PRIORITIZING THE RISK PRIORITY NUMBERS IN FMECA – A HEURISTIC APPROACH

Abstract

Risk management is one of the most important fields that diagnose hazards and traces by the application of various tools available. In any mines or industries it is necessary to estimate and predict the risk associated with the components/equipment or machineries in order to avoid the loss/damage. One of the tools often used for assessing the risk is Failure Mode Effect and Criticality Analysis (FMECA) which addresses causes, effects and risk of each failure mode. Risk priority number(RPN) evaluates the risk associated with each failure mode, which is obtained by the multiple of severity, occurrence and detection rankings. It is very convenient to point out the failure mode with the highest risk if the values of RPN are different. However, it is very difficult to come to a decision if the entire failure modes have the identical values of RPN. This is the major drawback that was found during FMECA analysis. This paper proposes a new methodology to overcome the drawbacks that was found in traditional FMECA.

Keywords: RPN, FMECA, Failure Mode, Criticality, Severity, Occurrence, Detection.

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I. INTRODUCTION

Failure Mode and Effects Analysis, abbreviated as FMEA, evolved into Failure Modes, Effects, and Criticality Analysis, often referred to as FMECA. FMECA is employed to identify every possible failure scenario within a system's design. The primary goal of FMECA is to pinpoint the aspects of product design, production, operation, and distribution that are crucial to different failure modes in order to minimize the risk of failure. Furthermore, it seeks to uncover all potential catastrophic and critical failure scenarios, allowing for their early mitigation. Consequently, FMECA should commence as soon as preliminary design information becomes available and should be continually updated as more information surfaces, especially in areas suspected of potential issues. [1]

FMEA and FMECA methodologies have been developed with the aim of identifying potential failure modes in both products and processes, evaluating the associated risks, prioritizing these issues, and implementing corrective measures to effectively address the most critical issues. While specific terminology and nuances may differ depending on the type of analysis (such as Process FMEA or Design FMEA), the fundamental approach remains largely consistent.

The FMECA process comprehensively deals with issues spanning design, manufacturing, processes, safety, and environmental concerns. During the FMECA process, the consequences of these issues are thoroughly examined when studying failure modes. When it comes to workplace safety and well-being, prioritizing preventive measures for potential failures should always be of utmost importance.

FMECA harnesses a wealth of collective experience, spanning design, technology, procurement, production/operations, distribution, marketing, and service, among other areas, in order to gauge the significance or criticality of potential issues and to formulate strategies aimed at mitigating these levels. Emphasizing FMECA as a pivotal element during the product or service design phase is essential.

While FMECA can be applied at various stages, including design, development, production/operations, or even during usage, its primary objective is the prevention of failures. As a result, it finds its most suitable application during the design stage, where it can efficiently identify and eliminate underlying causes of potential failures.

Design FMEA and Process FMEA are both explored, and a concise comparative analysis has been conducted. Nevertheless, in the case of intricate product or service systems, it may be advisable to treat them as smaller, distinct units or subsystems, with each one undergoing a separate FMECA analysis. [2]

II. LITERATURE REVIEW

Xiaoqing Cheng et al. (2013) [4] analysed the reliability of metro door system using FMECA. Initially, a statistical view was made for the various failed door components and sorted the components of major failure. Among various door components, EDCU was failed for 138 times in a period of 18 months. A total of 443 failures were occurred which includes door closing limit, nut component, EDCU and portable mast mounting that occupies 67% of

total failures. Further they carried out the criticality analysis to evaluate the risk of each failure mode. After analysing all the failure modes through FMECA, it was concluded that the criticality of EDCU and door closing limit have greater criticality than others and major concerned has be to done for these critical failures in the maintenance operations. **D. Ćatić et al. (2014) [5]** studied the failure causes of drum brakes of a motor vehicle and analysed the criticality. They started analysing the failure causes using fault tree analysis (FTA).

Further they carried out the criticality analysis for the drum brake elements for a 28 different failure modes. The results showed that the worn of brake shoe's has the highest criticality followed by failure modes of drum.**R.S. Mhetre & R.J.Dhake (2012) [6]** have conducted a case study in a medium scaled company which manufactures precision sheet metal parts. For the production of metal parts various machinery like CNC press brakes, CNC laser cutting, CNC punching were used. Authors aimed to enhance reliability by reducing errors and shorten the development duration using tools like FMECA and ishikawa diagram. Authors carried out a case study based on the complaints received from the customers and the complaints were fitment problem with mating part, aesthetically poor and cracks. Customer complaints were observed to be 87 out of 211 for bending workstation.

The root cause analysis showed that incorrect setting, lack of maintenance and raw material variation. The highest RPN was found as 480 for blank not resting properly in failure mode. Finally they have concluded that by following a standard set-up procedure set-up time will be reduced and part accuracy is improved thereby increasing the press break efficiency. **Bharath. G& R. Prakash (2014) [7]**in a paper carried out an analysis of criticality for a bleed valve used in fuel pump using FMECA. Initially they categorised the components of bleed valve which consists valve body, steel ball, spring and valve stop. The major defect that was found during the operation of bleed valve is the slit leakage which results in minimizing and fluctuating performance in the engine. In this case study they have found two failure mode namely material wear and loosing stiffness for four different components and the highest RPN was obtained for the spring component.

Finally they concluded Proper care and maintenance should be given to assembly parts while scheduling preventive maintenance. **Tejaskumar S. Parsana & Mihir T. Patel (2014) [8]**attempted FMEA tool for analysing and rectifying problems in manufacturing process of cylinder head company also to enhance the reliability. Firstly authors studies various operations carried out for manufacturing of cylinder head. Then they have sorted out the potential failure modes followed by their effects. Later the calculation of severity, occurrence and detection was done in order to find out the risk priority number. After analysing all the failure modes and allotting S, O and D, the highest RPN was found for Nozzle bore with a value of 54. At the end they concluded that the manufacturing efficiency and the quality can be improved by FMEA analysis and thus reducing the number of defects.

III. FMEC ANALYSIS GROUNDWORK

1. **Identifying the Component Functions:** Before going into the deep study of FMECA, analyser should be familiar with the components description and its functions. So that, one can easily analyse the causes and effects. After having a sound knowledge on the components data, analyser should specify each and every function of the component. These are the preliminaries for any study for carry for on FMECA.

2. **Identifying Potential Failure Mode:** The first basic step for any study to proceed with FMEC analysis is to identify all the potential failure modes of a system/component or equipment. This is done by considering the previous track record which can be available in the log records or excel document with maintenance operator. After deciding the time period for the study, one has to consider all the failures which have occurred in the past and then convert them in to technical terms. For example: broken, fractured, burnt, deformed etc.,

3. **Potential Effects of Failure:** Every failed component has an effect, which has to be noted immediately after the failure occurred. The effect may vary from minor to major based on the type of failure mode. After identifying the failure mode, it is necessary to analyse and brainstorm all the possible effect on the environment.

IV. FMECA METHODOLOGY

Figure 1 shows the process flow chart that carried out in FMECA methodology. FMECA process can be described in two phases.

The initial phase involves identifying and understanding potential failure modes and their associated effects. Subsequently, in the second phase, risk assessments are conducted to evaluate the severity of these failure modes. By the conclusion of the first phase, the detailed design is finalized, and design drawings are created.

During the second phase of FMEA, the engineering team, assembled for this purpose, scrutinizes and assigns risk levels to each failure mode. They then proceed to review and adjust specific design elements as necessary. The highest-ranked failure, indicating the most significant risk, takes precedence and is addressed first in the design modifications. The goal is to revise the design in a manner that minimizes the likelihood of the highest-ranked failure occurring.

To gather data and information for the FMEA process, it is imperative to draw from the company's own production lines, input from customers, and field data related to similar products. Consequently, the FMEA team must collaborate with customers to collect the requisite information essential for crafting an effective FMEA report.
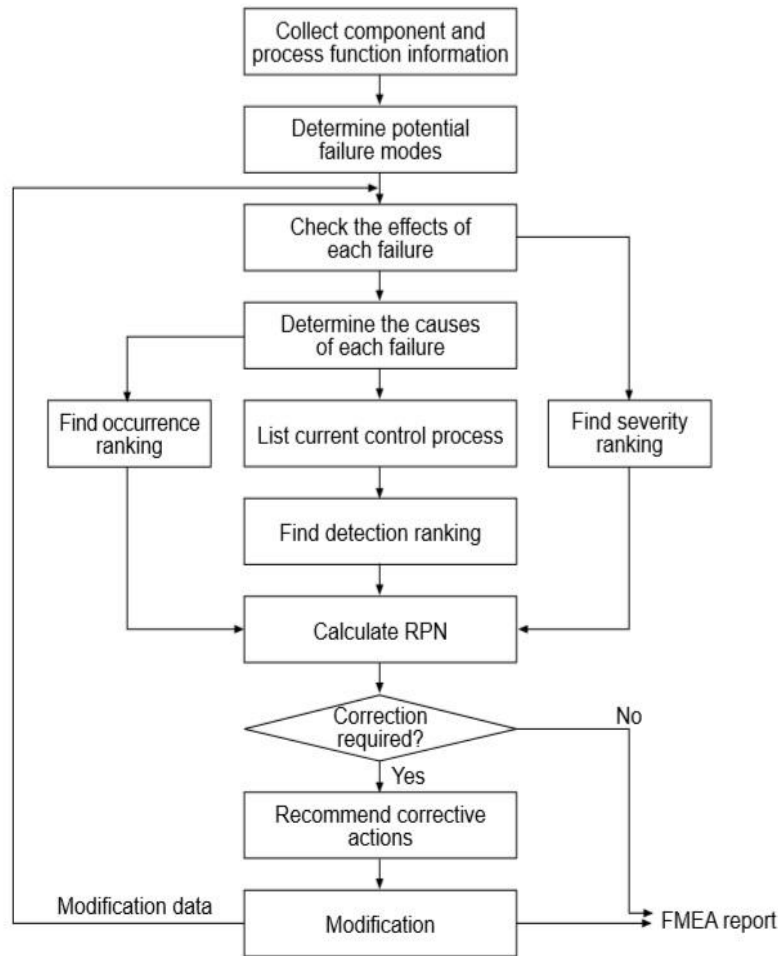
V. KEY INPUTS OF FMEC ANALYSIS

1. **Severity(s):** The estimation of the seriousness of the failure mode effect is measured by the variable known as severity. In other terms, it is a numerical measure of how serious is the effect of failure mode on the considered factors. Generally, it is represented with letter S. the degree of severity is generally taken depending upon different factors such as human risk, production, cost etc. The degree of severity is generally measured on the scale of 1 to 10, where 10 is the most severe. Severity classification categories that are consistent with MIL-STD-882 are defined as follows

Table 1: Severity Ranking

Linguistic Term	Severity Effect	Rank
None	No Effect	1
V minor	Fit & Finish/ squeak & Rattle item doesn't conform	2
Minor	Defect noticed by average customer.	3
Low	Defect noticed by most customers.	4
Moderate	Customer experiences some discomfort	5

Significant	Vehicle / item operable, but Comfort/Convenience items inoperable	6
Major	Customer dissatisfied.	7
Extreme	Vehicle / item inoperable, with loss of primary function.	8
V extreme	Very High severity ranking when a potential failure mode affects safe vehicle operation	9
Serious	Involves noncompliance with government regulation without warning.	10

2. **Occurrence (O):** The Occurrence metric assesses the likelihood of a specific failure mode or event happening within a defined time frame. It also quantifies the probability that a desired failure mode will actually be identified. The numerical ranking assigned to the likelihood of occurrence carries meaning rather than representing an actual probability value. Each failure mode is individually assigned a ranking based on how frequently it is expected to occur.

    The degree of occurrence is typically measured on a scale ranging from 1 to 10, with 10 indicating the highest probability of occurrence. These ratings are often determined by historical occurrence rates.

    To reduce the occurrence ranking, the only effective approach is to eliminate or control one or more of the underlying causes or mechanisms of the failure mode through design changes. Estimating the likelihood of occurrence for potential failure causes or mechanisms is done on a scale from 1 to 10, with 10 signifying the highest probability of occurrence. It's important to note that this ranking should consider only occurrences that result in the failure mode; measures related to detecting failures are not taken into account in this assessment.

Table 2: Occurrence Ranking

Linguistic Term	Occurrence Level	Rank
Unlikely	Once in 48 months	1
Very remote	Once in 36 months	2
Remote	Once in 24 months	3
Very low	once in 18 months	4
Low	once in 14 months	5
Moderate	once in 12 months	6
Moderately high	once in 10 months	7
High	once in 8 months	8
Very high	Once in 6 months	9
Almost certain	once in 4 months	10

3. **Detection (D):** Detection refers to the capacity to identify the underlying cause, mechanism, or weakness associated with an actual or potential failure. In Design FMEA, this detection process is essential prior to the component, subsystem, or system being

approved for production. In the case of Process or Service FMEA, detection must take place in a timely manner to prevent distribution issues in the case of a product or catastrophic events in the case of an Asset or Maintainable Unit. In System FMEA, detection should occur before scheduled maintenance is performed.

The level of detection is typically assessed on a scale ranging from 1 to 10, where a rating of 10 indicates a nearly complete inability to detect the fault. Generally, to achieve a lower detection ranking, there is a need to enhance the planned controls, such as preventative activities, to improve the detection capability.

Table 3: Detection Ranking

Linguistic term	Detection control	Rank
Almost certain	Almost certain	1
Very high	Very high chance of detection	2
High	High chance of detection	3
Moderate high	Slightly high chances of detection	4
Moderate	Medium chances of detection	5
Low	Low chances of detection	6
Very low	Slight chances	7
Remote	Remote chance of detection	8
Very remote	Very remote chance	9
Almost uncertain	Absolute Uncertainty of detection	10

VI. RISK PRIORITY NUMBER

One common approach in FMECA calculates a Risk Priority Number (RPN). A risk priority number (RPN) is a numerical and relative "measure of the overall risk" corresponding to a particular failure mechanism and is computed by multiplying the severity, occurrence, and detection numbers.

$$\text{RPN = Severity} \times \text{Occurrence} \times \text{Detection}$$

Inputs for the Calculation of RPN: The Risk Priority Number (RPN) is calculated using three inputs namely Severity (S), Occurrence (O) and Detection (D). The RPN is used to prioritize the failures so that the instances of failure can be minimized by taking necessary preventive measures and corrective actions. The product of severity, occurrence and detection gives the RPN.

VII. DRAWBACKS OF FMECA

1. **D_1: Ranking allocation Criterion**: The rankings of severity and occurrence may vary from person to person. Although FMEC analysis provides the guidelines for the Ranking a criterion, but it does not give any range between which it can be given.

2. **D_2: Difficulty in Ranking Detection:** While calculating the RPN value which is the product of severity, occurrence and detection, it is very difficult for one to detect a

particular failure mode in advance. Hence the ranking for detection is a difficult task. This is one of the major drawbacksin FMEC analyses.

3. **D₃: Identical RPN:** One of the major drawbacks in FMECA is getting identical RPN. The RPN is a valuable tool for setting priority. In the conventional approach, higher RPN values represent higher priority. As well known that RPN is the product of S, O, D and only 120 different RPN values are possible, while some can't occur like 17, 22, 925 and some may occur multiple times like 60, 72 and 120. It is very convenient to point out the failure mode with the highest risk if the values of RPN are different. However, it is very difficult to come to a decision if the entire failure modes have the identical values of RPN.

VIII. REMEDIES TO OVERCOME THE DRAWBACKS

1. **D1: Establishment of Range**
Before ranking severity or occurrence, a criterion on which the raking is to be made should be established. Failure mode severity can be allotted based on the sever effect on environment, or profit, or production or image etc. If a case has to be taken that the severity is ranked depending on the production loss due to the absence of machinery, then the failure mode which has more repair time has to be ranked most severe. This can be done using Total Time toRepair (TTR) which implies the time taken for repairing a particular failure. If time spent for a repair to correct the failure is high, then the unavailability of that machine is more in the field. This in turn causes a lot of production loss. In this paper it is considered that if there is huge production loss then it is taken as the most sever failure. In this paper a sample data was taken for a period and the criteria for severity ranking was established based on the time taken to repair the failure.

Duration of interruption (In hours)	Criterion	Severity Rank
>2250	Dangerously High	10
2000-2250	Extremely High	9
1750-2000	Very High	8
1500-1750	High	7
1250-1500	Moderate	6
1000-1250	Low	5
750-1000	Very Low	4
500-750	Minor	3
250-500	Very Minor	2
0-250	None	1

Each failure has certain value of occurring in the considered time. The repetition of each failure has evaluated and the count has taken in the presiding column. In this paper, daily occurring failure has taken as the most occurring one and ranked as 10. If the occurrence of a failure mode is 24, it is considered as occurring monthly. The

approximation of failure frequency was taken for occurrence ranking based on the ranking scale.

Occurrences	Criterion	Rank
Daily	Very High	10
Weekly	High	9
Fortnight		8
Monthly	Moderate	7
Bimonthly		6
Quarterly		5
Half-yearly	Low	4
Yearly		3
2 years	Remote	2
>2 years		1

2. **D_2: Use of Cause and Effect diagram, Brainstorm and Questioner form**
Detection is one of the most critical factor for establishing scale and rankings. No confined method has been developed to detect a failure. Detection ranks can be given based on the results of survey, cause and effect diagram and brain storming session. A questionnaire has prepared by the team,which consists multiple choice questions for the purpose of survey. Survey was done with the help of a questionnaire having multiple choice answers, prepared by the team by interviewing the experts in the fields. Detection rankings were made based on the survey results and also the detection ratings can be for each of the problem by the following ways

- Comparison method
- Brain storming
- Cause and effect diagram

3. **D_3: Priority based RPN ranking:**
When RPN value is equal

- **Severity Occurrence Multiple:** As a general rule, any failure mode that has effect resulting in severity 9 or 10 would have top priority. Severity is given the most weight when assessing risk. Next, the severity and occurrence (S*O) combination would be considered, since this in effect, represents the criticality.

Equal R.P.N value

S	O	D	S*O	RPN=S*O*D	RANKING
2	10	10	20	200	3
10	10	2	100	200	1
10	2	10	20	200	2

In the above table RPN value is equal. so, severity is given more importance. If severity is equal for any mode, then criticality(S*O) is given importance.

- **High Severity Failure Mode:** This is special case while considering the "threshold values" for RPN values when assessing the risk. In this case lowest RPN value is more critical

For example higher severity consideration

S	O	D	RPN	RANKING
10	2	2	40	1
3	10	2	60	2
2	5	10	100	3

Here, the failure modes with lowest RPN values are more critical. Because in RPN analysis severity is given most priority. In this case there is a large difference in severities of three modes, and higher severity case has lowest RPN. So, case failure mode 1 is taken as first ranking irrespective of RPN.

- **Maximin Approach:** A new approach has introduced in this paper to prioritize the risk priority numbers when the RPN values are identical. In general cases, it is very difficult to come to a decision when two or more failure modes have the identical RPN value. So it is desired to arrive a mechanics to prioritize the identical RPN values. This analysis was designed with an assumption that all the three variables, i.e., severity, occurrence and detection are equally important.

➢ **Step:1**
First sort out the maximum values of S, O, D for each failure mode separately. For example if there are five failure modes and the severity ranking for these five failure mode be 3, 6, 5, 8 and 4. Among these, the maximum value is 8. Similarly procedure in continued for occurrence and detection. So there will be three maximum values for S, O, D. Among these three maximum values, find out the minimum value. This value becomes the Comparative code.

➢ **Step: 2**
After calculating the comparative code, see the number of places for each failure mode for which the S, O , D values are greater that the comparative code.
For example: if comparative code is 6
FM1 5, 8, 7
FM2 2, 4, 9
FM3 1, 6, 9
In FM1 there are two values greater than 6
In FM2 there is one value greater than 6
In FM3 there is one value greater than 6
N (FM1) = 2; N (FM2) = 1; N (FM3) = 1
Critical failure mode becomes, maximum of N (FMi)'in this case FM1 is the critical failure.
But for remaining two failure modes there is a similar value. So it can be preceded to the next level.

> **Step: 3**
> Critical Failure Mode (CFM)
> $N(FM2) = \max \{ 3\text{-}4 , 8\text{-}6 , 5\text{-}5 \}$
> $\qquad\qquad = \max \{1, 2, 0 \} = 2$
> $N(FM3) = \max \{ 4\text{-}8 , 6\text{-}5 , 5\text{-}3 \}$
> $\qquad\qquad = \max \{4, 1, 2 \} = 4$

IX. CONCLUSION

FMECA is a useful tool in analyzing all the potential failure modes of a system/equipment and component. Initially a brief review has been done in the form of literature and the methodology and the basic ground work for FMECA was described. Later on the drawbacks which are encountered during the analysis of FMECA was sorted and pointed out which are ranking allocation criterion, difficulty in detection ranking and identical RPN's. These drawbacks are rectified and presented in the form of remedies. Among all the drawbacks the major drawback which was found is encountering the identical RPN's. This problem can be solved by identifying the priority constant. Maximin approach which was described in this paper is helpful in avoiding and overcoming such circumstances.

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