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Improving risk assessment for customer-oriented FMEA

Pisut Koomsap* and Thuangporn Charoenchokdilok

Industrial Systems Engineering, Asian Institute of Technology, Pathumthani 12120, Thailand

Since its introduction in the aerospace industry, failure mode and effects analysis (FMEA) has been proven to be an effective risk management tool and has gained popularity in various industries. All along, FMEA has been conducted according to manufacturers' perspective. As a matter of fact, customers are also a key stakeholder group who will be affected directly if any failure modes occur. Therefore, their involvement should be considered in FMEA, but has not received much attention. Presented in this paper is an attempt to improve a customer-oriented FMEA. Customer dissatisfaction has been integrated directly into a new approach for risk assessment. Kano model has been applied to identify how customers perceive failure mode effects. A new customer-oriented risk priority number (RPN) calculation has been developed and compared with the previous customer-oriented approach as well as the traditional one. The results from a case study show that this new approach represents the customers' perspective better than the previous one, and the factors influencing the prioritisation of the failure modes are different among the three approaches. In this new approach, how the customers perceive the effects of the failure modes has the most influence.

Keywords: FMEA; Kano model; customer involvement; customer dissatisfaction; risk assessment

1. Introduction

Initiated from reliability and safety concerns, failure mode and effects analysis (FMEA) has been developed for identifying potential failure modes and establishing corrective actions to avoid them from occurring (Sankar & Prabhu, 2001). FMEA can be seen as a proactive root cause analysis applied regularly in the early design stage of products with an aim to minimise the effects of failure modes and make sure that there will be no surprise leading to questioning of their reliability. FMEA is a structural formalised team-based approach that contains a set of activities including understanding of potential failure modes; assessing their effects; and recommending corrective actions, and that requires the participation of members from various disciplines to ensure that needed knowledge and experience are available (Stoll, 1999). All identified failure modes are assessed based on three risk factors: a chance that each failure mode will occur (O), the severity of its effect (S), and a chance that that failure mode will be detected (D). The assessment leads to the calculation of a risk priority number (RPN), which reflects a concern on how critical each failure mode is if it is not taken care. The higher the RPN value is, the more critical that failure mode will be. According to the obtained RPNs, priorities given to all failure modes can be determined.

FMEA, since its inception in the 1960s in the aerospace industry, has been proven to be an effective risk management tool and has gained popularity in various industries. Besides aerospace, its applications can also be found in, but not limited to, the automotive industry

*Corresponding author. Email: pisut@ait.asia

(Joo, Kim, Kim, & Moon, 2013; Segismundo & Miguel, 2008), electronic industry (Cassanelli, Fantini, Serra, & Sgatti, 2003), construction industry (Abdelgawad & Fayek, 2010), food industry (Scipioni, Saccarola, Centazzo, & Arena, 2002; Trafialek & Kolanowski, 2014; Varzakas, 2011; Varzakas & Arvanitoyannis, 2009), healthcare industry (Chiozza & Ponzetti, 2009; Latino & Flood, 2004), and service industry (Shahin, 2004). FMEA can also be seen being applied for society benefits such as for wildlife conservation (Dargahi et al., 2015). FMEA has been applied individually as well as in combination with other decision-making tools such as quality function deployment (QFD) (Almannai, Greenough, & Kay, 2008), statistical process control (SPC) (Khorshidi, Gunawan, & Esmaeilzadeh, 2013), and strengths, weaknesses opportunities, and threats (SWOT) analysis (Sutrisno & Kwon, 2012).

The RPN, a risk assessment index, is a key element to the success of FMEA. The calculation of the traditional RPN that is the product of the three risk factors is practically simple, straightforward, and easy to understand. However, it is unclear why the formula is in the multiplication form. Its simplicity has also brought up concerns, especially when there are more than one failure mode having the same RPN value that is resulting from the different combinations of severity, occurrence, and detection. Do they actually have the same level of risk? The question is raised because the non-linear nature of the three factors is assessed subjectively on the same linear scale. For each failure mode, its three factors will be assessed and rated on a 1 to 10 ranking scale as illustrated in Table 1. For each individual factor, one assessment with twice the assessed value of the other one does not mean that its risk will be double also. Among the three factors, having the same assessed value does not mean they have the same level of risk. Furthermore, the experience of team members can produce easily different assessment on the same failure mode. Besides, the three risk factors are also treated equally in the formula. Their relative importance is not considered. All these points are examples of the shortcomings that are not addressed in the risk assessment with the traditional RPN calculation. A comprehensive list of the shortcomings can be found in Liu, Liu, & Liu (2013).

Therefore, much research has been done to improve the drawbacks of the risk assessment with the traditional RPN. For instance, Sankar and Prabhu (2001) argued that there should be no tie among all one thousand possible combinations of the three factors and presented risk priority ranks (RPRs) in which one thousand ranks are tabulated by experts for all possible combinations. Chen (2007) argued that prioritisation should not consider only the causes and effects of failure modes. A chain reaction of corrective

Table 1. Suggested evaluation criteria and ranking system for severity, occurrence, and detection.

Rank	*S*	*O*	*D*
1	None	Nearly impossible	Almost certain
2	Very minor	Remote	Very high
3	Minor	Low	High
4	Low	Relatively low	Moderately high
5	Moderate	Moderate	Moderate
6	Significant	Moderately high	Low
7	Major	High	Very low
8	Extreme	Repeated failure	Remote
9	Serious	Very high	Very remote
10	Hazardous	Extremely high	Absolutely uncertain

actions should also be considered and utility priority number (UPN) was proposed. For each failure mode, the UPN is determined from the multiplication of the traditional RPN value and the weight of the utility of its corrective action. Recently, Chang, Chang, and Lai (2014) have proposed an exponential risk priority number (ERPN) which mathematically determines the priority in an exponential form where the three factors are presented as the exponents. With ERPN, many more unique values can be obtained, and the frequency of number duplications decreases at the same time. Besides, there are also reports of involving fuzzy logic (Liu, Chen, You, & Li, 2016; Liu, You, Lin, & Li, 2015a; Safari, Faraji, & Majidian, 2016; Xu, Tang, Xie, Ho, & Zhu, 2002), analytic hierarchy process (AHP) (Liu, You, Ding, & Su, 2015b; Zhao, Fu, & Wan, 2013), etc., with the RPN calculation. An extensive review of risk evaluation approaches used in FMEA can also be found in Liu et al. (2013).

Improvement of risk assessment has been reported regularly, but all along, FMEA has been conducted according to the manufacturers' perspective without customer involvement. As a matter of fact, their customers are also a key stakeholder group who will be affected directly when any failure modes occur. More importantly, they may perceive that the effects of the failure modes differ from the manufacturers as indicated in the study by Shahin (2004). Consequently, prioritisation with and without customer involvement will most likely be different. It is worth to note that how customers react when they experience the effects of failure modes will dictate whether or not they will still continue with the products. Therefore, customer involvement should be seriously considered in FMEA rather than be put aside, and so far only Shahin has integrated customers' point of view into FMEA. Severity was proposed to be a power function of occurrence where its exponent was determined from the customers' point of view. However, there are a few concerns on this customer-oriented approach. Therefore, a research has been conducted, and presented in this paper is the improvement of the customer-oriented FMEA. Customer dissatisfaction has been directly integrated into the RPN calculation, instead of being indirectly linked via severity. A comparison of this study with the reviewed literatures is shown in Table 2.

The next two sections present briefly Kano model and its integration with FMEA. The proposed customer-oriented FMEA will be presented in the fourth section, followed by its comparison with the existing approaches. The conclusion will be drawn in the last section.

2. Kano model

Customer satisfaction, a reaction from customers after comparing the perceived value of a product with their expectation, has gained the attention of manufacturers who would like to succeed in a competitive open market. A high customer satisfaction level motivates customers' willingness to purchase a product, and customers who are very satisfied with the product are most likely to have loyalty to the product (Matzler & Hinterhuber, 1998). It is, therefore, a task of the manufacturers to understand customer needs and to respond with appropriate products to ensure a high level of customer satisfaction.

However, a relationship between perceived product performance and customer satisfaction is not always linear and symmetric (Lin, Yang, Chan, & Sheu, 2010; Matzler, Bailom, Hinterhuber, Renzl, & Pichler, 2004). In fact, a non-linear and asymmetric relationship does exist. That is because customers have different levels of awareness and expectation on different product attributes. It is very important for manufacturers to differentiate these relationships, and the Kano model (Kano, Seraku, Takahashi, & Tsuji, 1984) has been recognised as an effective tool for relating product attributes to