Expert Systems with Applications 42 (2015) 6342–6349

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

FlowSort-GDSS – A novel group multi-criteria decision support system for sorting problems with application to FMEA

Francesco Lolli [a], Alessio Ishizaka [b,*], Rita Gamberini [a], Bianca Rimini [a], Michael Messori [a]

[a] Department of Sciences and Methods for Engineering, University of Modena and Reggio Emilia, Via Amendola 2 – Padiglione Morselli, 42100 Reggio Emilia, Italy
[b] Centre of Operations Research and Logistics, Portsmouth Business School, University of Portsmouth, Portland Street – Richmond Building, Portsmouth PO1 3DE, UK

ARTICLE INFO

Article history:
Available online 23 April 2015

Keywords:
FMEA
Criticality assessment
Flow-Sort-GDSS
MCDM
PROMETHEE

ABSTRACT

Failure mode and effects analysis (FMEA) is a well-known approach for correlating the failure modes of a system to their effects, with the objective of assessing their criticality. The criticality of a failure mode is traditionally established by its risk priority number (RPN), which is the product of the scores assigned to the three risk factors, which are likeness of occurrence, the chance of being undetected and the severity of the effects. Taking a simple "unweighted" product has major shortcomings. One of them is to provide just a number, which does not sort failures modes into priority classes. Moreover, to make the decision more robust, the FMEA is better tackled by multiple decision-makers. Unfortunately, the literature lacks group decision support systems (GDSS) for sorting failures in the field of the FMEA.

In this paper, a novel multi-criteria decision making (MCDM) method named FlowSort-GDSS is proposed to sort the failure modes into priority classes by involving multiple decision-makers. The essence of this method lies in the pair-wise comparison between the failure modes and the reference profiles established by the decision-makers on the risk factors. Finally a case study is presented to illustrate the advantages of this new robust method in sorting failures.

1. Introduction

The reduction of the non-quality costs is a main concern in all production and service systems because it increases the customer fidelity and reduces the after-sales costs. The FMEA is a long established quality improvement technique that dates back to 1940s. The first step in FMEA is to identify potential or known failure modes of a given system. These modes are then evaluated for their causes and effects, and the final purpose of FMEA is to correct the most critical failure modes. Traditionally, the criticality assessment of the failure modes in FMEA is carried out by calculating their risk priority numbers (or RPNs), which are given by the product of the likeness of occurrence (O), the severity of the effects (S), and the chance of being undetected (D), each one measured on a 1–10 scale, as follows:

$$RPN = O \times S \times D \quad (1)$$

Based on their RPN ranking, it is decided whether an improvement action needs to be implemented in order to reduce the RPN. The issue is to find the threshold that triggers this improvement action. This problem is therefore better solved with a sorting technique, where failures are sorted into predefined priority classes.

To the best of our knowledge, the most recent review on FMEA has been conducted by Liu, Liu, and Liu (2013) who have summarised a number of major shortcomings in the traditional FMEA approach. They have reviewed a number of academic journal articles published between 1992 and 2012 that aimed at overcoming these shortcomings. It is worth to remark that more than a half of the reviewed paper aim to overcome the following shortcomings:

(a) The relative importance of O, S and D is not taken into account.
(b) Different sets of the three risk factors can give the same RPN without considering their very different implications.
(c) The three risk factors are difficult to be precisely evaluated.

These shortcomings have been solved with multi-criteria decision making methods (see Section 2). However, these methods provide only a rank for the failure but do not sort them into priority classes. Having an ordered class of importance of failures allows the managers to focus in priority on all the elements of this class and then to tackle the elements of the next class. This gives a clear indication on which failures to correct first.

* Corresponding author. Tel.: +44 (0)23 9284 4171.
E-mail addresses: francesco.lolli@unimore.it (F. Lolli), Alessio.Ishizaka@port.ac.uk (A. Ishizaka), rita.gamberini@unimore.it (R. Gamberini), bianca.rimini@unimore.it (B. Rimini), 84942@studenti.unimore.it (M. Messori).

http://dx.doi.org/10.1016/j.eswa.2015.04.028
0957-4174/

Moreover, several experts are generally involved in the FMEA. For example, engineers, process managers, product managers, quality inspectors and inline operators are called to design and monitor the quality of products and processes. As a consequence, the sorting method introduces ad hoc approach for the FMEA and accommodates multiple decision-makers.

This paper proposes a group decision support system, named FlowSort-GDSS, for sorting the failure modes into priority classes. This method belongs to the PROMETHEE family methods and therefore inherits their properties. Particularly to this method is that the decision-makers are asked to provide the reference profiles on the risk factors to define the priority classes according to their experiences and skills. The essence of this method lies in the pair-wise comparison between the failure modes and the reference profiles, either limiting or central profiles, which provides their global net flow, so named according with the PROMETHEE notation. The structure of this paper is as follows: Section 2 reviews the developments of the FMEA. Section 3 proposes the new method termed FlowSort-GDSS. Section 4 describes the application of FlowSort-GDSS for the FMEA in a large company operating in the blow moulding field. Finally, Section 5 concludes the paper with some future research suggestions.

2. Literature review

The FMEA approaches introduced in the last decades can be divided into three categories according to their failure mode prioritization methods: MCDM, mathematical programming, and integrated approaches.

With regard to MCDM methods, Braglia (2000) introduced the multi attribute failure mode analysis (MAFMA), which uses the analytic hierarchy process (AHP) to calculate weights for the risk factors. The same technique was also used later in Carmignani (2009). Zammori and Gabbrielli (2012) further decomposed the occurrence, severity and detectability into subcriteria and used analytic network process (ANP) to evaluate their weights. In addition to the multiplication reported in Eq. (1), other aggregation techniques have also been proposed, e.g. decision making trial and evaluation laboratory – DEMATEL (Seyed-Hosseini, Safaei, & Asgharpour, 2006), grey theory (Chang, Liu, & Wei, 2001) and evidence theory (Chin, Wang, Poon, & Yang, 2009a, 2009b). Liu et al. (2013) reported a trend to incorporate MCDM methods with fuzzy logic in order to overcome the shortcoming (c) mentioned in Section 1. For a recent review on fuzzy MCDM techniques, reader may refer to Mardani, Jusoh, and Zavadskas (2015). Some researchers have in fact merged multi-criteria techniques and fuzzy logic to accommodate the imprecision of the evaluations: fuzzy technique for order preference by similarity to ideal solution (TOPSIS) (Braglia, Frosolini, & Montanari, 2003; Hadi-Vencheh & Aghajani, 2013; Liu et al., 2011; Liu, Liu, Liu, & Mao, 2012; Vahdani, Salimi, & Charkhchian, 2015); VIKOR (VIsekriterijumska optimizacija i KOmpromisno Resenje) with fuzzy logic (Liu et al., 2012); fuzzy AHP (Hu, Hsu, Kuo, & Wu, 2009; Kutlu & Ekmekçioğlu, 2012); fuzzy logic with grey theory (Chang, Wei, & Lee, 1999); or simply applied fuzzy logic on the risk factors (Petrović et al., 2014). Mandal and Maiti (2014) adopted the similarity measure of fuzzy numbers in order to overcome the drawback of standard de-fuzzification approaches. However, these approaches neither support a group decision nor solve a sorting problem. A group-decision FMEA approach was proposed by Liu, You, Fan, and Lin (2014) where grey relational projection and D numbers representing the uncertain information are merged in order to rank the failure modes. Examples of D numbers applications can be read in Deng, Hu, Deng, and Mahadevan (2014a, 2014b). This approach allows to handle various type of uncertainties and judgmental divergences during the assessment of the failure modes with respect to the risk factors, but, as the other contributions cited before, it does not sort failures by priority classes.

For the mathematical programming methods, Garcia, Schirru, and Frutoso e Melo (2005) used data envelopment analysis (DEA) to optimise the weights in order to measure the maximum risks of each failure mode. Chin et al. (2009a, 2009b) also used DEA to calculate the weights giving the maximum and the minimum RPN for each failure mode. Then, they used the geometric mean of the two extreme weights. Chang and Sun (2009) used the Charnes, Cooper, and Rhodes (CCR) assurance region DEA model, which introduces weights restrictions in order to prevent unrealistic values. Netto, Honorato, and Qassim (2013) proposed to first find subjective weights and then calculate objective weights in DEA by maximising the subjective weights. Wang, Chin, Poon, and Yang (2009) used a mathematical programming to find the best α cut in defuzzifying the fuzzy weighted geometric means of the fuzzy ratings of O, S and D. As in the previous family of methods, mathematical programming methods do not tackle any group-decision sorting problems.

Integrated approaches have also been proposed for ranking the failure modes. For instance, the DEMATEL approach has been integrated with the ordered weighted geometric averaging operator (Chang, 2009) and with the fuzzy ordered weighted averaging operator (Chang & Cheng, 2011). The fuzzy weighted least square method is integrated with nonlinear programming model (Zhang & Chu, 2011). The 2-tuple is combined with the ordered weighted averaging operator (Chang & Wen, 2010). The fuzzy evidential reasoning is integrated with the grey theory (Liu et al., 2011), and fuzzy TOPSIS with fuzzy AHP (Kutlu & Ekmekçioğlu, 2012). Fuzzy logic is used within the integrated approaches to deal with judgmental imprecision and vagueness. Bozdag, Asan, Soyer, and Serdarasan (2015) have highlighted the importance of group decision in the FMEA by measuring both the variation in one expert's understanding (intra-personal uncertainty) and the variations in the understanding among experts (inter-personal uncertainty) by adopting an interval type-2 fuzzy sets. The individual judgments are aggregated into group judgments in form of interval type-2 fuzzy numbers that deal with both intra- and inter-personal uncertainty. However designed for multiple experts, this approach does not sort failures into groups. Moreover, as it is based on fuzzy logic, it requires the definition of membership functions, which is subjective and difficult. Risk assessment of the FMEA is in fact a group exercise that requires cross-functional specialists from various functions (e.g. design, process, production and quality). Thereby, the membership function definition may vary from person to person (Ishizaka & Nguyen, 2013). Unfortunately, in previous researches the same membership function was used for all members of the risks assessment team. For these reasons, in our paper, we avoid to use fuzzy logic as the definition of membership functions is a difficult task. Instead, we have introduced the novel Flowsort-GDSS, a method of the outranking family, which allows us to deal with the inter-personal uncertainty regarding the reference profiles defining the priority classes and therefore reaching the classification of the failure modes as consensual as possible. Furthermore, it is partially compensatory; this means that a bad evaluation on a risk factor cannot be compensated by a good evaluation on other risk factors. The next section will describe the method in details.

3. FlowSort-GDSS

3.1. Introduction

FlowSort-GDSS is an extension of the FlowSort method, when several decision-makers are involved in the sorting decision