Risk evaluation with FMEA when the severity of a failure effect depends on its detection time

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1. Introduction

Failure mode and effect analysis (FMEA) is extensively used as a powerful tool for system safety and reliability analysis of products and processes within a wide range of industries, including the aerospace, nuclear, automotive, electronics and medical industries [6]. In conventional FMEA, the risk of a failure mode or cause is evaluated using its corresponding risk priority number (RPN). The RPN is obtained as a mathematical product of three risk components of failure; occurrence, severity, and detection. Each value of the three components is usually determined as to the guidelines provided by such a book as FMEA handbook [2]. Occurrence and detection basically include the probability concepts in their nature, but severity is merely the relative rank associated with the most serious effect of a failure within the scope of the individual FMEA.

The conventional application of FMEA has a number of limitations to be more carefully addressed for further improvement. Some important drawbacks are; (i) the subjective and inconsistent process of evaluating RPN, (ii) unreasonable allocation of the same weight on its three risk components, (iii) totally different contexts of risk possible with the same RPN, (iv) and dependence on intuition and experience rather than scientific method for estimating three risk components. Many authors have attempted to improve the risk evaluation metric of FMEA. Abdelgawad and Fayek [1] used a combination of Fuzzy FMEA and Fuzzy AHP for risk management in the construction industries. Kumru and Kumru [5] directly evaluate the linguistic assessment of factors based on fuzzy theory to obtain the RPN value. Liu et al. [6] employed an intuitionistic fuzzy hybrid weighted Euclidean distance operator to overcome the limitations of traditional FMEA. Liu et al. [8] proposed a risk priority model based on fuzzy set theory, treating the risk factors and their weights as fuzzy variables. And Liu et al. [7] proposed a risk priority model based on the grey relational projection (GRP) method.

There are few, if any, studies that consider the role of time in FMEA. Kwon et al. [4] constructed a time dependent model with a quadratic loss function for the unfulfilled mission period, presenting an optimal monitoring policy. Kwon et al. [3] proposed a time dependent expected loss model, assuming a homogeneous Poisson process for occurrence of failures and causes. Rhee and Ishii [9] introduced a life cost-based FMEA for analyzing design alternatives of a particular system with Monte Carlo simulation.

In this paper, we consider the time sequence of event occurrence, i.e. cause – failure – effect. It is quite natural to assume that a failure occurs after at least one of its causes has occurred. And also, it may take time to detect the failure after its occurrence. We consider a situation where the severity of a failure effect depends on the length of undetected time. Generally, the detection of a failure cause prior to the actual failure will only require a constant cost of fixing the cause. If the failure is detected after its actual occurrence, then the loss may be significantly large as to the undetected time duration of the failure. We consider two types of severity function for undetected time duration; linear and quadratic. Assuming exponential probability law for occurrence and detection times, we suggest a risk evaluation model for improving the conventional FMEA.

2. The model

A failure can happen only after its cause has occurred, and there will be a time elapse from occurrence of cause to its failure. And generally, it takes time to detect a failure. This situation is depicted in Fig. 1. Note that the cause may be detected before or after its corresponding failure actually occurs, as described by case A and B, respectively.
If the cause of a failure is detected before it actually occurs, the severity of its effect is assumed to be constant. The only cost incurred in this case will be attributable to corrective action for the failure cause and will not be so much dependent on the elapsed time to detection. If a failure is detected after its occurrence, the losses due to the failure may be accumulated until the corrective action is taken. Thus, the severity of its effect in this case will naturally depend on the elapsed time to detection. Fig. 2 shows these two possible situations where $D_j$ and $T_j$ are the detection and occurrence times of cause $j$ of failure $i$, respectively. Let $S_j$ denote the severity for the effect of failure $i$, then $S_j$ will be a non-decreasing function of $|D_j - T_j|$. In our model, we consider two types of $S_j$, i.e. linear and quadratic functions of $|D_j - T_j|$.

\[ S_j = \begin{cases} a_j, & 0 < D_j \leq T_j \\ a_j + b_j(D_j - T_j), & T_j < D_j \end{cases} \]  \hspace{1cm} (1)

for the linear type and

\[ S_j = \begin{cases} a_j, & 0 < D_j \leq T_j \\ a_j + b_j(D_j - T_j)^2, & T_j < D_j \end{cases} \]  \hspace{1cm} (2)

for the quadratic type. Note that $b_j$ and $a_j$ are constant coefficients corresponding to failure $i$ and its cause $j$, respectively.

3. Risk evaluation

Assuming exponential probability distribution for $D_j$ and $T_j$, the expected value of $S_j$ can be obtained to evaluate the severity for each failure cause as follows:

\[ E[S_j] = a_j + b_j \left( \frac{\lambda_j}{\mu_j(\mu_j + \lambda_j)} \right) \]  \hspace{1cm} (3)

for linear type and

\[ E[S_j] = a_j + b_j \left( \frac{\lambda_j^2}{\mu_j^2(\mu_j + \lambda_j)} \right) \]  \hspace{1cm} (4)

for quadratic type.

Assuming homogeneous Poisson process for cause occurrence additionally, a risk metric for each failure cause can be obtained. Evaluating and comparing the risk metrics for all the failure causes in the FMEA sheet, the priority of preventive action for each cause can be determined.

References


