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A Systematic Literature Review of Failure Mode and Effect Analysis (FMEA) Implementation in Industries

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Failure mode and effects analysis (FMEA) is a risk assessment tool that mitigates potential failures in systems, processes, designs, or services and has been used in a wide range of industries. The conventional risk priority number (RPN) method has been criticized for having many shortcomings. Various risk priority models have been proposed in various literature to improve the performance of the FMEA itself. However, there has been no literature review on this topic. This study reviewed 50 FMEA papers published between 1998 and 2019 in international journals and categorized them according to various industry and industry output. The automotive and manufacturing industries dominated the implementation of FMEA. For the industry's production: goods and services, mostly dominated by interests in implementing FMEA in their industries. Hopefully, this finding will be useful for goods and services industries willing to implement FMEA, especially the services industry.

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1. INTRODUCTION

Failure mode and effects analysis (FMEA), first developed as a formal design methodology in the 1960s by the aerospace industry, has proven to be a useful and powerful tool in assessing potential failures and preventing them from occurring. FMEA is a technique to analyze, identify, determine, and eliminate a known failure, problem, or error with the potential of a system, design, process, or service before they reach the customer. The primary purpose of FMEA is to identify potential failure modes, evaluate the causes of failure and the effects of various component failures. The analysis results can help analysts identify and correct the failure modes that have a detrimental effect on the system and improve its performance during the stages of design and production. And FMEA has been widely used in various industries, including aerospace, automotive, nuclear, electronics, chemical, mechanical, food and beverage, education, construction, medical technology, and other industries. It is frequently observed that productivity is related to guidelines for productivity improvements achieved through strategic planning (Gold, 1985). As a sector that contributes to more than 50% of Gross Domestic Product (GDP) in the global economy, the service

sector's importance will grow in the future (Gecky et al., 2010). Currently, most FMEA is used for industrial production that produces the goods, and not much services industry using FMEA method.

2. LITERATURE REVIEW

FMEA is an important technique used to identify and eliminate known failures or have the potential to improve the reliability and security of complex systems and is intended to provide critical information for making decisions in risk management. To analyze a specific product or system, a cross-functional team should be established for carrying out FMEA first. The first step in FMEA is to identify all possible potential failure modes of the product or system by a session of systematic brainstorming. After that, critical analysis is performed on these failure modes taking into account the risk factors: occurrence (O), severity (S), and detection (D). The purpose of FMEA is to prioritize the failure modes of the product or system to assign limited resources to the most serious risk items. In general, the prioritization of failure modes for corrective actions is determined through the risk priority number (RPN), which is obtained by finding the multiplication of the O, S, and D of a failure. That is: RPN = O x S x D. FMEA is a structured technique that can help in identifying all failure modes within a system, assessing their impact, and planning for corrective actions, and to extend the application of FMEA to risk management in the construction industry (Abdelgawad & Fayek, 2010). In FMEA, component failures are linked to risk events, while each failure can become the object of detailed failure analysis and corrective action planning (Aboutaleb et al., 2019). Due to innovation in implementing and managing projects, effective use of Failure Modes and Effects Analysis (FMEA) technique has been proposed (Bahrami et al., 2012). FMEA aims to delight and satisfies the customer by preventing failures that may occur at all levels from product conception to its completion for delivery to ensure improved quality and reliability of product delivered in time for the user (Belu et al. 2013).

3. RESEARCH METHOD

This research aims to explore deeper into FMEA implementation in various industries. The study was carried out using the goals in mind. The terms' FMEA' and 'Implementation in Industries' were used to search for articles. The range of journals published for this research from year 1998 to 2019. This research was conducted by reviewing 80 papers found using FMEA. However, 30 journals did not meet the requirements and aspects discussed. So it can be concluded that there are only 50 journals left in accordance with this discussion. So the data used in the journal is data that has been implemented correctly in their respective industries.

In this study, the author reviewed several international journals, all of which were related to the implementation of FMEA. The review in this study is based on two aspects: (1) goods output; (2) services output (Fig. 1).

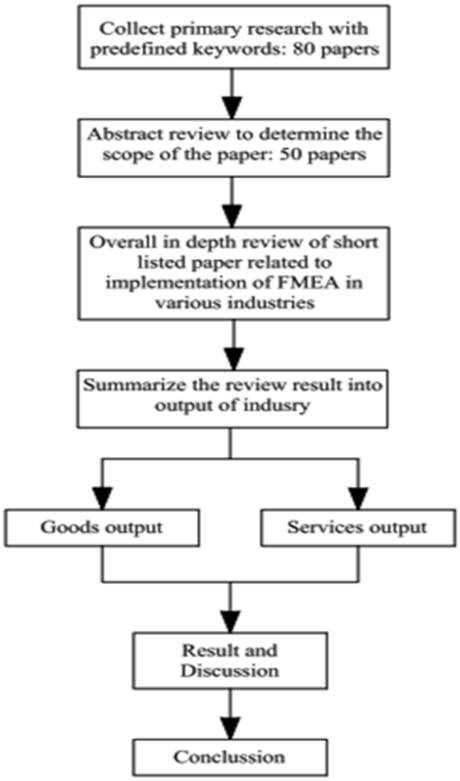

Fig 1. Study framework

4. RESULT AND DISCUSSION

The 50 journals of FMEA implementation in various industries were selected for review (Table 1). The selected journals or articles were analyzed from the aspect of FMEA methodologies, consist of FMEA basic concepts and FMEA enhancement, then also analyzed by research object and the result for following review of selected articles.

Table 1. Existing literature review of FMEA

No.	Literature	Type of industries	Industries output	Result
1	Abdelgawad & Fayek (2010)	Construction	Goods	The result to obtain a value of RCN of 286. The RCA was then used to calculate the RCN and the required corrective actions for each risk event.
2	Aboutaleb et al. (2012)	Project Implementation	Services	Some safety analyses are performed using FTA and FMEA methods. But it represents just a small part of the IS026262 functional safety.
3	Angara (2012)	Oil and gas, Biofuel	Goods	From the charts, also the Pareto rule, the critical value for RPN is 200 and for risk the score is 35.
4	Arvanitoyannis & Varzakas (2009)	Food and beverage	Goods	The application for corrective action, the second calculation of the RPN value that has been done, leads to a much lower value compared to before the improvement (< 130).
5	Arvanitoyannis & Varzakas (2008)	Food and beverage	Goods	After applying corrective actions, the second calculation of RPN values was carried out, resulting in substantially lower values (below the acceptable upper limit of 130).
6	Azadeh et al. (2009)	Oil and gas, maintenance	Goods	Based on the FMEA, faults (failure causes) are ranked and prioritized and with regard to this analysis, the appropriate preventive maintenance actions can be scheduled to improve the RCM procedure and increase the overall system reliability and help maintenance managers to provide suitable preventive actions
7	Puvanasvaran & Jamibollah (2014)	Automotive	Goods	The reject was decreasing from 4% become 0,9%.
8	Bahrami et al. (2012)	Construction	Goods	Collapse one part of a total of excavation Vertical includes with RPN (504, 810, 280, 324, 800, 216).
9	Baykasoğlu & Gölcük (2017)	Manufacturing	Goods	The priorities of the FMs may differ considerably if the causal dependencies are taken into consideration, and the main advantage of the proposed model is that decision-makers can better understand cause and effect relationships among FMs and interpret the results.
10	Baynal at al. (2018)	Automotive	Goods	The implementation of corrective and preventive activities increases the doorstep assembly's 96 % improvement in the door seal cuts problem.
11	Belu et al. (2013)	Automotive	Goods	Thermo-forming requirements with the process function of potential failure mode for missing material have the biggest RPN with 240.
12	Bevilacqua et al. (2015)	Medical, healthcare	Services	Failure to register failure mode and lack of transcription of urgent drug deliveries performed have the highest RPN 80.
13	Kumar & Parameshwaran (2018)	Manufacturing	Goods	The transportation is reduced from 42 meters to 10 meters approximately, hence reduces 76% of transportation activity. The time involved in total transportation activity also reduced from 2003 to 590 s; hence a saving of 70.5% is obtained. The number of labours required is reduced from 12 to 10.
14	Bluvband et al. (2004)	Electronic, communication device	Goods	Failed Product Due to Insufficient Strength for Change of process temperature (RPN 72), Change of raw material (RPN 45), Change of process pressure (RPN 29).
15	(Borković et al. 2017)	Media, newspaper	Goods	The production phase of time up to applying enough ink reaches the RPN of 96, the RPN of the production phase of time up to receive the first copy of the newspapers is 120, and the time of communication between foreman of the rotation and dispatch revealed two cases non-compliance is 100.
16	Braaksma et al. (2013)	Manufacturing, maintenance	Goods	PAFMEA expresses a new perception in the evaluation and prioritizes failure modes during failure analysis for maintenance, such as risk definition and resource availability, dealing with conflicting characteristics in a decision-making approach.

Table 1. Existing literature review of FMEA (continued)

No.	Literature	Type of industries	Industries output	Result
17	Ignáczová (2016)	Automotive, warehouse	Goods	Optimizing the storage space by 30% then brings advantages in the workload of warehouse equipment by 7% and increases employees' productivity by 25%.
18	Ioannis et al. (2013)	Oil and gas	Goods	Air compressor RPN increase from 90 to 270, Loss of function, internal leakage of media RPN increase from 72 to 144, Air actuator fails to open or fails to close the valve RPN increase from 36 to 108 fully.
19	Jahangoshai et al. (2017)	Mining, stone processing	Goods	By using the FMEA method in the Parsian stone processing industry company, there were 23 failures in the company that was identified and weighed, and the evaluation and priority of failures were carried out using the RPN calculation.
20	Kangavari et al. (2015)	Petrocemical	Goods	The RPN obtained to work at an altitude before taking corrective action was 120 and decreased to 96 after corrective action. Calculated RPN for all processes was significantly reduced ($p \leq 0.001$) by implementing the corrective actions.
21	Kania et al. (2014)	Manufacturing, tools	Goods	Considering this problem on the basis of similarity to quality management, one should introduce some systematics: principles of eco-management, methods of eco-management, tools of eco-management. The methodology of EFMEA is a part of the scope of the eco-management methods dedicated to the manufacturing processes.
22	Khorshidi et al. (2013)	Automotive, car battery	Goods	FMEA is not only used to select the high-risk processes but also is employed as a process capability index to evaluate the process chosen is still a key process or not.
23	Ku et al. (2008)	Manufacture, Maintenance	Goods	From the simulated experiments of the proposed BPN-based FMEA system (NFMEA), it has been found that the accuracy of the failure modes classification and the reliability calculation is knowledgeable and potential for performing pragmatic preventive maintenance activities.
24	Kumar (2011)	Manufacturing, foundry	Goods	The three main causes of waste accounted for 71.3 percent of the accumulated WPN.
25	Kumar & Kumar (2016)	Fertilizer	Goods	The FMEA method effectively and efficiently causes AC7, CL3, ST2, DR3 and NR3 heat exchangers, centrifugal compressors, ammonia reactors, ammonia separators, and cold condenser reactors have been identified as the most critical causes of failure of the system under consideration.
26	Kumru & Kumru (2013)	Medical	Services	With the implementation of all measures, it is expected to decline about 20% in procurement time and 15% in time spent by the workforce. Besides, the competition will increase among suppliers, and the purchases will be made more transparent.
27	Kurt & Ozilgen (2013)	Food and beverage	Goods	To help a large number of dairy product manufacturers produce safe products since the study provides comprehensive real data collected from 75 audits carried out in thirty dairy factories, and almost all dairy products share a common manufacturing stage.
28	Kuzmanov et al. (2017)	Manufacturing, Steel	Goods	Process for Transferring the done pieces into the warehouse has a potential failure for a Damaged piece (RPN 48), Long time for transfer (RPN 70), and Not appropriate conditions into the warehouses (RPN 72).
29	Layzell & Ledbetter (1998)	Construction, cladding	Goods	Investigates cladding failures on a system, component, and process level and maps the cladding supply chain and cladding related decision-making. The level of knowledge of losses and the fragmented industry structure prevents rigorous use of FMEA exemplified by other industries.
30	Lipol & Haq (2011)	Manufacturing, valve	Goods	RPN- Top 20% by Pareto and annoyance region [severity are low, but occurrence ranking is high].

Table 1. Existing literature review of FMEA (continued)

No.	Literature	Type of industries	Industries output	Result
31	Mozaffari et al. (2013)	Electronic, GEO satellite	Services	System complications can increase the initial increase of 79.15% rise to 97.52% for the specified life that can meet the desired requirements.
32	Namdari et al. (2011)	Agriculture	Goods	After implementing the results suggested by the FMEA, fuel consumption decreased by 16.40%.
33	Nauman & Bano (2014)	Medical, pharmaceutical	Goods	QRM increases awareness about risk and accelerates the detection of a potential problem by analyzing and comparing existing data from a quality perspective to manage a product's quality, manufacturing process, and compliance in a risk-based Quality Management System.
34	Özyazgan (2014)	Textile	Goods	The company's critical failures are weft runs, warp runs, basket, oil stain, slay, taras, leg failures, double weft and weft pile, and it was determined that those failures are caused by weaving machine and personnel.
35	Paciarotti et al. (2014)	Manufacturing, bathroom equipment	Goods	The revised FMEA allows to study the products' criticality from a quality control point of view and organize specific corrective actions to reduce the risk and improve the efficiency and efficacy of quality control tasks.
36	Panchal et al. (2018)	Fertilizer, maintenance	Goods	The causes CL4, CL6 with the same set of linguistic terms (Very High, High, Fair) and (High, Medium, Medium) produce different RPN score (216 and 189) and are ranked differently. Still, fuzzy FMEA and GRA approach to producing the same FRPN and grey output values (0.4819, 5.79 and 0.5523, 5.38), which entails that both these causes are given the same priority.
37	Pantazopoulos & Tsinopoulos (2005)	Steel	Goods	The use of an FMEA can also be applied successfully in various other business sectors (e.g., supplies, sales, financial), leading to continual improvement and increasing the bottom-line results.
38	Pareek (2012)	Manufacturing, foundry	Goods	After implementing FMEA to the core manufacturing process, core rejections and subsequent losses were reduced to 4.2% of total rejections.
39	Su et al.(2010)	Automotive, maintenance	Goods	The results show that the new risk priority model can help analysts find high-risk failure modes and create appropriate maintenance strategies.
40	Popović et al. (2010)	Maintenance, Automotive	Goods	Our efforts are new and, in our opinion, improved approach to vehicle failure analysis, which gives a new dimension to the entire process.
41	Ramli & ARffin (2012)	Automotive	Goods	The RCM framework can only be produced when Class A equipment is above the monthly maintenance frequency priority, followed by Class B equipment and Class C equipment, which has a lower critical value.
42	Rękas et al. (2014)	Manufacturing, beverage can	Goods	It results in low RPN for more than 85% of the failures defined for a process of forming a can on a Bodymaker.
43	Renu et al. (2016)	Automotive	Goods	The tool is used to identify and review quality issues within a complete vehicle. The top ten issues identified from the FMEA are submitted to design and manufacturing engineers for detailed evaluations.
44	Parsana & Patel (2014)	Manufacturing	Goods	For each specific process, the precautions suggested in the table can reduce losses to the manufacturing industry both in terms of time and cost.
45	Scipioni et al. (2002)	Food and beverage	Goods	The FMEA and HACCP methodologies operated in different production phases. Their simultaneous application allowed them to study and analyze every single step of production cycle and achieve exhaustive knowledge and improvement of products and processes.
46	Selim et al. (2016)	Food and beverage	Goods	Electrical and mechanical breakdowns decrease by about 15% and 53%, mean recovery times for the electrical and mechanical breakdowns decrease by 32% and 21%.

Table 1. Existing literature review of FMEA (continued)

No.	Literature	Type of industries	Industries output	Result
47	Shahin & Ravichandran (2011)	Oil and gas	Goods	After taking corrective actions, the percentage of waste oil is reduced from 1 to 0.08%, and the rate of canned canisters has been reduced from initially 50,000 to 5,000 ppm
48	Sinthavalai & Memongkol (2008)	Education	Services	CRM is considered a wise solution that can be applied to improve process efficiency and also to improve relations with these organizations. Other failures were analyzed as a result of the students' lack of preparation. As such, QFD is a support tool for designing intensive courses for student's practice.
49	Somsuk & Pongpanich (2008)	Electronic	Goods	By implementing FMEA, the defective parts could be reduced from 6,294.36 DPPM to 3,788.27 DPPM.
50	Su et al. (2014)	Electronic	Goods	The average failure time has increased from 1867 hours to 4852 hours, and the development period has been shortened to more than half a year.

4.1. Type of Industries

At the previous Table 1. Above, showing the most dominant implementation FMEA mostly in the manufacture and automotive industries. Of 50 papers collected in table 1, above mentioned 11 papers are discussions about the implementation of FMEA in manufacturing industries, and ten papers also talk about the implementation of FMEA in automotive industries. The classification articles based on the implementation of FMEA in various industries can see in Fig.2 below.

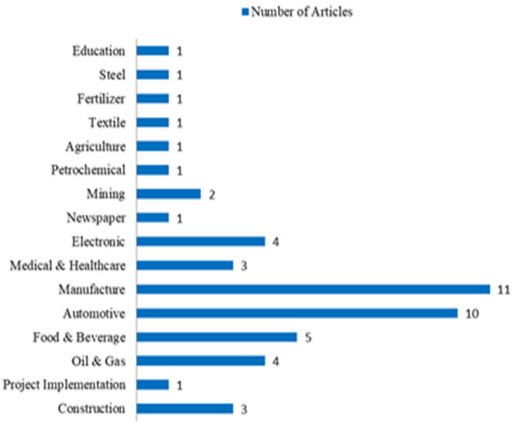

Fig. 2. Implementation FMEA in various industries.

The advantages of FMEA have resulted in its implementation into nearly every branch of modern industry, both for unitary and mass production and the example of application of FMEA in mass production is a production process of beverage cans (Rękas et al. 2014). Failure mode and effect analysis (FMEA) is methodologies that facilitate process improvement and manufacturing capabilities (Puvanasvaran & Jamibollah 2014). The classification based on percentage of implementation FMEA in various industries we can see at Fig.3 as below.

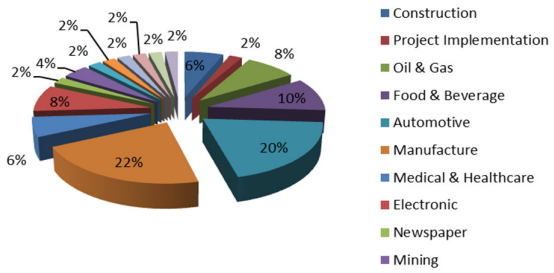

Fig. 3. Percentage implementation FMEA in various industries.

From the fig.3 above, it is showing that the percentage of comparison each industries in implementing FMEA, founded the big 3 are manufacture dominated 22% with the first rank, next the second rank is by automotive industries with 20% and the third is by food and beverage with 5% of implementing FMEA. This phenomenon indicated that most industries that produce goods implementing FMEA to assess the potential failure and improve, so the Severity, Occurrence, Detection, and RPN will be reduced. FMEA helps the SPC implementation either in process selection or output analysis. Also, this integration has been applied in a car battery industry that is less-developed (Khorshidi et al., 2013). FMEA method (Failure Modes and Effects Analysis), which is widely used in the motor vehicles industry (Popović et al. 2010).

4.2 Year of Publication

The distribution of final samples per year of publishing is shown in Figure 4. Some articles published online that have been included in this review can be seen from the following Fig. 4.

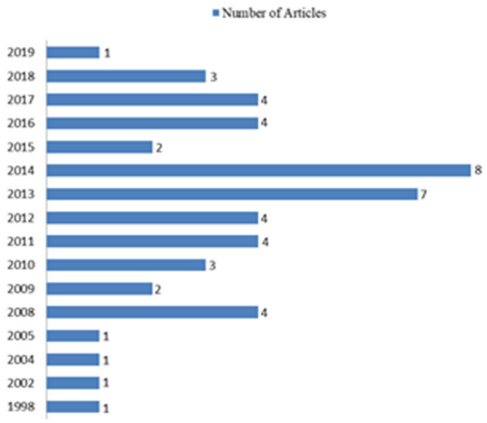

Fig. 4. Year of publication

From the data collected above, most researchers publish the article for implementation FMEA in the industry in year 2014, then followed in 2013. This also indicated that in those years, the researcher found some industrial problems that have been solved using FMEA.

4.3 Industries Output

Fig. 5. is the result of a journal review that has implemented FMEA of industries output. From 50 journals, showed 90% (around 45 journals) the output produce is goods and the rest only 5% showing the output produce is services.

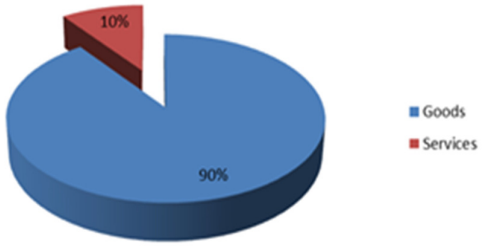

Fig. 5. Goods and services output produce in implementing FMEA

4.4 Research Challenge in Implementing of FMEA in Industries produces output

For service industries, providing error-free services is even more challenging because their intangible nature renders subjective perceptions of quality. Equally troublesome is the uncontrollable element of customer participation in the service process because production and consumption occur as simultaneous processes. Despite these challenges, however, service quality and customer satisfaction are closely related constructs. When service providers continuously strive to develop error-free strategies, customer satisfaction is sure to follow. And what potential rewards can FMEA provide? Does the Service Company that will conduct FMEA experience the following:

a. Minimized customer defection or increased customer satisfaction?
b. Increased consistency in service quality?
c. Reduction of costly design changes?
d. Reduced transaction costs/increased profits?
e. Reduced reliability?

5. CONCLUSION

Although many endeavors have been dedicated to utilizing FMEA in various industries sectors, driven by the challenges in modern business and the escalation of global disastrous events, the implementation of FMEA in services sector gaps is still left for future study. As this study is merely based on limited literature, we encourage future research to extend our initial survey using more databases and incorporating other references such as book chapters, dissertations, and literature. Moreover, we also suggest that other researchers to widen the discussion on the role of FMEA in enhancing six sigma-oriented service systems and its role in creating value within a collaborative business framework.

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