A REVIEW ON THE METHODOLOGIES USED IN FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

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Abstract - Failure mode and effect analysis is a risk evaluation technique that minimizes potential failures in any process or machine or system. The risk priority number forms the basis for prioritizing the failure modes. However, this method has been criticized as it has many deficiencies and various risk priority models have been proposed in the literature that has been reviewed in the paper. The paper reviews the literature pertaining to the Failure modes and how the models are proposed based on the decision making techniques. The fuzzy logic is seen to be the most common technique that has been used by various authors. But it still has some limitations which have been identified in this paper. The paper also describes the methods to overcome these limitations. Though various authors have proposed various methods, optimization techniques have never been used. After the review the authors suggest the use of optimization techniques to be used to overcome the limitations that have been found out in this paper.

Keywords: Decision Making, FMEA, Failure, Prioritization of failure.

I. INTORDUCTION

In the present generation, manufacturing is considered as the backbone of any industrialized nation. It comprises approximately 20 to 30% of all goods and services produced.[1] The industries cannot be expected to encounter failures, as they would cause an incredibly huge loss to the production rate. To reduce the failure rates in any industry, it is necessary to understand the failure that has occurred and narrow down to the reasons that had caused it. Several failure analysis techniques are applied to find out the reasons for failure. In this paper the failure analysis techniques employed by various experts has been reviewed and the suggestion for using a new method to select the critical failure mode is also made, which is different from the conventional techniques used. The paper is arranged in the following manner the traditional FMEA method is given in the section 2 followed by the literature survey which is section 3. The last two sections are the observations and findings and the conclusions are given in the last sections.

II. TRADITIONAL FMEA

Failure mode and effects analysis (FMEA) was first developed as a formal design methodology in the 1960s by the aerospace industry with their obvious reliability and safety requirements (Bowles and Pel´aez 1995). It is a structural and preventive reliability analysis approach that starts with known potential failure modes at one level and investigates their effects on the next and higher level of system hierarchy (Sharma, Kumar, and Kumar 2005).When it is used for a criticality analysis; it is also referred to as failure mode, effects and criticality analysis (FMECA). The purpose of FMEA is to identify potential failure modes, evaluate the causes and effects of different component failure modes, and determine what could eliminate or reduce the chance of failures, thereby providing information for making risk management decisions. Today, FMEA has been extensively used as a powerful tool for system safety and reliability analysis of products and processes in a wide range of industries, such as the aerospace, nuclear, automotive, electronics and medical industries (Chang and Cheng 2011; Chin, Wang, Poon, and Yang 2009b; Liu, Liu, and Liu, 2013; Liu et al. 2011; Sharma, Kumar, and Kumar 2008). To assign the limited resources to the most serious risk items, the risk of each identified failure mode needs to be evaluated and prioritized. Conventionally, the prioritization of failure modes is performed by developing a risk priority number (RPN), which is the mathematical product of three risk factors, i.e. RPN= O x S x D. Where O is the probability of the failure occurrence, S is the severity of the failure and D is the probability of the failure not being detected. In general, the three factors are scored by experts with a numeric scale from 1 to 10 based on commonly agreed evaluation criteria. A failure mode that has a higher RPN is assumed to be more important and will be given higher priority for correction than those with lower RPN values.[10]

III. LITERATURE SURVEY:

Xiaoyan Su et al. have presented an improved method to perform failure modes and effects analysis. They have improved the modification that yang et al. had done to the Dempster Shafer theory (DST). The DS theory has been used in recent times in FMEA due to its ability to process indeterminate information. To deal with the imprecision and uncertainty in FMEA, Yang et al. employed Dempster–Shafer evidence theory to quantify the imprecision and uncertainty in reliability and failure analysis and applied it to the risk priority evaluation of failure modes of rotor blades of an aircraft engine. Their method used DS theory's combination rule to fuse together different opinions which may be uncertain. However when the experts gave different values Yang et al. formulated the Basic Belief Assignment (BBA). But by this method the highly conflicting evidence could not be combined by using Dempster's combination rule. Therefore, Xiaoyan Su et al. had suggesting modifying the original evidence by using normal distribution. They had made a supplementary modification to construction of BBA by using normal distribution.[2] After determining the BBA and evaluating the function they have used risk priority number (RPN) to determine the severity of the failure. Myoung-suk Kang et al. have conducted the design failure mode and effect analysis for Korean demo fusion plant. They have conducted research in deterministic and probabilistic approach safety analyses. After this they had developed a function tree. They have identified the various failure modes and used these as the safety consideration to form the design paramenters. T. Senthilvelan et al. have performed FMEA on a sugar mill boiler and have optimized it. They have first created a cause and effect diagram to identify the various causes for the failure of the boiler. In this case they have taken the drum stoppage as the major failure of boiler based on the expert reviews. Then they have assigned the risk priority number to the various failure modes that have been identified using cause and effect diagram. Then they have optimized it using the Taguchi method, to improve the quality by reducing fuel feeder failure. Again, this fuel feeder failure was concluded as the most critical for the stoppage of drum by using RPN. The Taguchi methods' tools used were S/N ratio and orthogonal array. Kwai-Sang Chin et al. have used the data envelopment analysis technique to determine risk priorities in failure modes. The DEA is a performance measurement tool. The proposed FMEA measures the maximum and minimum risks of each failure mode. The two risks were then geometrically averaged to measure the overall risks of failure modes. The risk priorities are determined in terms of overall risks rather than maximum or minimum risks only.[3] They have criticized the conventional RPN method because:

- The hidden risk implications of the two events may not necessarily be the same. This may cause a waste of resources and time, and in some cases a high risk event may go noticed.
- The relative importance among O, S and D is not taken into consideration.
- The mathematical formula for calculating RPN is questionable and debatable.
- The three risk factors are difficult to be precisely evaluated.

They have defined the risks of failure modes as the weighted sum or weighted product of risk factors, and developed DEA models for measuring the maximum and minimum risks of failure modes. The geometric averages measure the overall risk of each failure mode and are therefore used for prioritizing failure modes.

Kwai-Sang Chin et al. have also proposed FMEA using group based evidential reasoning approach. They had developed the risk priority model using the ER approach and incorporate the relative importance weights of risk factors into the determination of risk priority of failure modes. They had developed a risk priority model for FMEA using the ER approach to model the diversity and uncertainty of the assessment information in FMEA. The new model allows FMEA team members to assess risk factors independently and express their opinions individually. It also allows the risk factors to be aggregated in a rigorous yet nonlinear rather than simple addition or multiplication manner.[4] Anand Pillay et al. have criticized the method that traditional FMEA employs to achieve a risk ranking. Their arguments match with those of Kwai – Sang Chin et al. They have proposed an approach using fuzzy rule base and grey relation theory to address these setbacks. A fuzzy rule base is used to rank the potential causes identified within the FMEA, which would have identical RPN values but different risk implications. The approach then extends the analysis to include weighting factors for Sf, S and Sd using defuzzified linguistic terms and grey relation analysis.[5] They have then applied their theory to a fishing vessel similar to Kwai-Sang Chin and validated their theory. Hu-Chen Liu et al. have presented the FMEA analysis integrated with VIKOR method under fuzzy environment. In traditional FMEA, the risk priorities of failure modes are determined by using risk priority numbers. However, the crisp RPN method has been criticized to have several deficiencies. In this paper, linguistic variables, expressed in trapezoidal or triangular fuzzy numbers, were used to assess the ratings and weights for the risk factors O, S, and D. For selecting the most serious failure modes, the extended VIKOR method was used to determine risk priorities of the failure modes that have been identified. As a result, a fuzzy FMEA based on fuzzy set theory and VIKOR method has been proposed for prioritization of failure modes, specifically intended to address some limitations of the traditional FMEA. [6] Ying-Ming Wang et al. have found out that the traditional FMEA methods are not completely reliable as the failure modes cannot be precisely evaluated, they have suggested that the failure modes can be calculated by using fuzzy risk priority numbers (FRPN). The FRPN have been proposed for prioritization of failure modes. The FRPN have been defined as fuzzy weighted geometric means of the fuzzy ratings for O,S,D and have been computed using the alpha level sets and linear programming models. For the ranking purpose, the FRPN were defuzzified using centroid defuzzification method, in which a new centroid defuzzification formula based on alpha level sets was derived.[7] Zaifang Zhang, Xuening Chu have prioritized risk in failure modes under uncertainty. They also have proposed the fuzzy methods and linear programming methods as a solution for the calculation of fuzzy RPNs. This is because they have also found that the traditional FMEA is vague and uncertainty exists in the traditional method. First, decision makers tend to use multigranularity linguistic term sets for expressing their assessments because of their different backgrounds and preferences. Second, numerical compensation may be existed among O, S and D that can derive different RPNs in the engineering applications. Third, the complete ranking results for fuzzy RPNs may be easily changed by the effects of uncertain factors. In this study, a fuzzy-RPNs-based method integrating weighted least square method, the method of imprecision and partial ranking method was proposed to generate more accurate fuzzy RPNs and ensure to be robust against the uncertainty. [8] Hu-Chen Liu, et al. have proposed the Fuzzy Failure Mode and Effects Analysis Using Fuzzy Evidential Reasoning and Belief Rule-Based Methodology. They proposed a new risk priority model for prioritizing failures in failure mode and effects analysis (FMEA) on the basis of fuzzy evidential reasoning (FER) and belief rule-based (BRB) methodology. The technique could resolve some of the shortcomings in fuzzy FMEA (i.e., fuzzy rule-based) approaches. The risk factors like occurrence (O), severity (S), and detection (D), along with their relative importance weights, were described using fuzzy belief structures. The FER approach was used to capture and aggregate the diversified, uncertain assessment information given by the FMEA team members; the BRB methodology is used to model the uncertainty, and nonlinear relationships between risk factors and corresponding risk level; and the inference of the rule-based system is implemented using the weighted average-maximum composition algorithm. The Dempster rule of combination was then used to aggregate all relevant rules for assessing and prioritizing the failure modes that have been identified in FMEA.[9] Hu-Chen Liu also presented Failure mode and effects analysis using intuitionistic fuzzy hybrid weighted Euclidean distance operator. They developed an efficient and comprehensive risk assessment methodology using intuitionistic fuzzy hybrid weighted Euclidean distance (IFHWED) operator to overcome the limitations and improve the effectiveness of the traditional FMEA. According to their method, the diversified and uncertain assessments given by FMEA team members are treated as linguistic terms expressed in intuitionistic fuzzy numbers (IFNs). Intuitionistic fuzzy weighted averaging (IFWA) operator has been used to aggregate the FMEA team members' individual assessments into a group assessment. IFHWED operator has been applied thereafter to the prioritization and selection of failure modes. Particularly, both subjective and objective weights of risk factors are considered during the risk evaluation process.[10] S.M. Seyed-Hosseini et al., have proposed the Reprioritization of failures in a system failure mode and effects analysis by decision making trial and evaluation laboratory technique. The authors have given an effective methodology related to decision making field for reprioritization of failure modes in a system Failure Mode and Effects Analysis (FMEA) for corrective actions. The proposed methodology covered some of inherent shortcomings of conventional Risk Priority Number (RPN) method. Traditional methods have two main deficiencies as: they have not considered indirect relations between components and are deficient for systems with many subsystems or components. The proposed method called Decision Making Trial and Evaluation Laboratory (DEMATEL) is effective for analyzing relation between components of a system in respect to its type (direct/indirect) and severity.[11] Seyed-Hosseini, Safaei, and Asgharpour (2006) proposed a method called decision making trial and evaluation laboratory (DEMATEL) for reprioritization of failure modes in a system FMEA for corrective actions. In the proposed methodology, the failure information in FMEA was described as a weighted diagraph, where nodes indicate the failure modes or causes of failures and directed connections (edges) indicate the effects failure modes on together. Also, the connection weights indicate the degree or severity of effects of one alternative on another. An indirect relationship was defined as a relationship that could only move in an indirect path between two alternatives and meant that a failure mode could be the cause of other failure mode(s). Alternatives having more effect to another were assumed to have higher priority and called dispatcher and those receiving more influence from another were assumed to have lower priority and called receiver. As a result, the prioritization of alternatives can be determined in terms of the type of relationships and severity of influences of them on another.[12] Zammori and Gabbrielli (2011) presented an advanced version of the FMECA, called analytic network process (ANP)/RPN, which enhances the capabilities of the standard FMECA taking into account possible interactions among the principal causes of failure in the criticality assessment. According to the ANP/RPN model, O, S and D were split into sub-criteria and arranged in a hybrid (hierarchy/ network) decision structure that, at the lowest level, contains the causes of failure. Starting from this decision-structure, the RPN was computed by making pairwise comparisons. In order to clarify and to make evident the rational of the final results a graphical tool was also presented in the paper.[13]

IV. OBSERVATIONS & FINDINGS:

The findings from the papers are that the most popular approach is the fuzzy logic approach as there is the ease with which the variables might be compared. The various advantages are as follows:

- The uncertain information, the ambiguous and unquantifiable information as well as quantifiable data can be analyzed in a convenient manner.
- It helps to combine the variables in a flexible manner and one in which not much losses are there.
- Allows for the risk evaluation based on the output
- The fuzzy logic can be fully incorporated to help the engineer to analyze the cost also.

A. LIMITATIONS

The limitations that have been found from the approaches are that the fuzzy expert system includes three phases namely fuzzification, inference, and defuzzufification. The risk factors are fuzzified using membership functions, to help relate each of them perfectly. The resulting fuzzy inputs are evaluated in fuzzy inference engine, which makes use of well defined rule based consisting of if then rules and fuzzy logic operator. The fuzzy conclusion is then defuzzified to get the RPN. Several limitations are:

- It is difficult to assign the various membership functions for factors of risk and the priority levels.
- It suffers the combinational rule explosion problem. The rules are huge in number and hence the tedious the process becomes as large number of rules gives better accuracy.
- The fuzzy construction is not easy as it requires a lot of time to construct functions and hence is time consuming
- The fuzzy if then rules are unable to be distinguished from one another. As a result the failure modes characterized from one another
- Information is lost when the when the complex calculations for producing the precise risk results without losing too much information.
- It is difficult to design appropriate software packages for risk input and output and failure priority.

The most common shortcoming around traditional FMEA is the relative importance among O, S, and D is not taken into consideration.

CONCLUSION

Due to disadvantages in the traditional FMEA and the risk factors many risk priority models were proposed. After the review of the papers the authors suggest that since fuzzy logic is the most widely used method, because of its capacity of selecting the variables in a flexible manner and realistic manner, the method has to be used. The outcome can then be optimized by using the teacher learner based optimization as this helps to select the output of the decision making in the first step. Hence the final method is to be as follows. First the variables have to be selected based on the fuzzy logic and then the risk priority has to be concluded. Then to check if the limitations have been overcome and to provide a revised method the output has to be optimized using the teacher learner based optimization technique so that the final optimized risk priority may be concluded from the optimization technique.

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