of transition from one to the other side of the water obstacle the disturbance of the combat units placement and their gathering on the small territory occurs, and valuable time is lost (the regrouping of forces) and the risk of losses is increased (units looseness is reduced); firing action of the enemy exerts significant influence especially when crossing water obstacle because it is about crossing across an object that is very hard to camouflage, and secure; crossing the pontoon bridge is of limited capacity in terms of the means weight that cross over it and the speed used for moving on the bridge.

All of this underlines the importance of the proper location selection where the BCP would be organized, so that the negative characteristics, which occur while overcoming water obstacles, would be reduced as much as possible.

CHARACTERISTICS OF THE MULTICRITERIA METHODS

Decision making often means valuing a set of possible solutions or alternatives. When the valuing is done in relation to one criterion, the solution (alternative) that extremes target function is determined, and the process is referred to as one criterion optimization, or simply optimization. Things get complicated when there are two or more criteria and when instead of optimal one should find the best solution. Each form of criteria unification in one (complete scalarization) and reducing the task to one criterion brings disadvantages that limit scope of analysis and accuracy of the results. Instead of full scalarization, multicriteria problem is usually treated in its original form, and the level of target function scalarization is controlled by decision maker or analyst. In other words, the decision maker usually measures criteria, or directly ranks them according to significance and in this way forms the target function according to own preferences. Whether it does so indirectly or directly at a given stage of the decision making process, the matrix of alternatives and criteria is formed, and is subject to analysis and processing because there is difficulty in obtaining alternative grades on the basis of which the alternatives are ranked.

Difficulty grades and ranks can be used individually or integrally depending on the type of problem. If one only looks for the best alternative, it is usually enough to rank. When it comes to allocation problems, difficulty grades can indicate the proportion of resources allocation according to alternatives ranks. The third case is that one wants to identify the first few best alternatives and the extent of their participation in the overall resources allocation. Multiple criteria and the hierarchical structures are part of the complex environment which analysts encounter in tackling the problems of decision making and creating high - quality methods for their solution in practice. Presence of different criteria, some of which should be maximized and some minimized, means that decisions are made in conflict conditions and that there must be applied instruments that are more flexible than strictly mathematical techniques related to the clean optimization. For such tasks special techniques of analysis and solving, among which the most important are the Promethee (Brans et al., 1986), Electre (Roy, 1968), AHP (Saaty, 1980), TOPSIS (Hwang and Yoon 1981) and CP (Zeleny, 1982) have been developed. The techniques fall into the category of soft optimization methods, since in addition to mathematical structures and instruments, they use heuristic parameters, measure distances, value scales and so on. Each of these methods have several versions (such as Promethee 1 and 2), all have advantages and disadvantages, and applications in various areas indicate that the methods are becoming indispensable as support to responsible decision making. Recently, both standard and fuzzy versions of methods are used in order to cover the complex issues associated with human subjectivity, expert knowledge and a tendency to use verbal instead of numerical grades (Triantaphyllou and Lin, 1996; Bender and Simonovic, 2000; Deng, 1999; Srđević et al., 2002; Zuffo et al., 2002; Ray and Triantaphyllou, 1999).

The application of fuzzy set theory (Zadeh, 1965) in multicriteria decision making happened because a decision maker often acts in terms of ambiguity or so called partial truths. Fuzzification of standard multicriteria methods (Feng et al., 2010) was performed by using triangular fuzzy numbers because they are simpler than the trapezoidal, and in general, of course, fuzzy arithmetic was used for determining the fuzzy weight value criteria and alternatives. The paper describes the designing of fuzzy logic system that presents support in decision making when choosing bridge crossing point across water obstacles, and then an example of application of the location valuing problem in relation to a given set of criteria is given. The obtained results of valuing show that through the multicriteria analysis a reliable grade of the locations can be obtained and measured on a unique value scale. In the paper, illustrative data and criteria grades are used. The example is inspired by the watercourses on the territory of the Republic of Serbia and their importance for the organization of defensive and offensive operations.

FUZZY LOGIC AND FUZZY SETS

Contrary to the conventional logic in fuzzy logic it has not precisely defined the membership of one element to a particular set, but the possession is measured in terms of percentages. Fuzzy logic is very close to human perception. Many similar situations that are not clearly separated, which are a mixture of more things are present around us every day.

Fuzzy logic is basically multi-valued logic that allows medium values defined between traditional attitudes: yes / no, true / false, black / white, etc. Phrases such as slightly warmer or pretty cold can be formulated mathematically and can be processed on a computer. Fuzzy logic uses the experience of human expert in the form of linguistic if-then rules, and approximate reasoning account mechanism uses managing action for the individual case. In this paper, approximate reasoning algorithm will be used to display the influence of the entry criteria on decision preference in choosing the most appropriate location on the river for setting up the pontoon bridge.

To design a fuzzy set A the first question is how to choose a specific membership function $\mu_A(x)$. This function shows how $x \in X$ meets the requirement of belonging to the set A. In classical theory, it can have one out of two values, 1 and 0, that is, the element belongs or does not belong to the set A. In the theory of fuzzy sets the membership functions can have any value between 0 and 1. If $\mu_A(x)$ is larger, there is more truth in the claim that the element x belongs to set A, that is, element x to a greater degree meets the requirements of belonging to the set A.

For membership function there has to be $0 \le \mu_A(x) \le 1$, for every $x \in A$, that is, $\mu_A : X \rightarrow [0,1]$.

Formally, fuzzy set A is defined as a set of arranged pairs

$$A = \left\{ \left(x, \mu_A(x) \right) \middle| x \in X, 0 \le \mu_A(x) \le 1 \right\}$$

X is a universal set or set of consideration where the fuzzy set A is defined and $\mu_A(x)$ is a membership function of element x to set A. Every fuzzy set is completely and uniquely defined by its membership function (Zadeh, 1965).

According to the fuzzy set theory, the selection of the membership function, that is, function shape and width of the confidence interval is most frequently done on the

Figure 1. The appearance of the pontoon bridge made from the set PM-M-71 class of 60 tons.

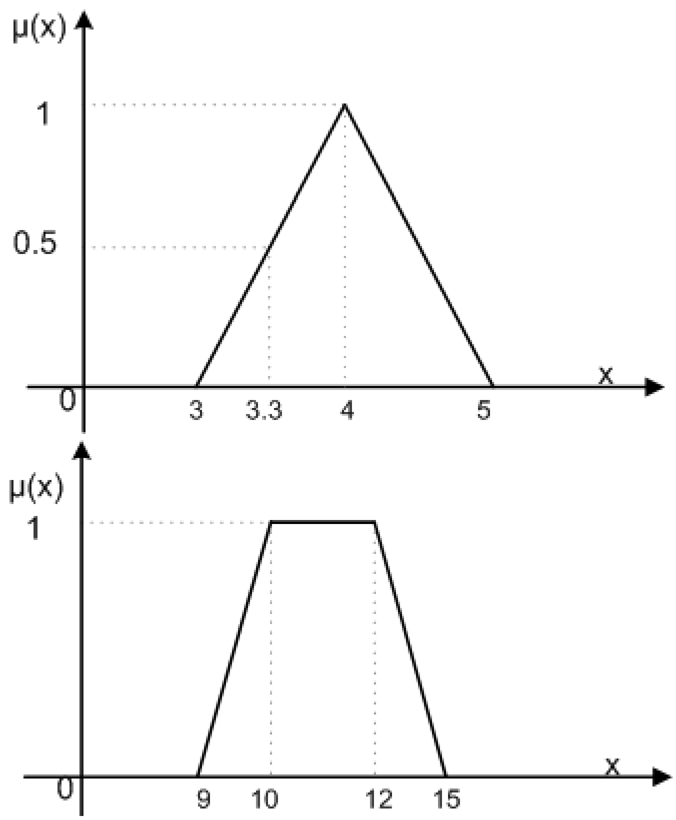

Figure 2. Possible forms of membership functions to fuzzy set.

basis of subjective assessment or experience. Most commonly one uses trapezoidal and triangular fuzzy numbers which have membership functions shown in Figure 2.

Triangular fuzzy numbers are most frequently displayed in the form $A=(a_1,a_2,a_3)$, where a_2 the value is where the membership function of the fuzzy number has value 1.0, a_1 presents the left distribution of the confidence interval and a_3 presents the right distribution of the confidence interval of the fuzzy number A.

Membership function of the fuzzy number A is defined

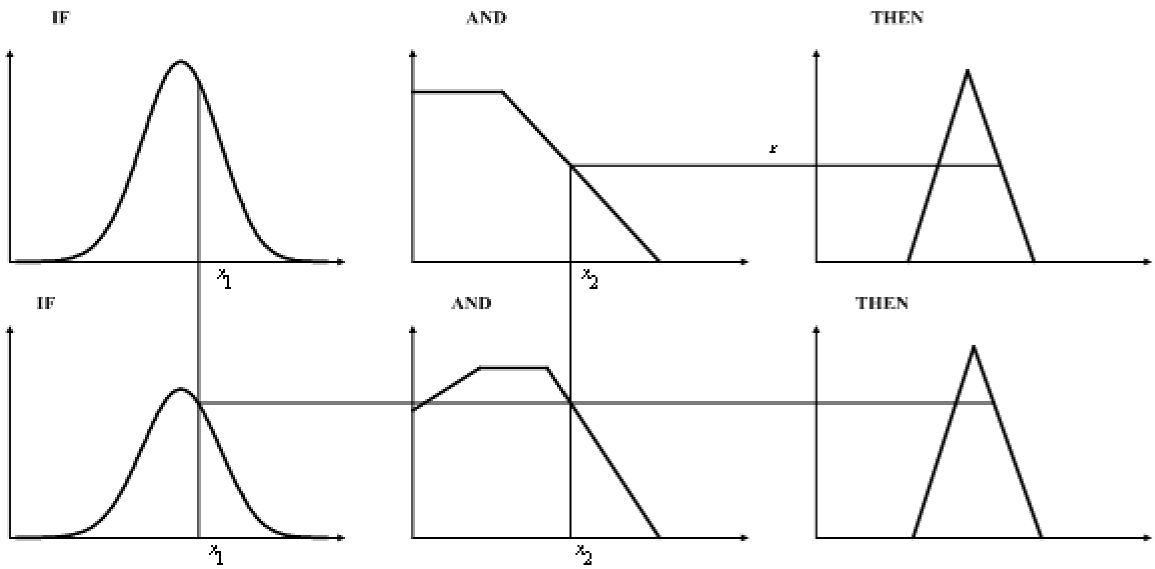

Figure 3. Applying rules.

as:

$$\mu_{\tilde{A}}(x)=\begin{cases}0, & x<a_1\\ \dfrac{x-a_1}{a_2-a_1}, & a_1\le x\le a_2\\ \dfrac{a_3-x}{a_3-a_2}, & a_2\le x\le a_3\\ 0, & x>a_3\end{cases}$$

For defuzzification, that is, copying of the fuzzy number $A=(a_1,a_2,a_3)$ value in real number, numerous methods are used (Herrera et al., 2000).

MODELLING OF THE FUZZY LOGICAL SYSTEM

Fuzzy logic is most frequently used for modelling complex systems, whereby applying other methods makes it difficult to determine interdependences that exist between certain variables. Models based on the fuzzy logic consist of "IF - THEN" rules. Each rule establishes a relation between the linguistic values trough an IF-THEN statement:

$$IF\ x_1\ is\ A_{j1}\ AND\ldots AND\ x_i\ is\ A_{ji}\ AND\ldots AND\ x_n\ is\ A_{jn}\ THEN\ y\ is\ B_j$$

where $x_i, i=1,\ldots,n$ are the input variables, y is the output variable A_j and B_j are linguistic values labelling fuzzy sets. The degree with which the output variable y matches the corresponding fuzzy set B_j, depends on the degrees of matching of the input variables $x_i, i=1,\ldots,n$ to theirs fuzzy sets, A_j, and on the logic format (AND, OR) of the antecedent part of the rule. So, it is immediate calculating the degree of matching in each rule as shown in Figure 3.

If the n parallel rules are interpreted by the conjunction "or" they can be shown by fuzzy relations:

$$\tilde{R}=\bigcup_{k=1}^{n}\tilde{R}_k$$

Membership function of this relation is shown as:

$$\mu_{\tilde{R}}(x,y)=\bigvee_{k}\mu_{\tilde{R}}(x,y)=\max_{k}\mu_{\tilde{R}}(x,y)=\max_{k}(\min\mu_{\tilde{R}}(x),\mu_{\tilde{R}}(y))$$

Each rule is given as a result of the fuzzy set, with a membership function cut in the higher zone. By the rules in entirety, a set of fuzzy sets is given with differently cut membership functions, whose deterministic values all have a share in the inferential result. A single value is needed in order to have a useful result (Figure 4).

A number of rules in which words describe the solution of certain problem present the basis of rules or expert rules. For easier understanding the rules are written in a suitable order, although the order is essentially not relevant. The rules are linked by the conjunction "or", which is often not mentioned. Each rule consists of antecedents that are usually connected by the conjunction "and". Antecedents are the criteria by which the selection of the suggested alternatives is done. Subsequently, the criteria (antecedents) that are used in the fuzzy logic system for the selection of location for the

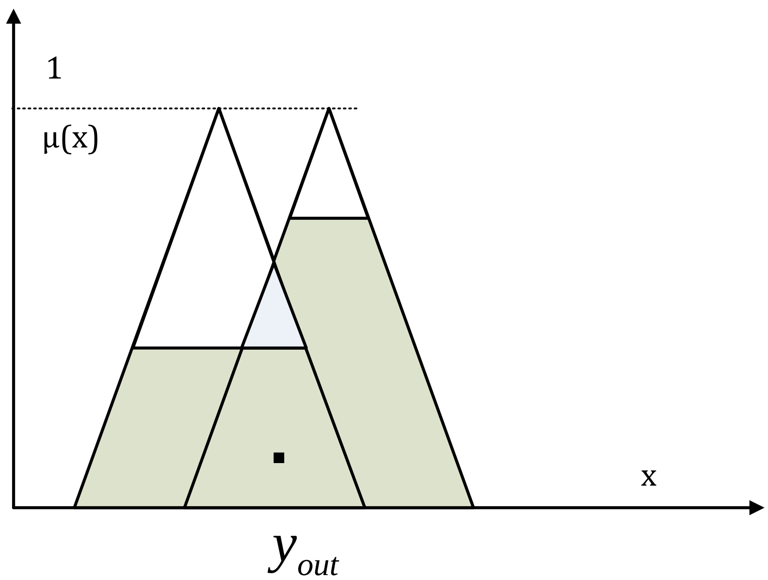

Figure 4. Defuzzification.

pontoon bridge setting up will be described. After receiving the task for overcoming water obstacle one usually does survey in order to gather the necessary data for making decision. On the basis of the collected data the most suitable location for setting up a pontoon bridge is selected. It is necessary that those responsible for the location selection formulate alternative solutions, and to perform ranking – valuation and rejection of those solutions that do not meet defined criteria. The criteria on the basis of which the location selection for crossing water obstacles is done are (Table 1):

(a) Water obstacle width (WOW).
(b) Water obstacle flow speed (WOFS).
(c) Condition of the access roads network (CARN).
(d) The size of arrangement works concerning terrains from the access roads to ramps (SAWAR).
(e) The size of arrangement works concerning ramps in the axis of the bridge and terrain to the access roads (SAWBAR).

Water obstacle width is defined as the distance from one coast to another coast as measured by surface water. When crossing water obstacle the width of the river affects:

(a) Speed of crossing (open space of the water surface additionally increases the vulnerability of the unit being transported, and that is why it is very important to reduce the period of transportation as much as possible).
(b) The type and quantity of vessels engaged in crossing water obstacle (the quantity and type of means that are engaged are limited, in most cases).

Water obstacle flow speed is a feature that occurs in running waters and includes the water flow speed per time unit. The flow speed is very important for the organization and way of overcoming water obstacles while establishing BCP through showing impact on the needs of anchoring of the bridge, bridge carrying capacity, as well as the organization of traffic on the bridge.

Condition of the access roads network includes the existing roads that lead (take away) to the immediate vicinity of water obstacle and characteristics that they do not need the additional works to be carried out. This criterion involves the number of roads and their quality to be viewed through the carrying capacity and width of roads, as well as the number of routes which they connect. They affect the possibility of introducing means for crossing as closer as possible to the BCP and the organization of traffic on BCP.

The size of arrangement works on the ramp in the axis of the bridge presents works to be undertaken in order to make the ramps in the axis of the bridge. This criterion implies the following:

(a) Works on the coast arrangement, which solve the problem of inadequate slope and height of the coast (because they influence the bringing and launching of vessels on the water, as well as loading and unloading of means that are being transported).
(b) Works to be carried out in order to strengthen the capacity of the soil in case that the soil is composed of poorly portable materials (peat, dust, clay, sand ,...).

The size of the arrangement works concerning terrain from access roads to ramps includes works that are

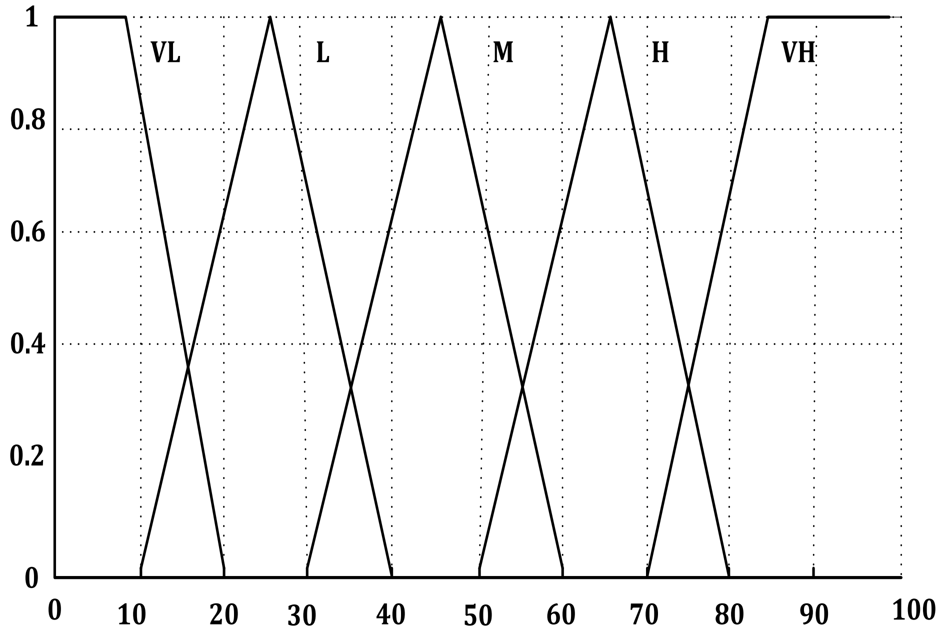

Figure 5. Graphic representation of the linguistic descriptors.

needed in order to provide easy access of means from access roads to the coast (ramps). It includes works arranging the hinterland (primarily due to afforestation of terrains), and then works on the arrangement of temporary military roads from the ramps to the access roads and / or repair and reconstruction of the existing roads. This criterion most affects the rate of establishing BCP, as well as the way and quantity of forces and means engagement.

The fuzzy system for valuing the offered locations input criteria values are presented in numbers or linguistic expressions. Fuzzy system consists of five input variables and one output variable.

A set of criteria $K_i\left(i=1,..,5\right)$ consist of two subsets:

(a) K^+ - subset of criteria of the benefit type which means that the higher value of the criterion is preferable, that is better (criterion K_3).

(b) K^- - subset of criteria of the cost type, which means that the lower value is preferable, that is better (criterion $K_1,\ K_3,\ K_4$ and K_5).

Criteria K_1 and K_2 are presented as numerical values, and criteria K_3 and K_4 as linguistic descriptors.

Values of input variables K_3, K_4 and K_5 were describe by the set of linguistic descriptors, $S=\{l_1,\ l_2,\ l_3...,\ l_i\},\ i\ \in\ H=\{0,\ ...,\ T\}$, where T is the total number of the linguistic descriptors. Linguistic variables are presented by triangular fuzzy number which is defined as $(a_i,\ b_i,\ \alpha_i,\ \beta_i)$, where a_i and b_i present the interval at which the membership function of the fuzzy number has a maximal value, that is 1.0. Values α_i and β_i present the left and right distribution of membership function of the value in which the membership function reaches its maximal value.

The number of linguistic descriptors is $T=5$: „ very low – VL “, „ low – L “, „ medium – M“, „ high – H“ and „ very high – VH“ (Figure 5).

Since linguistic values $l_{ki}\left(i=\overline{1,T},k=\overline{1,K}\right)$ are described by fuzzy numbers $\tilde{l}_{ki}=\left\{l_{ki},\mu_{\tilde{l}_{ki}}\right\}$ the process of normalization is realized according to the following:

(a) For beneficial criterion $k\left(k\in K\right)$ the process is realized according to the form

$$\left(l_{ki}\right)_n=\frac{\tilde{l}_{ki}}{l_k^{\max}} \tag{4}$$

where $l_k^{\max}$ is maximal value of fuzzy number

$\tilde{l}_{ki}, (k = 1, \ldots, K)$, for $\mu_{\tilde{l}_{ki}}\left(l_{ki}\right) \neq 0$.

(a) For costal criterion $k\left(k \in K\right)$ the process is realized according to the following

$$\left(l_{ik}\right)_n = 1 - \frac{\tilde{l}_{ki} - l_k^{\min}}{l_k^{\max}} \quad (5)$$

where $l_k^{\min}$ is minimal value in the area of fuzzy number $\tilde{l}_{ki}(k = 1, \ldots, K)$ for $\mu_{\tilde{l}_{ki}}\left(l_{ki}\right) \neq 0$.

After obtaining the linguistic values of the input variables, defuzzification and comparison of all monitored criteria are done. In this research the confidence interval range for each input variable is standardized as the numerical interval is from 0 to 1.

Confidence interval of the input variable WOW is moving in the numerical interval [0,200], because we took into consideration a set of PM-M-71 of which one can set up a pontoon bridge of class capacity 60 tons for overcoming water obstacle about 200 m long (necessary reserve provided). Confidence interval can vary depending on the bridge carrying capacity class or the amount of pontoon funds available.

Confidence interval of the input variable WOFS is in the interval [0, 2.5], because the pontoon bridge from the sets of PM-M-71 can be set up on water obstacles whose flow speed is maximum 2.5 m/s.

The value of other input variables and output variable decision preference is in the interval [0, 1].

Given system is described orally (qualitatively) through production rules. After that the mechanism of approximate reasoning processes the input data through the phases of aggregation, activation and accumulation. Output value is obtained by the defuzzification process.

In the phase of aggregation, one determines the degree of confidence (level of truth), in that some input values belong to a given fuzzy set. Aggregation is equivalent to fuzzification when there is only one entrance. Activation is a conclusion that is drawn in "then" part of the rule.

Models based on the fuzzy logic usually require more iteration. The first step is defining a set of rules and corresponding membership function. Upon perceiving obtained results, if necessary, one performs correction of certain rules and/or membership functions. Then, using the modified rules and/or membership functions, the model is being tested again.

Based on the described concept model one provided basis for modelling the given system of interdependence entrance criteria modeled as a complex fuzzy system. It was determined that all input variables in the model have three linguistic values, and the output variable has four linguistic values. A number of linguistic values were not needed because with a specified number of linguistic values one achieved satisfactory gradation and precision of the output while changing input values.

Choice of membership functions and their span on the confidence interval is a very important phase of the model development. In the fuzzy system one selected Gaussian curves, because they are easy to manipulate while fitting exit. However, membership functions of the input variables are shown in Figures 6, 7 and 8. Parameters of the membership functions of the fuzzy system are shown in Table 2.

Conclusion procedure in the fuzzy system takes place in the following way: at the very beginning fuzzification of the input variables values is done. In the process of fuzzification, membership functions defined for the input variables are applied to the actual value of the input variables, in order to determine the degree of the membership for the premise of each rule from the base. For example, if the width of the water obstacle has a value of 102 m, speed of the water obstacle flow has the intensity of 1.6 m/s, if the CARN is described by linguistic descriptor VH (Very High), the size of SAWBAR is described by linguistic descriptor M (Medium) and if SAWAR is described by linguistic descriptor L (Low), expert system, after obtaining these values, performs an analysis that is in accordance with previously defined graphs, that present the membership functions of individual variables. Each variable consists of more fuzzy sets and purpose of the fuzzyification is to determine where each input variable "belongs", as well as to show that membership by numerical value in the domain between 0 and 1.

Possible decision preference in the fuzzy model can be small, medium, large and very large.

By the fuzzification value of the WOW, one obtains values of the variable membership "WOW" (Figure 9). Result of the remaining input variables fuzzification is shown in Figure 10.

As a link between input and output fuzzy system linguistic rules are used. Expert knowledge about the process can be expressed in a number of linguistic rules by words of spoken or artificial language.

For defining rules in the fuzzy logical model one used data obtained by conducting a survey among the engineers officers who practically participated in the choice of location for setting up pontoon bridges.

In order for the base of rules to be defined, it is necessary to determine the relative importance of criterion $w_k, k = 1, \ldots, K\left(K = 5\right)$. After the survey with dispatchers in units and delivered prognosis the data is statistically elaborated.

Relative importance of criteria and the degree of their influence on preference of choice of dispatchers are gained by normalization of weights (Table 3).

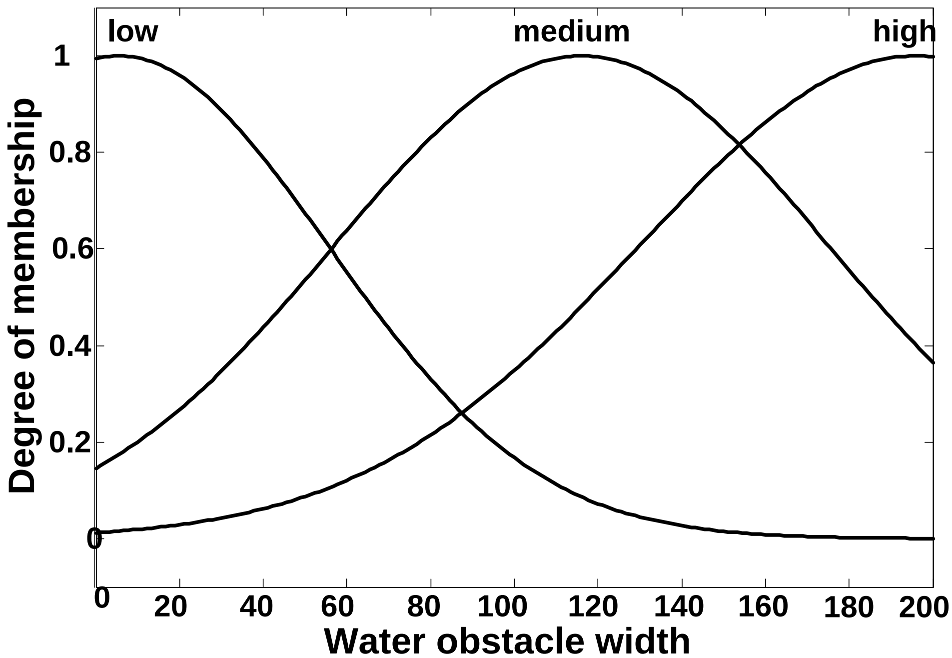

Figure 6. Membership function of the input variable WOW.

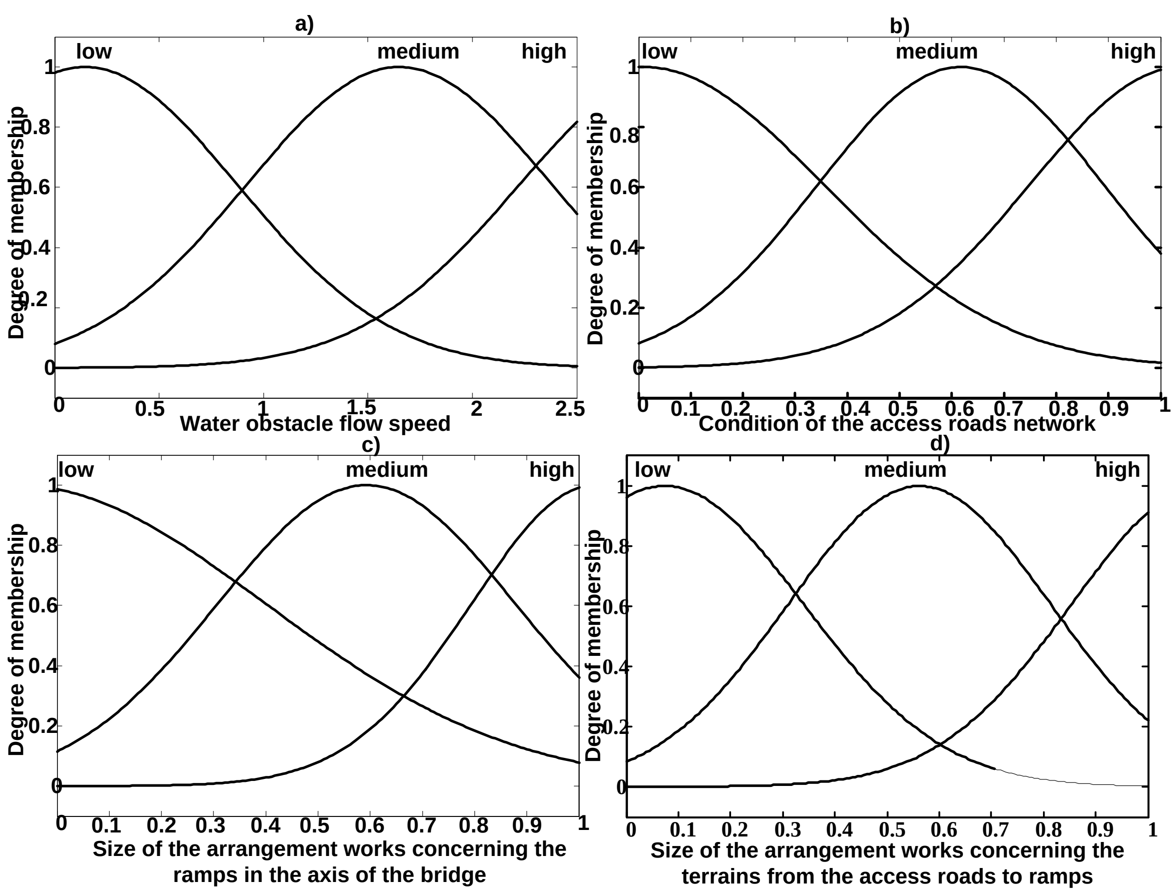

Figure 7. Membership function of the input variables of the fuzzy system.

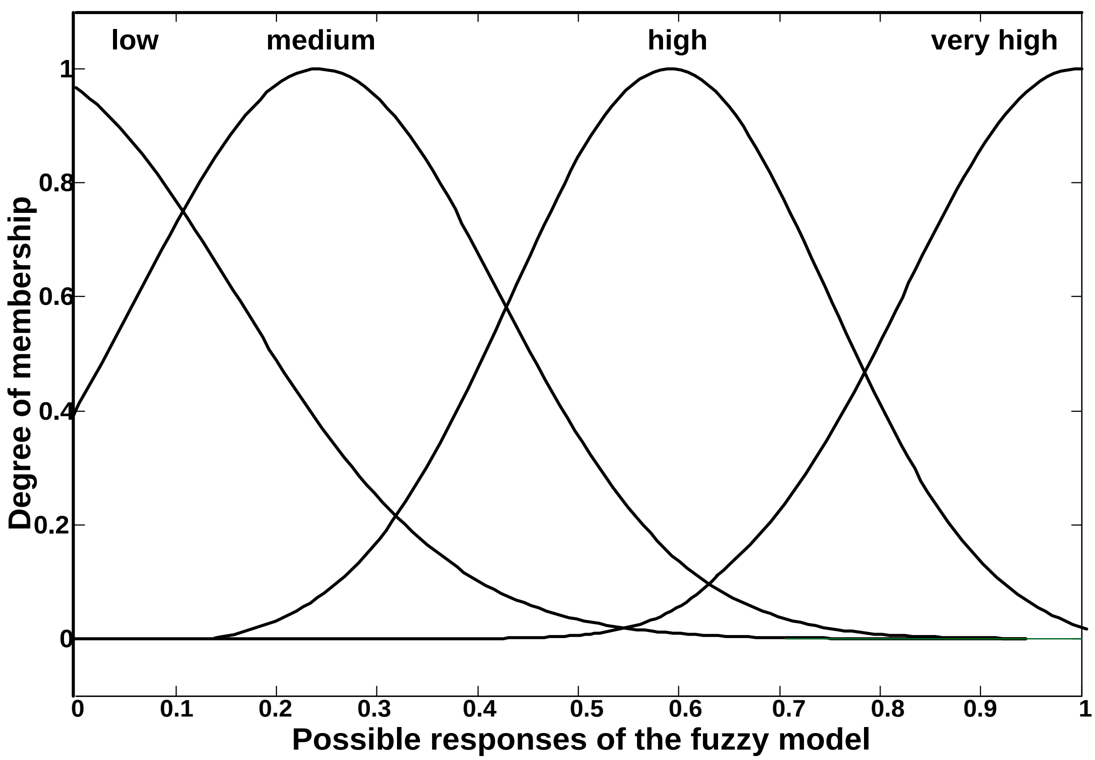

Figure 8. Possible responses of the fuzzy model.

Table 1. Criteria for valuing offered locations for crossing water obstacle.

Criterion mark	Criterion	Min	Max	Numerical	Linguistic
K_1	WOW	•		•	
K_2	WOFS	•		•	
K_3	CARN		•		•
K_4	SAWBAR	•			•
K_5	SAWAR	•			•

Table 2. Membership functions parameters of the fuzzy system.

Membership function/Input value	MF 1	MF 2	MF 3
WOW	(49.95, 5.590)	(59.11, 116.0)	(66.1, 196.0)
WOFS	(0.733, 0.144)	(0.734, 1.650)	(0.76, 2.982)
CARN	(0.346, 0.010)	(0.275, 0.617)	(0.292, 1.04)
SAWBAR	(0.48, -0.078)	(0.284, 0.593)	(0.236, 1.03)
SAWAR	(0.234, 0.101)	(0.234, 0.597)	(0.281, 1.142

$$W_k = \frac{w_k}{\sum_{k=1}^{K} w_k}, \sum_{k=1}^{K} w_k = 1 \qquad (6)$$

The main problem encountered by an analyst in the development of the fuzzy system is determining the base of fuzzy rules and membership functions parameters of the fuzzy sets which describe the input and output variables. In many applications of the fuzzy system in the process of making decision a final set of rules and selection of the membership functions that describe the

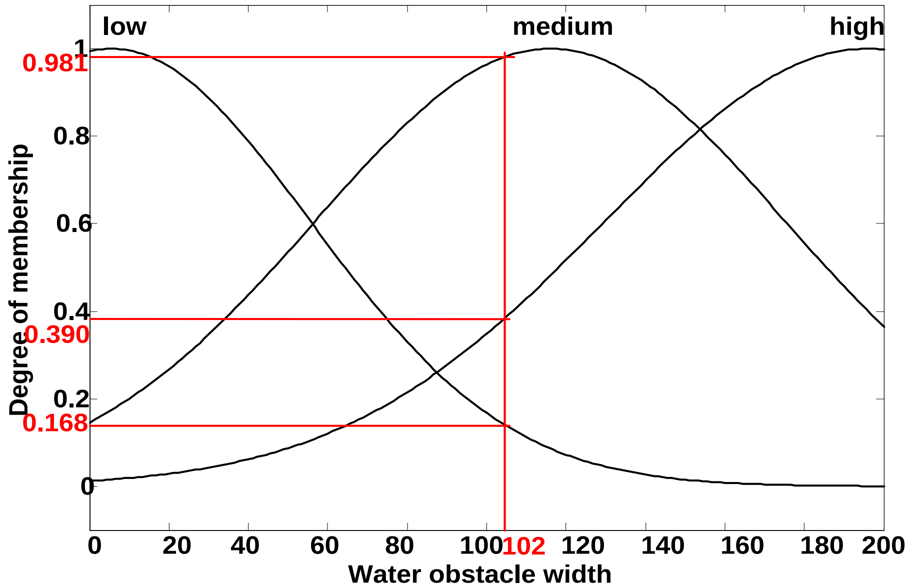

Figure 9. Fuzzyification of the input value of the WOW.

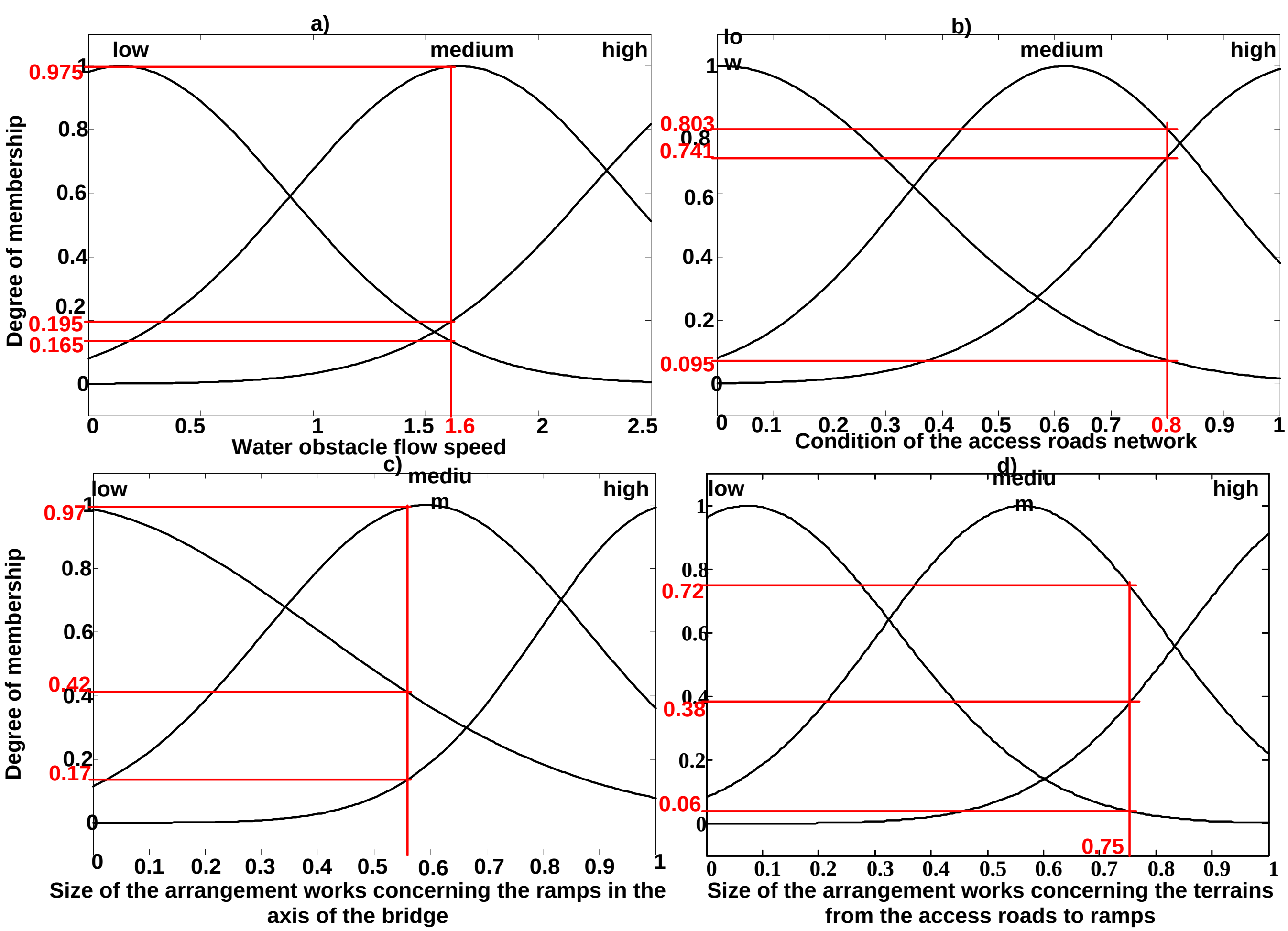

Figure 10. Fuzzyification of other input variables of the fuzzy system.

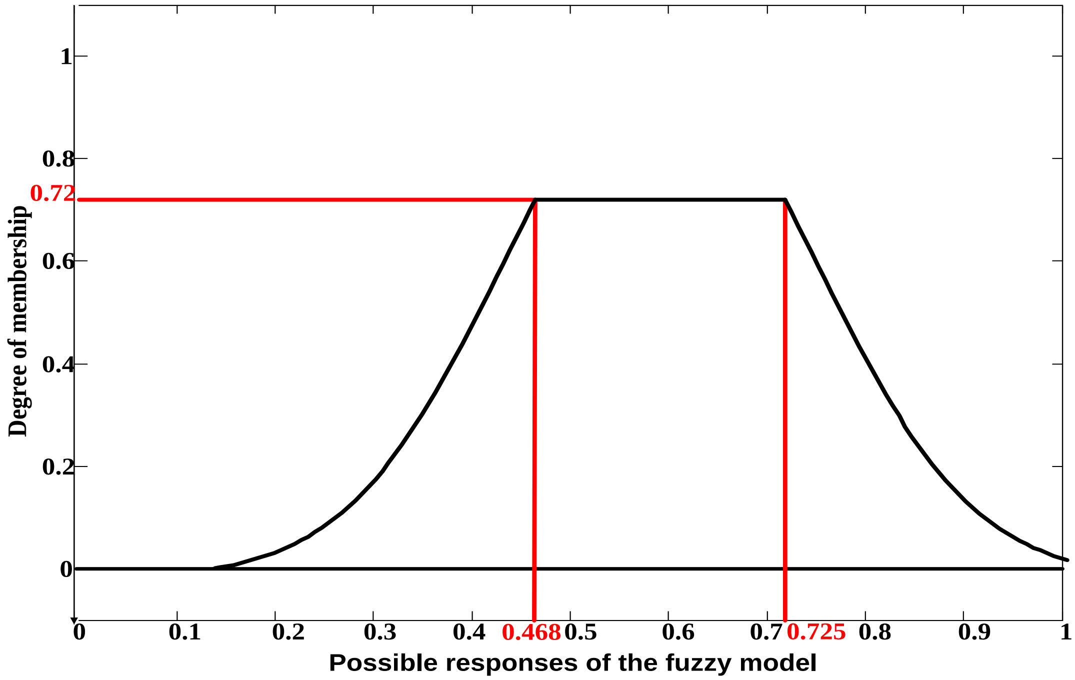

Figure 11. Graphical display of the interresults after performing the Rule number 2.

categories of input/output linguistic variables are obtained by experiments.

After fuzzification of the input values there follows analysis of these values and their comparison with the premises value sets from the rule base. In the mentioned example through analysis it was determined that the rules 2, 3, 8, 9 and 10 were performed. Each rule gives its interresult, which can be presented by corresponding fuzzy set.

A graphical display of the Rule 2 interresults from rule base with the explanation of the way the graph was obtained is shown in Figure 7. Other graphics are not presented and explained, because they can be obtained in the identical way.

Rule number two is the first to be performed. It reads:

"IF wide water obstacles small ^ water obstacles speed medium ^ CARN small ^ SAWAR small ^ SAWBAR medium 'THEN' decision preference great".

If we look at Figure 5, we notice that if the WOW is numerically presented by the input value 102, that value corresponds to a value of 0.981, which is within the fuzzy set medium of the WOW. Also, Figure 6 shows that:

(a) If the water obstacle speed is presented by the value of 1.6 it corresponds to value of 0.975 in the fuzzy set of the water obstacle speed (medium).

(b) If the condition of the access roads network is presented by linguistic descriptor VH (Very High), defuzzification and normalization of the linguistic descriptor one obtains value of 0.8, which in the fuzzy set of the access roads network condition (medium) which corresponds to a value of 0.803.

(c) If the size of the arrangement works concerning terrain from the access roads to ramps presented by linguistic descriptor M (medium), defuzzification and normalization of the linguistic descriptor one obtains a value of 0.55, which in the fuzzy set of the works SAWAR (medium) which corresponds to a value of 0.97.

(d) If the works size on arranging the ramp in the axis of the bridge presented by linguistic descriptor L (low), defuzzfication and normalization of the linguistic descriptor one obtains value of 0.75, which in the fuzzy set of the works size on arranging the ramp in the axis of the bridge (medium) which corresponds to a value of 0.72.

Since among the antecedents rules, one uses operator "and" (^), both conditions would be satisfied if one takes a smaller value, which in this example is 0.72. The obtained value is transmitted to the fuzzy set that presents the conclusion. In the concrete example fuzzy set "big" decision preference is a possible answer. The interresult obtained in this way is graphically shown in Figure 11.

The second rule to be performed is the Rule number 3. It reads:

"IF WOW small ^ water obstacle speed great ^ CARN great ^ SAWAR small ^ SAWBAR great 'THEN' decision preference medium".

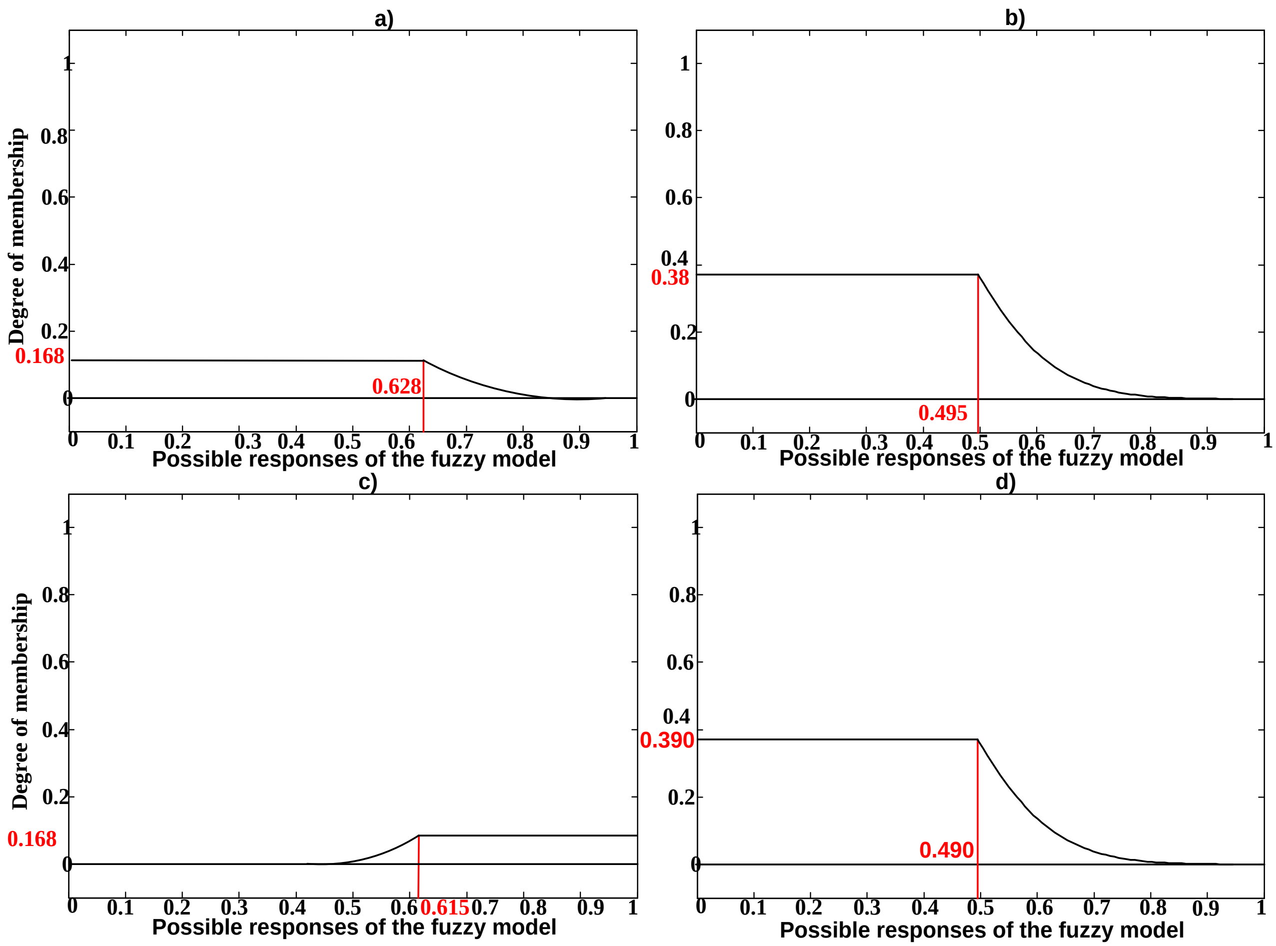

Figure 12. Graphic representation of the interresults after performing the rules number 3, 8, 9 and 10.

The interresult after performing the rule is given in the fuzzy set, in Figure 12a.

The third rule to be performed is the Rule number 8. It reads:

"IF WOW medium ^ water obstacle speed medium ^ CARN great ^ SAWAR medium ^ SAWBAR great 'THEN' decision preference medium".

The intersect after performing the rule is given in the fuzzy set, in Figure 12b.

The fourth rule to be performed is the Rule number 9. It reads:

"IF WOW small ^ water obstacle speed medium ^ CARN great ^ SAWAR small ^ SAWBAR small 'THEN' decision preference very big".

The interesult after performing the rule is given in the fuzzy set, in Figure 12c.

The fifth rule to be performed is the Rule number 10. It reads:

"IF WOW great ^ water obstacle speed medium ^ CARN great ^ SAWAR medium ^ SAWBAR medium 'THEN' decision preference medium".

The interresult after performing the rule is shown in the fuzzy set, in Figure 12d.

At the interresults (Figure 8) we apply operation union of the fuzzy sets and on that occasion we get the resulting fuzzy set that is at the same time the result of conclusion in this example. If we apply the sets operation union on the fuzzy sets in Figure 13 we get the resulting fuzzy set (Figure 13).

In the end, due to more efficient results conclusion explanation, we do defuzzification of the result obtained which is in the form of the fuzzy set. Using CENTROID defuzzification method, we get the result of 0.6985 which gives us a possible answer the Big preference decision.

The most widely used min-max method of direct conclusion is Mamdani method. This method is a common choice when it is not important to operate the whole confidence interval of the output variable. However, in many simulation models it was shown that

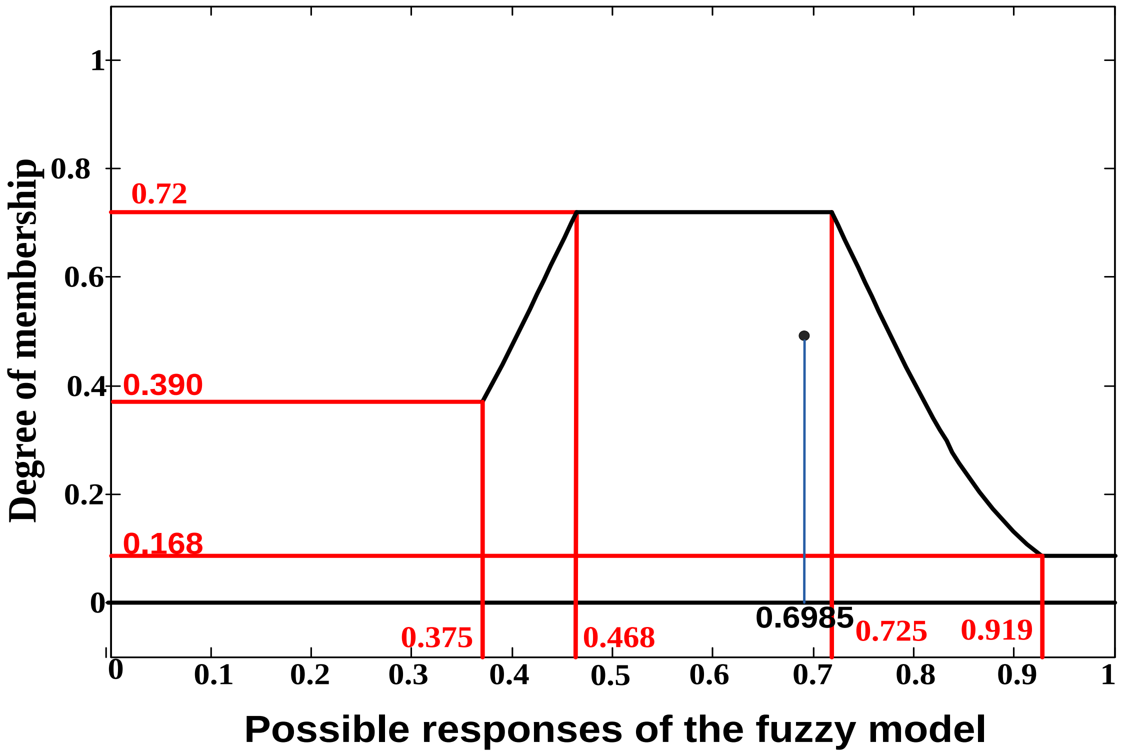

Figure 13. Graphic representation of the resulting fuzzy set.

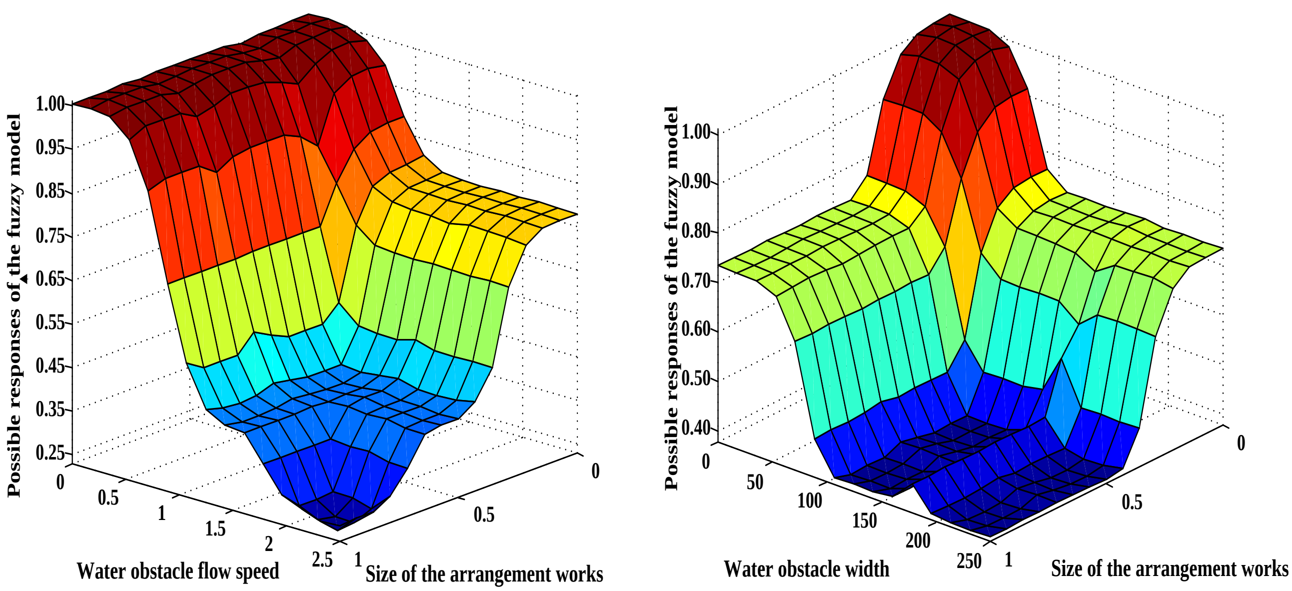

Figure 14. Graphic representation of the set of the possible solutions of input variables according to the Min-Max method.

the min-max method in this case is unsuitable. One of the main requirements was to achieve a satisfactory sensitivity of the system. This means that while doing certain small changes in input, the output from the fuzzy system must also have small value changes that were not possible to achieve by the min-max method. Graphical representation of the solution by the min-max method (Figure 14).

Table 3. Criterion level influence on decision preference.

Criteria	Importance of the criteria
WOW	0.40
WOFS	0.28
CARN	0.15
SAWAR	0.10
SAWBAR	0.07

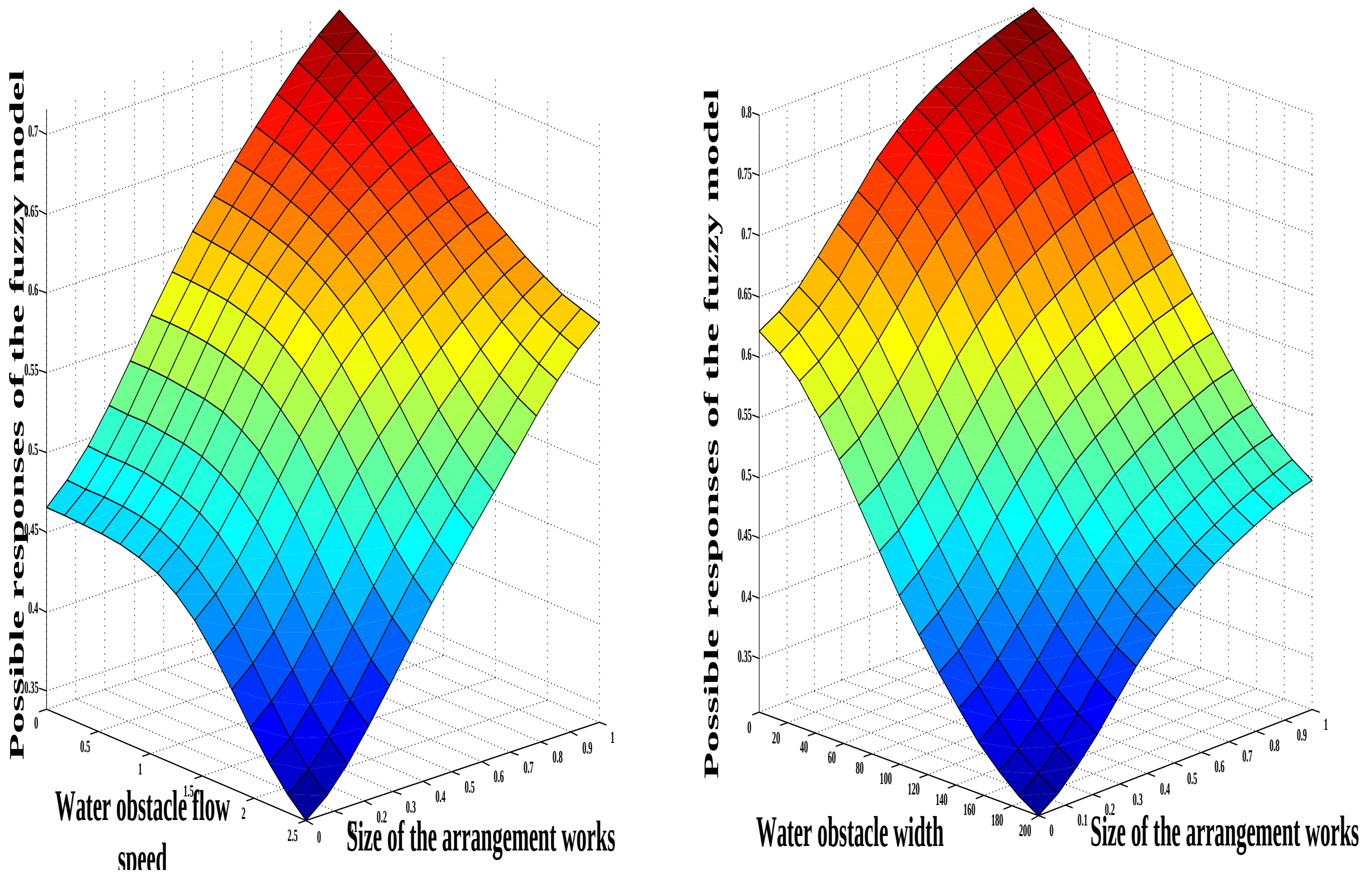

Figure 15. Graphic representation of the set of the possible solutions of input variables according to the Prod-Sum method.

By the mentioned method we get a system that is extremely insensible, as can be seen in the plateaus in Figure 15. The desired shape could not be reached by settings. Even if we achieved this, it would be worth only for certain values of input variables. By changing the parameters the surface would look more unacceptable, therefore the system would be more insensible. Selecting Prod-Sum method and adjusting membership functions the solutions have received an acceptable form, which was adopted (Figure 15).

As a method for defuzzification we chose the center of gravity method, as usual, and suitable for the creation of this fuzzy system, because it ensures the necessary continuity and gradualness of output.

By selecting Prod-Sum methods and adjusting possession functions solutions got acceptable form.

TESTING OF THE FUZZY SYSTEM

In order to test the described model we used illustrative data that describe the river courses. Characteristics of the selected places (Table 4) for crossing the water obstacles are shown through water obstacle speed criteria, state of the access roads, size of the arrangement works concerning the field from access

Table 4. Characteristics of the chosen crossing points.

Criteria/ Crossing point	River speed (m/s)	Condition of the roads network	Size of the arrangement works concerning the ramps	Size of the arrangement works concerning the terrains	River width (m)
Location 1	0.95	Very Low (VL)	Very Low (VH)	Very High (VH)	210
Location 2	1.00	Very Low (VL)	Medium (M)	High (H)	197
Location 3	1.20	Low (L)	High (H)	High (H)	175
Location 4	1.18	Low (L)	Low (L)	Very High (VH)	177
Location 5	1.00	Low (L)	Very High (VH)	Very High (VH)	189
Location 6	0.80	Low (L)	High (H)	Medium (M)	218
Location 7	1.05	Medium (M)	High (H)	Medium (M)	201
Location 8	1.30	Medium (M)	High (H)	Low (L)	168
Location 9	1.52	High (H)	Very High (VH)	Low (L)	154
Location 10	1.62	Very High (H)	Low (L)	Low (L)	148
Location 11	1.40	Very High (VH)	Low (L)	Very Low (VL)	163
Location 12	1.10	Very High (VH)	Very Low (VH)	Very Low (VH)	179
Location 13	1.05	High (H)	Medium (M)	Low (L)	188
Location 14	1.00	High (VH)	Medium (M)	Medium (M)	194

roads to ramps, Size of the arrangement works concerning the ramp in the axis of the bridge and water obstacle width. Values of the mentioned criteria for observed locations are shown in Figure 16.

Comparing results of the fuzzy logical system with the decisions maker preferences, that is, engineers officers, it can be seen that the value of criterion function of the fuzzy system is approximately equal to the decision maker preference

($F_{fuzzy} \approx F_{officer}$).

After application of the model the obtained results were shown in Table 5. For the most suitable location for the bridge crossing point of the water obstacle one selects the location whose objective function satisfies the following condition:

$$f_{V_i} = \max\left(f_{V_i}\right), i = 1,..,12 \tag{7}$$

Location under number 12 was chosen as the most suitable, since the observed objective function has the highest value with respect to the observed preferences.

CONCLUSION

Fuzzy multicriteria approach that was developed in this paper allows the quantification of the criteria and selection of the best alternative from the set of offered alternatives. The presented model allows valuation of the proposed locations and selection of the best alternative from the set of offered that are described with the criteria that can be of benefit or cost type. Relevant criteria for selecting places for bridge crossing point of a water obstacle, as well as their impact on the choice of alternatives have values that are shown by numerical values or fuzzy linguistic descriptors.

Analyzing the obtained results we can conclude that the developed fuzzy system can successfully value the selected locations and formulate a decisions making strategy while selecting a location.

The development of fuzzy model enabled the strategy of choice of the bridge crossing point across the river to transform into an automatic control strategy. Performances of the developed system depend on the number of experienced engineers officers who participated in the research and development of the system, as well as the ability of analysts to formulate a decision strategy with them after a long communication. In the phase of data collection, a problem about

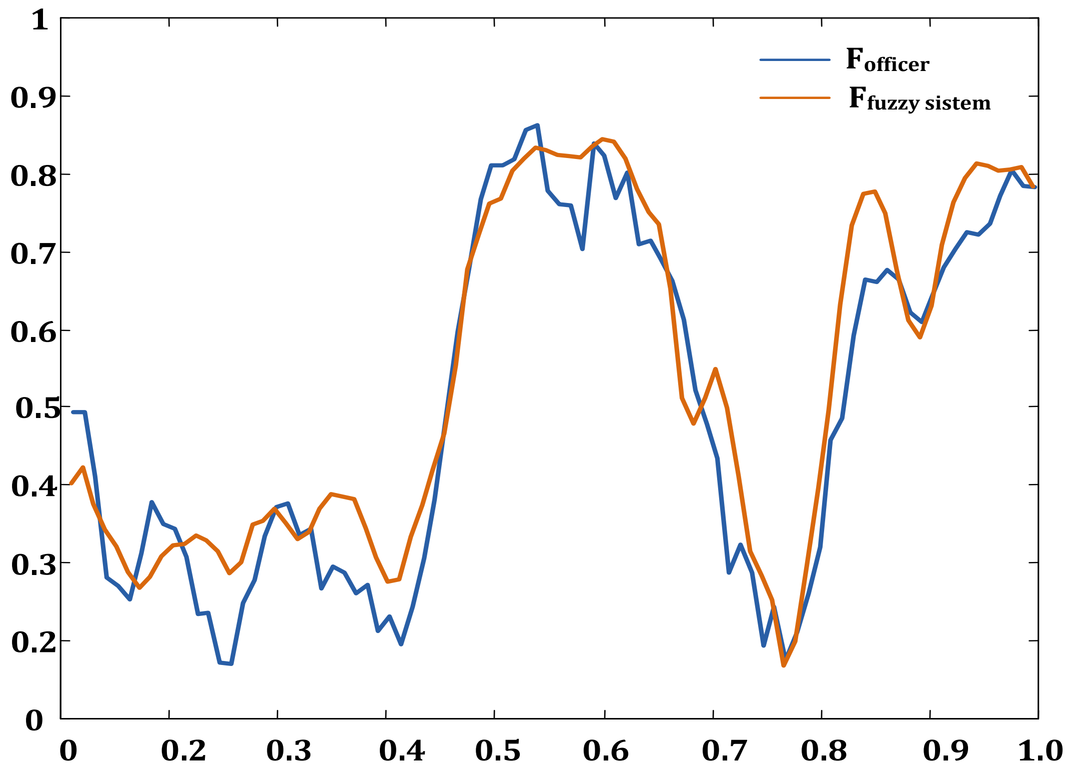

Figure 16. Comparative review of the fuzzy system output and decision preference of the engineers officer.

Table 5. Decision preference.

Crossing point	Decision preference				Rank
	Conviction level $\alpha = 0.35$	Conviction level $\alpha = 0.5$	Conviction level $\alpha = 1$	$\sqrt[3]{\prod_{k=1}^{3} W_{\alpha}}$	
Location 1	0.375	0.400	0.483	0.420	12
Location 2	0.378	0.403	0.483	0.421	11
Location 3	0.605	0.645	0.725	0.658	5
Location 4	0.584	0.608	0.689	0.627	6
Location 5	0.495	0.519	0.599	0.538	9
Location 6	0.301	0.325	0.405	0.344	14
Location 7	0.364	0.389	0.472	0.408	13
Location 8	0.618	0.642	0.722	0.660	4
Location 9	0.745	0.767	0.839	0.783	2
Location 10	0.756	0.778	0.850	0.794	1
Location 11	0.726	0.552	0.716	0.665	3
Location 12	0.540	0.564	0.644	0.582	7
Location 13	0.508	0.533	0.616	0.553	8
Location 14	0.431	0.456	0.539	0.475	10

defining the values of works size concerning ramp arrangement in the axis of the bridge and works size concerning arrangement of the terrain from access roads to ramps, can occur because it depends more on parameters such as slope and height of the coast, soil composition, afforestation of the coast, and (non) existence of temporary roads. Recognition of the values of these criteria is more complex than the other which can be precisely defined.

The presented model contributes to the saving of time needed for making decision. Performances of the developed fuzzy system can successfully be improved by copying fuzzy system to an adaptable neuronal network, which has the capability of learning and imitating of the engineers superiors decision making. The development of the mentioned ANFIS system will be subject of some future research in this field.

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