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Fuzzy failure modes and effects analysis by using fuzzy TOPSIS-based fuzzy AHP

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ABSTRACT

Failure mode and effects analysis (FMEA) is a widely used engineering technique for designing, identifying and eliminating known and/or potential failures, problems, errors and so on from system, design, process, and/or service before they reach the customer (Stamatis, 1995). In a typical FMEA, for each failure modes, three risk factors; severity (*S*), occurrence (*O*), and detectability (*D*) are evaluated and a risk priority number (RPN) is obtained by multiplying these factors. There are significant efforts which have been made in FMEA literature to overcome the shortcomings of the crisp RPN calculation. In this study a fuzzy approach, allowing experts to use linguistic variables for determining *S*, *O*, and *D*, is considered for FMEA by applying fuzzy 'technique for order preference by similarity to ideal solution' (TOPSIS) integrated with fuzzy 'analytical hierarchy process' (AHP). The hypothetical case study demonstrated the applicability of the model in FMEA under fuzzy environment.

1. Introduction

Failure mode and effects analysis (FMEA) is a widely used engineering technique for designing, identifying and eliminating known and/or potential failures, problems, errors and so on from system, design, process, and/or service before they reach the customer (Stamatis, 1995). 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 (Chang, Wei, & Lee, 1999).

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 = $S \times O \times D$ (Chin et al., 2008). Then the RPN value for each failure mode is ranked to find out the failures with higher risks.

The crisp values of RPNs have been considerably criticized for a many reasons most of which are stated below (Ben-Daya & Raouf, 1996; Bowles, 2004; Braglia & Bevilacqua, 2000; Braglia, Frosolini, & Montanari, 2003; Chang, Liu, & Wei, 2001; Gilchrist, 1993; Pillay & Wang, 2003; Sankar & Prabhu, 2001; Wang, Chin, Poon, & Yang, 2009):

- The relative importance among the three risk factors occurrence, severity, and detection is not considered as they are accepted equally important.
- Different combinations of *O*, *S* and *D* may produce exactly the same value of RPN, although their hidden risk implications may be totally different. For instance, two different failures with the *O*, *S* and *D* values of 4, 3, 3 and 9, 1, 3, respectively, have the same RPN value of 36.
- It is mostly difficult for *O*, *S* and *D* to be precisely evaluated. However linguistic terms can be adopted to convey much information in FMEA.

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- The use of multiplication method in the calculation of RPN is questionable and strongly sensitive to variations in criticality factor evaluations.

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 & Lim, 2006).

Xu, Tang, Xie, Ho, and Zhu (2002) state the reasons for considering the fuzzy logic approach as following:

- All FMEA-related information is taken in natural language which is easy and plausible for fuzzy logic to deal with as it is based on human language and can be built on top of the experience of experts.
- Fuzzy logic allows imprecise data usage so it enables the treatment of many states.

Furthermore, fuzzy FMEA allows both quantitative data and vague and qualitative information to be used and managed in a consistent manner and makes it possible for the combination of severity, occurrence and detectability in a more flexible structure (Bowles & Pelaez, 1995; Braglia et al., 2003).

In this study firstly, a fuzzy approach, allowing experts to use linguistic variables for determining *S*, *O*, and *D*, is considered for FMEA by applying fuzzy TOPSIS integrated with fuzzy AHP. First Chang's (1996) fuzzy AHP is utilized to determine the weight vector of three risk factors; severity, occurrence and detectability. Then by using the linguistic scores of risk factors for each failure modes, and the weight vector of risk factors, Chen's (2000) fuzzy TOPSIS is utilized. According to the results most important failure modes are obtained. This model allowing the use of different importance weights for the risk factors (*S*, *O*, *D*) in fuzzy TOPSIS for scoring and ranking of the potential failure modes, can be taken as a contribution in the fuzzy FMEA literature.

The rest of the paper is organized as follows: In Section 2, Literature Reviews of fuzzy FMEA, fuzzy AHP and fuzzy TOPSIS are expressed. In Section 3, a fuzzy multi-criteria method, an integration of fuzzy AHP and fuzzy TOPSIS, is proposed for fuzzy FMEA. In Section 4, the proposed methodology is applied to an assembly process with 8 potential failure modes at a manufacturing facility. A sensitivity analysis is also realized. Finally, conclusions are given.

2. Literature review

2.1. Fuzzy FMEA

There are significant efforts have been made in FMEA literature to overcome the shortcomings of the traditional RPN (Wang et al., 2009). 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; Guimarães & Lapa, 2004, 2007; Pillay & Wang, 2003; Sharma et al., 2005; Tay & Lim, 2006; Xu et al., 2002). 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* (Chin et al., 2008; Guimarães & Lapa, 2004), 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 and 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. They proposed the use of AHP for obtaining the rules for a particular fuzzy criticality assessment model to overcome this problem. Besides, AHP is employed in another study to cope with multiple criteria situations involving intuitive, rational, qualitative and quantitative aspects for the evaluation of the final ranking for every failure cause and this new approach is called multi-attribute failure mode analysis (MAFMA) (Braglia, 2000).

Braglia and Bevilacqua (2000) criticize that the failure modes characterized by the fuzzy if–then rules could not be prioritized or ranked and there is no way to incorporate the relative importance of risk factors into the fuzzy inference system by using fuzzy if–then rules. Therefore they develop a new fuzzy logic approach where fuzzy risk priority numbers (FRPNs) are defined as fuzzy weighted geometric means of the fuzzy ratings for *O*, *S* and *D* and can be computed using alpha-level sets and linear programming models.

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 (GC-RPN) 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.

2.2. Fuzzy AHP

AHP is one of the well-known multi-criteria decision making techniques that was first proposed by Saaty (1980). The classical AHP takes into consideration the definite judgments of decision makers (Wang & Chen, 2007). Although the classical AHP includes the opinions of experts and makes a multiple criteria evaluation, it is not capable of reflecting human's vague thoughts (Seçme, Bayrakdaroğlu, & Kahraman, 2009).

As the uncertainty of information and the vagueness of human feeling and recognition, it is difficult to provide exact numerical values for the criteria and to make evaluations which exactly convey the feeling and recognition of objects for decision makers. Therefore, most of the selection parameters cannot be given precisely. Thus experts may prefer intermediate judgments rather than certain judgments. So the fuzzy set theory makes the comparison process more flexible and capable to explain experts' preferences (Kahraman, Cebeci, & Ulukan, 2003).

Different methods for the fuzzification of AHP have been proposed in the literature. AHP is firstly fuzzified by Laarhoven and Pedrycz (1983) and in this study, fuzzy ratios which were defined by triangular membership functions were compared. Buckley (1985) used the comparison ratios based on trapezoidal membership functions. Chang (1996) introduces a new approach for handling fuzzy AHP, with the use of triangular fuzzy numbers for pair-wise comparison scale of fuzzy AHP, and the use of the extent analysis method for the synthetic extent values of the pair-wise