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

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ABSTRACT

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: $RPN = O \times S \times D$. 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.

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.

17 Ignáczová (2016) Automotive, warehouse Goods Optimizing the storage space by 30% then beings advantages in the workfoad of warehouse equipment by 7% and increases employee' productivity by 25%. 18 Ioannis et al. (2013) Oil and gas Goods Air compressor RPN increases from 90 to 270. Loss of function, internal leakage of media RPN increase from 70 to 104, Air actuator fails to open 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 2 alloures in the company that was identified and weighed, and the evaluation and priority of failures were carried out using the RPN obtained to work at an altitude hefore taking corrective action. (2014) 21 Kania et al. (2014) Manufacturing, fould'y Goods Considering this problem on the basis of similarity to quality management, one should introduce some systematics: principles of eco-management. The methodology of EFMEA is a part of the scope of the eco- management, nethods deficient causes of waste accounted for 71.3 percent foundry 22 Khorshidi et al. (2013) Automotive, car foundry Goods FMEA is not only used to select the high-risk processes but also is croppoed BPM- select weight and process consen is all a key process or not. 24 Kumar (2011) Manufacturing, foundry Goods FMEA is not only used to select the high-risk processes	No.	Literature	Type of industries	Industries output	Result
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 28 Kuzmanov et al. Manufacturing, Goods (2017) 29 Layzell & Construction, Ledbetter (1998) 30 Lipol & Haq (2011) 30 Lipol & Haq (2011)<td></td><td>(2013)</td><td>beverage</td><td></td><td>produce safe products since the study provides</td>		(2013)	beverage		produce safe products since the study provides
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 (2017) (2017)	20	(2017)	Steel	Goods	warehouse has a potential failure for a Damaged piece
 29 Layzell & Construction, Ledbetter (1998) 30 Lipol & Haq (2011) 30 Lipol & Haq ((= • - ·)			(RPN 48), Long time for transfer (RPN 70), and Not
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 30 Lipol & Haq (2011) 30 valve 30 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 RPN- Top 20% by Pareto and annoyance region [severity are low, but occurrence ranking is high]. 		Ledbetter (1998)	cladding		and process level and maps the cladding supply chain and
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(2011) valve are low, but occurrence ranking is high].	30	Lipol & Hag	Manufacturing	Goods	RPN- Top 20% by Pareto and annovance region [severity
	50	(2011)	valve	20005	are low, but occurrence ranking is high].

No.	Literature	Type of industries	Industries output	Result
31	Mozaffari et al.	Electronic, GEO	Services	System complications can increase the initial increase of
	(2013)	satellite		79.15% rise to 97.52% for the specified life that can meet
				the desired requirements.
32	Namdari et al.	Agriculture	Goods	After implementing the results suggested by the FMEA,
	(2011)	C		fuel consumption decreased by 16.40%.
33	Nauman & Bano	Medical,	Goods	QRM increases awareness about risk and accelerates the
	(2014)	pharmaceutical		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.	Manufacturing,	Goods	The revised FMEA allows to study the products' criticality
	(2014)	bathroom		from a quality control point of view and organize specific
		equipment		corrective actions to reduce the risk and improve the
			a .	efficiency and efficacy of quality control tasks.
36	Panchal et al.	Fertilizer,	Goods	The causes CL4, CL6 with the same set of linguistic terms
	(2018)	maintenance		(Very High, High, Fair) and (High, Medium, Medium)
				produce different RPN score (216 and 189) and are ranked
				unterently. Suil, fuzzy FMEA and GRA approach to
				5.70 and 0.5522 5.28) which antails that both these
				5.79 and 0.5525, 5.58), which entails that both these
27	Pantazonoulos &	Steel	Goods	The use of an EMEA can also be applied successfully in
57	Tainazopoulos &	Steel	Clous	various other business sectors (a.g. supplies seles
	(2005)			financial) leading to continual improvement and
	(2005)			increasing the bottom-line results
38	Pareek (2012)	Manufacturing	Goods	After implementing FMEA to the core manufacturing
50	1 urbon (2012)	foundry	Goods	process, core rejections and subsequent losses were
		roundry		reduced to 4.2% of total rejections.
39	Su et al.(2010)	Automotive.	Goods	The results show that the new risk priority model can help
		maintenance		analysts find high-risk failure modes and create
				appropriate maintenance strategies.
40	Popović et al.	Maintenance,	Goods	Our efforts are new and, in our opinion, improved
	(2010)	Automotive		approach to vehicle failure analysis, which gives a new
				dimension to the entire process.
41	Ramli & ARffin	Automotive	Goods	The RCM framework can only be produced when Class A
	(2012)			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.	Manufacturing,	Goods	It results in low RPN for more than 85% of the failures
	(2014)	beverage can		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
	D 0 D 1		G 1	manufacturing engineers for detailed evaluations.
44	Parsana & Patel	Manufacturing	Goods	For each specific process, the precautions suggested in the
	(2014)			table can reduce losses to the manufacturing industry both
15	Coinioni et el	Food and	Casda	in terms of time and cost.
43	(2002)	rood and	Goods	different production phases. Their simultaneous
	(2002)	beverage		application allowed them to study and applying survey
				single step of production cycle and achieve every
				knowledge and improvement of products and processes
46	Selim et al	Food and	Goods	Electrical and mechanical breakdowns decrease by about
10	(2016)	heverage	20040	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
48	Sinthavalai & Memongkol (2008)	Education	Services	ppm 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.

Table 1. Existing literature review of FMEA (continued)

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 (Rekas 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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