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DEVELOPMENT OF FAILURE MODES AND EFFECTS ANALYSIS USING ANP AND FUZZY SAW

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ABSTRACT
Making decisions about selecting the most important risk factors play an essential role at industry and in today's global competitive environment, companies and many factories do not pay much attention to product failures and defeats of process until quality of final products and services improved by reduce costs. One of the methods of risk analysis, analysis of failure modes or the FMEA is the most used method among other methods. The Failure modes analysis of multi-criteria decision included qualitative and quantitative criteria that many of these criteria may not be mutually exclusive, so complicates the decision-making process. The aim of this study selected the most risky, especially in cases where traditional RPN cannot separate them. This research used the fuzzy set for closer the linguistic scale to what exists in reality until the minds of experts and consumers with more powerful analysis of potential failure modes for transformed into quantitative data. The industrial example is shown that both of ANP and SAW combined at fuzzy environment is able to more break down for identify important factor in the failure than the traditional FMEA.

KEYWORDS: Failure modes and effects analysis, Fuzzy numbers, Network analysis method, The cumulative weight of a simple method.

INTRODUCTION

One of the newest techniques for system safety analysis is FMEA which the first time in 1950 was founded by engineers to assess the safety of military systems and then this method use to expanded rapidly so that the United States, France and respectively to evaluate the safety of Concord and Airbus aircraft. In 1970, at the nuclear power and in 1980, that was used in Japan industry. And military standard MIL-STD-1626 as a method flaw analyzing and that significance published in November 1949 at America's army. In February 1992 SAE-J-1739 standard was introduced as the FMEA reference standard in the automotive industry. Then, in recent years, the development of quality assurance systems in the automotive industry, especially the situation of automotive standard America QS-9000 makes more used of FMEA (Rezaee *et al.*, 2005). Each failure mode can be evaluated by three factors as severity, likelihood of occurrence, and the difficulty of detection of the failure mode. In a typical FMEA evaluation, a number between 1 and 10 (with 1 being the best and 10 being the worst case) is given for each of the three factors. By multiplying the values for severity (S), occurrence (O), and detectability (D), a risk priority number (RPN) is obtained, which is RPN = S_ O_ D. Then the RPN value for each failure mode is ranked to find out the failures with higher risks (Chin *et al*., 2008).
Traditional risk priority number has been criticized for many reasons, some of the drawbacks mentioned below:

- The relative importance of the three factors, the severity, occurrence and detection have been considered, but they have been not accepted with equal importance.
- Various combinations of O, S and D may be giving the same production RPN values, although the actual value at risk could be quite different. For example, two different failure with O, S and D, respectively value of 4, 3, 3 and 9, 1, 3, has a value of 36 for RPN.
- Use a multiplication of the RPN in calculation, questionable and highly sensitive to changes in the assessment of risk factors (Kutlu, 2012).

Due to the disadvantages and problems that, much research has been done to fix bugs risk priority number. The research by Liu et.al suggested that more studies trying to solve ignoring the relative importance of risk factors in reaching their traditional risk ones at past (Liu et.al,2013).
On the other hand, the ANP method has been proposed recently with group attitudes, fuzzy and goal programming that can be the relative importance of risk factors (severity, occurrence, frequency) of each failure mode to identify the problem.

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Literature review about failure modes and effects analysis in fuzzy environment:
In 1989, Kara-Zaitri and Keller are proposed the use of rules to express relationships between cause and effect (Kara-Zaitri and Keller, 1989). In 1992, Bell and *et al*. have developed a tool that automates the reasoning portion of a failure modes and effects analysis (FMEA). It is built around a flexible causal reasoning module that has been adapted to the FMEA procedure (Bell *et.al*, 1992).

Bowles و Pelaez (1995) described a fuzzy logic based approach for prioritizing failures in a system FMEA, which uses fuzzy linguistic terms to describe O, S, D, and the risks of failures. The relationships between the risks and O, S, D were characterized by fuzzy if–then rules extracted from expert knowledge and expertise. Crisp ratings for O, S, and D were then difuzzified to match the premise of each possible if–then rule. All the rules that have any truth in their premises were fired to contribute to fuzzy conclusion. The fuzzy conclusion was finally difuzzified by the weighted mean of maximum method (WMoM) as the ranking value of risk priority (Bowles and Pelaez, 1995). In another article published in 1996, Bowles and *et al*., used maps and fuzzy graphs for showing the relationship between causes and effects of errors and stated that this method can show the relationship between cause and the effect and tools to assist the detection of the FMEA.

In this study, the combination of triangular and trapezoidal membership function is used (Bowles and Pelaez, 1996). Another work by fuzzy FMEA method is proposed by Chang and Wei in 1999 that none of fuzzy model is easy relatively to obtain accurate values of the linguistic variables. In their model, initially assigning linguistic variable to each of the three parameters and then using a triangular membership function is attributed to each of fuzzy number linguistic variables (Chang and Wei, 1999). In 2005, an approach based on fuzzy logic was proposed that the assessment of risk priority number (RPN) is performed based on fuzzy logic. They were used judgments of experts (Sharma *et al*., 2005). Chee and Kai introduced a general approach of fuzzy modeling, risk priority number (RPN) and then proposed a method for reduced the number of rules (Chee and Kai, 2005). When the traditional FMEA and the fuzzy approach are compared, the fuzzy approach has an advantage of allowing the conduction of risk evaluation and prioritization based on the knowledge of the experts (Tay and Lim, 2006).

Literature review about method of network analysis:
The Analytic Network Process (ANP) is a generalization of the Analytic Hierarchy Process (AHP). The basic structure is an influence network of clusters and nodes contained within the clusters. Priorities are established in the same way they are in the AHP using pairwise comparisons and judgment. Many decision problems cannot be structured hierarchically because they involve the interaction and dependence of higher-level elements in a hierarchy on lower-level elements. Not only does the importance of the criteria determine the importance of the alternatives as in a hierarchy, but also the importance of the alternatives themselves determines the importance of the criteria. Feedback enables us to factor the future into the present to determine what we have to do to attain a desired future. To illustrate ANP, one example is also presented. Due to the lack of reciprocity risk factors in FMEA conventional and in addition to its network analysis efficacy to identify and the interactions of decision criteria makes the combining approach of these two methods do better more in the analysis accurate and precise risk.

literature review about SAW method
SAW method is one of the most well-known multi-criteria decision-making methods that are widely used because of its simplicity in solving problems. In 2005, a SAW method proposed as a classical method, due to the simplicity and practicality (Modarres and Sadi-nezhad, 2005). In 2012, SAW method, was proposed for implementation in industry (Mohammaditabar *et al*., 2012). The fuzzy SAW method was used for solving facility location (Chou *et al*., 2008). Also in the telecommunications sector of the SAW method is used to select employees (Afshari *et al*., 2010). Composition SAW and Fuzzy AHP and DEA method is also suitable for inventory control (Mohammadghasemi and Vencheh, 2011).

MATERIALS AND METHODS
Traditional FMEA method
Before anything we need to know that what would cycle activities or Process of procedure in this method be to done stages of FMEA completely engineering and precise with keep pace with this cycle. Therefore, this process is represented with priority and regency of processes in Figure 1.

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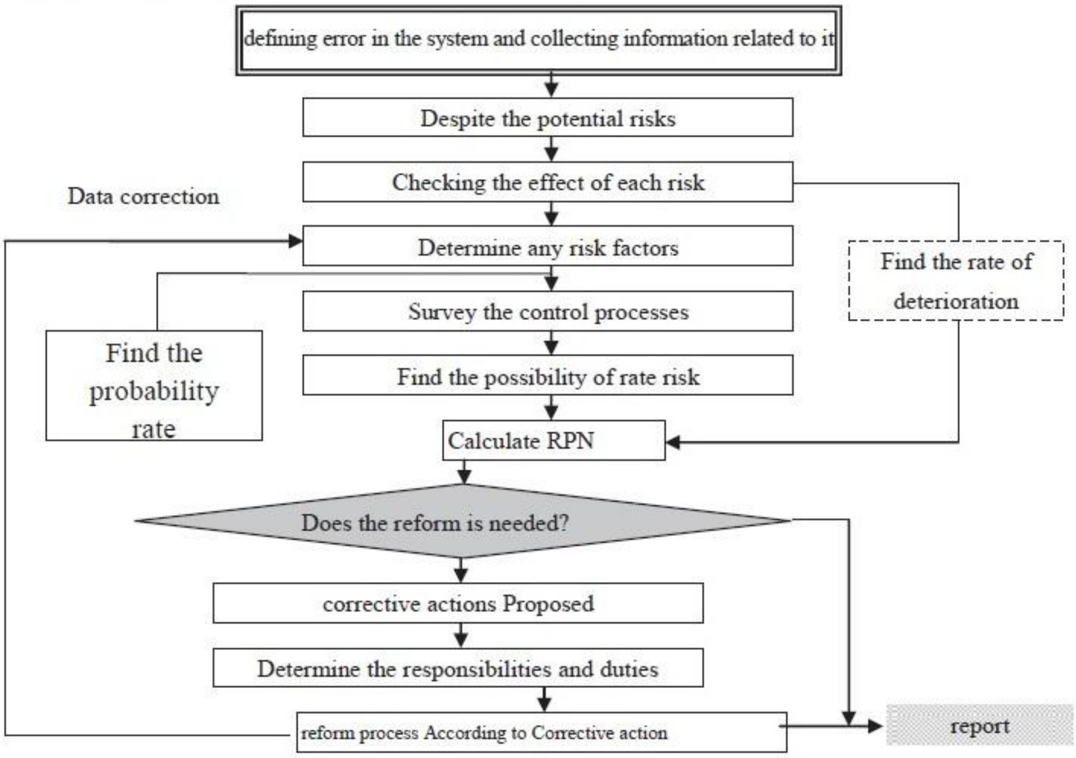

Figure 1. Cycle implementing FMEA techniques (Bahrami *et al*., 2012)

ANP method

ANP approach comprises four steps (Satty, 1996):

Step 1: Model construction and problem structuring: The problem should be stated clearly and decomposed into a rational system like a network

Step 2: Pairwise comparisons and priority vectors: In ANP, like AHP, pairs of decision elements at each cluster are compared with respect to their importance towards their control criteria. In addition, interdependencies among criteria of a cluster must also be examined pairwise; the influence of each element on other elements can be represented by an eigenvector. The relative importance values are determined with Saaty's scale.

Step 3: Supermatrix formation: The supermatrix concept is similar to the Markov chain process. To obtain global priorities in a system with interdependent influences, the local priority vectors are entered in the appropriate columns of a matrix. As a result, a supermatrix is actually a partitioned matrix, where each matrix segment represents a relationship between two clusters in a system.

Step 4: Synthesis of the criteria and alternatives' priorities and selection of the best alternatives: The priority weights of the criteria and alternatives can be found in the normalized supermatrix.

Fuzzy SAW method

The SAW method is probably the best known and widely used method for its multiple attribute decision making MADM. The basic concept of SAW method is to find a weighted sum of rating the performance of each alternative on all attributes. In this approach, using the weighted average, the importance of each item earns and the highest value chose as the best option (Askari and Shokrizade, 2014).To applies this model, the following steps are necessary:

1- Create a matrix of decision
2- Eliminate scale of decision matrix
3- multiply Matrix obtained in the weight indexes

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4- Choose the best option

FSAW method has been developed SAW method is used fuzzy numbers. FSAW method has three main steps.

STEP-1: Determine the fuzzy decision matrix X_{ij} for i[th] alternative for the j[th] criterion. It should be noted that $X_{ij} = (a_{ij}, b_{ij}, c_{ij})$ is Triangular fuzzy number.

$$\tilde{D} = \begin{bmatrix} X_{11} & \cdots & X_{1n} \\ \vdots & \ddots & \vdots \\ X_{m1} & \cdots & X_{mn} \end{bmatrix} \quad (1)$$

STEP-2: Now, based on the Equation 3 and 4, we normalized decision matrix, which is computed as Equation 3 for the benefit and Equation 4 for the cost criterion.

$$\tilde{R} = [\tilde{r}_{ij}]_{m \times n} \quad (2)$$

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \rightarrow c_j^* = \text{Max}_i\, c_{ij} \quad (3)$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right) \rightarrow a_j^- = \text{Min}_i\, a_{ij} \quad (4)$$

STEP-3: The analytical structure of the SAW method for M alternatives and N attributes (criteria) can be summarized as follows:

$$S_i = \sum_{j=1}^{n} W_j r_{ij} \quad , \quad i = 1,2,\ldots,m \quad (5)$$

Also in the decision matrix for values of S, O and D are used fuzzy numbers, that, these values are obtained of Table 1. In this study, we have used the opinions of three experts according Table 1, and to summarize the views of experts is used Equation 6 (Chen, 2000).

$$\tilde{x}_{ij} = \frac{1}{k}[(x_{ij}^1) + (x_{ij}^2) + \cdots + (x_{ij}^k)] \quad (6)$$

Finally for ranking, we should diffuzzy scores. If $\tilde{M} = (m_1, m_2, m_3)$ is a fuzzy number, to convert it to a number of diffuzzy is used Equation 7.

$$P(\widetilde{M}) = M = \frac{m_1 + 4m_2 + m_3}{6} \quad (7)$$

Also in the decision matrix for values of S, O and D are used of fuzzy numbers Table 1.

Table 1. Fuzzy values to evaluate options

Linguistic variable	Fuzzy number
Very low (VL)	(0, 0, 1)
low (L)	(1, 2, 3)
Middle Low(ML)	(2, 3, 4)
Middle (M)	(4, 5, 6)
Middle High (MH)	(5, 6, 7)
High (H)	(7, 8, 9)
Very High (VH)	(9, 10, 10)

Proposed model:

According to mentioned methods the proposed model are discussed below:

1- Obtain FMEA form by the experts
2- Use the degree of risk factors (S, O, D) by fuzzy numbers
3- Achieve the weight of risk factors (W_S, W_O, W_D) by the experts
4- Obtain the decision matrix based on Criterions (failure modes in risk assesment) and indexs (S, O, D)
5- Quantify of decision-making matrix
6- Scale up the decision matrix as linear
7- The scaled up matrix will be multiplied by the weight of risk factors
8- Choice the best option

RESULTS AND DISCUSSION

For finding the result of solving proposed model, an example was applied from automotive industry. In the form of FMEA have three main failure categories that are show in table 2.

After finding failure modes and the reasons of them, FMEA experts were evaluated the numbers of factors from (1 to 9) the linguistic scales and calculated their RPN, in table 2 is shown. The structure of network was considered by failure categories. The ANP model was solved by Super Decision Software with pair wise compares. So the weights of risk factors were given in Figure 2.

Table 2. Failure modes from the FMEA form

RPN	D	O	S	Symbol	Reasons for each failure modes	Failure mode process	Symbol
120	5	4	6	A	PH	greasy parts	**1**
120	5	4	6	B	Temperature		
120	5	4	6	C	Maintenance time		
150	5	5	6	D	Too much fat on the piece		
150	5	5	6	E	Total acid number	lack no of appropriate phosphate layers on the parts	**2**
150	5	5	6	F	Free acid number		
180	5	6	6	G	Accelerator		
90	5	3	6	H	Temperature		
90	5	3	6	I	Maintenance time		
90	5	3	6	J	PH		
75	5	3	5	K	Sediment		
80	4	4	5	L	Low temperature	uncompleted sealer on the parts	**3**
80	4	4	5	M	High speed		
60	4	3	5	N	High temperature		
60	4	3	5	O	Low speed		

Name	Graphic	Ideals	Normals	Raw
d		1.000000	0.415329	0.135257
o		0.766341	0.318284	0.103653
s		0.641386	0.266387	0.086752

Figure 2. The weights of risk factors by Super Decision Software

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The experts were appraised risk factors (S, O and D) in table 3 and normal weighted matrix by SAW method is shown 4 Table. In final step, table 5, failure modes was ranked and observed G is more important failure to recommend corrective action.

Table 3. Assessment of risk factors by experts

Symbol	S	O	D
A	ML, MH, MH	ML, M, M	**M, MH, M**
B	M, MH, M	ML, ML, M	**M, ML, MH**
C	M, MH, ML	L, MH, ML	**M, MH, MH**
D	M, M, H	M, M, MH	**MH, MH, MH**
E	M, MH, M	MH, MH, M	**MH, MH, ML**
F	M, H, MH	MH, MH, M	**MH, M, ML**
G	MH, MH, H	MH, MH, H	**M, M, M**
H	VH, H, H	L, L, ML	**ML, ML, H**
I	M, MH, H	VL, VL, L	**M, MH, M**
J	M, M, MH	L, VL, L	**M, M, L**
K	ML, ML, M	VL, ML, ML	**L, L, VL**
L	MH, MH, M	ML, ML, L	**ML, ML, M**
M	H, M, H	ML, M, M	**ML, ML, VL**
N	MH, MH, H	L, L, ML	**ML, MH, H**
O	ML, M, M	L, ML, ML	**VL, VL, L**

Table 4. The normal weighted decision matrix

Symbol	W_S=0.267	W_O=0.32	W_D=0.42
A	(0.097, 0.151, 0.204)	(0.079, 0.148, 0.216)	**(0.169, 0.261, 0.353)**
B	(0.097, 0.151, 0.204)	(0.057, 0.125, 0.193)	**(0.138, 0.231, 0.323)**
C	(0.080, 0.133, 0.186)	(0.068, 0.125, 0.193)	**(0.2, 0.292, 0.384)**
D	(0.115, 0.168, 0.212)	(0.125, 0.193, 0.261)	**(0.231, 0.323, 0.415)**
E	(0.097, 0.151, 0.204)	(0.148, 0.216, 0.284)	**(0.169, 0.261, 0.354)**
F	(0.133, 0.186, 0.23)	(0.148, 0.216, 0.284)	**(0.138, 0.231, 0.323)**
G	(0.151, 0.203, 0.248)	(0.193, 0.261, 0.318)	**(0.138, 0.231, 0.323)**
H	(0.204, 0.248, 0.266)	(0.011, 0.057, 0.125)	**(0.138, 0.231, 0.307)**
I	(0.133, 0.186, 0.23)	(0, 0.011, 0.057)	**(0.169, 0.261, 0.353)**
J	(0.097, 0.151, 0.204)	(0, 0.023, 0.079)	**(0.092, 0.169, 0.261)**
K	(0.044, 0.097, 0.151)	(0.023, 0.068, 0.125)	**(0, 0.031, 0.108)**
L	(0.115, 0.168, 0.221)	(0.057, 0.125, 0.193)	**(0.077, 0.169, 0.261)**
M	(0.15, 0.204, 0.248)	(0.079, 0.148, 0.216)	**(0.031, 0.092, 0.17)**
N	(0.15, 0.204, 0.248)	(0.011, 0.057, 0.125)	**(0.2, 0.292, 0.369)**
O	(0.621, 0.115, 0.168)	(0.023, 0.079, 0.148)	**(0, 0.31, 0.108)**

Table 5. Final ranking

Symbol	Numbers of SAW method	Numbers of difuzzy	Ranking
A	(0.336, 0.56, 0.773)	0.5597	**5**
B	(0.293, 0.506, 0.72)	0.5063	**9**
C	(0.348, 0.55, 0.764)	0.5519	**7**
D	(0.47, 0.684, 0.89)	0.6829	**2**
E	(0.414, 0.628, 0.841)	0.6279	**4**
F	(0.42, 0.633, 0.838)	0.6311	**3**
G	(0.482, 0.696, 0.89)	0.6924	**1**
H	(0.354, 0.536, 0.698)	0.5324	**8**
I	(0.302, 0.46, 0.641)	0.4631	**10**
J	(0.19, 0.342, 0.545)	0.3508	**13**
K	(0.067, 0.196, 0.383)	0.2060	**15**
L	(0.249, 0.462, 0.676)	0.4625	**11**
M	(0.261, 0.444, 0.624)	0.4435	**12**
N	(0.362, 0.553, 0.743)	0.5525	**6**
O	(0.085, 0.225, 0.424)	0.2351	**14**

The ranking of proposed model and traditional FMEA is shown in table 6.So proposed model separated modes of failures that were more important than modes were detected by traditional FMEA. This Model could solve the problems of traditional FMEA. The failure mode that is symbol with G (Accelerator) is more important in two methods. The traditional FMEA found D, E, F in second ranking after G, So the proposed model was shown D, F, E in next rankings for doing corrective actions.

Table 6. The result of solving traditional FMEA and proposed model

Symbol	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
traditional FMEA	3	3	3	2	2	2	1	4	4	4	6	5	5	7	**7**
proposed model	5	9	7	2	4	3	1	8	10	13	15	11	12	6	**14**

CONCLUSION

The failure mode and effect analysis (FMEA) may be a very helpful tool for identifying weak points in the design stage of a plant. This method is based on team work which requires familiarity and awareness. In addition, experts should be interested to work in groups and this is a limitation of the method. The same reason and the needed coordination along this course can exert limitations in the process of getting things happen. (Dory *et al*., 2010) were used ANP method as one of the multi-scale decision making approaches to solve FMEA problems. In this study, it has been tried to consider the relationships existing between the failure clusters (risk factors) by utilizing the ANP model. On the other hand, in the conclusions drawn based on the Liu and colleagues' study in 2013, two methods of artificial intelligence (the rule-oriented system, the fuzzy rule-oriented system) and the multi-criteria decision making method accounted of the studies in the years from 1992 to 2012. Kutlu *et al*., (2012) proposed fuzzy MCDM methods. In the current study, it has been tried to improve the conventional FMEA method inefficiencies through the application of the ANP and FSAW. The risk factors importance is not considered identical in the FMEA through the use of the ANP method and their mutual effects are taken into account. This study by using a combination of the ANP and FSAW in fuzzy environment, improve the sensitivity and resolution of risk priority number (RPN).For future research according to the results and the findings of the current study in relation to the failure modes analysis and the fuzzy analytical network, Dematel method or the clustering methods be recommended in the fuzzy environment.

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