Computers & Operations Research 36 (2009) 1768 – 1779

Contents lists available at ScienceDirect

Computers & Operations Research

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

Failure mode and effects analysis using a group-based evidential reasoning approach

Kwai-Sang Chin[a,*], Ying-Ming Wang[b], Gary Ka Kwai Poon[a], Jian-Bo Yang[c]

[a]*Department of Manufacturing Engineering and Engineering Management, City University of Hong Kong, 83 Tat Chee Avenue, Kowloon Tong, Hong Kong*
[b]*School of Public Administration, Fuzhou University, Fuzhou 350002, PR China*
[c]*Manchester Business School, The University of Manchester, Manchester M15 6PB, UK*

A R T I C L E I N F O

Available online 14 May 2008

Keywords:
Failure mode and effects analysis
Evidential reasoning approach
Uncertainty modeling
Minimax regret ranking

A B S T R A C T

Failure mode and effects analysis (FMEA) is a methodology to evaluate a system, design, process or service for possible ways in which failures (problems, errors, risks and concerns) can occur. It is a group decision function and cannot be done on an individual basis. 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 evidential reasoning (ER) approach, a newly developed methodology for multiple attribute decision analysis. The proposed FMEA is then illustrated with an application to a fishing vessel. As is illustrated by the numerical example, the proposed FMEA can well capture FMEA team members' diversity opinions and prioritize failure modes under different types of uncertainties.

1. Introduction

Failure mode and effects analysis (FMEA) is an engineering technique used to define, identify and eliminate known and/or potential failures, problems, errors and so on from the system, design, process and/or service before they reach the customer [1–3]. When it is used for a criticality analysis, it is also referred to as failure mode, effects and criticality analysis (FMECA). FMEA has gained wide acceptance and applications in a wide range of industries such as aerospace, nuclear, chemical and manufacturing. A good FMEA can help analysts identify known and potential failure modes and their causes and effects, help them prioritize the identified failure modes and can also help them work out corrective actions for the failure modes. The main objective of FMEA is to allow the analysts to identify and prevent known and potential problems from reaching the customer. To this end, the risks of each identified failure mode need to be evaluated and prioritized so that appropriate corrective actions can be taken for different failure modes. The priority of a failure mode is determined through the risk priority number (RPN), which is defined as the product of the occurrence (O), severity (S) and detection (D) of the failure, namely

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

The three factors O, S and D are all evaluated using the ratings (also called rankings or scores) from 1 to 10, as described in Tables 1–3. The failures with higher RPNs are assumed to be more important and should be given higher priorities.

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. However, the RPN has been extensively criticized for various reasons [4,5,7–11]:

- 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 and 4, 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. 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.

* Corresponding author. Tel.: +852 2788 8306; fax: +852 2788 8423.
E-mail address: mekschin@cityu.edu.hk (K.-S. Chin).

0305-0548/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cor.2008.05.002

- 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 the bottom of the scale from 1 to 1000. This causes problems in interpreting the meaning of the differences between different RPNs. For example, is the difference between the neighboring RPNs of 1 and 2 the same or less than the difference between 900 and 1000?
- The RPN considers only three factors mainly in terms of safety. Other important factors such as economical 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 both 10, then a 1-point difference in severity rating results in a 100-point difference in the RPN; 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 both 4, then a 1-point difference produces a 16-point difference in the RPN.
- 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 so on.

A number of approaches have been suggested in the literature to overcome some of the drawbacks mentioned above. For example, Gilchrist [10] gave a critique of FMEA and proposed an expected cost model. It was formulated as $EC = CnP_fP_d$, where *EC* is the expected cost to the customer, *C* the cost per failure, *n* the items produced per batch or per year, P_f the probability of a failure and P_d the probability of the failure not to be detected. P_f and P_d were assumed to be independent and their product represents the probability that the customer receives a faulty product. The nP_fP_d is the expected number of failures reaching the customer. The expected cost model was claimed to be more rigorous yet practical than the RPN model and to have great benefit of forcing people to think about quality costs.

Ben-Daya and Raouf [7] argued that the probabilities P_f and P_d in the expected cost model were not always independent and very difficult to estimate at the design stage of a product and the severity was completely ignored by the expected cost model. Based on these arguments, they proposed an improved FMEA model which addressed Gilchrist's criticism and gave more importance to the likelihood of occurrence over the likelihood of detection by raising the ratings for the likelihood of occurrence to the power of 2. The improved FMEA model was combined with the expected cost model to

Table 1
Traditional ratings for occurrence of a failure [4–6].

Rating	Probability of occurrence	Possible failure rate
10	Very high: failure is almost inevitable	$\geqslant 1/2$
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	$\leqslant 1/1,500,000$

Table 2
Traditional ratings for severity of a failure [4–6].

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 [4–6].

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