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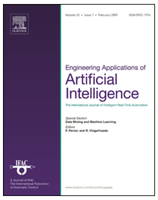

Evaluating the risk of failure modes with extended MULTIMOORA method under fuzzy environment

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ABSTRACT

Failure mode and effects analysis (FMEA) is a prospective risk assessment tool which has been widely used within various industries, particularly the aerospace, automotive and healthcare industries. However, the conventional risk priority number (RPN) method has been criticized much for its deficiencies in risk factor weights, computation of RPN, evaluation of failure modes and so on. Therefore ranking of failure modes based on their related risk factors is necessary seeking to overcome the shortcomings and enhance the assessment capability of the traditional FMEA. In this paper, we treat the risk factors and their weights as fuzzy variables and evaluate them using fuzzy linguistic terms. As a result, a new risk priority model is proposed for evaluating the risk of failure modes based on fuzzy set theory and MULTIMOORA method. An empirical case of preventing infant abduction is provided to illustrate the potential applications and benefits of the proposed fuzzy FMEA. The main findings of this article are related with the proposed technique for failure modes assessment and ranking, and application of this technique for the prevention of infant abduction, which is a devastating problem for a healthcare facility.

1. Introduction

Failure mode and effects analysis (FMEA) was first developed as a formal design methodology in the 1960s by the aerospace industry with their obvious reliability and safety requirements (Bowles and Peláez, 1995). It has been proven to be a useful and powerful tool in defining, identifying, and eliminating known and/or potential failures or problems in products, process, designs, and/or services before they reach the customer (Stamatis, 2003). When it is used for a criticality analysis, it is also referred to as failure mode, effects and criticality analysis (FMECA). FMEA can be employed to improve the reliability of a system by identifying the critical potential failure modes and taking the necessary preventive (or corrective) actions in the redesign stage of the system. Being an important method of preventive quality assurance, FMEA is a team-based and proactive technique. The purpose of FMEA is to estimate the risk of potential failures and prioritize the failures that require the most attention in order to assign the limited resources to the most serious risk items. Nowadays, FMEA has been extensively used to help ensure the safety and reliability of products and processes in a number of industries, including the aerospace, automotive, nuclear, mechanical and healthcare industries (Chang et al., 2012; Kutlu and Ekmekçioğlu, 2012; Liu et al., in press; Song et al., in press; Vinodh et al., 2012).

In order to take priority action for safety improvement, the risk ranking of traditional FMEA is conducted by risk priority number (RPN) which is a mathematic product of the occurrence (O), severity (S) and detection (D) of a failure mode. In mathematical form

$$\mathrm{RPN} = O \times S \times D, \tag{1}$$

where O is the frequency of the failure, S is the seriousness of the effect of the failure, and D is the probability of the failure being detected before the impact of the effect is realized. The higher the RPN of a failure mode, the more urgently corrective action is needed, because of the higher risk that the failure will be. Although FMEA is an effective risk analysis tool, it is by no means perfect. The crisp RPN method has been extensively criticized in the literature for various reasons (Chin et al., 2009b; Gargama and Chaturvedi, 2011; Kutlu and Ekmekçioğlu, 2012; Liu et al., 2013b; Pillay and Wang, 2003; Seyed-Hosseini et al., 2006; Wang et al., 2009; Zhang and Chu, 2011), and the most important ones are as follows: (1) the relative importance among the three risk factors is not taken into consideration, which may not be true in a practical scenario; (2) different combinations of risk factors may produce

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exactly the same value of RPN, but their hidden risk implications may be totally different; (3) the three risk factors are difficult to be precisely estimated due to their subjective quantification on 1–10 scales; and (4) the mathematical formula for calculating RPN is debatable and lacks a complete scientific basis.

To overcome the shortcomings of traditional FMEA, a number of alternative approaches have been developed in the literature, such as technique for ordering preference by similarity to ideal solution (TOPSIS) (Song et al., in press), grey relational analysis (GRA) (Liu et al., 2011), data envelopment analysis (DEA) (Chin et al., 2009a), decision making trial and evaluation laboratory (DEMATEL) (Seyed-Hosseini et al., 2006), VIsekriterijumska optimizacija i KOmpromisno Resenje (VIKOR) (Liu et al., 2012) and evidential reasoning approach (Chin et al., 2009b). The fuzzy set theory was proposed by Zadeh (1965) as a modeling tool for complex systems that are hard to define exactly in crisp numbers. It allows coping with vague, imprecise and ambiguous input and knowledge. Thus, fuzzy set theory has been incorporated to deal with the uncertainty associated with the risk analysis problems by many researchers. For example, Zhang and Chu (2011) developed a fuzzy-RPNs-based method by integrating weighted least square method, the method of imprecision and partial ranking method to generate more accurate fuzzy RPNs and ensure to be robust against the uncertainty. Mandal and Maiti (2014) proposed the use of similarity value of fuzzy numbers and subsequent application of possibility theory approach for risk analysis using FMEA. Kutlu and Ekmekçioğlu (2012) considered a fuzzy approach for FMEA by applying fuzzy TOPSIS integrated with fuzzy AHP and Song et al. (2014) proposed a failure evaluation structure based on fuzzy TOPSIS approach and comprehensive weighting method to improve the conventional FMEA. In (Liu et al., 2013a), the authors suggested a risk priority model for prioritization of failure modes on the basis of fuzzy evidential reasoning (FER) and belief rule-based (BRB) methodology. Bowles and Peláez (1995) first used fuzzy rule base system for prioritizing failures in FMEA, which uses a fuzzy if-then rule base developed from expert knowledge and expertise to describe the relationships between the risk factors and riskiness. Similar fuzzy inference methods also appeared in (Jong et al., 2013; Kahraman et al., 2013; Pillay and Wang, 2003; Sharma et al., 2005; Vinodh et al., 2012). Instead of using fuzzy if-then rules, Wang et al. (2009) treated the risk factors *O*, *S* and *D* as fuzzy variables and proposed the use of fuzzy weighted geometric mean (FWGM) for risk evaluation and prioritization of failure modes in FMEA. In addition, a comprehensive review of the risk evaluation approaches in FMEA can be found in (Liu et al., 2013b).

In other way, FMEA is typically a group multi-criteria decision making (MCDM) problem involving several risk factors on which decision maker′s knowledge is usually vague and imprecise. Therefore, MCDM methods are those suitable for providing rationale for FMEA (Franceschini and Galetto, 2001; Liu et al., 2013b). The MULTIMOORA method (Brauers and Zavadskas, 2010), a recently introduced new MCDM method based on the multi-objective optimization by ratio analysis (MOORA) (Brauers and Zavadskas, 2006), may provide the basis for developing FMEA models that can effectively deal with characteristics of this problem. Due to its characteristics and capabilities, the use of MULTIMOORA method has been increasing in the literature. For instance, Brauers et al. (2013) employed the MULTIMOORA to analyze the construction sector of the European countries from a macroeconomic point of view by comparing construction market variations appeared during the recession. Streimikiene and Balezentis (2013) proposed a MCDM methodology using the MULTIMOORA for climate change mitigation strategies assessment and applied it for ranking of climate change mitigation policies in Lithuania. Streimikiene et al. (2012) developed a multi-criteria decision support framework based on the MULTIMOORA and TOPSIS methods for choosing the most sustainable electricity production technologies. Brauers et al. (2012) used the MULTIMOORA to estimate the economic worth of the European Union (EU) member states towards 2020 and Karande and Chakraborty (2012) applied the ratio system, the reference point approach and the full multiplicative form of MOORA method to solve some of the common material selection problems. On the other hand, some researchers have updated the MULTIMOORA method with uncertainty treatment theories. For example, Brauers et al. (2011) modified the MULTIMOORA with triangular fuzzy number theory and used the theory of dominance to rank the EU member states according to their performance in reaching the indicator goals. Baležentis et al. (2012) extended the fuzzy MULTIMOORA for linguistic reasoning under group decision making and applied the fuzzy MULTIMOORA for group decision making (MULTIMOORA-FG) to solve a personnel selection problem. Additionally, Baležentis and Zeng (2013) extended the MULTIMOORA method with generalized interval-valued trapezoidal fuzzy numbers for multi-criteria decision making related to uncertain assessments. Kracka and Zavadskas (2013) proposed a technique for an effective selection of building refurbishment elements by applying MULTIMOORA method with interval fuzzy data. Balezentiene et al. (2013) offered a multi-criteria framework for ranking of sustainable energy crops based on fuzzy MULTIMOORA method which enables to deal with imprecise information.

With the background introduced above, this paper is aimed at applying the fuzzy set theory and MULTIMOORA method for determination of risk priority of the failure modes in FMEA. The risk factors and their relative weights are treated as fuzzy variables and evaluated by using fuzzy linguistic terms and fuzzy ratings. The extended MULTIMOORA method is used to determine the risk priority order of the failure modes that have been identified. Consequently, a new risk priority model based on fuzzy MULTIMOORA method is proposed for failure modes assessment and ranking, specifically intended to solve the problems and improve the effectiveness of the traditional FMEA. Moreover, a case study of preventing infant abduction is presented seeking to illustrate the potential applications and benefits of the proposed fuzzy FMEA.

The rest of the paper is structured in the following way. Section 2 introduces the fuzzy set theory and the MULTIMOORA method, whereas Section 3 describes the proposed model for risk evaluation under fuzzy environment. The following section explains the application of the new risk priority model for prevention of infant abductions and its results. Finally, some conclusions are drawn in Section 5.

2. Fuzzy set theory and the MULTIMOORA method

2.1. Fuzzy set theory

Definition 2.1. A fuzzy set $\tilde{A}$ in a universe of discourse X is characterized by a membership function $\mu_{\tilde{A}}(x)$, which maps each element $x \in X$ to a real number in the interval [0,1]. The function value $\mu_{\tilde{A}}(x)$ is termed the grade of membership of x in $\tilde{A}$ (Zadeh, 1965, 1975).

Definition 2.2. A fuzzy number is a fuzzy subset in the universe of discourse X that is both convex and normal (Chen, 2000). A fuzzy set $\tilde{A}$ of the universe of discourse X is convex if and only if for all x_1, x_2 in $X, \mu_{\tilde{A}}(\lambda x_1 + (1-\lambda)x_2) \geq \min(\mu_{\tilde{A}}(x_1), \mu_{\tilde{A}}(x_2))$, where $\lambda \in [0,1]$. A fuzzy set $\tilde{A}$ of the universe of discourse X is called a normal fuzzy set implying that $\exists x_i \in X, \mu_{\tilde{A}}(x_i) = 1$.

Triangular and trapezoidal fuzzy numbers are the most common used fuzzy numbers both in theory and practice. In fact, a