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Evaluation of Risk Priority Number (RPN) in Design Failure Modes and Effects Analysis (DFMEA) using Factor Analysis

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Abstract
The couple of past decades many industries are forced to use Failure Modes and Effects Analysis (FMEA) technique to improve their product design and manufacturing process, due to the growing global competitive market. FMEA is a risk assessment tool developed to identify potential failures that may occur in product and process. FMEA is carried out systematically by brainstorming team to identify the potential failure modes and its effects of a product and process. The aim of this paper is to present a new approach for evaluation of RPNs and failure modes to enhance the utility of the traditional FMEA technique. A case study is also presented to prove the applicability of the proposed method. At the end, statistical method like factor analysis is used to confirm the effectiveness of the proposed methodology.

Keyword: RPN, FMEA, RPN Prioritization, Failure Modes and Factor Analysis

Introduction

Failure Modes and Effects Analysis (FMEA) is a widely used systematic tool for evaluating a system, product and process. The purpose of using FMEA technique is to examine how a system, product or a process could fail. Normally, FMEA is carried out by cross functional team during product development cycle to identify potential failure modes along with its causes and effects Carlson (2014). A successful development of FMEA is very important for product manufacturers to deliver high quality products to their customers on time in turn the manufacturers will be able to compete in the global market Vaibhav and Quazi (2014). FMEA is one of the reliability tool for continuous quality improvement. Quality of a product and process can be improved by identifying and preventing failures during development cycle. FMEA tool could be used for new or existing product and process for quality improvement ISSI (2015).

Design Failure Modes and Effects Analysis (DFMEA) is an analytical technique used during design phase of a product development. It is a pro-active technique used to identify the weak points of a product design in early stages. The objective of design FMEA is to identify and evaluate potential failure modes of a product Nada Javadieh *et al*., (2014). It is an important and powerful tool in any safety analysis process, hence it has been used extensively in analysis of potential failure modes by various industries Bonfiglio (2015). DFMEA is a specific tool used during product design phase to develop robust and more reliable product. It aims to identify and mitigate or eliminate the product failures before releasing the production drawing for the manufacture Vivek and Prasad (2014).

FMEA helps the engineer to design reliable and safe product by mitigating the anticipated failure modes. The risk associated with each failure mode is evaluated using Risk Priority Number (RPN) which is calculated by multiplying severity (S), occurrence (O) and detection (D) ratings. Severity rating is assigned according to seriousness of an effect of a failure mode. Occurrence rating is based on the failure probability during the product life. Similarly, detection rating is according to ability to identify a risk occurrence. In general, the three risk factors S, O and D are rated on a scale 1 – 10 for each failure mode using the guidelines for deign FMEA as described in Table 1 Mehrzad *et al*., (2014).

Risk Priority Number (RPN)=Severity (S) x Occurrence (O) x Detection (D)

The RPN value ranges between 1 and 1000 for each failure mode. According to RPN value, the failure modes are prioritized and suitable correctives actions will be proposed for the highest RPN value. After implementation of corrective actions, new RPN values will be calculated for each failure mode Nadia Belu *et al*., (2013). Generally, there is no threshold value for addressing RPNs in traditional FMEA approach. The FMEA team will identify necessary corrective action for the failure mode with highest RPN Lefayer and Jahirul (2011). The effectiveness of any FMEA is depends on understanding the fundamentals and procedures of FMEA, selection of right FMEA and FMEA team with company-wide involvement Yonas and Moorthy (2014). This RPN evaluation and prioritization method has been criticized extensively for the following such as traditional FMEA approach suggested that taking average value, if there is a disagreement in the FMEA team for assigning rank for S, O and D. This may produce an identical value of RPN for different failure modes and the relative importance among the three failure mode indexes S, O and D is not taken into consideration. Normally, FMEA team gives top priority for the failure mode which has higher severity rating. In a practical situation, sometimes all three failure modes are equally important and should be evaluated with equal weightage in RPN prioritization.

Variant approaches have been suggested in the literature by many researchers to improve traditional FMEA method. From the literature review, it is found that Fuzzy Rule-based System and Fuzzy Data Envelopment Analysis (DEA) are widely used as alternative to traditional FMEA approach. Pinnarat *et al.*, (2014). It is important to mention that any of the proposed approaches does not remove the drawback of traditional approach, in case of disagreement in the rating scale of S, O and D.

Table 1: Severity, occurrence and detection guidelines for design FMEA

Rank	Severity (S)		Occurrence (O)		Detection (D)	
	Effect	**Criteria**	**Effect**	**Criteria**	**Effect**	**Criteria**
10	Hazardous	Hazardous effect	Almost certain	Failure almost certain	Almost impossible	No known techniques available
9	Serious	Potential hazardous effect	Very high	Likely very high number of failures	Remote	Only unproven techniques available
8	Extreme	Customer very dissatisfied	High	Likely high number of failures	Very slight	Providing durability tests
7	Major	Customer dissatisfied	Moderately high	Likely moderate high number of failures	Slight	Test on products with prototypes
6	Significant	Customer experiences discomfort	Medium	Likely medium number of failures	Low	Test on similar system
5	Moderate	Customer experiences some dissatisfaction	Low	Likely occasional number of failures	Medium	Test on preproduction system
4	Minor	Customer experiences minor nuisance	Slight	Likely few failures	Moderately high	Test on early prototype
3	Slight	Customers slightly annoyed	Very slight	Likely very few failures	High	Modeling in early stage
2	Very Slight	Customer not annoyed	Remote	Likely rare number of failures	Very high	Proven computer analysis available
1	No	No effect	Almost never	History shows no failures	Almost never	Proven detection methods available

This paper presents a novel approach for prioritization of RPNs with a case study analysis. The proposed methodology of RPN evaluation is analyzed using statistical techniques to prove the usefulness of the approach.

New Approach for Evaluation of RPNs

Case Study-DFMEA for Mobile Phone

The proposed methodology for evaluation of RPN is able to deal with the situation when; the FMEA team has a disagreement in the rating scale for S, O and D indexes, the RPN means are identical for more than one failure mode and the three failure indexes S, O and D are equally important.

The potential failure modes of a mobile phone are listed in Table 2. It shows that there is a disagreement in rating scale for S, O and D indexes. We calculated RPNs and their mean for all possible combinations of severity, occurrence and detection ratings. However, various combinations of S, O and D values are produces an identical value of RPN mean 225. In this situation, RPN range for each failure mode is computed. Smaller RPN range shows the degree of disagreement among the FMEA team members is closer. Hence, first priority should be given to the failure mode which has smaller RPN range.

Table 2: Potential failure modes of a mobile phone

Product Name	Failure Mode	Potential Effect of Failure	Potential Cause of Failure	Severity (S)	Occurrence (O)	Detection (D)	RPNs	RPN	
								Mean	Range
Mobile Phone	(1) Display	Difficult to use the functions	Low material quality	8 7	5 7	4 6	160, 240, 224, 336, 140, 210, 196, 294	225	**196 (1)**
	(2) Camera showing a black screen / taking blurry pictures	Not able to take photos / record videos	Lens probably damaged / third party camera app	6 9	3 7	8 4	144, 72, 336, 168, 216, 108, 504, 252	225	**432 (2)**
	(3) Auto restart	User annoyed	Hardware malfunction	8 2	5 10	9 3	360, 120, 720, 240, 90, 30, 180, 60	225	**690 (5)**
	(4) Battery drain fast / not charging	Needs frequent charging	Poor quality	8 4	2 8	7 8	112, 128, 448, 512, 56, 64, 224, 256	225	**456 (3)**
	(5) System hanging	User annoyed	Software corrupted	7 5	1 9	9 6	63, 42, 567, 378, 45, 30, 405, 270	225	**537 (4)**

The proposed methodology for the prioritization of failure modes for the above case study is given as;

"The failure mode with higher RPN is more severe and the failure mode with smaller RPN range is more severe, if the RPNs mean are same".

Statistical Analysis and Discussion

In this paper statistical tools have been used to evaluate the proposed RPN prioritization methodology. The result of each analysis provides sufficient evidence for the usefulness of the proposed method. It is important to select the correct statistical test depending on the type of data and the purpose of analysis. Selection of incorrect test will produce invalid results and misleading conclusion may be drawn from the study Evie McCrum-Gardner (2008).

Descriptive Statistics:

The descriptive statistics for the five failures modes such as FM1, FM2, FM3, FM4 and FM5 of mobile phone shows that the means of the RPNs are identical. Standard deviation of the failure modes are 65.273, 140.347, 226.779, 173.090 and 208.723. It shows that the most critical failure mode needs to be addressed first. Similarly, it is one of the vital role to be adapted the rank of the failure modes of a mobile phone.

Correlation Matrix:

From the Table 3 it reveals that the correlation coefficients between a single variable and every other variable in the investigation.

Table 3: Correlation Matrix for S, O and D

Correlation Matrix				
		S	O	D
Correlation	S	1.000	-.590	.175
	O	-.590	1.000	-.590
	D	.175	-.590	1.000

The eigenvalue for the above correlation matrix is 0.2486, 0.8255 and 1.9260. A measure of the multicollinearity among three independent variables is computed from the correlation matrix using the following computation Senthamarai Kannan *et. al*., (2005);

$$C = \sqrt{\frac{Max.Eigenvalue}{Min.Eigenvalue}} = \sqrt{\frac{1.92596}{0.24857}} = 2.7834$$

The computed value is less than 4, thus it provides strong evidence for there is no multicollinearity among these three independent variables.

Kruskal-Wallies Test:

The non-parametric Kruskal-Wallies test is useful for the five failure mode RPNs. The test provides a statistical procedure for testing whether the population means are identical. According to the test result the value of H = 0.75, P = 0.944 and $\chi^2 = 9.48773$. From the value of χ^2, do not reject the null hypothesis. It concludes that the RPN means for the five failure modes are identical.

KMO and Bartlett's Test:
Kaiser-Meyer-Olkin (KMO) and Bartlett's test measures strength of the relationship among variables. KMO measures sampling adequacy which is recommended 0.5 as minimum for a satisfactory factor analysis. According to the result of the KMO measure is 0.470 which is around 0.5. Hence, factor analysis is likely to be appropriate.
Bartlett's measures tests the null hypothesis that the original correlation matrix is an identity matrix. Bartlett's test significance value is 0.084 which is little higher than 0.05. The extraction of the S, O and D is 0.532, 0.863 and 0.532 respectively. It reveals that 53 % of S, 86 % of O and 53 % of D variables are account for RPN. Total variance of all the factors extractable from the analysis along with their eigenvalues, the percent of variance attributable to each factor is such as 64%, 28% and 8%. The first factor is account for 64% of the variance and the remaining factors are not significant.

Scree Plot:
The scree plot is a graph of the eigenvalues against all the factors. The graph is useful for determining how many factors to retain. The point of intersect is where the curve starts to flatten.

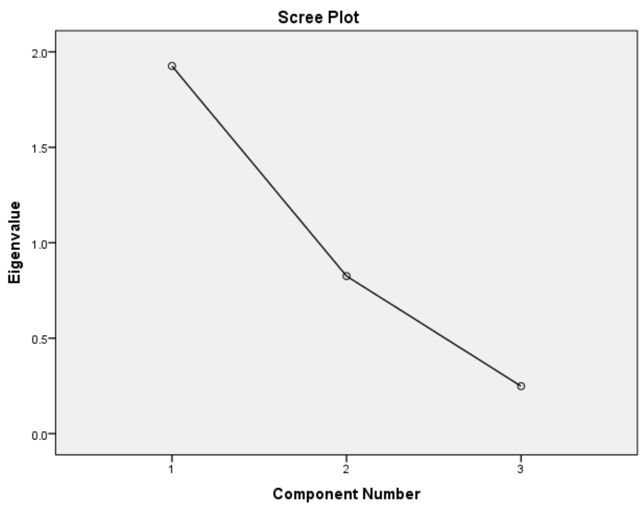

Figure 1: Scree plot

It can be seen from Figure 1 that the curve begins to flatten between factors 2 and 3. From the component matrix of the variables S, O and D scores 0.729, -0.929 and 0.729 respectively. The loading of the three variables on one factor is extracted. The higher the absolute value of the loading, the more the factor contributes to the variable.

Conclusion
In this paper, we have proposed a new methodology for evaluation of RPNs and failure modes. Statistical analysis results are support the usefulness of the proposed methodology. Thus we can conclude that the proposed methodology can be used successfully for prioritization of failure modes in design failure modes and effects analysis, when:

- The FMEA team has a disagreement in the rating scale for S, O and D indexes.
- The RPN means are identical for more than one failure mode.
- Three failure indexes S, O and D are equally important.

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