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FUZZY MULTI-CRITERIA DECISION MAKING MODEL FOR RISK ASSESSMENT

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ABSTRACT

Decision making and risk assessment are becoming a challenging task in oil and gas due to the risk related to the uncertainty and imprecision. This paper proposed a model for the risk assessment based on multi-criteria decision making (MCDM) method by integrating Fuzzy-set theory. In this model, decision makers (experts) provide their preference of risk assessment information in four categories; people, environment, asset, and reputation. A fuzzy set theory is used to evaluate likelihood, consequence and total risk level associated with each category. A case study is presented to demonstrate the proposed model. The results indicate that the proposed Fuzzy MCDM method has the potential to be used by decision makers in evaluating the risk based on multiple inputs and criteria.

Keywords: risk assessment, multi-criteria decision making, fuzzy set theory.

INTRODUCTION

Risk assessment is the combination of likelihood and consequences of any unwanted event or hazard as shown in Figure-1 [1, 2]. It is the process of categorizing and measurement of risk related outcomes from a specific incident and in a particular scenario. It can be caused by personal injuries of workers, environmental damages, degradation and damage of the assets which have high effects on the reputation of the industry. In the human decision making process, the risk is present because of uncertainty and imprecision [3-5]. Usually, uncertainty and imprecision exist due to the lack of information, incompatible evidence, vague information and individual information.

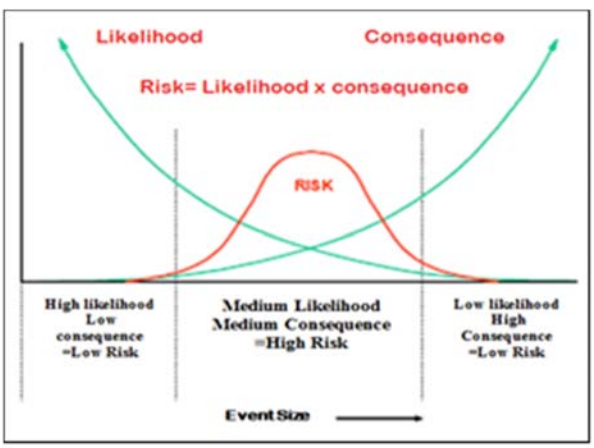

Figure-1. Graphical representation of risk.

Uncertainty and imprecision related to multi-criteria decision making in which the best alternatives have to be selected from a set of available and suitable alternatives with respect to multiple. In order to handle the risk various approaches and techniques have been developed and adopted for effectively modeling the uncertainty and imprecision in multi-criteria decision making. Risk assessment and decision making have been considered as a critical factor in oil and gas industries, the investigation of risk assessment factors assists the decision maker in oil and gas industry to minimize the risk related issues and take the appropriate decisions regarding risk level [6-10].

This study proposed a multi-criteria decision making model by integrating with a fuzzy logic theory which will support in risk analyzing and risk ranking. A case study is presented for illustrating the use of proposed fuzzy multi-criteria decision making model.

LITERATURE REVIEW

Multi criteria decision support system (MCDSS)

Multi-criteria decision support system (MCDSS) is the method which helps in decision making under multiple and conflicting criteria. It provides a systematic procedure to help decision makers to choose the most essential and acceptable alternative under certain situations. Usually, decision making problems are different with respect to the nature of the problem, size of the problem, available time to making decisions and imprecision process of the human decision making. Also, it can be described as an integrated system by analyzing technique called multi-criteria decision making (MCDM) [11, 12].

Multi-criteria decision making (MCDM)

Typically, MCDM is used to solve the operation research models and decision making problems under the presence of decision criteria. Decision making is an important activity that occurs frequently in everyday human functioning. It usually consists of finding the finest alternative from the available alternatives. MCDM has been divided into following categories; multi-objective decision making (MODM) and multi-attribute decision making (MADM) [13]. Figure-2 indicates the process of MCDM.

Various methods are used in MODM and MADM categories such as; "priority based, outranking, distance based and mixed method applied to several issues".

Several studies have been done on multi-criteria decision making method and criteria prioritizing. Previously, various MCDM models, techniques, and algorithm have been successfully implemented [14-16].

These techniques assist in making decisions for decision makers on prioritizing criteria. Generally, for decision problems following approaches are commonly used;

a) Weighted sum method (WSM)
b) Weighted product method (WPM)
c) Analytical hierarchical process (AHP)
d) The elimination and et choice translating reality (ELECTRE)
e) The technique for order preference by similarity to ideal solution (TOPSIS)
f) Preference ranking organization method for enrichment evaluation (PROMETHEE)

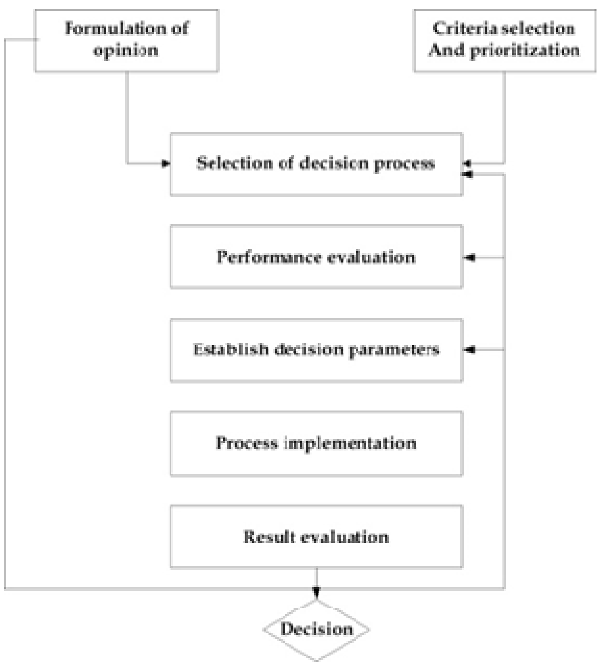

Figure-2. MCDM process [13].

a. Weighted sum method (WSM)

Weighted sum method is most widely used for decision making. Especially this method is used in single dimensional problems. In this method, the total value/score of the alternative is equal to the sum of product of attribute data and weight criteria. Suppose in decision making, problem there are K alternative and L criteria. Then, the best alternative is P*. Equation (1) is used for WSM [12].

$$P^*_{WSM} = \underset{K \geq i \geq 1}{MAX} \sum_{j=1}^{L} a_{ij} W_j \qquad (1)$$

Where
P^* WSM is the WSM priority value of the best alternative. When WSM applied on multi-dimensional decision making a conceptual difficulty emerges.

b. Weighted product method (WPM)

This method is similar as WSM. It is used for the ranking alternatives with multiplication. In this method, each alternative has been compared with other alternatives by multiplying the number of ratios for each criterion. Further, each ratio is raised to the equivalent power of relative weight of a matching criterion. Following Equation (2) is used to compare the two alternatives [17].

$$R\left(\frac{A_K}{A_L}\right) \prod_{j=1}^{n} \left(\frac{a_{Kj}}{a_{Lj}}\right)^{wj} \qquad (2)$$

c. Analytical hierarchy process (AHP)

AHP is a decision making tool. Saaty proposed this tool in 1980. The AHP is integrated with different procedures and it assists to make decisions with the overall score for alternative ranking. The main characteristic of AHP is based on judgment pairwise comparison [16]. The application of AHP consists of following three stages: hierarchical design, pairwise comparison and performance aggregation.

The AHP is based on following steps.

Step 1:

This step involves in hierarchical design and formulating the all decision problem elements into a multi-level structure for a multi-criteria decision making problem. The

Step 2:

This step involves the pairwise comparison for comparing the entire element at a level of hierarchy in a pairwise method with each element in the level. A rating scale from 1-9 has been used for representing the subjective assessment in this step.

Step 3:

The final step is to produce the performance aggregation of the final ranking of the element of the alternative. Additionally; the AHP is used in both decision making problems; single dimensional and multi-dimensional [18, 19].

d. Elimination Et choice translating reality (ELECTRE)

Roy proposed this method in 1990. ELECTRE method is based on "outranking relations and exploitation notions of concordance". These relations are based on the indexes of concordance and discordance in order to investigate the outranking relation between alternatives. This process is based on two main procedures; development of outranking relations and exploitation of outranking relations [20, 21]. The aim of both procedures is to compare the pairwise alternative in a comprehensive manner. This method is also capable of handling separate criteria of both qualitative and quantitative which provides the complete ordering of the alternatives.

e. The technique for order performance by similarity to ideal solution (TOPSIS)

Hwang and Yoon developed TOPSIS method. This method is based on selecting the distance which is shortest from the ideal solution and farthest from the undesirable ideal solution with respect to the best alternative. The main advantage of the TOPSIS is to assist the decision makers in problem-solving and assist in comparison, and also helps to assist in ranking of alternatives with respect to distance between the different alternatives [17, 22].

f. Preference ranking organization method for enrichment evaluation (PROMETHEE)

In 1986, Brans *et al* developed the PROMETHEE method. This method is a simple ranking method which is based on the evolution table. This method is based on the following types of information; information of relative criteria and information about decision maker's preference.

This method is well appropriate for decision problems, in which the limited number of alternatives has been ranked with respect to conflicting criteria [8].

RESEARCH METHOD

MCDM is the best method for decision making from available alternatives, and it helps to deal with the decision problems which rely under the various decision criteria. In this study, a fuzzy MCDM model is proposed for the risk assessment in Oil and Gas industry.

Fuzzy set theory (FST)

The FST is a powerful mathematical tool which has been used for modeling and controlling the uncertain system in industries [23]. Zadeh introduced FST to solve the problem with uncertain description and observation [24, 25]. A fuzzy set theory is defined as the collection of the set whose elements have the different degree of belonging to the set. In this study, we use a triangle fuzzy number (TFN) to represent the rating alternative and importance weight of the criterion. The TFN can be expressed in Figure 3, and also can be represented by the equation (3) [26].

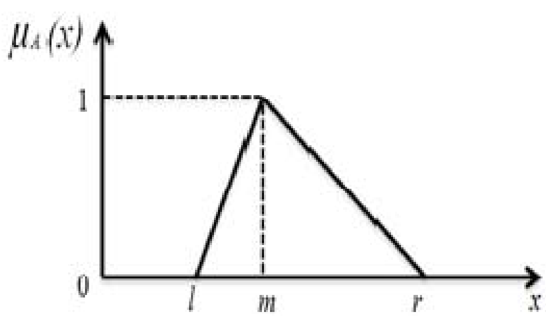

Figure-3. Membership functions of TFN.

$$\mu A\,(x) = \begin{cases} 0, & a_1 \le x < a_2, \\ \frac{x-a_1}{a_2-a_1} & \\ \frac{a_3-x}{a_3-a_2} & a_2 \le x < a_3 \end{cases} \quad (3)$$

Following are some algebraic operation of TFN.
Let A and B two TFN,
Addition of A and B two TFN,
If A= (a_1, a_2, a_3) and B = (b_1, b_2, b_3)
Then,
The sum of A and B is defined in Equation

$$A + B = (a_1 + b_1,\ a_2 + b_2, a_3 + b_3) \quad (4)$$

- Subtraction of two TFN

$$A - B = (a_1 - b_1,\ a_2 - b_2, a_3 - b_3) \quad (5)$$

- Multiplication of two TNF

$$A * B = (a_1 * b_1,\ a_2 * b_2, a_3 * b_3) \quad (6)$$

- Division of two TFN is defined in Equation

$$A/B = (a_1/b_3,\ a_2/b_2, a_3/b_1) \quad (7)$$

Fuzzy multi-criteria decision making model (FMCDM)

The FMCDM problems are mostly involved in the selection and ranking of single or various alternatives. The FMCDM can be expressed as Equation (8) [11, 17].

$$R = [R_{ij}]_{k \times l} \quad \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_k \end{array} \begin{array}{c} \begin{array}{ccccc} C_1 & C_2 & \cdots & C_l \end{array} \\ \left| \begin{array}{cccc} R_{11} & R_{12} & \cdots & R_{1l} \\ R_{21} & R_{22} & \cdots & R_{2l} \\ \vdots & \vdots & \ddots & \vdots \\ R_{k1} & R_{k2} & \cdots & R_{kl} \end{array} \right| \end{array} \quad (8)$$

Where, R is denoted as risk,
A_1, A_2, A_k is the possible available alternatives $i=1, 2\ldots.k$, and C_1, C_2, C_l are the evaluation and selection criteria $j=1,2,\ldots l$.

Fuzzy logic Toolbox of the MATLAB software was used to develop a risk matrix with the variables and membership functions. The FMCDM model consists of two input variables with five attributes and one output variable with four attributes. The input variables are represented by; Likelihood and consequence. Where, the output variable represented as the risk. FMCDM model is based on the following steps.

Step 1: Transfer the real risk matrix into fuzzy numbers (Likelihood, Consequence, and risk)

Step 2: Establish a risk matrix using fuzzy numbers. The triangular fuzzy numbers are used in this study. Tables 1 to 3 show the Triangular fuzzy number.

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Table-1. Fuzzy scale of likelihood.

Likelihood	Fuzzy numbers
Remote	(1, 1, 3)
Unlikely	(1, 3, 5)
Possible	(3, 5, 7)
Likely	(5, 7, 9)
Almost Certain	(7, 9, 11)

Table-2. Fuzzy scale of consequence.

Consequence	Fuzzy numbers
Insignificant	(1, 1, 3)
Minor	(1, 3, 5)
Moderate	(3, 5, 7)
Major	(5, 7, 9)
Catastrophic	(7, 9, 11)

Table-3. Fuzzy scale of risk.

Risk level	Fuzzy numbers
Low	(1, 1, 25)
Medium	(1, 25, 50)
High	(25, 50, 75)
Very High	(50, 75, 100)

Step 3: Assume that decision making group consists of *d* assessors. Then, risk can be estimated by using an equation

$$Rij = (1/d)\,(R_{ij}1 + R_{ij}2 + \ldots R_{ij}d) \quad (9)$$

Step 4: Rank the categories; People, environment, asset and reputation according to risk value.

RESULTS AND DISCUSSIONS

A case study has been taken into account from oil and gas industry. The case study is based on the risk evaluation of failed equipment. An Excel-based template has been created for data collection. The template has been sent to five risk assessors in oil and gas industry for input and filling up the template. Assessors assessed individually the effects of failed vessel as likelihood and consequence of four categories; people, environment, asset, and reputation as shown in Table-4.

Table-4. Consequence and likelihood value of assessors.

Categories	Assessor 1		Assessor 2		Assessor 3		Assessor 4		Assessor 5	
	Consequence	*Likelihood*	*Consequence*	*Likelihood*	*Consequence*	*Likelihood*	*Consequence*	*Likelihood*	*Consequence*	*Likelihood*
People	8	9	6	9	6	9	8	9	8	9
Environment	4	9	4	9	4	9	4	9	2	11
Asset	6	9	6	7	6	7	6	7	8	9
Reputation	6	9	4	7	4	7	4	7	2	9

Table-5. Risk score and ranking category.

Categories	Risk Score	Ranking
People	72.5	1
Asset	62.5	2
Asset	39	4
Environment	52.66	3

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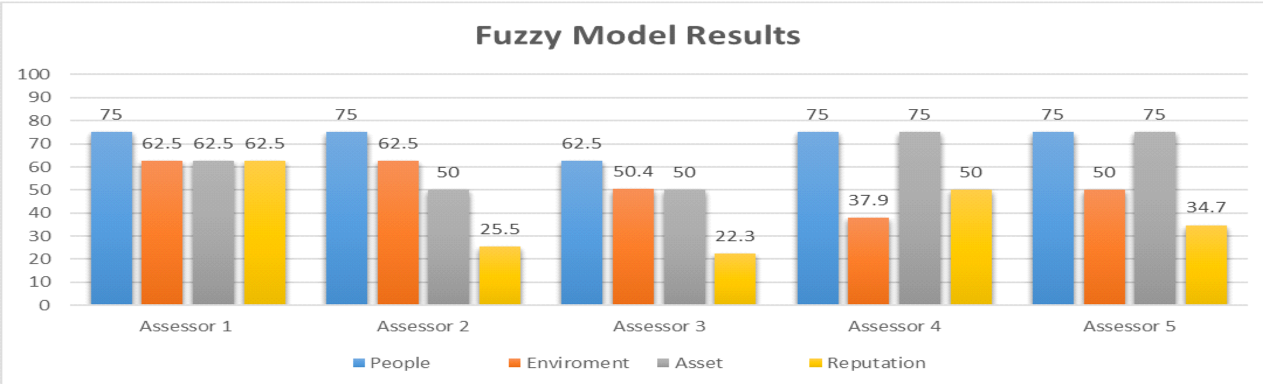

Figure-4. Individual risk of four categories.

Individual risk has been evaluated by using the proposed model with MATLAB software. Where, the overall risk of four categories; people, environment, asset, and reputation were calculated by combining the likelihood and consequence in a worst case scenario as shown Figure-4. The calculated average score of assessors of the four categories is shown in Figures-5.

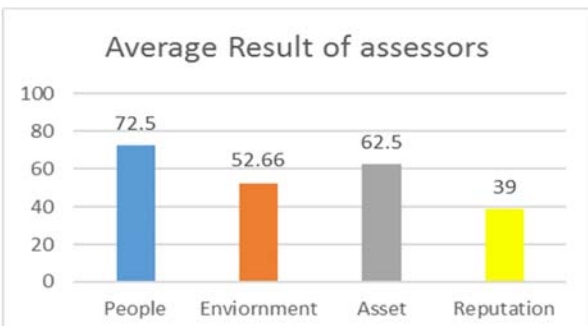

Figure-5. Average result of assessors.

Figure-5 shows the overall risk score and risk ranking of four categories. It indicating the overall risk score of category people has the highest ranking with their risk score 72.5. However, the other categories; environment, asset, and reputation have the least priority as compared the category; people.

CONCLUSIONS

In this study, a fuzzy multi-criteria decision making model has been proposed for risk assessment in oil and gas industries. Results from the model can assist to select or prioritize the more affected category from; people, environment, asset, and reputation. Results show that the category; people have the highest risk ranking and risk score 72.5 as compare the other categories the remaining risk score of categories were less in priority as shown in Table-7. The proposed model provides a useful way to deal with multi-criteria decision making problems.

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