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Prioritizing the Equipment Failures Modes Under Epistemic Uncertainty Environment

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Abstract

This paper presents a novel approach based upon the dempster Shafer theory of evidence to prioritize the various failure modes under the epistemic environment. The potential failures in equipment can be examined by a failure mode effect analysis approach. The FMEA approach prioritizes (Rank) the various failure modes based upon the risk priority number which depends upon three factors viz severity, occurrence, and detection of failure. This approach uses the group-based consensus to reach a particular value that is subjective in nature. Thus, the result obtained is not realistic. To address this issue, we attempted to consider the epistemic uncertainty involved in the data to rank various failure modes of the equipment. A numerical illustration is provided to explain the proposed methodology.

1.Introduction

The Failure mode effect analysis is a system engineering and analysis technique in an organization to identify the trouble area of the system. According to [16] it is a bottom-up approach that initiates with known potential modes at a level and then investigates the effect at another level. This approach was first proposed by Nasa in 1963 to identify the various reliability indices. Since its inception, it has been widely used as a powerful tool in various industrial applications related to the manufacturing, aerospace and automobile sectors [8,12,5]. Generally, FMEA considers all the failure modes of components and determine their effect on the other component or system as a whole [6]. FMEA is by large group base activity in which relies upon the aggregating all FMEA team member's ratings to reach a conclusion. Traditionally the FMEA calculates the risk priority number (RPN) for assessment of failure mode based upon three criteria of occurrence, severity, and detection of failure. The RPN is calculated on the basis of multiplication of all these factors i.e. RPN = Occurrence(O) x Severity (S) x Detection (D). The traditional FMEA is a very popular technique for reliability modeling but it suffers from certain shortcomings. [13,15].
The traditional FMEA techniques limitations as discussed below.

1. The RPN is based upon the multiplication of the three factors of severity, occurrence and detection results in the same value even though all the three factors have individual values.

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2. All three factors considered in the calculation of RPN have been given the same weight, although their impact may be different.
3. The small variation in one rating can produce altogether different values of RPN.
4. It considers only three criteria for calculation of RPN and neglects another important factor such as cost etc.

As discussed FMEA is a group-based activity that needs the aggregation of the expert's ratings. In real-time, the experts give their ratings based upon their experience which is subjective in nature and sometimes experts have incomplete information available to him/ her pertaining to support their claim. To address such issues the present paper proposes the dempster Shafer based approach to robustly aggregate the expert's ratings in the epistemic uncertainty environment.

2.Literature Review

In the literature, various authors have discussed the modified methods to repress the limitations of the traditional FMEA.[16] discussed the fuzzy-based FMEA approach to calculate the risk priority number. [15] developed a new methodology of risk priority ranking to overcome the shortcomings of traditional FMEA. Various authors [4,7,9] discussed the use of which vary in used the same fuzzy inference system approach but their work different in the type of membership functions, rule base, and defuzzification methods.[7] used the fuzzy arithmetic to calculate the new fuzzy RPN and used the centroid method for further defuzzification. Further Ching et al. used the fuzzy methodology and grey theory to rank the various failures by assigning the relative weights. Besides the fuzzy logic, many authors suggested another multi-criteria decision-making techniques to improve the FMEA.[14] presented the TOPSIS technique for machine maintenance. Since the FMEA is group-based activity therefore the aggregation of individual member ratings needs attention. [20] addressed this issue and suggested a linear square method for aggregation of team members' ratings. [1] compared the two aggregation methods of averaging the individual responses and group consensus for expert's ratings.[11] carried out the FMEA for the braking system of an automobile [4] Pointed out an application of fuzzy-based FMEA for maintenance. It is observed from the above literature that although the authors used fuzzy-based and other techniques to address the limitations of traditional FMEA, all of them do consider the epistemic uncertainty involved in the data related to the expert. This paper addresses the issue of epistemic uncertainty (lack of information) with an expert using the dempster Shafer based approach for ranking the various failure modes of the equipment. A few applications of DST have been seen in the literature in various other fields.[2] presented the application of DST in finding the transport sustainability index for a city.[16] pointed out the application of DST in water quality monitoring for a distribution system.[12] pointed out the use of DST in the early design phase of the automotive industry.

3.Dempster Shafer Theory

This theory is a doctoral work of dempster which is formally extended by Shafer in 1967. According to [20] this theory is consisting of higher and lower bound belief assignments pertaining to the hypothesis under study. This theory uses three basic concepts of basic probability assignment, belief and plausibility function. All the elements under the hypothesis of a set constitute a frame of discernment which is represented by a universal set (Θ). The

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power set of subsets of Θ is 2^{Θ} which includes the null set. Every element of a subset is called as the focal element and is having a value between [0-1].

The basic probability assignment (BPA) represents the proportion of evidence available that an event belongs subset of a powerset. It is represented by (m). Mathematically it is shown as

$$\sum_{A \in P(X)} m(A) = 1$$

$$m: \mathscr{P}(x) \longrightarrow [0,1]$$

$$m(\phi) = 0.$$

Where $\mathscr{P}(x)$ is a power set of x, A is a subset in the power set ($A \in p(x)$). Usually, the value for BPA is taken from the historical maintenance data and expert opinions in case of a lack of data. The other two dual measures belief and plausibility function are used to describe the probability of an event in case uncertainty. The belief function (Bel) is the degree of belief of evidence available which supports the claim that an event is a subset of powerset. It is mathematically shown as

Bel (A) = $\sum_{B|A \subseteq B} (B)$, Bel(ϕ)=0 and Bel (Θ)=1.

The plausibility function is the higher bound of the two measures. It is given by

Pl(A)= $\sum_{B|B \cap A \neq 0} m(B)$. It is dual to the belief function.

Like BPA, both the belief and plausibility functions are mapping of power set to a unit interval.

The DST is differing from the traditional probability theory that it considers the powers set against the singleton set in the probability theory. This unique feature of DST allows it to capture all the available evidence especially in case of uncertainty. In the context of FMEA, it assigns the basic probability assignment to the set which allows using all the information available especially in case of incomplete information for the cause of failure.

4.Methodology

The FMEA technique ranks the various failures using risk priority number based upon three criteria of occurrence of failure, the severity of failure and detection of failure. As discussed in the above section the in case of incomplete information about the cause of the failure available with the expert is dealt with DST. The various factors considered are discussed below.

1. **Occurrence of failure:** It tells how frequently the failure occurs. It is generally measured by the mean between failures (MTBF). The MTBF is found from the maintenance logbooks, historical data and from the expert's experience. Table 1 shows the various ratings for the occurrence of failure.

Occurrence of Failure	Mean Time Between Failure	Ratings
Almost Never	MTBF > 3Yrs	1
Rare	1-3 Yrs.	2-3
Few	1/2-2 Yrs.	4-5
Moderate	3-6 Months	5-6
High	1-3 Months	7-8

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Very High	< 30 days	9-10

Table 1. Ratings for the occurrence of failure

2. **Severity of failure:** It is the consequences of the failure on the system and human life. The effect can range from mild to catastrophic depending upon the type of failure. The ratings for the severity of failure are shown in Table 2.

Severity of failure	Description	Ratings
Very Less Impact on human life	No Injury or loss	1-3
Less Impact on human life	Minor loss or Injury	4-5
Moderate Impact on human life	Noticeable Injury	5-6
High Impact on human life	Serious injuries	7-8
Very high impact on human life	Death of the operator	9-10

Table 2. Ratings for Severity of failure

3. **Non-detection of failure (D):** This represents the ability to find the fault by an operator with an eye and with an aid of certain diagnostic aids such as alarms, sensors, etc. The ratings are shown in Table 3.

Non-detection of failure	Ratings
Fault visible to naked eye	1
Fault detectable with the help of automatic sensors	2-3
Fault detectable with degraded performance through inspection.	4-5
Fault detectable with periodic inspection	5-6
Fault detectable with regular inspection	7-8
Fault non detectable	9-10

Table 3. Ratings for Non-Detection

To illustrate the DST approach for modified FMEA, let us consider an example of three failure modes P, Q and R for which experts are consulted to give their ratings. Since in DST we consider a power set instead of singletons, therefore we have 2^3= 8 elements consisting of the frame of discernment. The experts give ratings to all these elements for the three criteria considered above. The ratings provided by the experts are normalized to achieve the value of basic probability assignment. The expert can also provide the value of basic probability assignment to the power directly in case lack of information about the failure mode to them which is a very common scenario in an industry. Once the BPA has been assigned by the experts the value of belief and plausibility functions are calculated as per equations discussed

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above. The value for BPA, belief and plausibility function for the occurrence of failure is shown below in table 4. The experts are consulted to input the value of BPA for powerset.

Failure Modes	BPA Value (m)	Belief Function (Bel)	Plausibility Function (Pl)
Φ	0	0	0
P	0.3	0.3	0.46
Q	0.25	0.25	0.39
R	0.25	0.25	0.4
$P \cup Q$	0.05	0.6	0.75
$P \cup R$	0.06	0.61	0.75
$Q \cup R$	0.04	0.54	0.7
$P \cup Q \cup R$	0.05	1.00	1.00

Table 4. Basic Probability Assignment for Occurrence of Failure

The belief function value of 0.3 corresponding to failure mode P tells that 30% of the evidence is available with expert which supports the claim that failure is due to mode P. The belief function of 0.6 for failure modes (PUQ) shows that 60% of evidence is available to e expert which supports the claim for failure mode is either P or Q. In case the evidence is available to the direct ratings are provided by the experts as shown in tables (5-6) for Severity and non-detection of failures.

Failure Modes	Ratings by experts for severity due to failure	BPA Value (m)	Belief Function (Bel)	Plausibility Function (Pl)
Φ	0	0	0	0
P	3	0.14	0.14	0.46
Q	4	0.19	0.19	0.51
R	5	0.23	0.23	0.45
$P \cup Q$	4	0.19	0.52	0.74
$P \cup R$	2	0.09	0.46	0.78
$Q \cup R$	2	0.09	0.51	0.83
$P \cup Q \cup R$	1	0.04	1.00	1.00

Table 5. Basic Probability Assignment for Severity of Failure

Failure Modes	Ratings by experts for Non detection of failure	BPA Value (m)	Belief Function (Bel)	Plausibility Function (Pl)
Φ	0	0	0	0
P	6	0.21	0.21	0.53
Q	5	0.17	0.19	0.49
R	5	0.17	0.19	0.46
$P \cup Q$	4	0.14	0.52	0.81
$P \cup R$	3	0.11	0.49	0.81
$Q \cup R$	3	0.11	0.45	0.77

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$P \cup Q \cup R$	2	0.07	1.00	1.00

Table 6. Basic Probability Assignment for Non-Detection of Failure

Based upon the belief and plausibility values for the three parameters, the combined values of Belief and plausibility function are calculated by multiplying the corresponding values and the ranking is done on the basis of higher plausibility values as shown in Table 7. Since the failure mode P gets the highest plausibility value so that it is the most critical failure mode and needs attention.

Failure Modes	Occurrence of Failure (O)		Severity (S)		Non-Detection of failure(D)		Combined Values of Belief and Plausibility(x1000)		Priority Ranking (RPN)
	Belief	Plausibility	Belief	Plausibility	Belief	Plausibility	Belief	Plausibility	
P	0.3	0.46	0.14	0.46	0.21	0.53	0.00882	0.112148	I
Q	0.25	0.39	0.19	0.51	0.19	0.49	0.009025	0.097461	II
R	0.25	0.4	0.23	0.45	0.19	0.46	0.010925	0.0828	III

Table 7. Ranking of failure modes based upon DST.

5.Conclusion

The FMEA is widely used in the industry but it has its own shortcomings which are addressed by various authors, but they did not address it in the light of epistemic uncertainty. The paper presents a framework for risk priority ranking of the failure mode under epistemic uncertainty in context to FMEA based upon the Dempster Shafer theory. This approach overcomes the shortcomings of the traditional FMEA technique by aggregating the expert's knowledge and experience. This approach uses the concept of belief and plausibility functions to rank the various failure modes which are more realistic in nature as there is a lack of information about the maintenance data available with the expert.

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