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Implementation of safety and health management system by the fuzzy method in construction projects

Abstract

The present study's objective is the implementation of the general HSE[1] Plan in civil projects; at first, it is required to formulate the WBS[2] (work breakdown structure) in the relevant project to come to a proper time plan. In this study, the scope of the implementation of this system includes two items in which the probability and risks of timing projects can come to light. The two substantial items in timing projects are activity and time itself which, in some projects, given the un-clarity of the scope of these two items, one is required to take into consideration the probable and approximate value of such scope with the analysis of the fuzzy expert method. And, one of the methods used for the analysis of the scope of timing probabilities is the use of the practical implications of fuzzy logic in engineering sciences; thus, in the essay at hand, the basic information required for risk assessment, fuzzy logic, the theory of fuzzy numbers, and the method used for analyzing, disintegrating, and composing them, to apply them in projects' risk assessment, is presented. Fuzzy logic can be introduced as a powerful and flexible tool for analyzing the scope of risk of projects which is enabled to provide us with the mathematical formulation of the unclear or unspecific parameters and, eventually, represent the analysis and evaluation of data in a numerical format.

Keywords: *Risk Analysis, Fuzzy Logic, Project's Risk Item, HSE PLAN*

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1. Introduction

The A-to-Z structural phases of a civil project (called the Project Life Cycle or PLC) and also coming to a proper confidence coefficient of safety factor in the execution of the project from the viewpoint of the HSE system are always faced with risk and uncertainty concerning the scope and limits of the project in question and thus the risk involved is required to be managed in the most optimal way (ALARP) with the use of logical and rational methods and also a precise approach to the facts[1-5]. The existence of uncertainty or confidence in the milieu surrounding managers can create a sense of unease and difficulty in most individuals. Determining the criteria that one would be able to use to make certain decisions is thus considered a fundamental problem in a way that distinguishing and setting a distinction between right and wrong is always a source of dispute and debate[6-9]. The Traditional and common response to such uncertainties is mostly divided based on a two-dimensional and value-based in which events are divided into good or bad and/or possible and impossible. However, effective and efficient management depends on making right or wrong decisions and the proper or improper analysis of data [10-11]. The logic that states which side is indeed right and which one is wrong can be said to have given form to the underlying foundations of a major part of organizational management in recent decades[12].

Fuzzy thinking was brought about for the first time in 1965 in the area of new calculations by Professor Lotfi Zadeh and following the articulation of the theory of fuzzy sets. The fuzzy world is based on approximated arguments and, in it, facts are represented based on a gradually ordered scale of good or bad. Fuzzy logic is an approach with the use of which one can achieve modeling sophisticated or complex systems with much more simplicity and flexibility whose modeling has been formerly either very difficult or entirely impossible with the use of classical methods and mathematics in the modeling area[13-15]. The practical implications of fuzzy logic in the area of engineering sciences and the like have been frequently applied, yet the practical application of this method in the area of HSE PLAN has been thus far a matter of rarity. In complex and sensitive issues such as projects' safety, which involve uncertainties, one can feel an undeniable need for more comprehensive and inclusive methods in comparison with the usual ones. Fuzzy theory can mathematically formulate many concepts and variables which are considered unclear and ambiguous and thus prepare the ground for presenting arguments and making decisions in uncertain situations[16-

[1] HSE refers to a branch, or department, within a company that is responsible for the observance and protection of occupational health and safety rules and regulations along with environmental protection.

2 WBS is a deliverable-oriented breakdown of a project into smaller components. When we are defining activities and assess project's risks, at first we should prepare the WBS in order to identify project's risks and take the necessary measures.

19]. With this technique, in the present study and concerning its intended objectives, about which one can find but very few quantitative data, such concepts can be quantified quite effectively and modeled with more flexibility.

2. The Benefits of Using Fuzzy Logic Theory

The proper implementation of the structure of the HSE PLAN system in civil projects, in terms of predicting and preventing project risks, necessitates profound understanding and sufficient studies in the relevant area. For this purpose, it is necessary to choose a proper technique to recognize and evaluate all those causes that can lead to the occurrence of accidents in a project. Fuzzy theory is an analytical and scientific method that enables the decision-making system to successfully calculate and assess such parameters as the feasibility rate of the fulfillment of the project and the intensity of the risks involved in it by taking into consideration more details. Chong Monk et al. have applied this technique in their risk analysis of a pipe manufacturing factory. With this method, they managed to identify various impactful factors of the project (that is, feasibility rate, stress factors, encounter rate, and the like) and, at the same time, apply them for risk analysis. In common methods relevant to risk analysis, perhaps one can identify all impactful factors, yet, at the time of analyzing risks, one cannot apply them all simultaneously in the process of relevant calculations. In the year 1996, Mc Kolly and Badiro applied the same technique for analyzing and assessing the risks involved in such activities that would result in cumulative muscular-skeletal disorders and abnormalities. The results provided by doing so can demonstrate that analyzing risks by the use of this method can include a wide range of impactful factors and thus the analysis of the risks involved can be conducted and fulfilled with more details and descriptions.

3. Risk Analysis

3.1. Risk Analysis Function

Presently, one of the highly common and diverse methods of risk analysis available is HSE. Risk is often defined as a combination of two primary elements probability (repetition) and intensity (the significance of events). As a result, the majority of risk analysis methods are based upon these two primary elements.

The common formula for assessing and analyzing risk equals the following function:

$$R = f(F, M) \quad (1)$$

Here, F represents the value of the materialization of the project in terms of its annual number, and also M represents the value of the probable damage and loss resulting from the risk analysis of the project. In HSE discussions, the value of M is calculated through the following formula:

$$\mathrm{M} = f(\mathrm{S}, \mathrm{E}) \quad (2)$$

In this equation, S is the project's intensity, and E is the factor used for assessing contact. Now, if another influential factor, such as L which demonstrates the level of the application of safety measures and safety equipment at the site of the project being executed (PPE) be taken into account and added to the equation, then the function of risk analysis will be measured through the AND logic and would be formed as such:

$$R = F \times S \times E \times L \quad (3)$$

L can be determined through interviews and questionnaires given to individuals working on the project site or any relevant workplace. The construction of the equation in question is considered the initial step of beginning risk analysis through the use of the fuzzy logic method. After collecting the necessary information, each of the input parameters into the equation will be weighed out and evaluated in a realistic way concerning their significance and frequency. As mentioned earlier, in this method, there is no restraint pushed upon exerting more parameters, and given the conditions and opinions of the experts involved, if necessary one can add other parameters to the equation. The advantage of this method is that each of the parameters can be evaluated and brought into a calculation based on their actual impact and with further details. The impactful parameters of factors involved in risk are called lingual or fuzzy variables in a fuzzy system.

4. Fuzzy Theory

Even though research is required to have sufficient knowledge of fuzzy logic when applying its theory, still it is necessary to give some account of fuzzy concepts, at least to some extent, before introducing fuzzy techniques. Given the fact that trapezoid and triangular fuzzy numbers are going to be applied more than other types of fuzzy numbers, in the present article, they will be discussed further.

4.1. Fuzzy Variables

Linguistic variables, which are the inputs of a fuzzy system, are those variables whose acceptable value can replace numbers, words, or statements. Linguistic variables are expressed based on speech values. For instance, the variable known as the project's severity can be determined through various opinions and/or conditions within the framework of a set of expressions such as low, average, high, or very high. As a result, such speech values as low, average, high, and the like are called fuzzy values each of which is modeled based on their membership function.

4.2. Fuzzy Numbers

Fuzzy numbers are fuzzy sets used for describing such concepts as limits, approximation, and being close to. As said before, in many problems in which triangular numbers (visual no. 1) or trapezoids (visual no. 2) are applied to represent or demonstrate speech values.

4.3. Membership Functions

The degree of membership a expresses the value of the membership of the element x in the fuzzy set of A. if, the degree of membership of an element in a set is equal to zero, then that member is entirely out of the set and if it is equal to one, then the member is entirely within the set. Now, if the degree of membership of a member is between zero and one, the number at hand represents a gradual membership degree [2]. As demonstrated in graph no. 1, the fuzzy set A is situated between two points, a1 and a2. The value of membership of these numbers is between zero and one and the highest membership degree belongs to the point aM. Unlike triangular functions in which only one of the membership degrees equals 1, in trapezoid ones, the number of membership degrees between one or the maximum number would exceed one single point. In fuzzy trapezoid numbers, all points situated between b1 and b2 will have a membership degree of one.

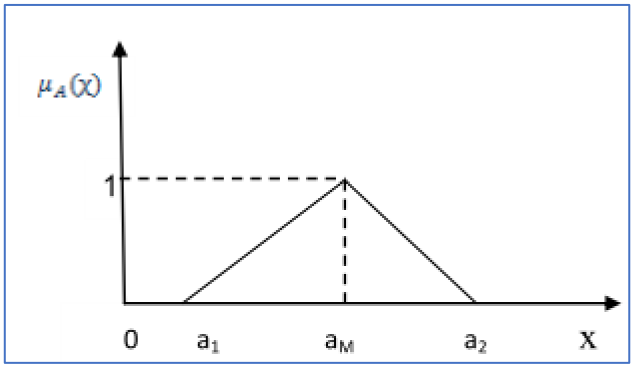

Figure 1: a fuzzy triangular function

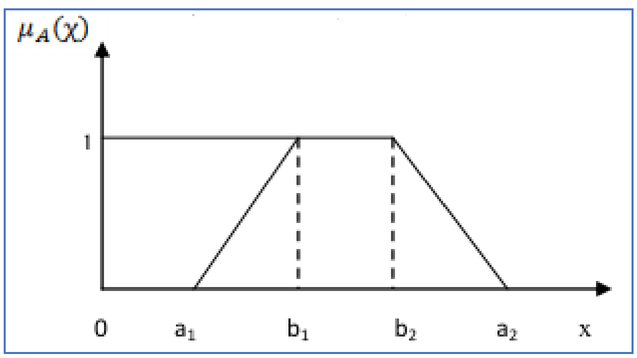

Figure 2: a fuzzy trapezoid function

4.4.Fuzzy Technique

To constitute a fuzzy system, 4 stages are required:

- Fuzzification or constructing fuzzy sets: at this stage, variables are accounted for as the inputs of a system and the output must be a fuzzy set.
- Give definitions for such rules as "if-then" which illustrates the relationship between input data and output sets. In this part, the probable qualitative situations of each of the impacts are specified.
- The collection of all constructed rules as a point of reference
- A de-fuzzification process that turns the output results into the form of a quantitative and comprehensible number.
- Following that, the mode and manner of analyzing risks will be explained with the use of fuzzy logic theory and "if...then" rules. Quantifying and fuzzifying the data will be pursued and fulfilled through the use of the Fuzzy Tool Box section in the Matlab application.

5. Recognizing the Impactful Factors in Risk Measures

Similar to other techniques of risk analysis, the initial stage is gathering the necessary information and recognizing risks and hazards. For this purpose, the totality of the impactful factors in the materialization of a project is needed to be determined and their severity specified. Investigating the backgrounds of former projects and the reasons and causes behind their occurrence can provide one with considerable help in recognizing the risks and hazards of the current project. For example, measuring the probability of a particular project can be pursued and brought to fruition in a much more precise manner given one studies similar projects in the past. The impactful parameters in risk measures are allowed into a fuzzy system in form of linguistic variables. As a result, the more these inputs are determined with precision and accuracy, the more the outputs of the fuzzy systems, too, will be as precise and accurate, hence more approximated to the factual conditions. Linguistic variables vary based on the type of industry and the type of operations and activities involved. Yet, in a general sense, in the present study, four factors, which are L, E, M, and S, are chosen as input variables and so will be evaluated.

5.1. Rating the Input Variables

At this stage, each variable is divided based on various levels and each of these levels or intervals will be rated itself. The maximum-minimum domain of these variables can differ based on its nature and various standards and/or the assessing expert's opinion. Employing illustration, the limits or scale for representing danger (s) can be determined between zero to ten, on an annual basis, and the probability of a project (F) can be determined between 0 to 50 in an annual manner and such numbers demonstrate the lowest and highest extends for the intended parameter. As mentioned above, the value of the variables varies based on the type of activity and risk and thus the interval used for the degree of temperature and one used for sound intensity are different from one another. In a particular application, we may be required to use 1000 stages, while in another, only two of them would suffice. Rating or evaluating the data linguistically depends on the skills, expertise, and mastery of the assessing individual, which, yet, quite strongly dictates being in line with the existing rules and standards. For instance, if the probable rate of the occurrence is between 0 and 50, one can divide these numbers into four categories, i.e., 4-10, 10-25, 25-50, and then give them a respective rating with the use of such expressions as very low, low, average, and high. Fuzzy values, however, have the flexibility required for each of the aforesaid conditions and the existence of disagreements and nuances in the classification of the variables will not bring about any complications or problems in fuzzy system assessments and the ultimate result of it.

Another method available is to unify all the variables into units of measurement. In a fuzzy system, the number zero demonstrates the lowest degree and one the highest, thus one can turn all the inputs into one single specified unit, that is, the scale of 0 to 10. Doing so is nevertheless easily achievable through de-scaling fuzzy formulae. In this case, the inputs are given a certain unit, and thus the task of calculating and interpreting data would be rendered easier. In table 1, the rating and evaluation of the input variables in the risk equation are represented. In the present study, an effort has been made to keep all scales unified in form of one certain unit and thus all values are translated into a zero-to-one scale.

Necessary measures	Risk	Safety measures	Contact assessing factor	Project severity	Probability
Acceptable, no measure necessary	low	Inappropriate	low	Very low	Very low
	0-0.25	0-0.3	0-0.3	0-0.3	0-0.3
Usual interfering measures	average	inappropriate	average	low	low
	0.26-0.5	0.2-0.5	0.2-0.5	0.2-0.5	0.2-0.5
Continuous reforming measures	high	good	high	average	average
	0.46-0.75	0.4-0.7	0.4-0.7	0.4-0.7	0.4-0.7
Immediate and continuous reforming measures	Very high	Very good	Very high	Severe	high
	0.76-1	0.76-1	0.76-1	0.76-1	0.76-1

Table 1: rating input variables in fuzzy system

5.2. Fuzzification of Input Numbers

Given the fact that input numbers are actual mathematical ones, it is required to change these values to fuzzy numbers. Constituting fuzzy numbers will be carried on by Matlab application and, in the present study, using trapezoid fuzzy numbers are chosen. The choice in question has been entirely arbitrary and dependent upon the expert's opinion and the type of input values. As one can see in the table above, to explain the assessment regulations and laws of fuzzy risk analysis, at first linguistic variables are applied which adopt such speech values as low, average, and severe. For coming to a better understanding and further explanation of such linguistic values as love or high, one needs to use fuzzy numbers. This is because they can give a sufficient account of the membership degree of each element in a fuzzy set. Figures 3 and 4 can give a convenient account of risk components and details relevant to membership functions, probability, and severity. The horizontal axis represents the value of the intended parameter in terms of a zero-to-one scale and the vertical one demonstrates the membership degree or the degree of affiliation of each value. These graphs are the actual input variables that have been turned into and represented as trapezoid fuzzy numbers by the use of the Matlab application (1, 8). Since, in the present study, the value of each input variable has turned into a unified measure, that is from 0 to 10, it results that we will have identical fuzzy numbers. For this reason, the visual of the graph related to the two parameters of severity and occurrence probability are presented here. Figure of the system or, in other words, the fuzzy number related to risk measures.

5.3. The Construction of Fuzzy Rules

The rules of "if...then" are conditional phrases that reveal the interdependence of one (or more) linguistic variables upon one another. The analytical format of an "if...then" rule is a fuzzy relation called a relation of implication. The process of the fuzzification of the inputs, evaluating rules, and the summed set of all laws required is known as fuzzy deduction. The principles of fuzzy deduction are found in various sources yet one of the most frequently used cases of them is relevant to Mamdani and Sugeno's linear models.

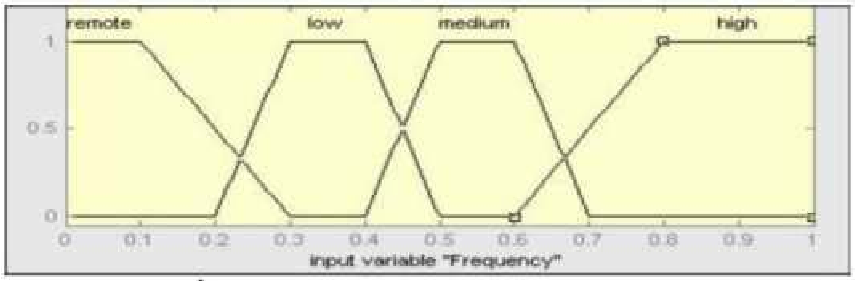

Figure 3: membership function of the input variable of "probability" (Matlab software)

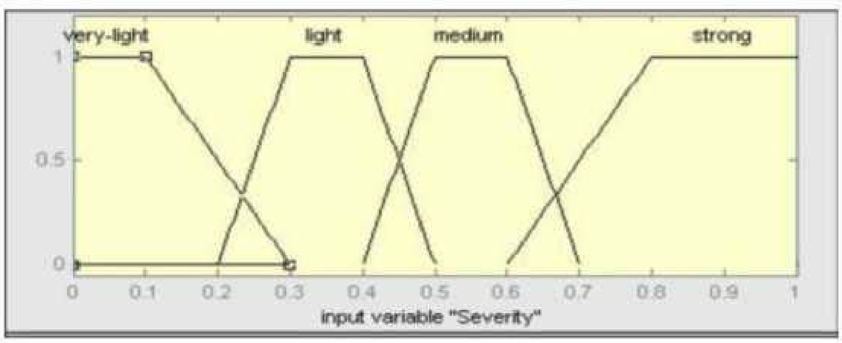

Figure 4: membership function of the input variable of "severity" (Matlab software)

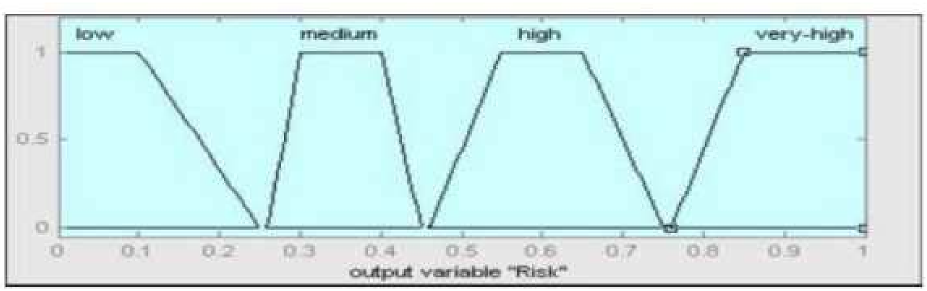

Figure 5: membership function of the output risk variable (Matlab software)

Mamdani's method, which has been applied in the present article and on Matlab software, requires the output function to be a fuzzy set. The following example is fuzzy modeling in which the rules of "if...then" are used based on fuzzy logic.

- The value risk is in direct proportion to the severity
- The value of risk is in opposite proportion to safety measures

Which will be interpreted as such:

1) If the severity of the project is high (low) then the risk value is high (low).
2) If the level of safety measures is high (low) then the risk value is high (low).

The fuzzy assessment and evaluation results from the experience of a human operator and/or engineer where the experience and knowledge in question are mainly based on their qualitative knowledge and understanding of the system at issue. This means that one can claim that the set of fuzzy laws is a linguistic model of those measures taken by a human operator and such rules are based on the way of thinking and attitude of the risk evaluating or assessing expert concerning the type and severity or value of risks and hazards involved. Fuzzy rules represent a logical relationship between fuzzy input and output variables. The application of fuzzy evaluation rules can help us with coming to the best possible scenario for predicting the project with the use of the available experiences and information so that the critical points are recognized in this way and thus the necessary measures are taken. The fuzzy argument is regarded as an argument of approximation based on incomplete or ambiguous knowledge.

Now, in this section, and concerning the points outlined above, it is required to constitute fuzzy rules for risk analysis. Assuming that the impactful parameters on risk level be considered as the four cases of L, F, S, E, and each of them has four levels or classes of low, average, high, and very high, then ... and, in other words, 256 fuzzy modes or rules can be constructed. For further clarification, here, three different instances of such rules are presented.

- **Example 1:** if (the probability low) and (project's severity very low) and (contact factor very high) and (the use of safety equipment appropriate), then (risk level low).
- **Example 2:** if (the probability very low) and (project's severity low) and (contact factor average) and (the use of safety equipment appropriate), then (risk level average).
- **Example 3:** if (the probability average) and (project's severity high) and (contact factor very high) and (the use of safety equipment average), then (risk level high).

In this manner, the rest of the 256 possible rules are constructed and graphic table no. 6 demonstrates the fuzzy rules constituted by Matlab software. These laws are archived in the system as the referent database and, in the following stages, used for analyzing the risks recognized.

54.. De-fuzzification and Quantification of the Output Data

The set of the fuzzy numbers and rules which were constructed in the previous stage cannot, in their sheer appearance, determine the results of the functions of a fuzzy system and its outcome, thus, it is needed to extract a number from this set capable of determining the level of risk, which is an operation come to known as de-fuzzification. The de-fuzzification process can turn fuzzy numbers into a precise output in form of a mathematical number. As a result, at this stage, the average of the input variables and other impactful factors on the assessment of risk will be represented numerically. The resulting output number is indicative of the value or risk and its degree will be from 0 to 10.

To de-fuzzify, there are five available methods among which the most frequently used one is called the Centroid Method which represents the center of the under-curve surface. In the present study, and in Matlab software, too, the Centroid Method has been chosen to use. Thus, after the defuzzification, a new set is constituted which represents the value of risk in form of a mathematical number.

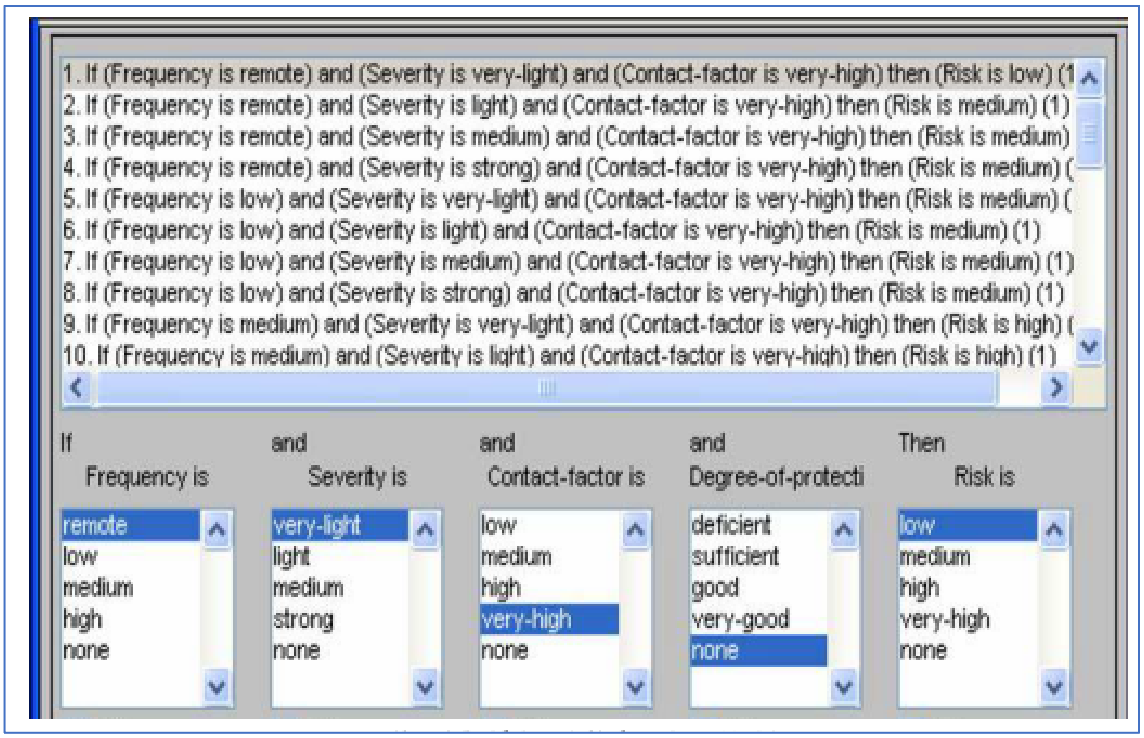

Figure 6: The Graphic Representation of the Fuzzy Rules' Base

With having a base of rule-making at hand and with the application of this new set, one can assess a variety of risks and uncertainties quantitatively. After the recognition and assessment of the status quo and grading of the impactful parameters on risk and then entering such data into the fuzzy set already constructed, it will be possible to analyze the risks involved. As presented in figure no. 6, first the operator or assessing individual will specify the values relevant to risk elements which consist of the probability, severity of the project, contact factor, and safety level. After that, risk or risk analysis will be constructed through a fuzzy set in Matlab software and then calculated and presented in a numerical format. For instance, based on data presented in table no. 1 (it is worth reminding here that the numbers referred to are assumptive and used for further explanation), if the probability of a project is regarded as 0.8, its severity 0.17, and the contact factor for a particular activity 1, then the level of risk will equal 0.603 (figure 7).

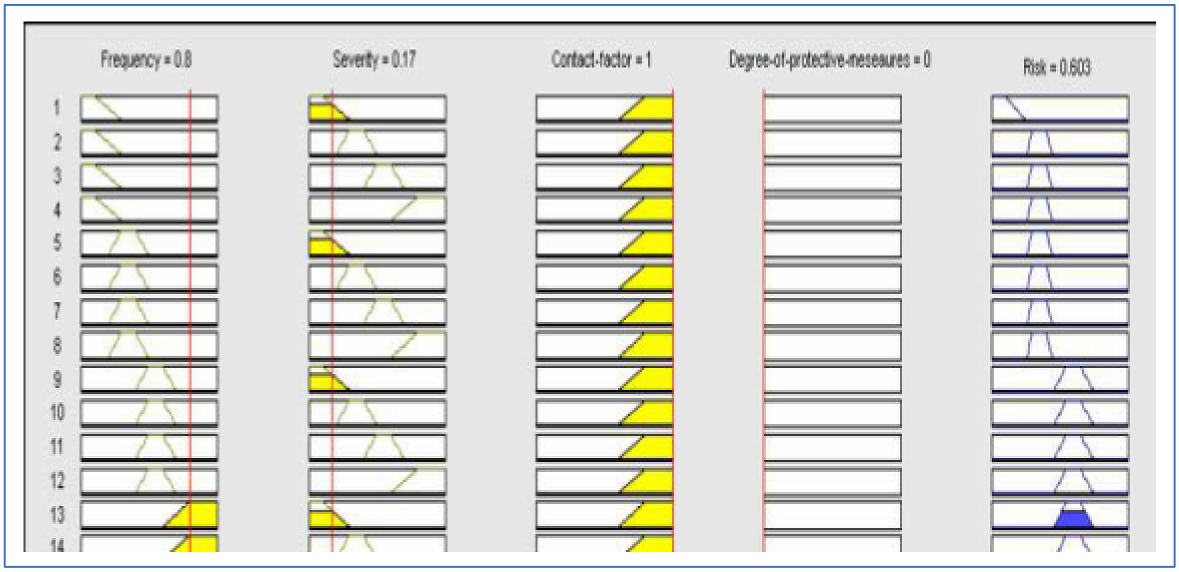

Figure 7: De-fuzzification stage of the output in Matlab software

6 - Conclusion and Further Discussion

In this paper, the attempt was made to assess projects' risks and identify relevant hazards using fuzzy logic and preparation of WBS. The objective is to prevent administrative problems. A precise risk assessment leads to high project efficiency and effectiveness as well as the right management of projects' time, cost, and quality. The implementation of an HSE PLAN System in projects needs to be placed within three separate temporal intervals or stages which include (the start of the contract, the execution of the contract, and the final control and assessment of the project) and this task, too, requires the precise recognition of the activities and the implementation of the necessities concerning the work breakdown structure and the most important objective in the recognition of these activities is risk analysis; the fuzzy logic method is a convenient and proper solution for evaluating the ambiguous and imprecise data in such risk analysis where, with the use of fuzzy logic, one can come to a clear prediction of the uncertainties and thus minimize the risk level or ALARP to its lowest possible degree. With having the value of the project's severity, probability, contact level, and the level of using safety equipment for a certain activity in a particular project and with entering these data as the input variables to the fuzzy system, one can analyze the risk with taking all conditions and uncertainties into consideration and calculate it with precision and in a mathematical format. In the present article, an effort has been made to provide a model based on fuzzy logic and with the application of Matlab software to analyze the level of risk in a project. In the first stage, the determination and evaluation of the input variables were explained and it became clear as to why and to what end input and output variables and fuzzy numbers were made. After that, the task of constructing fuzzy rules was dealt with. Such rules can be then applied as the referent database in the task of risk analysis. At the final stage, and after the construction of fuzzy rules, all possible scenarios of the project which can be rendered problematic are recognized and determined and the actual level of risk in each scenario was calculated and presented in form of a mathematical number. In the present study, an effort has been made to explain fuzzy logic's application in safety studies along with its primary introduction. In the end, it is worth mentioning that in case of having access to more precise statistics and actual data from the work environment (ergonomics, and spatial planning) one can come to more precise and comprehensive modeling and thus advance the level of exploitation, effectiveness, and quality of the projects and manage project's timing and cost more efficiently.

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Conflict of interest

None.

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Ethics Statement

All Permissions to conducting this research has been approved.

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