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FUZZY MODES AND EFFECTS ANALYSIS BY USING FUZZY AHP

[1]Lotfi AZZABI,[2]Dorra AYADI
Lotfi_azzabi@yahoo.fr ,dorra_ayadi@yahoo.fr
LASQUO/ISTIA/Université d'Angers

***Abstract*:**Failure mode and effects analysis (FMEA) is a powerful tool for identifying and assessing potential failures. The tool has become increasingly important in new product development, manufacture or engineering applications. The FMEA team often demonstrates different opinions and knowledge from one team member to another and produces different types of assessment information such as complete and incomplete, precise and imprecise and known and unknown because of its cross-functional and multidisciplinary nature. These different types of information are very difficult to incorporate into the FMEA by the traditional risk priority number (RPN) model and fuzzy rule-based approximate reasoning methodologies. In this paper we present an FMEA using the fuzzy approach, a newly developed methodology for multiple attribute decision analysis. The proposed fuzzy FMEA is based to attribute the fuzzy analytical hierarchy process. As is illustrated by the numerical example in treatment gas industry.

***Keywords*:** Fuzzy FMEA, Fuzzy AHP.

1. INTRODUCTION

FMEA is a systematic process for identifying potential design or process failure before they occur. The aim is to eliminate them or minimize the risk associated with them. The method is a procedure to analyze failure modes and classified them by severity. It is a systematic process for identifying potential failures before they occur with the intent to eliminate them or minimize the risk associated with them. A group of experts make this quantification gathering information from memory and experience of the plant personal (Ravi Sankar & al,. 2001). The most known way to implement this analysis is in an ordinary tabular form which is difficult to trace. FMEA, providing a framework for cause and effect analysis of potential product failures (Chin, Chan, & Yang, 2008), has a purpose of prioritizing the risk priority number (RPN) of the product design or planning process to assign the limited resources to the most serious risk item.
FMEA, designed to provide information for risk management decision-making (Pillay & Wang, 2003), was first developed as a formal design methodology by NASA in 1963 for their obvious reliability requirements and then, it was adopted and promoted by Ford Motor in 1977 (Chin et al., 2008). Since then, it has become a powerful tool extensively used for safety and reliability analysis of products and processes in a wide range of industries especially, aerospace, nuclear and automotive industries (Gilchrist, 1993; Sharma, Kumar, & Kumar, 2005).

- A typical FMEA is consisted of the following components; the identification and listing of failure modes and the consequent faults, assessment of the chances of the occurrence of faults, then assessment of the chances of the detection of faults, assessment of the severity of the consequences of the faults, calculation of a measure of the risk, the ranking of the faults based on the risk, taking action on the high-risk problems, and checking the effectiveness of the action with the use of a revised risk measurement (Ben-Daya & Raouf, 1996). 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 (Can Kutlu et al., 2012). Then the RPN value for each failure mode is ranked to find out the failures with higher risks.

2. THE TRADITIONAL FMEA

In order to analyze a specific product or system, a cross-functional team should be established for carrying out FMEA. The members can be from the fields of design, manufacturing, management, service, etc. The first step in FMEA is to identify all possible potential failure modes of the product or system. After that, critical analysis is performed on these failure modes considering the following three risk factors: O, S and D. Generally, risk degree of a failure can be represented by a RPN that is defined as the product of the scores of O, S and D: RPN = O. S. D

FMEA has been proven to be one of the most important early preventative initiatives during the design stage of a system, product, process or service (Bowles 2004). However, the RPN has been extensively criticized for various reasons:

• Different sets of O, S and D ratings may produce exactly the same value of RPN, but their hidden risk implications may be totally different. For example, two different events with values of 2, 3, 2 and4, 1, 3 for O, S and D, respectively, will have the same RPN value of 12. However, the hidden risk implications of the two events may be very different because of the different severities of the failure consequence (Sankar & al., 2001). This may cause a waste of resources and time, or in some cases, a high-risk event being unnoticed.

• The relative importance among O, S and D is not taken into consideration. The three factors are assumed to have the same importance. This may not be the case when considering a practical application of FMEA.

•The mathematical formula for calculating RPN is questionable and debatable. There is no rationale as to why O, S and D should be multiplied to produce the RPN.

•The conversion of scores is different for the three factors. For example, a linear conversion is used for O, but a nonlinear transformation is employed for D.

•RPNs are not continuous with many holes and heavily distributed at thebottomofthescalefrom1to1000.Thiscauses problems in interpreting the meaning of the differences between different RPNs. For example, is the difference between the neighboring RPNs of 1and 2 thesameorlessthanthedifferencebetween900and 1000?

•The RPN considers only three factors mainly in terms of safety. Other important factors such as economic aspects are ignored.

•Small variations in one rating may lead to vastly different effects on the RPN, depending on the values of the other factors. For example, if O and D are both10, then a1-point difference in severity ratingresultsina100-pointdifferenceintheRPN;if O and D are equal to 1,then the same 1-point difference results in only a 1-point difference in the RPN ;if O and D are both4,thena1-point difference producesa16-pointdifferenceintheRPN.

•The three factors are difficult to precisely determine. Much information in FMEA can be expressed in a linguistic way such as likely, important or very high and soon (Ben-Daya & al., 1996).

Table.1 Traditional ratings for occurrence of a failure

Rating	Probability of occurrence	Possible failure rate
10	Very high: failure is almost inevitable	⩾1/2
9		1/3
8	High: repeated failures	1/8
7		1/20
6	Moderate: occasional failures	1/80
5		1/400
4		1/2000
3	Low: relatively few failures	1/15,000
2		1/150,000
1	Remote: failure is unlikely	⩽1/1, 500, 000

Table.2 Traditional ratings for severity of a failure

Rating	Effect	Severity of effect
10	Hazardous without warning	Very high severity ranking when a potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulations without warning
9	Hazardous with warning	Very high severity ranking when a potential failure mode affects safe vehicle operation and/or involves noncompliance with government regulations with warning
8	Very high	Vehicle/item inoperable, with loss of primary function
7	High	Vehicle/item operable, but at reduced level of performance. Customer dissatisfied
6	Moderate	Vehicle/item operable, but comfort/convenience item(s) inoperable. Customer experiences discomfort
5	Low	Vehicle/item operable, but comfort/convenience item(s) operable at reduced level of performance. Customer experiences some dissatisfaction
4	Very low	Cosmetic defect in finish, fit and finish/squeak or rattle item that does not conform to specifications. Defect noticed by most customers
3	Minor	Cosmetic defect in finish, fit and finish/squeak or rattle item that does not conform to specifications. Defect noticed by average customer
2	Very minor	Cosmetic defect in finish, fit and finish/squeak or rattle item that does not conform to specifications. Defect noticed by discriminating customers
1	None	No effect

Table.3 Traditional ratings for detection

Rating	Detection	Criteria
10	Absolutely impossible	Design control will not and/or cannot detect a potential cause/mechanism and subsequent failure mode; or there is no design control
9	Very remote	Very remote chance the design control will detect a potential cause/mechanism and subsequent failure mode
8	Remote	Remote chance the design control will detect a potential cause/mechanism and subsequent failure mode
7	Very low	Very low chance the design control will detect a potential cause/mechanism and subsequent failure mode
6	Low	Low chance the design control will detect a potential cause/mechanism and subsequent failure mode
5	Moderate	Moderate chance the design control will detect a potential cause/mechanism and subsequent failure mode
4	Moderately high	Moderately high chance the design control will detect a potential cause/mechanism and subsequent failure mode
3	High	High chance the design control will detect a potential cause/mechanism and subsequent failure mode
2	Very high	Very high chance the design control will detect a potential cause/mechanism and subsequent failure mode
1	Almost certain	Design control will almost certainly detect a potential cause/mechanism and subsequent failure mode

In traditional FMEA approach, the diversity and ability of the team are the most important considerations, followed by training for the team members. This leads to a high cost.

Furthermore, industrial practitioners usually find it hard to share their experience among team members of different background. This indeed prohibits the application of FMEA in a broader scope (Pillay & al., 2003). Many decision-making and problem-solving tasks are too complex to be understood quantitatively; however, people succeed by using knowledge that is imprecise rather than precise.

3. THE FUZZY FMEA

The studies about FMEA considering fuzzy approach use the experts who describe the risk factors O, S, and D by using the fuzzy linguistic terms. The linguistic variables were used for evaluating three risk factors O, S, and D as an interpretation of the traditional 10-point scale (1–10) FMEA factor scores. In the fuzzy FMEA literature, the studies have mostly concerned with the fuzzy rule- base approach by using if-then rules (Bowles & Pelaez, 1995; Chin et al., 2008; Guimaraes & Lapa, 2004, 2007; Pillay & Wang, 2003; Sharma et al., 2005; Tay & Lim, 2006). After the assignments of the linguistic terms to the factors, if-then rules were generated taking the linguistic variables as inputs to evaluate the risks. The outputs of the fuzzy inference system were variously named as risk, the critically failure mode (Xu et al., 2002), priority for attention (Pillay & Wang, 2003), and fuzzy RPN (Sharma et al., 2005; Xu et al., 2002) in the fuzzy FMEA studies which consider the fuzzy rule-base approach. (Braglia & Bevilacqua 2000) drew attention to the doubts remained due to the difficulties in defining many rules and membership functions required by this methodology considering the applicability of the real industrial cases.

A conventional form of FMEA includes the design function of parts, the potential failure mode (categories of failure), the potential effects of failure (measured by the severity index), the potential causes of failure (measured by the occurrence (frequency) index), the detection method (measured by the detectability index), and the risk priority number (RPN). The RPN is used to evaluate the risk level of a part's failure mode in design stage, and is determined by the multiplication of three characteristic failure mode indexes, the severity of the potential failure (S), the frequency of potential failure (O), and the detectability index (D), respectively, as RPN = S .O .D. (Liang-hsuan & al., 2009)

Severity, Occurrence, and Detect, as in the traditional RPN function, are also used as the input factors for the fuzzy RPN function. The membership functions of these three factors are determined by interpreting the linguistic terms. Tables 4, 5, and 6:

Table.5 Scales for occurrence

Frequency of occurrence	Rating	Possible failure rate
Remote	1	<1:20,000
Low	2	1:20,000
	3	1:10,000
Moderate	4	1:2000
	5	1:1000
	6	1:200
High	7	1:100
	8	1:20
Very high	9	1:10
	10	1:2

Table.6 Scales for severity

Severity	Rating
Remote	1
Low	2
	3
Moderate	4
	5
	6
High	7
	8
Very high	9
	10

Table.7 Scales for detection

Detectability	Rating	Probability of detectability (%)
Remote	1	86–100
Low	2	76–85
	3	66–75
Moderate	4	56–65
	5	46–55
	6	36–45
High	7	26–35
	8	16–25
Very high	9	6–15
	10	0–5

4. THE FUZZY AHP

Analytic Hierarchy Process (AHP) is a powerful method to solve complex decision problems. Any complex problem can be decomposed into several sub-problems using AHP in terms of hierarchical levels where each level represents a set of criteria or attributes relative to each sub-problem. The AHP method is a multi-criteria method of analysis based on an additive weighting process, in which several relevant attributes are represented through their relative importance. Through AHP, the importance of several attributes is obtained from a process of paired comparison, in which the relevance of the attributes or categories of drivers of intangible assets are matched two-on-two in a hierarchic structure. However, the pure AHP model has some shortcomings (Yang & al., 2004). They pointed out that the AHP method is mainly used in nearly crisp-information decision applications; the AHP method creates and deals with a very unbalanced scale of judgment; the AHP method does not take into account the uncertainty associated with the mapping of human judgment to a number by natural language; the ranking of the AHP method is rather imprecise; and the subjective judgment by perception, evaluation, improvement and selection based on preference of decision-makers have great influence on the AHP results (Ahmad & al., 2001). To overcome these problems, several researchers integrate fuzzy theory with AHP to improve the uncertainty. Hence, Buckley (Buckley 1985) used the evolutionary algorithm to calculate the weights with the trapezoidal fuzzy numbers.
The fuzzy AHP based on the fuzzy interval arithmetic with triangular fuzzy numbers and confidence index with interval mean approach to determine the weights for evaluative elements (Azamathulla & al., 2011).

4.2. Determining the evaluation dimensions weights
This research employs Fuzzy AHP to fuzzify hierarchical analysis by allowing fuzzy numbers for the pair-wise comparisons and find the fuzzy preference-weights. In this section, we briefly review concepts for fuzzy hierarchical evaluation. Then the following sections will introduce the computational process about Fuzzy AHP in detail.
Then we will briefly introduce that how to carry out the fuzzy AHP in the following sections.
Step 1: Construct pair-wise comparison matrices among all the elements/criteria in the dimensions of the hierarchy system.
Assign linguistic terms to the pair-wise comparisons by asking which is the more important of each two dimensions, as following matrix Ã

$$\tilde{A}=\begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} = \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ 1/\tilde{a}_{12} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{a}_{1n} & 1/\tilde{a}_{2n} & \cdots & 1 \end{bmatrix}$$

Where;

$$\tilde{a}_{ij}=\begin{cases} \tilde{9}^{-1},\tilde{8}^{-1},\tilde{7}^{-1},\tilde{6}^{-1},\tilde{5}^{-1},\tilde{4}^{-1},\tilde{3}^{-1},\tilde{2}^{-1},\tilde{1}^{-1},\tilde{1},\tilde{2},\tilde{3},\tilde{4},\tilde{5},\tilde{6},\tilde{7},\tilde{8},\tilde{9}, & i\neq j \\ 1, & i=j \end{cases}$$

Step 2: To use geometric mean technique to define the fuzzy geometric mean and fuzzy weights of each criterion by (Hsieh & al., 2004).

$$\tilde{r}_i=(\tilde{a}_{i1}\otimes\cdots\otimes\tilde{a}_{ij}\otimes\cdots\otimes\tilde{a}_{in})^{1/n}$$
$$\tilde{w}_i=\tilde{r}_i\otimes[\tilde{r}_1\oplus\cdots\oplus\tilde{r}_i\oplus\cdots\oplus\tilde{r}_n]^{-1}$$

where

is fuzzy comparison value of dimension i to criterion j, thus, is a geometric mean of fuzzy comparison value of criterion i to each criterion, w˜ i is the fuzzy weight of the ith criterion, can be indicated by a TFN,w˜ i = (lwi, mwi, uwi).

The lwi, mwi and uwi stand for the lower, middle and upper values of the fuzzy weight of the ith dimension.

The fuzzy analytic hierarchy process (FAHP) approach was considered by Hua, Hsu, Kuo, and Wua (2009) for evaluating the relative weightings of the risk factors of FMEA to analyze of the risks of green components in compliance with the European Union (EU) the Restriction of Hazardous Substance (RoHS) directive in the incoming quality control (IQC) stage. In the study, Severity factor was explained by two criteria and with considering the occurrence and the detection factors, the FAHP was utilized to determine the weights of four criteria by two experts. The traditional FMEA was modified to form green component risk priority number (GCRPN) for the calculation of the risks with regard to each category of green components. GC-RPN was formulated by the sum of the terms of products of the factor scores and weights. Braglia et al. (2003) proposed a fuzzy TOPSIS approach for Failure Mode, Effects and Criticality Analysis (FMECA). The fuzzy version of TOPSIS was applied allowing the traditional FMECA factors O, S, and D and their equally important weights to be evaluated
using triangular fuzzy numbers.

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