A Review of Failure Mode Effect and Criticality Analysis (FMECA)

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Abstract

FMECA is being used extensively in the manufacturing sector to assess risks. Risk assessment mainly helps deliver a quality product to the customer on time. This would enhance customer satisfaction. This would also improve the company's reputation in front of the customer. FMECA would help anticipate modes of failures and thus would make the machine available when required. The reliability of the machine tool is very significant, and every effort must be made to make the machine up and running whenever its service is required. FMECA would help improve the machine availability, which will help deliver a quality product to the customer. The present research work aims to (i) study methods related to FMECA proposed by researchers, (ii) understand the advantages and limitations of various methods, (iii) Identify the research gaps and provide directions for future research. The paper concludes that the researchers must explore performing risk analysis in other sectors, which remained untouched. Much work remains to be done in the occupational health and safety associated risks.

Keywords:
FMEA, FMECA, DEMATEL, Risk analysis, Risk identification

1. Introduction

Customer satisfaction is possible only when quality products are delivered on time. To provide quality products, machines should be available, when required. FMECA would help in identifying possible modes of failure of a machine tool. Thus, FMECA would help in improving the availability of a machine tool. Identification of equipment failure modes is attempted in many sectors such as steel manufacturing, machine tool manufacturing, electronic industries, and paper manufacturing. Identifying failure modes would help prevent equipment failure and the associated downtime. The equipment downtime might result in delayed product deliveries and customer dissatisfaction. This clearly shows the importance of FMECA. The following paragraphs will highlight the methods proposed by different researchers for identifying failure modes along with advantages and limitations. This research also makes an effort to identify research gaps and provide recommendations for future research as this would help academicians, researchers, and practitioners interested in pursuing further study.

2. Research Methodology

In the present research, the following steps are followed.

1. Collect reputed papers from the SCOPUS database
2. Classify the technical articles based on topic
3. Studying the technical papers with a focus on merits and demerits
4. Identifying research gaps.
5. Future directions

3. Literature Review

FMEA was designed and developed by Grumman in America in 1950 for performing failure analysis. Ford Motor Company implemented FMEA. Many researchers have contributed to developing methods related to FMECA (Chang

2014, Dabbagh 2019, Gu 2019, Liu 2015, Mirzaei 2016, Kiran M.B. 2021). They have studied how failure modes and causes are related to risk factors. They have demonstrated the significance of identifying failure modes and risk analysis in automobile industries. Dabbagh et al. (2019) proposed techniques for assessing work-related risk and employee safety. They have stressed the importance of studying occupational health and safety risks. The hybrid method was based on FCM and MOORA. The technique identified the occupational health and safety risks and ranked the identified risks. The study shows that identifying and prioritizing occupational hazards should help minimize workplace accidents and diseases. The study showed how identifying occupational health and safety risks would help provide both corrective and preventive measures. They have also demonstrated that the hybrid method is better than the Risk priority number (RPN) based on normal FMEA. The technique reflects both risk evaluation and risk ranking. The RPN method utilizes three parameters –failure severity, failure probability, and failure detecting probability- to explain failure mode. The failure mode with the highest RPN value should require immediate attention. To overcome the drawback of the FMEA, Bragilla (2000) developed FMEA using Analytical Hierarchy Process. Carpitiella et al. (2018) studied the FMECA with the multi-criteria procedure to identify failures in automobile manufacturing.

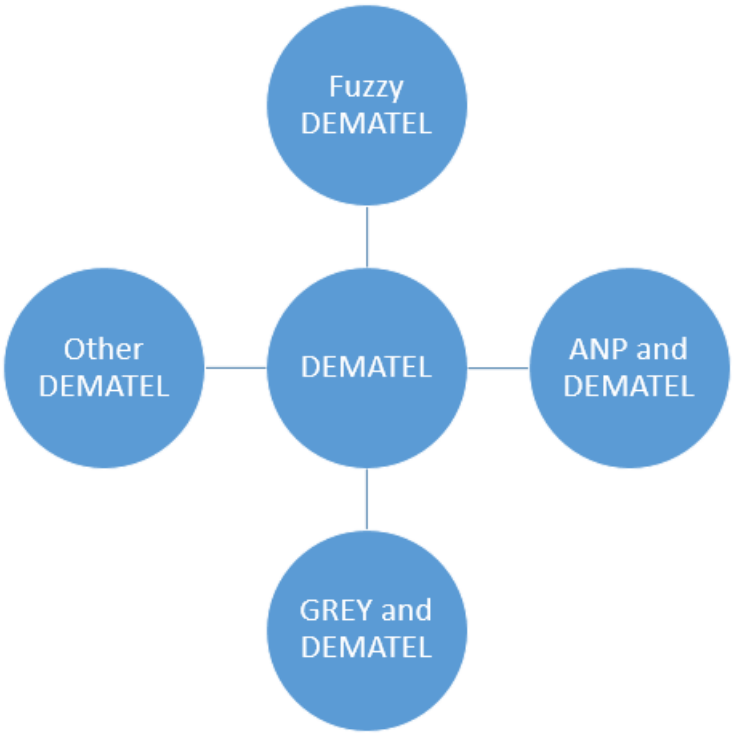

Figure 1. Classification of DEMATEL technique

Baghery et al.(2018) studied failure identification and classification for automobile spare parts manufacturing, using data envelopment analysis and gray relational analysis. They identified problems with RPN-based prioritization and its inability to prioritize critical processes. They proposed the PFMEA technique to overcome these problems. Using PFMEA, they could able to identify all failures. Then for performing prioritization, they used interval data envelopment analysis (DEA). Yousefi et al. (2018) have stressed the importance of studying health, safety, and environmental (HSE) risks and found that the existing RPG-based FMEA could not be applied for HSE risk prioritization. They proposed a DEA-based technique for classifying HSE risks successfully. They have demonstrated how organizations can enhance productivity by properly prioritizing HSE risks. Chang et al. (2014) have studied spare parts manufacturing failure prioritization by TOPSIS technique. They identified many drawbacks with the existing RPN-based FMEA method. They proposed a TOPSIS and DEMATEL (DM) process to rank the risks (Figure 1). This technique is very effective in identifying the relationships among the components of a complex system. This method would greatly help researchers and practitioners in solving complex problems. Literature reported researchers using DM in many sectors, including but not limited to control systems, in formulating marketing strategies, developing managers' capabilities, and making group decisions.

Many researchers (Figure 2) have been working on DM and proposed many variants. DM would extract the associations existing among system elements and classify them to help make decisions. Ranjan et al. (2016) have analyzed Indian Railway zones using DM. In DM, values are given to the relationships of factors for establishing a model. In reality, human judgments are not explicit, so numbers cannot represent a given situation. To solve this situation, Fuzzy logic was applied to DEMATEL (Wu 2007, Liou 2008, and Tseng 2009). In this method, expert's unclear judgments as Fuzzy sets into integer values for constructing matrix and then DM is applied. A fuzzy scale is established to convert very high and slightly less into numbers in this approach. Kuo (2011) used this technique to determine the location of a distribution center.
Many researchers have been trying to expand the scope and strength of DM by mixing it with other MCDM methods. Altuntas et al. (2014) proposed a method that includes a combination of ANP for classification and TOPSIS. The process also uses Fuzzy DM for providing answers to the facility layout problem. To determine the optimum location for starting a new facility. The location selection for a facility is an essential class of facility layout problems. The choice of location involves consideration of both supplier and customer. The facility layout problem is complex and is an NP-hard problem. Fuzzy logic and DEMATEL (FD) were applied in the manufacturing and service sectors (Tseng et al., 2009).

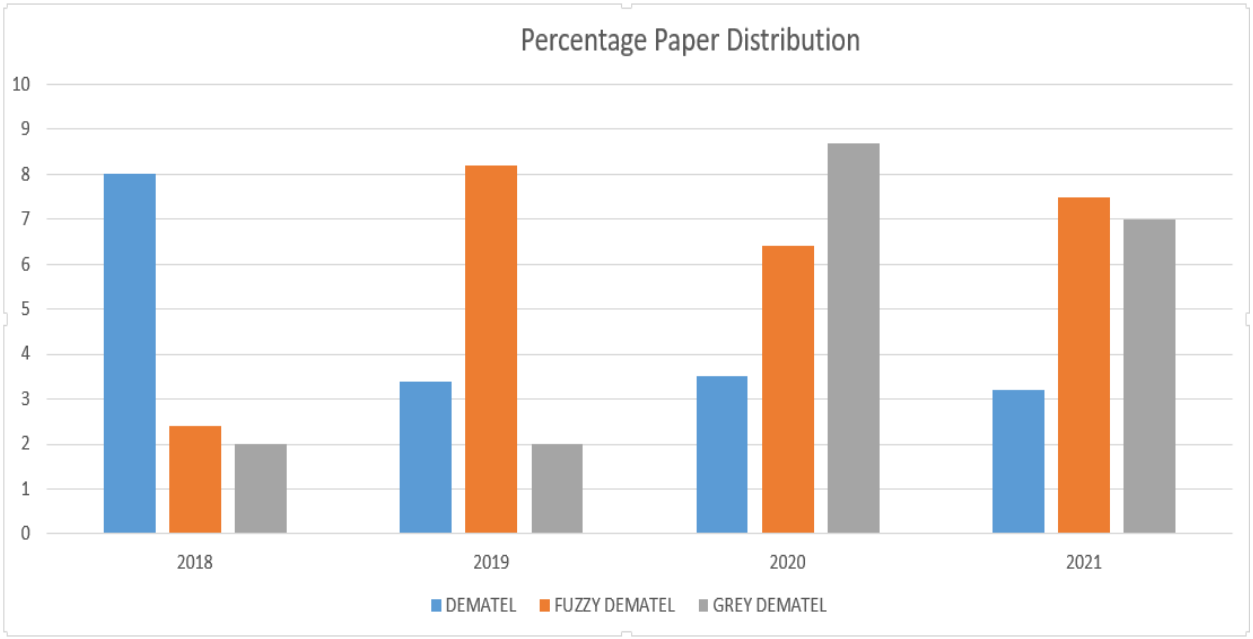

Figure 2. Percentage distribution of Technical papers from 2018 to 2021 on topic wise

In their study, they measured service quality assessment in a hotel. They have demonstrated FD implementation. Tyagi et al. (2015) explored the performance assessment of SCM using this technique. For SCM to excel, all the supply chain components must work coordinated. Sharing critical information is very significant for a supply chain (SC), as all the SC components know the status of different activities in real-time. This will also enhance the transparency and trust among all the supply chain members. Every supply chain design is unique in terms of challenges. Visibility is also brought inefficiency to the supply chain. Designing a company's supply chain is a complex activity and making all the components work in coordination is very challenging. With the advent of Industry 4.0, many researchers have started designing SCM using Industry 4.0 technologies. Wu et al. 2015 have analyzed the green supply chain and identified critical factors that would enhance productivity under conditions of uncertainty. One of the challenges of a company's supply chain is demand volatility. Researchers have proposed best practices for managing supply chain volatility.

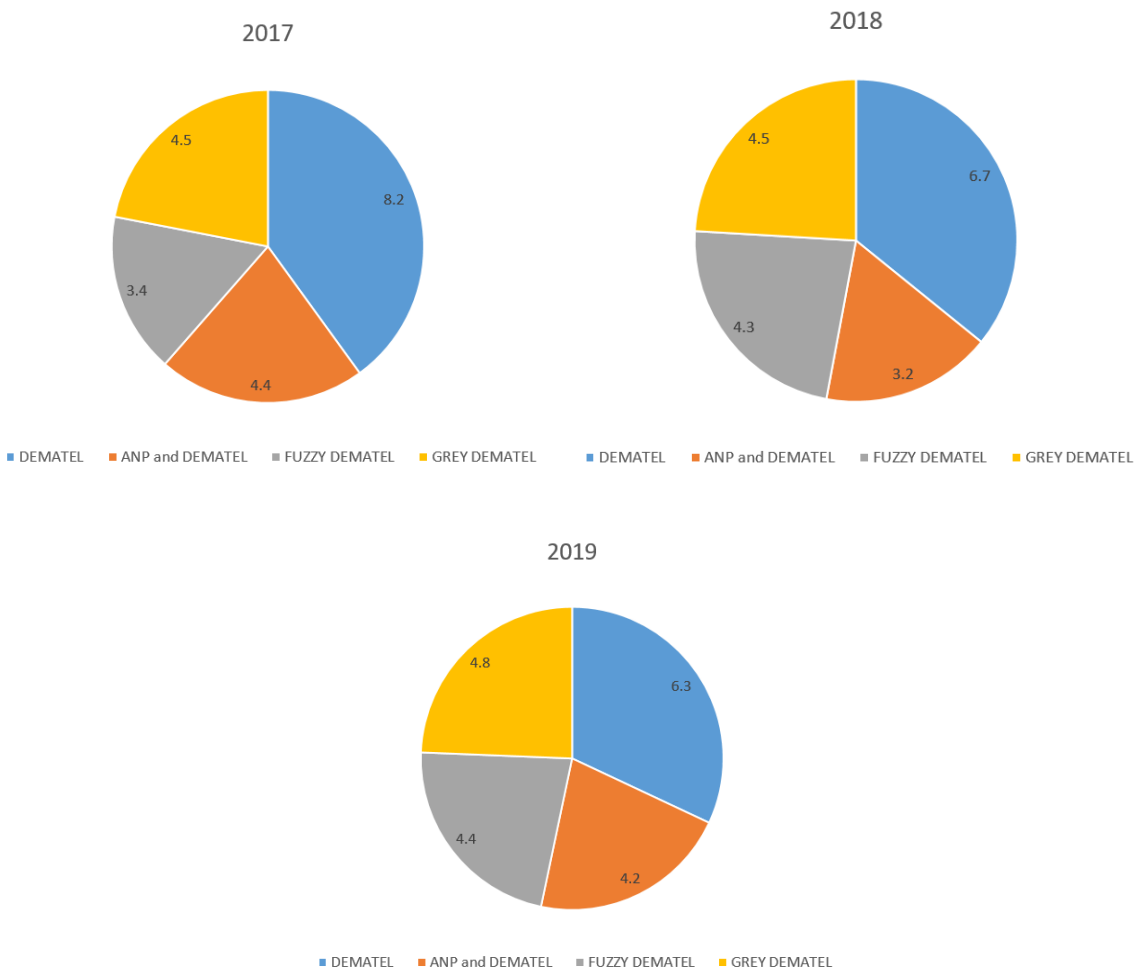

Figure 3. Percentage distribution of papers on topic wise fin 2017, 2018 and 2019

Patil et al. (2013) studied knowledge management aspects in the company's supply chain and identified the critical factors for implementing knowledge management. Altuntas et al. (2016) studied essential elements for success in marketing in small and medium scale industries using FD. Kabak et al. (2016) explored the critical factors necessary for success in the manufacturing industry using FD; Luthra et al. (2016) studied essential elements needed for high performance in the solar sector using FD. They studied the effect of different enablers on strategies regarding development initiatives in India. The study showed that FD could handle uncertainties involved with various enablers. Researchers have tried comparing DEMATEL with other MCDM methods (Figure 3).

Deng (1989) proposed a technique based on grey theory. The method is applicable for analyzing theoretical systems having incomplete information. The grey DEMATEL (GD) can solve many types of real-world problems. To be competitive in today's world require the implementation of GSDP. These modeling tools would help make the companies environmentally competitive. Fu et al. (2012) have studied green supplier development (GSDP) initiatives at telecommunication system providers, using the GD technique. They identified the need for the models for evaluating GSDP initiatives. The authors have studied interrelationships among influencing factors by converting grey values into real numbers by the CFCS method. DEMATEL technique is then applied to obtain IRM. The authors took input from multifunctional managers during the study to evaluate GSDP. The research showed the significance of understanding the relationships of different programs. This was first implemented in China. The failure modes analysis is used across multiple industrial sectors (Figure 4).

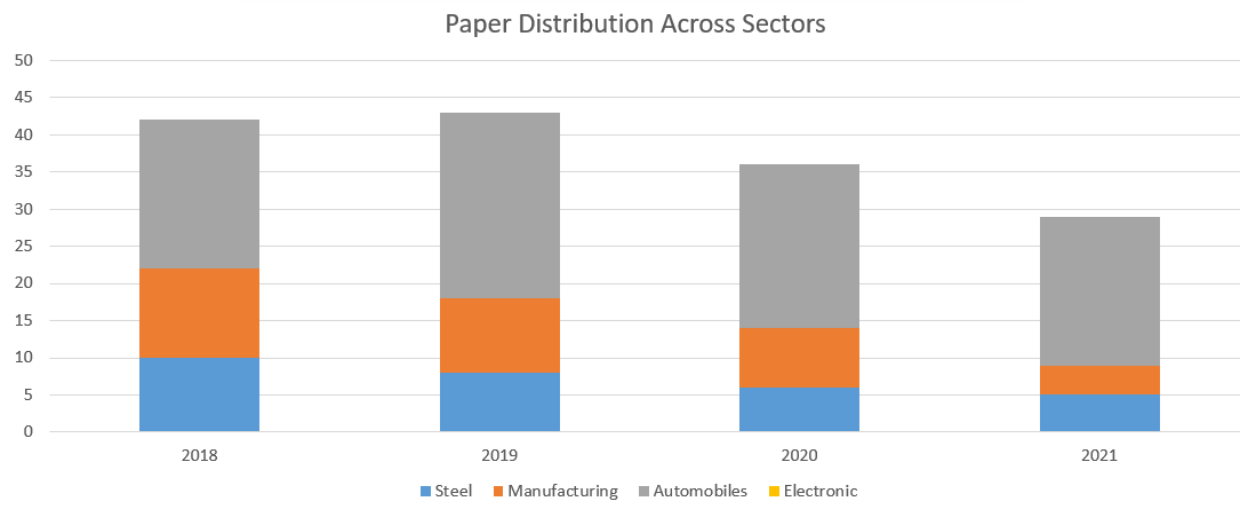

Figure 4. Paper distribution across sectors

Rajesh et al. (2015) have applied the GD technique for evaluating the enablers in the supply chains of an electronic manufacturing company. Their review work was focused on supply chain risk management (SCRM). They studied technical articles published from 2005 to 2018. They concluded that many researchers focused on quantitative methods and simulation techniques to evaluate supply chain-associated risks. The study focused on strategies used to mitigate supply chain-associated risks. The study also concluded that researchers least attempted the risk prevention strategy.

FD method involves the following steps.

1. To study the factors and their relationships using a Fuzzy scale.
2. To construct the direct influence fuzzy matrix (Z)
3. To generate the standard fuzzy matrix ($Z_R = = \frac{Z}{R}$)
4. To calculate the total influence matrix(T)
5. To calculate IRM: Row +Column and Row-Column of matrix T. Conversion of fuzzy numbers Row+Column and Row-Column into real numbers using defuzzification algorithm.

The causes of soldering failure and the failure modes were prioritized using a Fuzzy interference system. The method uses entropy measurement and GRA (Tsai et al., 2015). This work mainly focuses on identifying failure modes during the soldering process, and finally, these failure modes were classified for decision making. Guo (2016) analyzed aerospace electronic manufacturing companies' attempts to study failures and organize failures using intuitionistic fuzzy sets (IFS). The method also makes use of DM. They claimed that their approach is superior to the conventional RPN-based technique. Lo et al. (2018) studied failure modes in a smartphone manufacturing company. The study classified the different failure modes using MCDM and FMEA techniques. They added the expected cost while computing RPN. They applied their proposed model to an electronic industry for measuring effectiveness. They used grey theory to overcome some of the advantages of FMEA. The method uses grey interval linguistic variables for uncertainty management. In this method, failure mode classification was done using BWM. The researchers also claimed that their approach applies failure mode identification in a product manufacturing company. Vahdani et al. (2015) have identified failure modes in steel manufacturing companies by using the new FMEA technique. This technique combines TOPSIS and will also be using belief structure to eliminate the shortcomings of the traditional FMEA. The merit of this method is that the weights of components can be different—this way, the authors claim that their technique is close to accurate world decision-making. The method makes provision to define risk factors in meaningful ways. In this technique, expert judgments are attached with belief degrees. In this method, TOPSIS is used to classify the failure modes. The technique is an improved risk evaluation technique.

Bhulyan et al. (2022) have identified economic indicators in the prediction of Bioenergy. In 14 developed economies, they made this prediction by using random forest and FDM. They used both quantitative as well as qualitative data in the prediction process. They verified the result of their method by performing sensitivity analysis. The prediction was both accurate and reliable.

Hasan Dincer et al. (2022) studied the cost management aspects of renewable energy projects. The method is used for selecting appropriate policies for low-carbon projects. They measured the accuracy of the result by using the VIKOR technique. They concluded that employee qualification is essential for completing the tasks. Bibhas Chandra Giri et al. (2022) have used PFDT for selecting suppliers in a company's supply chain management. The result showed that the method is applicable even if the information is incomplete or uncertain. Peng Li et al. (2022) have studied the critical factors that would help select renewable energies. They used DM to select appropriate elements and used the method for evaluation. They found that the procedure is applicable in solving complex problems. The process also uses MILP for simultaneous ranking of results.

4. Conclusion

FMECA is a handy tool for Risk analysis. Researchers have designed hybrid approaches to improvise conventional FMECA—the hybrid approaches help solve problems. Risk analysis methods have been employed in many industries. There is a need to design and develop a robust and accurate risk analysis method for solving complex industrial problems. Risk analysis is reported in specific manufacturing, machine tools, electronics, energy, and automobile sectors. The researchers are required to explore performing risk analysis in other sectors. Much work remains to be done in the Occupational health and safety associated risks.

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Acknowledgments

The Author would like to thank the management of Pandit Deendayal Energy University, for supporting this work.

Biography:

Dr. M. B. Kiran is working as Associate Professor at Pandit Deendayal Energy University in Mechanical Engineering Department. He has been guiding several Research scholars pursuing MTech. and Ph.D.
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