

Fuzzy Risk Analysis for Construction Projects

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Abstract: The construction industry projects are more subjective and risky compared with the others industries because of the unique characteristics of construction activities such as poor working condition, the significant frequency of accidents and the occupational risky situation. Risk analysis and management on the project sites is the first key to achieve adequate level of security. However, the modern construction and the new sophisticated design have shown a significant obstacles and uncertainties to complete the project safely; thereby it is inevitable to search a new approach to deal with uncertainties. The ability of a fuzzy system to deliver its reasoning process is presented to have absolute result within the field of risk analysis. As well as, fuzzy set theory is mainly subjective and associated to deal with inexact and vague information in construction projects. This paper describes the stages of the fuzzy risk analysis model which is developed to assess the risks related with construction projects and their uncertainties based on evaluations of cost, time and quality. Ultimately, using this model we can prioritize and rank all risk factors cited in the construction project; besides that we can easily manage them in the best appropriate way.

Key words: Construction projects • Fuzzy logic • Risk analysis

INTRODUCTION

The importance of construction industry to nation building necessitates that project implemented achieves project success. Nevertheless, for more than a century, researchers have been grappling with applying innovative computer modeling techniques to assist decision makers in finding better solutions regarding these criteria of cost, time, performance, quality and safety. Thus, fuzzy set theory and fuzzy logic are applied in this area while the data represented are in subjective verbal forms or the scarcity of the information.

The ability of a fuzzy system to illustrate its reasoning process is presented to have definite result within the field of risk analysis. Also fuzzy set theory is highly subjective and related to uncertainty and vague information human perception or subjective likelihood judgments. Whilst, this uncertainty and vague information might be due to a lack of knowledge or experience, wrong historical analysis. Thus, in construction research area one of the applications of

fuzzy risk analysis is to outline an approach to the assessment of the construction project risk by linguistic analysis.

Literature: The nature of construction project has imposed, on the risk analysis process, high uncertainties and subjectivities, which have obstructed the applicability of many risk assessment methods that are used in large-scale in construction. Projects that require high quality information, such as: Event Tree Analysis (ETA), Failure Mode and Effect Analysis, Fault Tree Analysis (FTA), Probability and impact matrix, Sensitivity Analysis, Evaluation of System Reliability [2]. In many circumstances, the application of old risk assessment methodologies might not give satisfactory responses because of incomplete risk information or the substantial degree of uncertainty involved in the risk data presented. It is therefore essential to develop risk analysis methods to evaluate the risks in conditions of project execution where classical approaches cannot be efficiently applied according to A. Nieto-Morote [3].

Besides all these methods showed some weakness to identify and quantify the uncertainty aspects and risks at workplace. A formalized risk management process is still a rarity within many construction organizations and the groundwork needs to be laid to enable risk management to become an accepted part of construction process. Moreover, the prototype is focus about the practical concerns of the construction through applying an accurate approach for further development to satisfy the needs of construction project safety [8]. To this end, FUZZY approach is introduced to enable quantitative risk assessment development to be modelled mathematically. Additionally, relationships between risks, risk factors and their consequences are shown on cause and impact.

Fuzzy Risk Analysis: Risk analysis can be applied through using the theory of probability which evaluates the Likelihood and consequence of any risk listed as a hazardous to complete project safely. Due to some vague and unknown factors which influence project success, probability theory cannot always deal with principal aspects of project uncertainty and cannot illustrate some important aspects of discovered project management practice [9].

The risk analysis process, utilizing fuzzy logic, is found to be a best approach to handle project risk management which is mainly subjective and varies substantially from project to project. The fuzzy risk quantitative process is described here stage by stage; the level of severity is the result of multiplication of likelihood and the impact, whilst probability and impact charts are proposed as fuzzy variables [7].

$$\text{Severity} = (\text{likelihood}) * (\text{impact}) \tag{1}$$

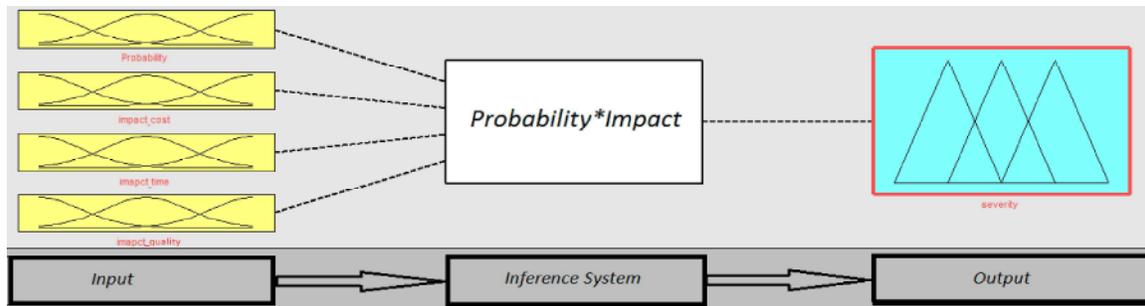


Fig. 01: The structure of fuzzy risk analysis (input /output)

Stage 01: Natural Language Representation: Generally, in this phase, the verbal judgments is converted to a numerical scale where the likelihood and impact can be quantified in a number of different ways, applying trapezoidal fuzzy numbers which pose several advantages over triangular fuzzy numbers as they are a more generalized form Abhinav [1].

A trapezoidal fuzzy number A can be expressed as $[a, b, c, d]$ and its membership function is defined as:

$$U(x) = \begin{cases} \frac{x-a}{b-a} & a < x < b \\ 1 & b \leq x \leq c \\ \frac{d-x}{d-c} & a < x < b \\ 0 & \text{Otherwise} \end{cases}$$

In the context of this research, these terms are based on expert opinion in verbal form. To illustrate, based on each project's specifications and the involved parties' opinions, Management project experts should provide the charts through meetings, previous similar jobs, company databases, experts interviews, or any other appropriate way. Consequently the key attributes of risks and risk factors are likelihood and impact (cost, time and quality) [5]. Where estimation cost is of great importance in project management as it provides substantial information for decision making, cost scheduling and resource management [4].

Table and charts show customizable standard terms for quantifying likelihood and the impacts of cost, time and quality respectively as follow:

Table 01: Customizable standard terms for quantifying probability and impact of cost, time and quality

Probability	Impact (cost)	Impact (time)	Impact (quality)
Extremely unlikely (E-UN)	Negligible (Neg)	Negligible (Neg)	Negligible (Neg)
Unlikely (UN)	Marginal (Marg)	Marginal (Marg)	Marginal (Marg)
Moderate (M)	Moderate (Mod)	Moderate (Mod)	Moderate (Mod)
Somehow Likely (S-L)	Substantial (Sub)	Substantial (Sub)	Substantial (Sub)
Very likely (V-L)	Severe (Sev)	Severe(Sev)	Severe(Sev)
Highly likely(H-L)	Disastrous (Dis)	Disastrous (Dis)	Disastrous (Dis)

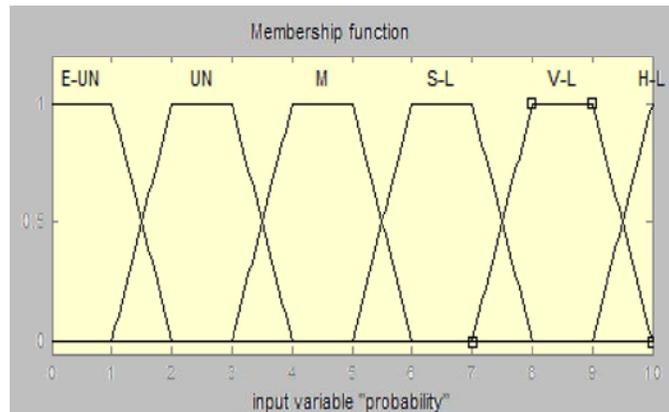


Fig. 02: Membership function of likelihood

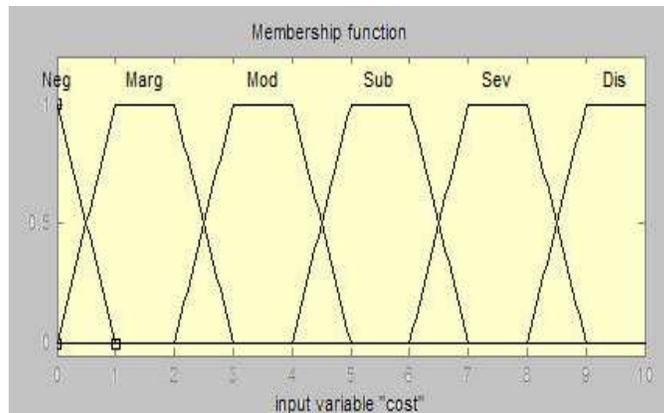


Fig. 03: Membership function of impact of cost

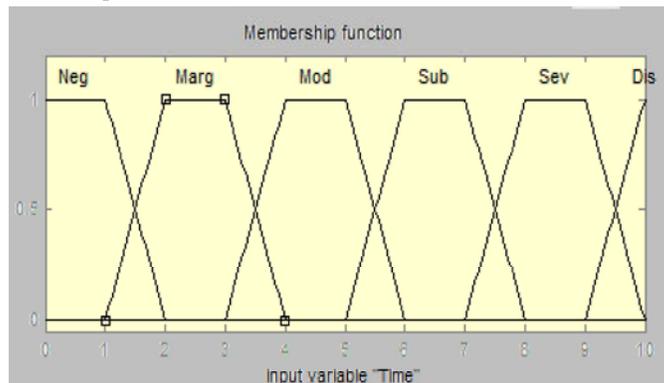


Fig. 04: Membership function of impact of time

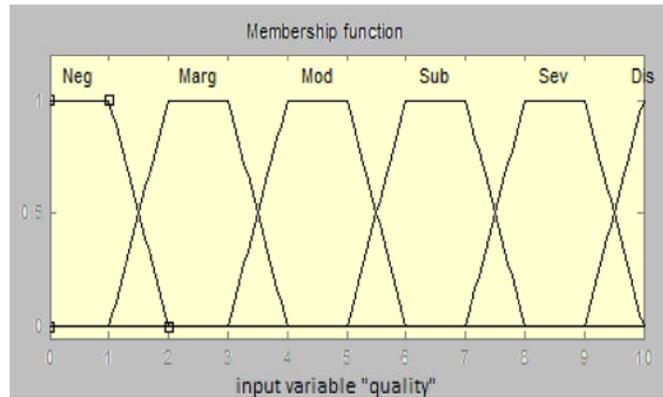


Fig. 05: Membership function of impact of quality

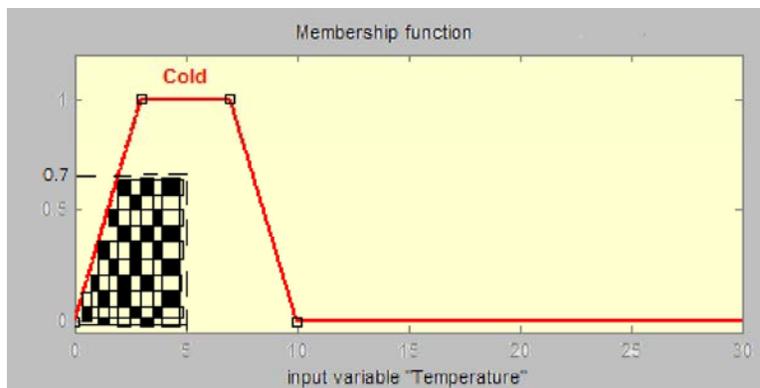


Fig. 06: Alpha-cut illustration for $\alpha = 0.7$

The membership function of probability are considered from “extremely unlikely” to “Highly likely” in six equal intervals. While, the impact function is split from “Negligible” to “Disastrous” in six intervals also.

Stage 02: Alpha- Cuts Equations: Zeng & Shi [12] stated that the α -cut decomposition theorem is one of the fundamental concepts in the field of fuzzy sets. The power behind this theorem lies in the capability to decompose fuzzy sets into a collection of crisp sets. This decomposition along with the extension principle forms a methodology for extending mathematical concepts directly from crisp sets to fuzzy sets. A fuzzy set is a collection of objects with various degrees of membership. Often it is useful to consider those elements that have at least some minimal degree of membership “ α ”. This is like asking who has a passing grade in a class, or a minimal height to ride a roller coaster. We call this process an α -cut.

For every $\alpha \in [0,1]$ a given fuzzy set A a crisp set A_α which contains those elements of the universe X who have membership grade in A of at least α ” α ” :

$$A_\alpha = \{x \in X / A(x) \geq \alpha\}$$

We cannot emphasize enough that an α -cut of a fuzzy set is not a fuzzy set, it is a crisp set. For example, in next figure a fuzzy set is displayed explaining a cold temperature and an α -cut is shown. The interval $[0, 5]$ is the α -cut of 0.7 for this set. Where includes all elements of this set which have the same value or exceeding to 0.7.

For fuzzy set operations, the α -cut is considered the bridge between the intervals and crisp numbers, simplifying different operations on the numbers. For more understanding of process referring to [12-11]. Specifically, in this phase, the purpose is to find the α -cut of each diagram. Thus, to conduct the calculation the variable should be converted from graphical format to a numerical equation in phase 1.

Stage 03: Computation: From the previous explanation, the severity is a result of likelihood multiplied by impact. After finding the α -cut of both probability and the impact of all criteria cost, time and quality. Hence, the multiplication will be done following the main operation of fuzzy logic multiplication:

$$[a, b] * [c, d] = \{x * y / a \leq x \leq b, c \leq y \leq d\} \quad (2)$$

In fact, the a-cut of both of probability and impact is completely defined using this operation to prepare crisp sets for next step. This is actually a significant finding, because computation for the a-cuts multiplication may easily simplify defuzzification for the next step.

Stage 04: Defuzzification: Mainly, the fuzzy grade is converted to crisp output, where the fuzzy data obtained from the fuzzification process is not suitable for the real time applications and have to be converted into crisp form. The conversion of data from fuzzy form to crisp form is known as the defuzzification. It reduces the collection of membership function values into a single quantity.

Thus, defuzzification is the process of converting the degrees of membership of output linguistic variables into numerical values. Which means, convert the fuzzy set obtained from the multiplication into a single crisp number output. Thus, choosing defuzzification method may produce for the fuzzy output number a good results for the fuzzy set [10].

The most common and meaningful method is center of gravity/ area method, where the fuzzy logic first calculates the area under the scaled membership functions and within the range of the output variable. Besides that, there are other methods such as: center of maxima; mean of maxima, largest of maxima and smallest of maxima [12].

Centroid Method (Center of Gravity) (COG): This method, the most prevalent and physically appealing of all the defuzzification methods as explained by Takagi (1985) and Lee (1990), centroid defuzzification returns the center of area under the curve. If you think of the area as a plate of equal density, the centroid is the point along the x axis about which this shape would balance.

$$COG = \frac{\int [U(x)x]dx}{\int U(x)dx} \quad (3)$$

where the $U(x)$ is the fuzzy output value; in order words, it is the membership value of the element x.

Maxima Methods: COG is a defuzzification method regarding the area under the membership function. Maxima method consider values with maximum membership. This method takes all points whose membership value is equivalent to the largest membership value and then, based on different methodologies it considers different applications [6]. There are different

maxima methods with different conflict resolution strategies for multiple maxima, e.g., MOM, SOM and LOM stand for Middle, Smallest and Largest of Maximum, respectively. These three methods key off the maximum value assumed by the aggregate membership function. More explanation are shown in Figure 7. However, it is not suitable for this research because this methods just focus on maximum membership values and all other points and values are excluded.

Stage 05: Adopt Weighted Average Method: Many criteria such as time, cost, quality, safety and so on for a project in a shape of various perspectives has been affected by risk factors. In this research, a weighted average method is stratified so that to collect all risk factors severities in the form of one risk factor index number. As has been performed, in the previous phases, many computations to obtain the result of nature of the work, the involved parties' opinions..etc, with considering the weight for each area and the center of gravity [6].

$$Total\ Severity = \frac{\sum W * COG}{\sum W} \quad (4)$$

where:

● : Is the index for each area of risk, i.e cost, time, quality, etc.

W : Shows the assigned weighted for each area

COG : Is the center of gravity for each area

Stage 06: Linguistic Approximation and Prioritizing: Basically, this phase is the contrary of the first phase which means the numerical scale obtained from the previous step is converted to verbal format. Additionally, the risk factors is prioritized and ranked on their level of severity. To illustrate, the last step of risk analysis is prioritize and rank all risk factors based on their order of importance through interpreting and converting the numerical result of five previous steps to a meaningful verbal form. Meanwhile “Risk categories” chart is the accurate tool to rank and prioritize all project’s risk factors.

In the following table shows a customizable standard terms for quantifying severity as has been stated by Tah and V. Carr [5] where all risk factors drop in a given zone regarding on probability of occurrence multiplied by the magnitude of impact. Ultimately, the initial criteria for choosing the zones are fully dependent on company tolerance or the opinions of involved parties.

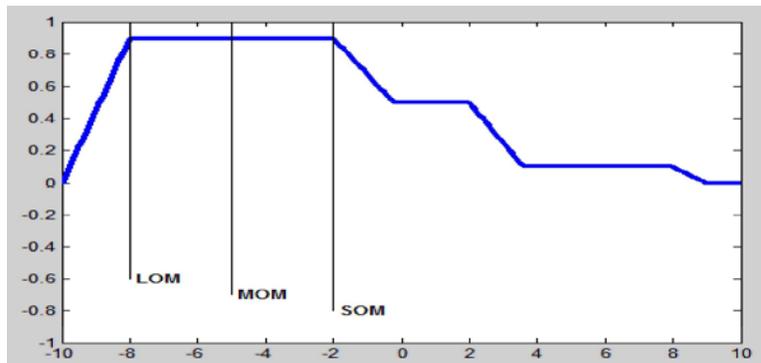


Fig. 07: Representation of SOM, MOM and LOM

Table 05: Customizable standard terms for quantifying severity.

Severity	Values “S”
Negligible	$5\% < S$
Acceptable	$5\% < S < 15\%$
Important	$15\% < S < 35\%$
Serious	$35\% < S < 55\%$
Critical	$55\% < S < 75\%$
Intolerable	$75\% < S$

Example: An example is solved to explain the methodology of the model that have mentioned before.

Input Data: Risk factor K; probability and the impact of criteria (cost, time, quality)

Probability		Somehow likely
Impact	Cost	Sever
	Time	Substantial
	Quality	Negligible

To solve this example, we should follow the six stages that has been explained before .

Stage 01: Natural Language Representation: In this phase the verbal judgment must be converting to a numerical data.

Firstly, we have to find the right diagram of Risk factor K probability as well as the 3 diagrams of impacts: quality, cost and time from the previous prototypes diagrams.

1-Probability Input Diagram

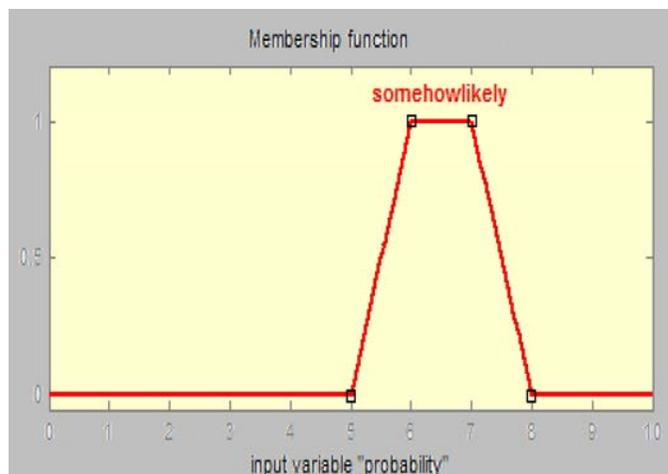


Fig. 08: probability “somehow likely” membership function for risk factor K

2- Cost Input Diagram

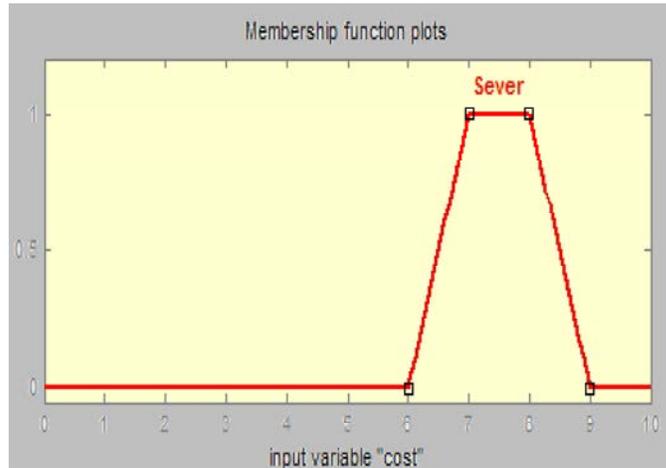


Fig. 09: The membership function for the impact of cost “Substantial “

3-Time Input Diagram

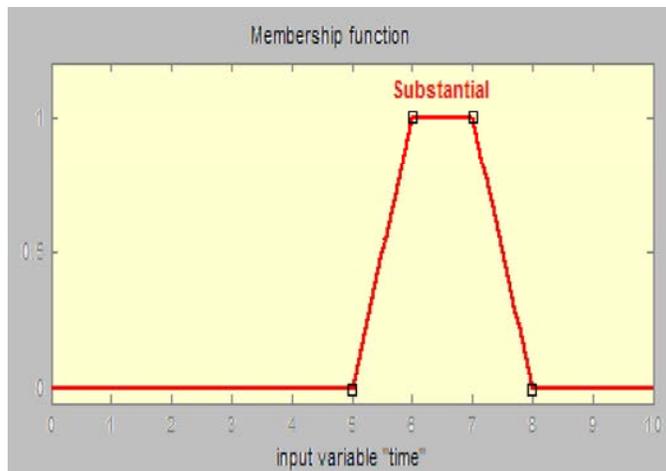


Fig. 10: The membership function for the impact of time “substantial “

4-Quality Input Diagram

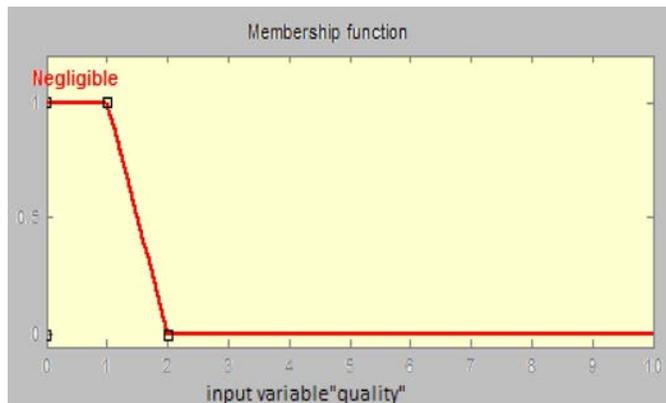


Fig. 11: The membership function for the impact of quality “negligible “

Stage 02: Finding α Cuts Equation: In order to proceed the fuzzy logic calculation, first of all, we must to convert the diagrams to equations to find " α cuts" for each criteria.

Inputs	Functions	Supporting Intervals	α cuts $U(\alpha U) = \alpha$
Probability " Somehow likely"	$\begin{cases} x - 5 \\ 1 \\ 8 - x \\ 0 \end{cases}$	$\begin{cases} 5 < x < 6 \\ 6 \leq x \leq 7 \\ 7 < x < 8 \\ \text{otherwise} \end{cases}$	$\begin{cases} P(P_1) = (P_1 - 5) = \alpha \implies P_1 = 5 + \alpha \\ P(P_2) = 1 = \alpha \\ P(P_3) = (8 - P_3) = \alpha \implies P_3 = 8 - \alpha \end{cases}$
Impact on Cost " Sever "	$\begin{cases} x - 6 \\ 1 \\ 9 - x \\ 0 \end{cases}$	$\begin{cases} 6 < x < 7 \\ 7 \leq x \leq 8 \\ 8 < x < 9 \\ \text{otherwise} \end{cases}$	$\begin{cases} Ic(Ic_1) = (Ic_1 - 6) = \alpha \implies Ic_1 = 6 + \alpha \\ Ic(Ic_2) = 1 = \alpha \\ Ic(Ic_3) = (9 - Ic_3) = \alpha \implies Ic_3 = 9 - \alpha \end{cases}$
Impact on Time " substantial "	$\begin{cases} x - 5 \\ 1 \\ 8 - x \\ 0 \end{cases}$	$\begin{cases} 5 < x < 6 \\ 6 \leq x \leq 7 \\ 7 < x < 8 \\ \text{otherwise} \end{cases}$	$\begin{cases} It(It_1) = (It_1 - 5) = \alpha \implies It_1 = 5 + \alpha \\ It(It_2) = 1 = \alpha \\ It(It_3) = (8 - It_3) = \alpha \implies It_3 = 8 - \alpha \end{cases}$
Impact on Quality " negligible "	$\begin{cases} 1 \\ 2 - x \\ 0 \end{cases}$	$\begin{cases} 0 \leq x \leq 1 \\ 1 < x < 2 \\ \text{otherwise} \end{cases}$	$\begin{cases} Is(Iq_1) = 1 = \alpha \\ Is(Iq_2) = (2 - Iq_2) = \alpha \implies Iq_2 = 2 - \alpha \end{cases}$

Stage 03: Computation: Next move, we apply the multiplication on the probability and the impact factors " α cuts " to each others as follow:

3-1 Severity calculation on cost	3-2 Severity calculation on time	3-3 Severity calculation on Quality
$\alpha(P * Ic) = [(5 + \alpha), (8 - \alpha)] * [(6 + \alpha), (8 - \alpha)]$ $\alpha(P * Ic) = [(a^2 + 11a + 30), (a^2 - 17a + 72)]$ <ul style="list-style-type: none"> • left endpoint (30,42) $a^2 + 11a + 30 = x$ $\alpha = \sqrt{x + 0.25} - 5.5$ • right endpoint (56,72) $a^2 + 17a + 72 = x \implies$ $\alpha = 8.5 - \sqrt{x + 0.25}$ Severity = probability * impact $(P * Ic)(x) = \begin{cases} \sqrt{x + 0.25} - 5.5 \\ 1 \\ 8.5 - \sqrt{x + 0.25} \\ 0 \end{cases}$	$\alpha(P * It) = [(5 + \alpha), (8 - \alpha)] * [(5 + \alpha), (8 - \alpha)]$ $\alpha(P * It) = [(a + 5)^2, (8 - a)^2]$ <ul style="list-style-type: none"> • left endpoint (25,36) $(a + 5)^2 = x \implies \alpha = \sqrt{x} - 5$ • right endpoint(49,64) $(8 - a)^2 = x \implies \alpha = 8 - \sqrt{x}$ Severity = probability * impact $(P * It)(x) = \begin{cases} \sqrt{x} - 5 \\ 1 \\ 8 - \sqrt{x} \\ 0 \end{cases}$	$\alpha(P * Iq) = [(5 + \alpha), (8 - \alpha)] * [(5 + \alpha), (8 - \alpha)]$ $\alpha(P * Iq) = [(a^2 - 10a + 16), (a^2 - 10a + 16)]$ <ul style="list-style-type: none"> • interval (7,16) $(a^2 - 10a + 16) = x \implies$ $\alpha = 5 - \sqrt{x + 9}$ Severity = probability * impact $(P * Iq)(x) = \begin{cases} 5 - \sqrt{x + 9} \\ 1 \\ 0 \end{cases}$

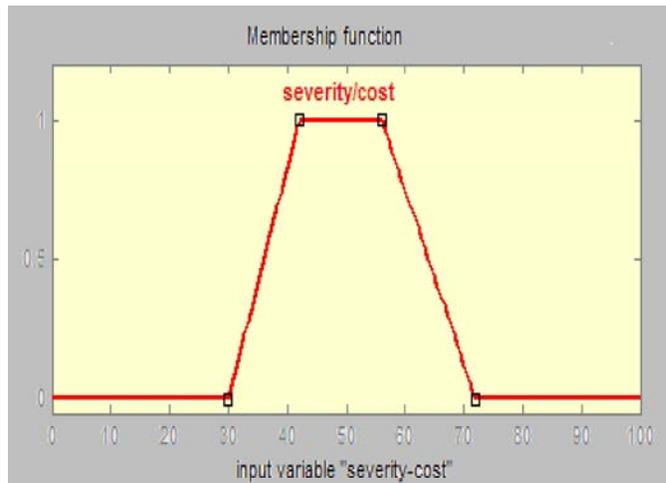


Fig. 12: Risk severity of risk factor K on cost

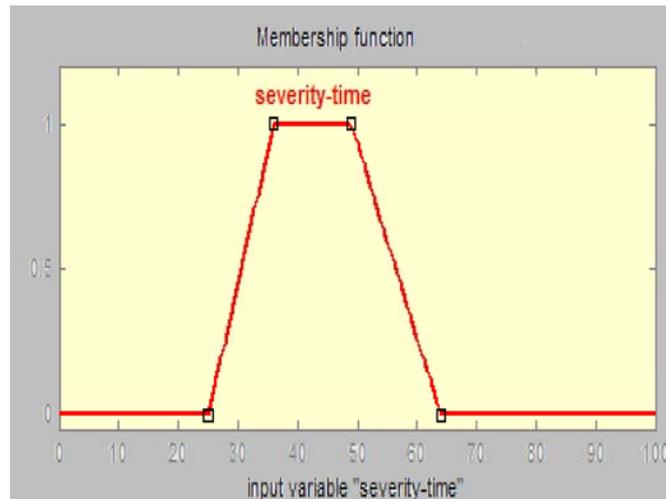


Fig. 13: Risk severity of risk factor K on Time

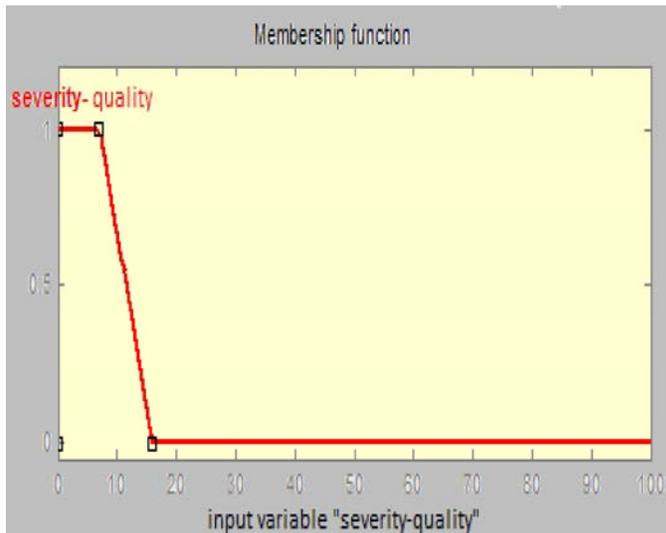


Fig. 14: Risk severity of risk factor K on quality

Stage 04: Defuzzification: In this phase, we are going to apply Centroid method (center of gravity) to find an index number for each diagram through following this equation 03:

$$COG = \frac{\int [U(x).x]dx}{\int U(x)dx}$$

Center of Gravity of Cost Diagram:

$$COG(cost) = \frac{\int_{30}^{42} (\sqrt{x + 0.25} - 5.5)x dx + \int_{42}^{56} x dx + \int_{56}^{72} (8.5 - \sqrt{x + 0.25})x dx}{\int_{30}^{42} (\sqrt{x + 0.25} - 5.5) dx + \int_{42}^{56} dx + \int_{56}^{72} (8.5 - \sqrt{x + 0.25}) dx}$$

$$COG(cost) = 50$$

Center of Gravity of Time Diagram:

$$COG(time) = \frac{\int_{25}^{36} (\sqrt{x} - 5)x dx + \int_{36}^{49} x dx + \int_{49}^{64} (8 - \sqrt{x})x dx}{\int_{25}^{36} (\sqrt{x} - 5) dx + \int_{36}^{49} dx + \int_{49}^{64} (8 - \sqrt{x}) dx}$$

$$COG(time) = 43.5$$

Center of Gravity of Quality Diagram:

$$COG(quality) = \frac{\int_0^7 x dx + \int_7^{16} (5 - \sqrt{x + 9})x dx}{\int_0^7 dx + \int_7^{16} (5 - \sqrt{x + 9}) dx}$$

$$COG(quality) = 5.4$$

Stage 05: Weighted Average Method Application

We have general formula:

$$Total\ Severity = \frac{\sum W * COG}{\sum W}$$

To simplify, we assume that all three weights are equal to 1 for each criteria [cost weight(Wc), timeweight (Wt), qualityweight (Wq)]. Therefore, the result is as follow:

$$Total\ Severity = \frac{(Wc * 50) + (Wt * 43.5) + (Wq * 5.4)}{Wc + Wt + Wq} = 32.96$$

The Total Severity is 32.69 on a scale of zero to 100.

Stage 06: Linguistic Approximation and Prioritizing:

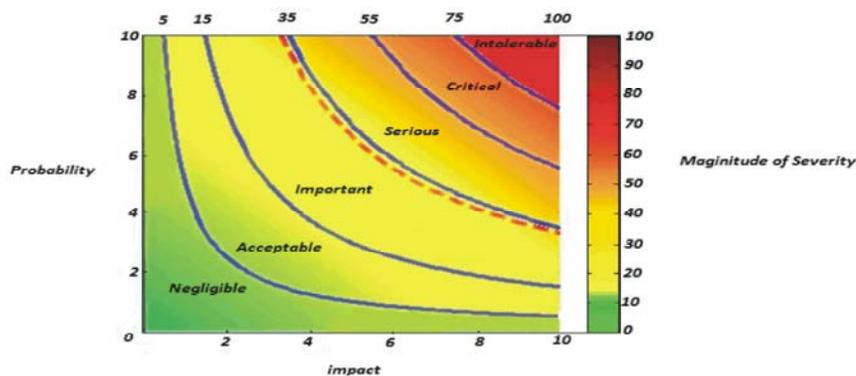


Fig. 15: Risk categories curve

Eventually, based on the average of risk factor, we can prioritize and rank it. To illustrate, the final step of risk analysis is to interpret the previous steps to verbal format as well as prioritize and rank the risk factor according to the risk categorized chart. Level of severity of risk is split to equal area from low risk on the down left to the greatest risk in the upper right location. As can be clearly seen that it is colored gradually following the previous scale from the left position towards the right position. Additionally, it is separated following the previous data to 5 zones in different amount progressively (Negligible, Acceptable, Important, Serious, Critical and Intolerable). The points from our example are also presented in this diagram and the result showed that the suggested risk factor is located in the third zone "important severity risk".

In the end, utilizing this method we can prioritize and rank all risk factors cited in the construction project as well as we can easily mitigate, control them in the best suitable way.

CONCLUSION

Construction industry projects have plunged in a challenging and complex environment. Significant levels of severity of risks are associated with these industries. An adopted way to analyze the related risks is vital to realize project success. In this paper we tried to develop a fuzzy risk analysis for construction industry projects. In spite of the fact that, the calculations used in the fuzzy risk analysis model are dull if performed manually, so it is a simple task and the time for risk analysis may be considerably minimized. The managers of construction projects can predict the total risk of the project prior proceed the implementation. The gross risk index can be utilized as early factors of project troubles and deferent potential obstacles. The proposed model fuzzy analysis provides an accurate, systematic and much more natural approach to assess the deferent associated risks within the three sensitive criteria "cost, time and quality". Evaluators may just easy utilize the risk assessment checklist and explore the linguistic terms to estimate construction projects severity level. In addition, there are some limitations in this research. To illustrate, the membership functions were distributed by trapezoid fuzzy numbers; as well as deferent membership sets must be evaluated to be as realistic as possible.

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