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Risk Analysis Model for Construction Projects Using Fuzzy Logic

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ABSTRACT:
The construction industry project is 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.

KEYWORDS:
Construction projects; Fuzzy logic, Risk analysis

1- 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.

2- 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, (Ahmed et al., 2007). 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, (2011).

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 (Qian Shi, 2014).To this end, FUZZY approach is introduced to enable quantitative risk assessment development to be modeled mathematically. Additionally, relationships between risks, risk factors and their consequences are shown on cause and impact.

3- 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 (Steven Pender, 2001).

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. (PMI, 2008)

Severity=	**(likelihood)*(impact)**
Equation 1	

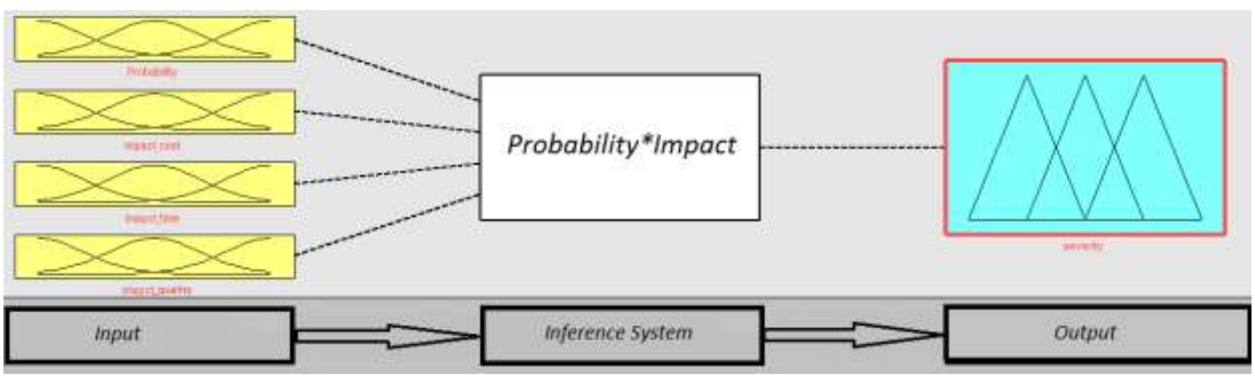


Figure 01: the structure of fuzzy risk analysis (input /output)

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,2011).

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

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

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) (J.H.M Tah and V. Carr, 2000). Where estimation cost is of great importance in project management as it provides substantial information for decision making, cost scheduling and resource management (Carr, 1989).
Tables and charts show a customizable standard term for quantifying likelihood and the impacts of cost, time and quality respectively as follow:

Table 01: customizable standard terms for quantifying probability

Probability	**Trapezoid Number**	**Supporting Intervals**
Extremely unlikely (E-UN)	(0,0,1,2)	[0,2] 0≤x≤2
Unlikely (UN)	(1,2,3,4)	[1,4] 1≤x≤4
Moderate (M)	(3,4,5,6)	[3,6] 3≤x≤6
Somehow Likely (S-L)	(5,6,7,8)	[5,8] 5≤x≤8
Very likely (V-L)	(7,8,9,10)	[7,10] 7≤x≤10
Highly likely(H-L)	(9,10,10,10)	[9,10] 9≤x≤10

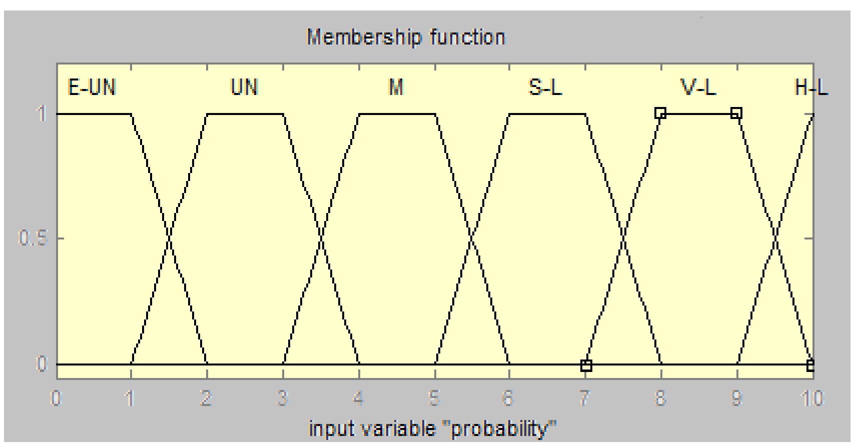


Figure 02: Membership function of likelihood

Table 02: customizable standard terms for quantifying impact of cost

Impact (cost)	**Trapezoid Number**	**Supporting Intervals**
Negligible (Neg)	(0,0,0,1)	[0,1] 0≤x≤1
Marginal (Marg)	(0,1,2,3)	[0,3] 0≤x≤3

Moderate (Mod)	(2,3,4,5)	[2,5]	2≤x≤5
Substantial (Sub)	(4,5,6,7)	[4,7]	4≤x≤7
Severe (Sev)	(6,7,8,9)	[6,9]	6≤x≤9
Disastrous (Dis)	(8,9,10,10)	[8,10]	8≤x≤10

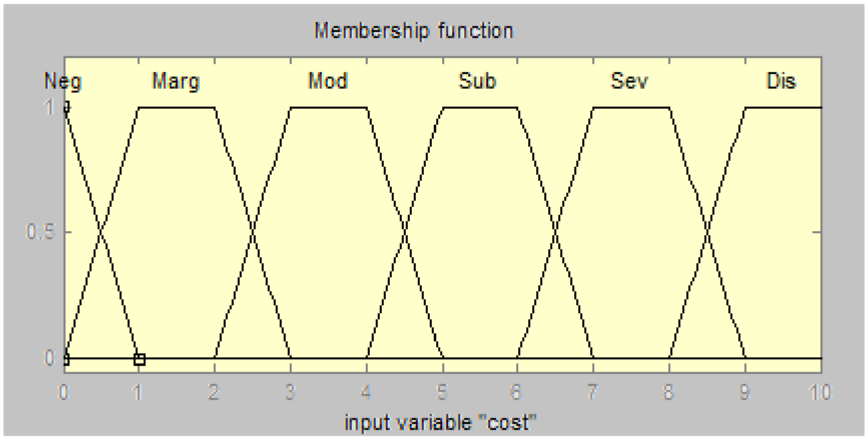


Figure 03: Membership function of impact of cost

Table 03: customizable standard terms for quantifying impact of time

Impact (time)	**Trapezoid Number**	**Supporting Intervals**	
Negligible (Neg)	(0,0,1,2)	[0,2]	0≤x≤2
Marginal (Marg)	(1,2,3,4)	[1,4]	1≤x≤4
Moderate (Mod)	(3,4,5,6)	[3,6]	3≤x≤6
Substantial (Sub)	(5,6,7,8)	[5,8]	5≤x≤8
Severe(Sev)	(7,8,9,10)	[7,10]	7≤x≤10
Disastrous (Dis)	(9,10,10,10)	[9,10]	9≤x≤10

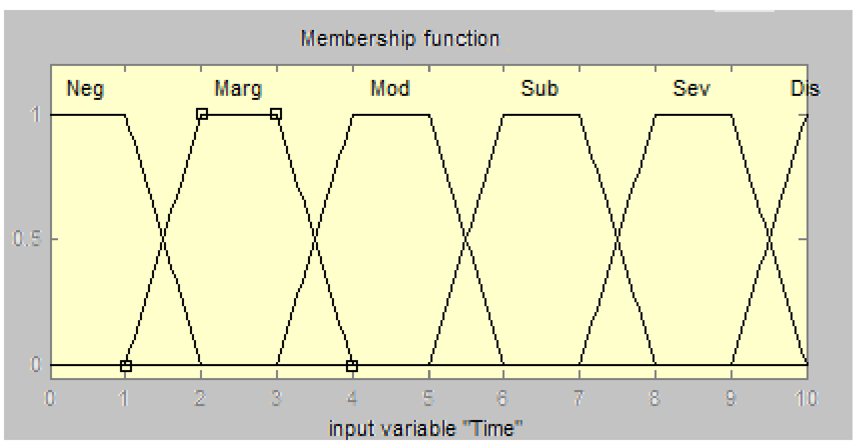


Figure 04: Membership function of impact of time

Table 04: customizable standard terms for quantifying impact of quality

Impact (quality)	Trapezoid Number	Supporting Intervals
Negligible (Neg)	(0,0,1,2)	[0,2] $0 \le x \le 2$
Marginal (Marg)	(1,2,3,4)	[1,4] $1 \le x \le 4$
Moderate (Mod)	(3,4,5,6)	[3,6] $3 \le x \le 6$
Substantial (Sub)	(5,6,7,8)	[5,8] $5 \le x \le 8$
Severe(Sev)	(7,8,9,10)	[7,10] $7 \le x \le 10$
Disastrous (Dis)	(9,10,10,10)	[9,10] $9 \le x \le 10$

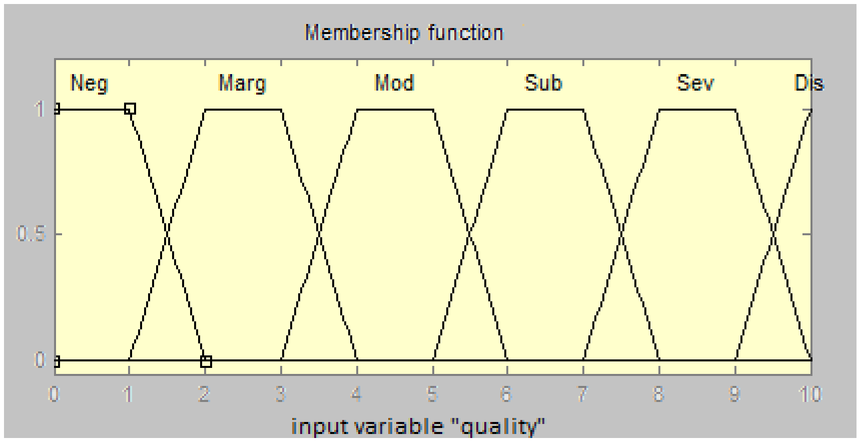


Figure 05: Membership function of impact of quality

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 (2005) is stated that the a-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 is it useful to consider those elements that have at least some minimal degree of membership "alpha ". 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 alpha-cut.

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

$$\mathbf{A}^{\alpha} = \{\mathbf{x} \in \mathbf{X} / \mathbf{A}(\mathbf{x}) \geq \boldsymbol{\alpha}\}$$

We cannot emphasize enough that an alpha-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 alpha-cut is shown .The interval [0,5] is the alpha-cut of 0.7 for this set .where includes all elements of this set which have the same value or exceeding to 0.7.

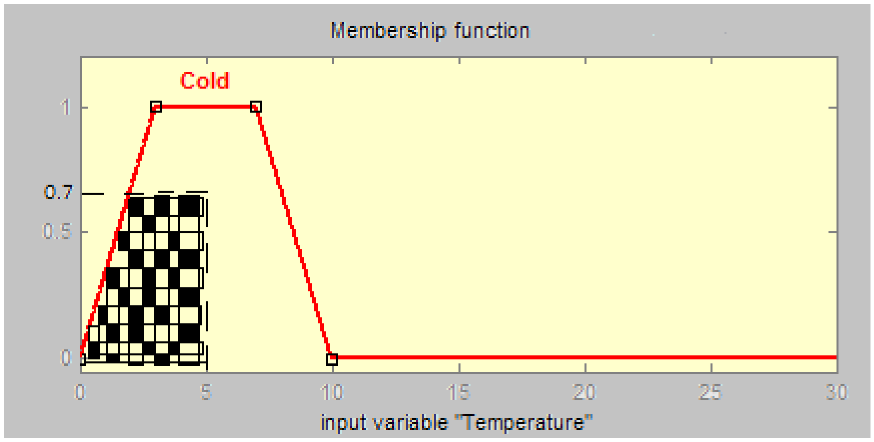


Figure 06: Alpha –cut illustration for α=0.7

For fuzzy set operations, the alpha-cut is considered the bridge between the intervals and crisp numbers, simplifying different operations on the numbers. For more understanding of process referring to Zeng & Shi (2005) and Yager (2008b) Specifically, in this phase, the purpose is to find the alpha-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 alpha-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:

$$[a, b] * [c, d] = \{x * y \ / \quad a \le x \le b \, , c \le y \le d\} \text{Equation 2}$$

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 has 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 defuzzication method may produce for the fuzzy output number a good results for the fuzzy set (Takagi,1985).

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 (Zeng & Shi,2005)

4-1 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.

$$\mathrm{COG} = \frac{\int [\mathrm{U}(x).x\,]dx}{\int \mathrm{U}(x)dx} \quad \text{Equation 3}$$

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

4-2 MAXIMA METHODS:

COG is a defuzzification method regarding the area under the membership function. Maxima methods 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 (lee, 1990). 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 .

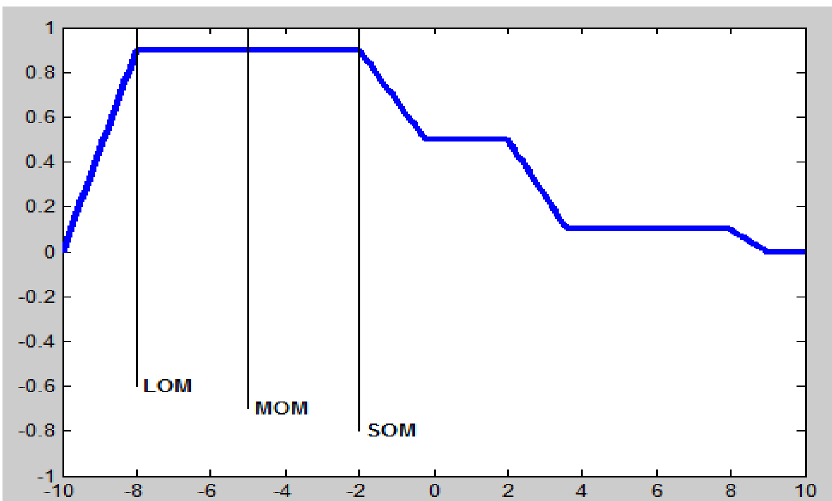


Figure 07: Representation of SOM, MOM, and LOM

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 perspective 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 (lee,1990).

$$\textbf{Total Severity} = \frac{\sum \mathbf{W}_{\gamma} * \mathbf{COG}_{\gamma}}{\sum \mathbf{W}_{\gamma}} \quad \text{Equation 4}$$

Where:

γ **:** 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 (2000) 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.

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	$75\% < S$

4- 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 convert 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:

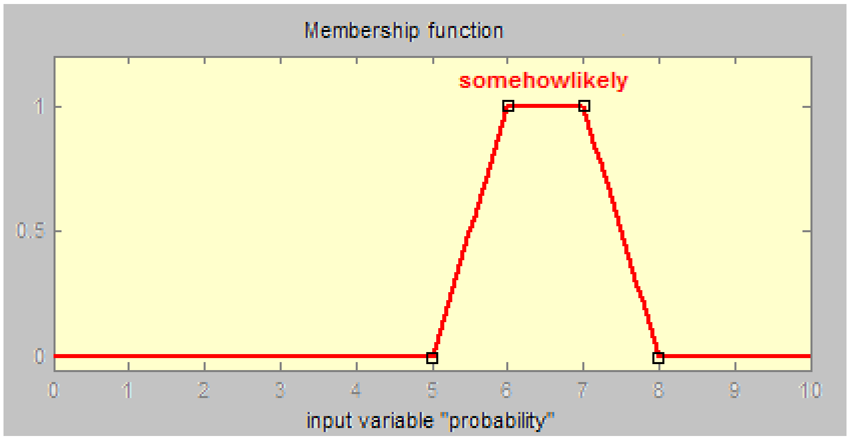


Figure 08: probability "somehow likely" membership function for risk factor K

2 - COST INPUT DIAGRAM:

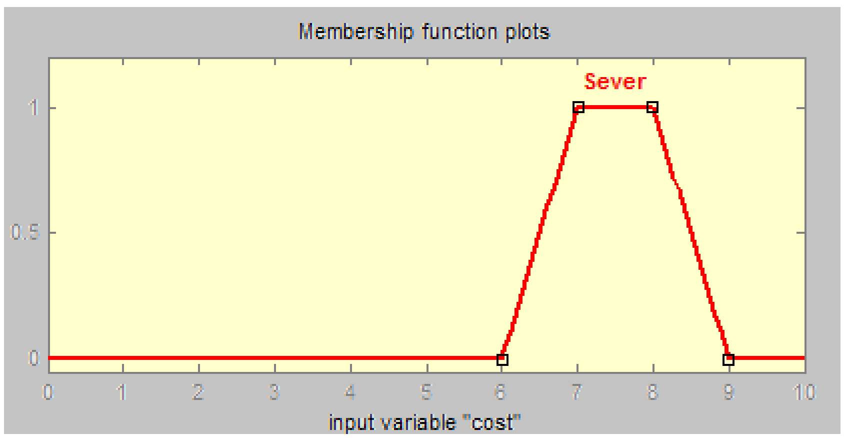


Figure 09: the membership function for the impact of cost "Substantial "

3 - TIME INPUT DIAGRAM:

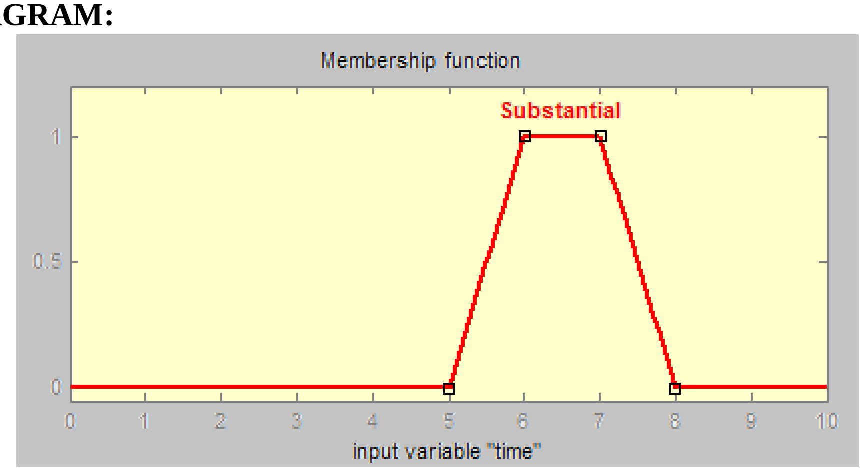


Figure 10: the membership function for the impact of time "substantial "

4 –QUALITY INPUT DIAGRAM:

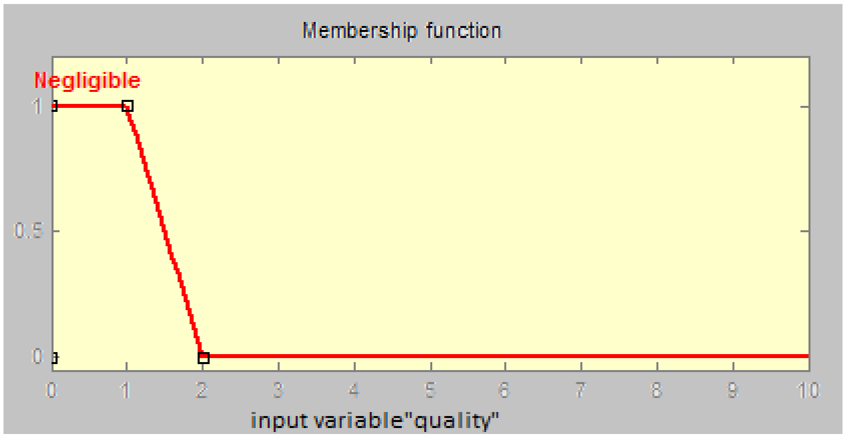


Figure 11: the membership function for the impact of quality "negligible "

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 tofind"**α**cuts"for each criteria.

Probability
" Somehow likely"

$$\begin{cases} x-5 & 5 < x < 6 \\ 1 & 6 \leq x \leq 7 \\ 8-x & 7 < x < 8 \\ 0 & \text{otherwise} \end{cases}$$

Impact on Cost
" Sever "

$$\begin{cases} x-6 & 6 < x < 7 \\ 1 & 7 \leq x \leq 8 \\ 9-x & 8 < x < 9 \\ 0 & \text{otherwise} \end{cases}$$

Impact on Time
" substantial "

$$\begin{cases} x-5 & 5 < x < 6 \\ 1 & 6 \leq x \leq 7 \\ 8-x & 7 < x < 8 \\ 0 & \text{otherwise} \end{cases}$$

Impact on Quality
" negligible "

$$\begin{cases} 1 & 0 \leq x \leq 1 \\ 2-x & 1 < x < 2 \\ 0 & \text{otherwise} \end{cases}$$

In order to measure theSeverity, we should determine the" **α**cuts" for each equation as follow:

Generally, we have this equation:$U({}^{\alpha}_{x}U) = \alpha$

1- Probability

$$\begin{cases} P({}^{\alpha}P_1) = ({}^{\alpha}P_1 - 5) = \alpha & \Longrightarrow \quad {}^{\alpha}P_1 = 5 + \alpha \\ P({}^{\alpha}P_2) = 1 = \alpha & \\ P({}^{\alpha}P_3) = (8 - {}^{\alpha}P_3) = \alpha & \Longrightarrow \quad {}^{\alpha}P_3 = 8 - \alpha \end{cases}$$

2- Impact on cost

$$\begin{cases} Ic({}^{\alpha}Ic_1) = ({}^{\alpha}Ic_1 - 6) = \alpha & \Longrightarrow \quad {}^{\alpha}Ic_1 = 6 + \alpha \\ Ic({}^{\alpha}Ic_2) = 1 = \alpha & \\ Ic({}^{\alpha}Ic_3) = (9 - {}^{\alpha}Ic_3) = \alpha & \Longrightarrow \quad {}^{\alpha}Ic_3 = 9 - \alpha \end{cases}$$

3- Impact on time

$$\begin{cases} It({}^{\alpha}It_1) = ({}^{\alpha}It_1 - 5) = \alpha & \Longrightarrow \quad {}^{\alpha}It_1 = 5 + \alpha \\ It({}^{\alpha}It_2) = 1 = \alpha & \\ It({}^{\alpha}It_3) = (8 - {}^{\alpha}It_3) = \alpha & \Longrightarrow \quad {}^{\alpha}It_3 = 8 - \alpha \end{cases}$$

4 - Impact on quality

$$\begin{cases} Is({}^{\alpha}Iq_1) = 1 = \alpha & \Longrightarrow \quad {}^{\alpha}Iq_2 = 2 - \alpha \\ Is({}^{\alpha}Iq_2) = (2 - {}^{\alpha}Iq_2) = \alpha & \end{cases}$$

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

$$\alpha\,(P * Ic) = [(5 + \alpha), (8 - \alpha)] * [(6 + \alpha), (9 - \alpha)]$$
$$\alpha(P * Ic) = [(\alpha^2 + 11\alpha + 30), (\alpha^2 - 17\alpha + 72)]$$

- Left endpoint (30,42)

$$\alpha^2 + 11\alpha + 30 = x \Longrightarrow \alpha^2 + 2(5.5)\alpha + 30 = x$$
$$(\alpha + 5.5)^2 = x + 0.25$$
$$\Longrightarrow \alpha = \sqrt{x + 0.25} - 5.5$$

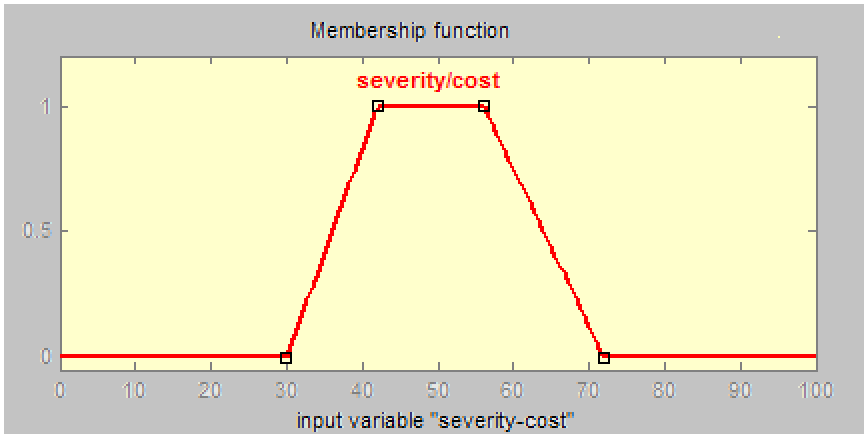
- Right endpoint (56,72)

$$\alpha^2 + 17\alpha + 72 = x \Longrightarrow \alpha^2 + 2(8.5)\alpha + 72 = x$$
$$(8.5 - \alpha)^2 = x + 0.25$$
$$\Longrightarrow \alpha = 8.5 - \sqrt{x + 0.25}$$

As we known: Severity =probability *impact

Multiplying two intervals to each others leads us to the following equation:

$$(P * Ic)(x) = \begin{cases} \sqrt{x + 0.25} - 5.5 & 30 < x < 42 \\ 1 & 42 \le x \le 56 \\ 8.5 - \sqrt{x + 0.25} & 56 < x < 72 \\ 0 & \text{otherwise} \end{cases}$$



3-2 SEVERITY CALCULATION ON TIME:

$$\alpha\,(P * It) = [(5+\alpha),(8-\alpha)] * [(5+\alpha),(8-\alpha)]$$
$$\alpha(P * It) = [(\alpha+5)^2,(8-\alpha)^2]$$

- Left endpoint (25,36)

$(\alpha+5)^2 = x \Longrightarrow (\alpha+5) = \sqrt{x} \Longrightarrow \alpha = \sqrt{x}-5$

- Right endpoint (49,64)

$(8-\alpha)^2 = x \Longrightarrow (8-\alpha) = \sqrt{x} \Longrightarrow \alpha = 8-\sqrt{x}$

As we known: Severity =probability *impact
Multiplying two intervals to each others leads us to the following equation:

$$(P * It)(x) = \begin{cases} \sqrt{x}-5 & 25 < x < 36 \\ 1 & 36 \le x \le 49 \\ 8-\sqrt{x} & 49 < x < 64 \\ 0 & \text{otherwise} \end{cases}$$

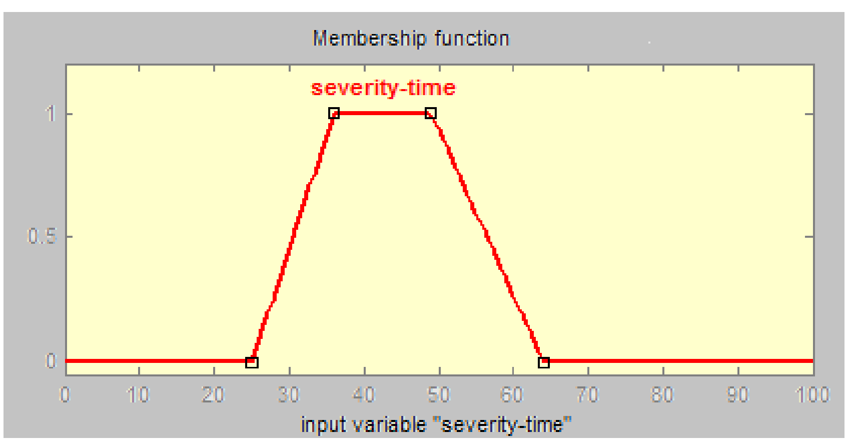


Figure 13: Risk severity of risk factor K on Time

3-3 SEVERITY CALCULATION ON QUALITY:

$$\alpha\ (P * Iq) = [(5+\alpha),(8-\alpha)] * [0,(2-\alpha)]$$
$$\alpha(P * Iq) = [(\alpha^2 - 10\alpha + 16)]$$

- interval (7,16)

$(\alpha^2 - 10\alpha + 16)$ =x $\Longrightarrow$ $(\alpha+5)^2 = x + 9$ $\Longrightarrow$ $\alpha = 5 - \sqrt{x+9}$

Thus, the result of severity of quality as follow:

$$(P * Iq)(x) = \begin{cases} 1 & 0 \le x \le 7 \\ 5 - \sqrt{x+9} & 7 < x < 16 \\ 0 & \text{otherwise} \end{cases}$$

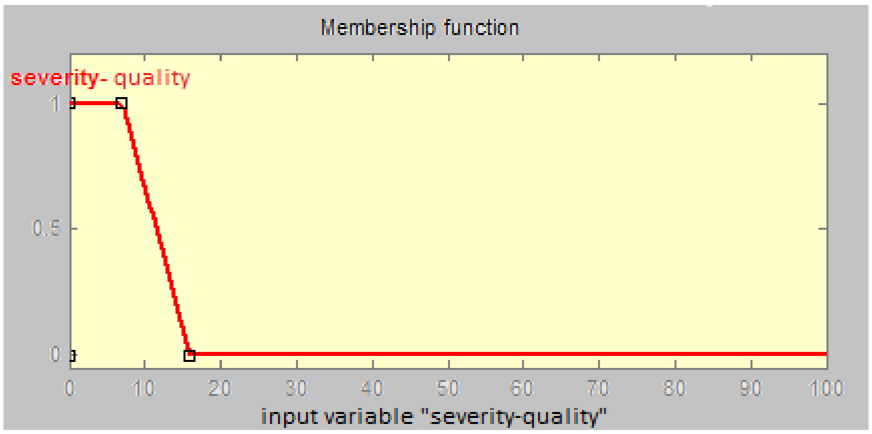


Figure14: Risk severity of risk factor K on quality

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:

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

4-1CENTER OF GRAVITY OF COST DIAGRAM:

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

$$\mathrm{COG(cost)} = 50$$

ILLUSTRATION USING MATLAB:

```
x = 0:100;
mf1 = trapmf(x,[30 42 56 72]);
figure('Tag','defuzz');
plot(x,mf1,'LineWidth',3);
x1 = defuzz(x,mf1,'centroid'); % #ok<*NOPTS>
h1 = line([x1 x1],[0,1],'Color','k');
t1 = text(x1,0.1,' centroid','FontWeight','bold');
```

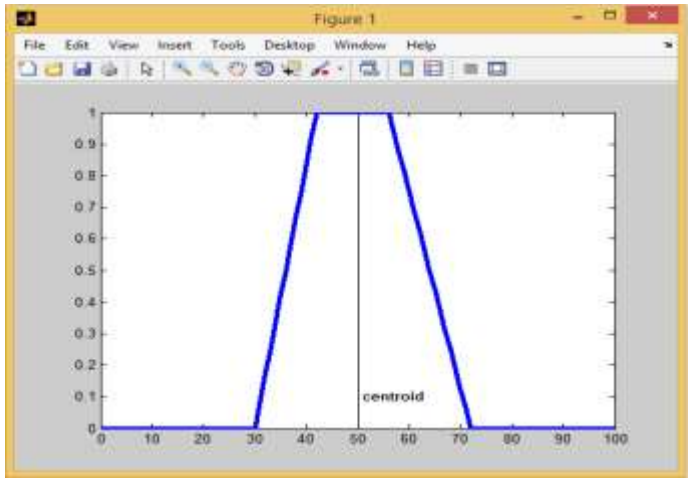


Figure 15: Center of gravity of Cost diagram

4-2 CENTER OF GRAVITY OF TIME DIAGRAM:

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

COG (time)=43.5

Illustration using Matlab

```
x = 0:100;
mf1 = trapmf(x,[25 36 49 64]);
figure('Tag','defuzz');
plot(x,mf1,'LineWidth',3);
x1 = defuzz(x,mf1,'centroid'); % #ok<*NOPTS>
h1 = line([x1 x1],[0,1],'Color','k');
t1 = text(x1,0.1,' centroid','FontWeight','bold');
```

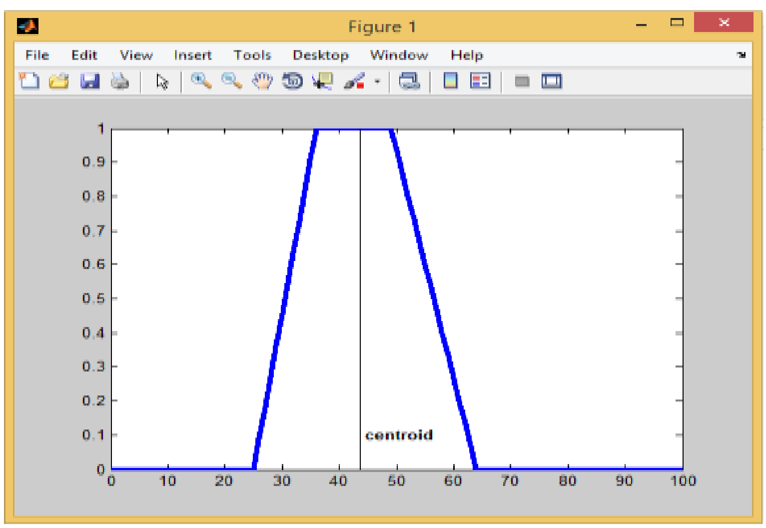


Figure 16: Center of gravity of Time diagram

4-3 CENTER OF GRAVITY OF QUALITYDIAGRAM:

$$\mathrm{COG(quality)} = \frac{\int_{0}^{7} x\,dx + \int_{7}^{16}(5-\sqrt{x+9})\,x\,dx}{\int_{0}^{7} dx + \int_{7}^{16}(5-\sqrt{x+9})\,dx}$$

$$\mathrm{COG(quality)} = 5.4$$

Illustration using Matlab

```
x = 0:100;
mf1 = trapmf(x,[0 0 7 16]);
figure('Tag','defuzz');
plot(x,mf1,'LineWidth',3);
x1 = defuzz(x,mf1,'centroid'); % #ok<*NOPTS>
h1 = line([x1 x1],[0,1],'Color','k');
t1 = text(x1,0.1,' centroid','FontWeight','bold');
```

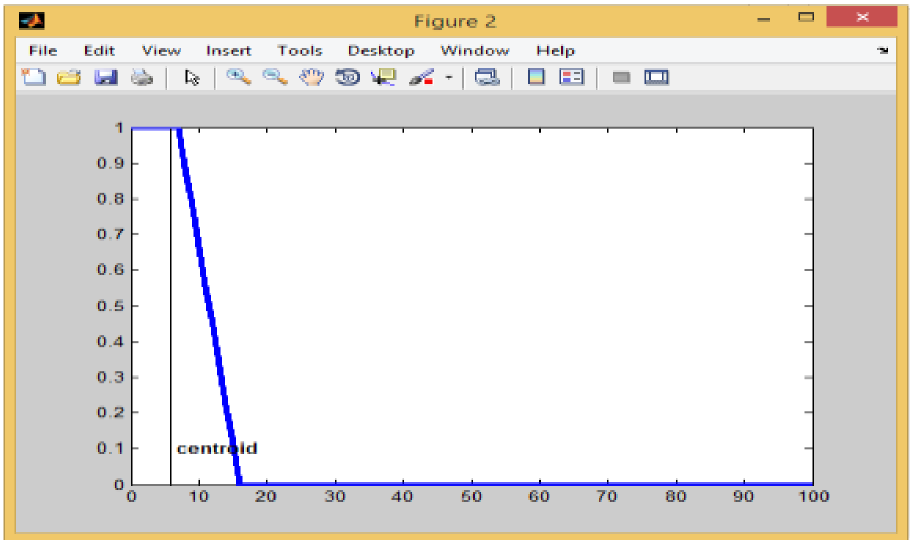


Figure 17: Center of gravity of quality diagram

STAGE 05: WEIGHTED AVERAGE METHOD APPLICATION:

We have general formula:

$$\textbf{Total Severity} = \frac{\sum \mathbf{W}_\gamma * \mathbf{COG}_\gamma}{\sum \mathbf{W}_\gamma}$$

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:

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

$$\textbf{Total Severity} = \mathbf{32.96}$$

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

STAGE 06: LINGUISTIC APPROXIMATION AND PRIORITIZING:

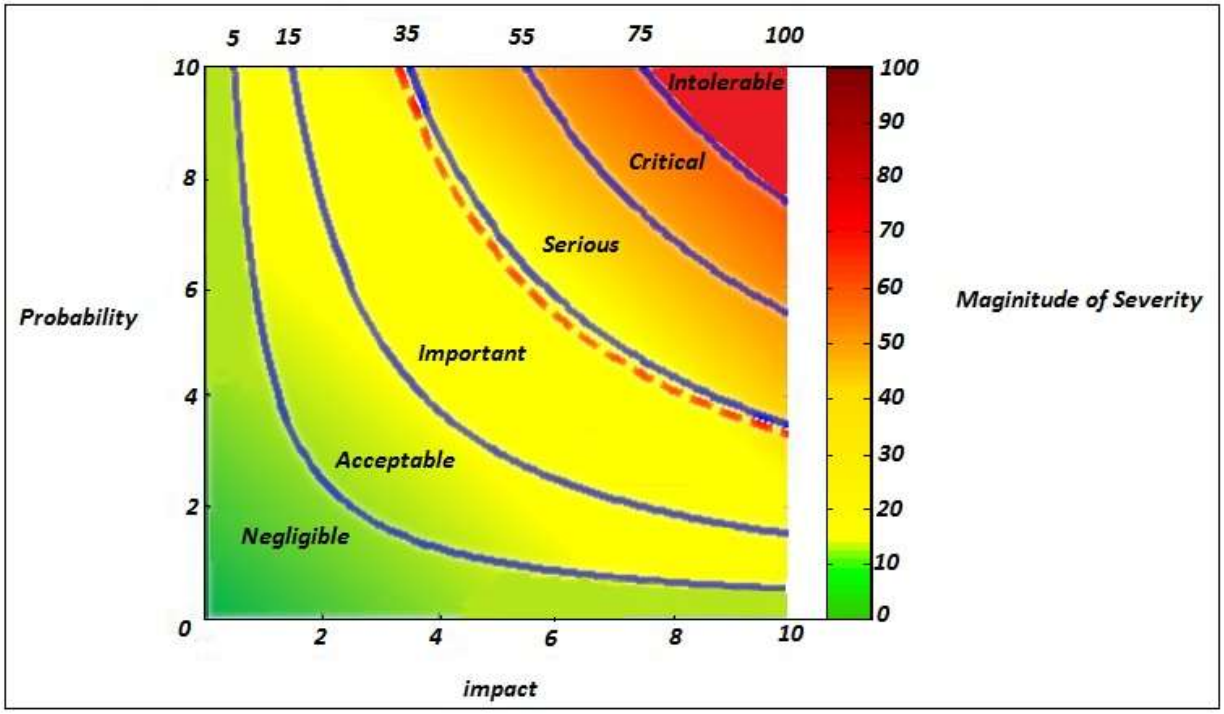


Figure 18: risk categories curve

Illustration using Matlab

```
>> x=linspace(0,10);
y=5./x;
plot(x,y,'linewidth',3);
axis([0 10 0 10])
hold on
y=15./x;
plot(x,y,'linewidth',3);
y=35./x;
plot(x,y,'linewidth',3);
y=55./x;
plot(x,y,'linewidth',3);
y=75./x;
plot(x,y,'linewidth',3);
y=33./x;
plot(x,y,'--r','linewidth',3)
```

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 .

5 – CONCLUSION:

Construction industry projects have plunged in a challenging and complex environment. Significant levels of severity of risks are associated with this in dustries. 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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