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Quality Control Analysis Using FMECA Method in Identifying Critical Point in the Can Manufacturing Industry

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ABSTRACT
The tighter the competition between companies in gaining market access, the more companies compete to implement market transformation strategies. A business generally has the same main goal, which is to achieve optimal profits based on business growth in the long run. But besides that, the company must be able to maintain the quality of the products it produces or improve the quality of the products it produces, both in the form of services and goods. In this research PT XYZ is a company engaged in packaging manufacturing, including food and paint. The main purpose of this study is to find the Risk Priority Number (RPN) and Criticality Point using the FMECA method. FMECA aims to analyze the potential risks that can arise in tools, processes and systems. The results of the analysis of the RPN results and criticality points that there are 5 priority failure modes, namely the accumulation of too many production goods, the assemble control tool does not work, the raw materials hit each other, the raw materials suffer physical damage, and the machine often jams due to a lot of dust. The conclusion of this study is that the company can make improvements to its production process in an effort to improve the quality of its canned products through the details of improvements that have been determined

INTRODUCTION

The business landscape in Indonesia is currently experiencing extraordinary growth, which is further supported by advancements in science and technology. As a result, the complexity of the business environment is also expanding. Globalization has significantly impacted the changes in the strategic landscape. Globalization is an inevitable phenomenon that affects all types of organizations, including public organizations, corporations, and social entities. In today's globally competitive world, innovation is essential for businesses to innovate by creating new ideas, new processes, new products, and improving the quality of existing products. As competition among companies to gain market access becomes more intense, more companies are competing to implement market transformation strategies. A business generally has the same main goal, which is to achieve optimal profits based on long-term business growth. However, in addition to that, companies must also have the ability to maintain or improve the quality of their products, whether in the form of services or goods. Quality control is very important in both the service and manufacturing industries. Corporations aim to attract clients and meet their needs and desires by ensuring high quality of their services or products. By improving product quality, sales will increase, and the costs required for production can be minimized. On the other hand, there has been little quality control testing for the use of these techniques during work. The current methods have proven to be unreliable or too complicated to implement during work.

PT XYZ is a company engaged in the production of packaging materials specifically for the food and paint industries. Established in the 1970s, PT XYZ has grown into one of the leading manufacturing companies in Indonesia. The company's main products are the production of paint cans and food cans branded with names such as "Khongguan, Nissin, Emco Lux, and others," produced based on a make-to-order production system. In practice, there are often obstacles related to errors in the manufacturing process or the failure of products to meet the standards set by the company and consumers. This is evident in the daily production reports from August to November 2023, where each shift had nearly 5-10% of the total production being reject goods. As a result, some products were rejected due to non-compliance, and the goods produced often suffered from damage, such as scratches, asymmetry, and even handprints left by employees, making them unsuitable for shipment to consumers. This caused delays in the production schedule that had been agreed upon between the company and its consumers, as well as excessive costs for the company to purchase raw materials. Based on the issues observed in the field, the company needs to measure the causes of defects in production and identify critical quality points in the production process to help minimize the potential for delays and reduce rejected products caused by poor production processes. The company aims to obtain specific information about the functions and interaction relationships of a system through a systematic examination of cause-and-effect relationships.

A study with the same objective as the case study was conducted by Fikri et al. (2024), where identified the causes of defects or failures during production, specifically on the Rotary Kiln in the Cement Industry, using the FMECA method. The results of this study found 11 types of failure modes in the rotary kiln machine, including cracks in the tire, leakage in the damper valve controller, jammed reject gate, rough noise in the reducer inching, detached deflector, worn-out gate, damage to the lamela inlet, detached actuator inlet, worn-out pinion bearing, worn-out support bearing, and noise in the marland coupling. After conducting the FMECA analysis, the failure mode that requires special attention is the crack in the tire. Therefore, this research also applies the FMECA method to identify which risks have significant potential and require preventive actions to prevent incidents and identify the causes of production defects. The reason for choosing the FMEA method in this research is because FMEA is a combination of the FMEA method and critical point analysis using a critical matrix. FMECA can be easily implemented without advanced analytical techniques, but it is essential to understand its objectives and operations. In general, FMECA is performed after design to determine whether component failures prevent the system from meeting the safety levels associated with its function. Rahman and Fahma (2021) state that FMECA is a method used to assess potential risks in equipment, processes, and systems. FMEA is used to identify factors that may cause errors, evaluate their impact on production outcomes, identify preventive actions, and take necessary steps to prevent failures.

In an innovative step toward a deeper understanding of quality improvement through the FMECA method, this study is designed to introduce novelty by combining elements such as cause-and-effect diagrams and Risk Priority Number (RPN) from previous research. This study not only measures the causes of defects in production and critical points but also seeks improvements in solving issues faced by the company. Therefore, this research incorporates sub-elements of RPN from the study by Rizqika.A

& Manbubah.N (2022), focusing on criticality levels to determine the classification of issues within critical areas. It also incorporates Rahman & Fahma's (2021) research on sub-elements of Pareto diagrams, prioritizing failure modes, fishbone diagrams, and adds the 5W-1H method for recommendations aimed at PT. XYZ. This research is not only an extension of the FMECA method but also includes improvement recommendations to reduce problems occurring at PT. XYZ. By combining elements from previous studies, this research creates a deeper and more contextual narrative, helping the company measure the causes of defects in production and critical points while providing recommendations for improvements. The main objective of the study is to measure the causes of production defects and critical quality points in the production process at PT. XYZ using the FMECA method. With a clear background and objective, this study is expected to provide insights into the causes of production defects and critical points at PT. XYZ, aiming to minimize potential delays in goods and reduce rejected products caused by suboptimal production processes.

MATERIALS AND METHODS

This research is based on a qualitative descriptive approach using valid data in the form of written information from individuals or observable behavior. The FMECA method is used to identify the causes and factors of component failure. Surveys, interviews, focus groups, and documents are used as data collection methods. The survey is conducted to assess the condition of equipment and gather historical data and documents. Maintenance activities determine company operations, equipment performance, and provide detailed descriptions. In this study, the Risk Priority Number (RPN) and criticality points are used as failure levels.

FMECA is a systematic approach used to identify and analyze all possible failure modes of various components in a system. It also assesses the consequences of system failures and provides strategies to prevent or mitigate the impact of those failures. FMECA is divided into two parts: failure mode effects analysis (FMEA) and criticality analysis (CA). The FMECA method is an advanced level of FMEA designed to assess risks associated with all types of errors. The goal of FMEA is to design the necessary maintenance procedures to eliminate failure points and prevent catastrophic or severe consequences from those failures. Its fundamental purpose is to initiate actions that reduce the likelihood of process errors. "Failure Modes and Effects Analysis (FMEA) is a systematic process to identify potential failure modes, their causes, and their impacts on system performance." This is done by combining the frequency ranking of occurrence (usually referred to as O), the severity rating (usually referred to as S), and the detection index (commonly referred to as D), where $RPN = O \times S \times D$.

The occurrence, severity, and non-detection failure modes have ranking values/scales from 1 to 10. The final results of the risk factors for all failure modes will be prioritized in descending order, and the most severe level will be determined. Then, the criticality value is calculated using the CA method, which is the sum of each failure mode's criticality in a production process at the corresponding severity level.

Table 1. Criticality Level

<table>
<tr><td>Degree of criticality</td><td>Value</td><td>Criticality</td></tr>
<tr><td>Minor</td><td>0-30</td><td>Acceptable</td></tr>
<tr><td>Medium</td><td>31-60</td><td rowspan="2">Tolerable</td></tr>
<tr><td>High</td><td>61-180</td></tr>
<tr><td>Very High</td><td>181-252</td><td></td></tr>
</table>

Critical	253-324	Unacceptable
Very critical	>324	

Severity	Occurrence	Detection	Score
Dangerously High	$\lambda > 0.01$	Absolute Uncertainty	10
Extremely High	$0.01 > \lambda > 5^*10^{-3}$	Very Remote	9
Very High	$5^*10^{-3} > \lambda > 2.5^*10^{-3}$	Remote	8
High	$2.5^*10^{-3} > \lambda > 10^{-3}$	Very Low	7
Moderate	$10^{-3} > \lambda > 5^*10^{-4}$	Low	6
Low	$5^*10^{-4} > \lambda > 10^{-4}$	Moderate	5
Very Low	$10^{-4} > \lambda > 5^*10^{-5}$	Moderately High	4
Minor	$5^*10^{-5} > \lambda > 10^{-6}$	High	3
Very Minor	$10^{-6} > \lambda > 10^{-7}$	Very High	2
None	$10^{-7} > \lambda$	Almost Certain	1

Figure 1. FMECA's Severity, Occurrence, and Detection

The information from observations and interviews consists of failure mode data or defect data that causes significant waste throughout the process. This data includes information on the severity, occurrence, and detection of each failure, which is then used to determine the Risk Priority Number (RPN). Field observations are used to collect data to identify the failure modes that occur during the production process at PT. XYZ, and the next step requires calculating the RPN values. The RPN values are obtained by the company after assessing the severity, occurrence, and detection levels. At this stage, the researcher compiles a comprehensive list of potential issues that may arise and documents the actual errors that occurred during the production process.

The next step after the RPN values are available is to establish priorities by assigning priority rankings. The sequence of criticality levels is arranged from the highest to the lowest using a Pareto diagram. The goal is to implement improvements efficiently with the available resources, with a particular emphasis on prioritizing the improvements.

The results of the prioritization process using the Pareto diagram show three categories of criticality levels for each failure mode. Then, a further prioritization process is conducted using a criticality matrix. The main priority sequence is determined based on the data obtained from the criticality matrix. The next step involves identifying the root causes of the failures using a fishbone diagram technique. Finally, the last step is to make recommendations using the 5W+1H method. The 5W+1H method is very simple, and due to its simplicity, it can generate new ideas for improvements. These improvement suggestions are used by the company to enhance its production process.

RESULTS AND DISCUSSIONS

Results

The FMECA analysis conducts field observations to obtain data related to system errors that occur during the manufacturing process. For each step, prioritizing the use of FMECA allows the team to quickly identify the issues. The data is obtained from observations and the author's considerations of the company, identifying the company based on the experience of management who have long been involved in the company's production process. Failure modes are classified based on contingency analysis, and their impact is predicted using a system risk matrix. In this case, the company involves production and QC managers to obtain the Risk Priority Number (RPN). Another weakness is related to the Risk Priority Number (RPN). Subsequently, after determining the critical points through general communication with the company, the determination of these critical points aims to prioritize the types of errors according to their severity and occurrence levels. Table 2 shows the results of the RPN values and each failure mode.

Table 2. Risk Priority Number (RPN) Values and Each Failure Mode.

Process	Num. Identity	Failure Mode	Severity	Occurance	Detection	RPN	Criticality
Distribution	1.1	The raw materials are experiencing physical damage.	8	7	2	112	Tolerable
Cutting	2.1	The cutter blade is not sharp.	6	5	7	210	Unacceptable
	2.2	The cutting machine is overheating.	1	2	6	12	Acceptable
	2.3	The cutting machine sensor is not functioning.	4	5	1	20	Acceptable
Assembling	3.1	The assembly control tool is not functioning.	7	6	4	168	Tolerable
	3.2	The machine frequently jams due to excessive dust.	8	7	1	56	Tolerable
	3.3	The raw materials are colliding with each other.	9	9	2	162	Tolerable
	3.4	The machine chain is not running.	4	4	4	64	Tolerable
	3.5	The machine feeder is broken.	5	3	1	15	Acceptable
Packing	4.1	There are fingerprints left by employees.	4	6	10	240	Unacceptable
	4.2	The production items fell from the packing machine.	2	2	7	28	Acceptable
	4.3	The accumulation of production items is too high.	6	8	4	192	Unacceptable

Before determining the selection of failure modes, the priority of failure modes must be established. To determine the priority of failures, a Pareto diagram is required. Since there are many different factors that will influence the process outcomes, a Pareto analysis helps classify key factors that contribute to the maximum errors. The purpose of the Pareto Diagram is to visually represent the failure levels in descending order, starting from the far right of the chart and peaking at the far left. With this order, it becomes easier to identify the failure points that should be prioritized for investigation and finding the causes of the failures. "The data obtained from PT. XYZ consists of failure modes with a total of 12 failure modes." After reviewing the 12 failure locations listed in Table 2 and considering the 3 different levels of criticality, the next task is to establish the main priorities of these failure points. This can be achieved by referring to the Pareto diagram illustrated in Figure 2.

Table 3. Priority of Production Process Failure Modes

Num.	Failure Mode	RPN	Cumulative (%)
1.1	There are employee fingerprints left on the items.	240	19%
2.1	The cutter blade is not sharp.	210	35%
2.2	The accumulation of production items is excessive.	192	50%
2.3	The assembly control tool is not functioning.	168	63%
3.1	The raw materials are colliding with each other.	162	76%
3.2	The raw materials are experiencing physical damage.	112	85%
3.3	The machine chain is not working.	64	90%
3.4	The machine frequently jams due to excessive dust.	56	94%
3.5	The production items fell off the packing machine.	28	96%
4.1	The cutting machine sensor is not functioning.	20	98%
4.2	The machine feeder is damaged.	15	99%
4.3	The cutting machine is overheating.	12	100%

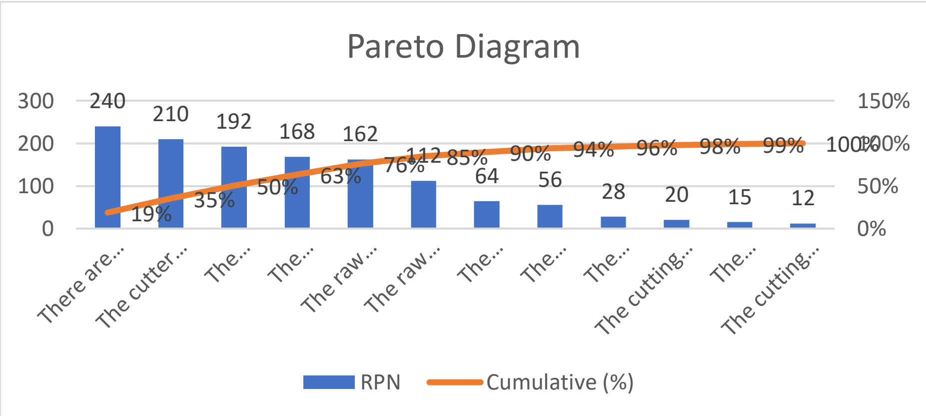

Figure 2. Pareto Diagram

Based on the observations of the author and the company, it was found that codes 2.2, 2.3, 3.5, and 4.2 are Acceptable. Acceptable means that the production process at these stages has been carried out well, and no improvements are needed. At levels 1.1, 3.1, 3.2, 3.3, and 3.4, they are Tolerable, meaning the production process can continue, but revisions need to be made at these stages. Codes 2.1, 4.1, and 4.3 are Unacceptable, where the production process should be halted and immediate improvements are necessary, as a failure at these points could result in the loss of the quality of incoming raw materials.

Discussions

Based on the calculated RPN values, a total of 12 failure modes were identified using data obtained from PT. XYZ. The RPN calculation results were then examined using the Pareto diagram. The principle of the Pareto diagram prioritizes "critical issues" by arranging failure modes in descending order of magnitude. The analysis results using the Pareto diagram showed that there are 8 primary failure modes with the highest priority, which are: Employee fingerprints left on the items, Cutter blade not sharp, Excessive accumulation of production items, Assembly control tool not functioning, Raw materials colliding with each other, Raw materials experiencing physical damage, Machine chain not running, and Machine frequently jamming due to excessive dust. After identifying the 8 failure modes from the Pareto diagram, the next step in prioritization is done using the criticality matrix. The criticality matrix works by reassessing priorities when identical RPN values are identified, taking into account the severity and occurrence levels.

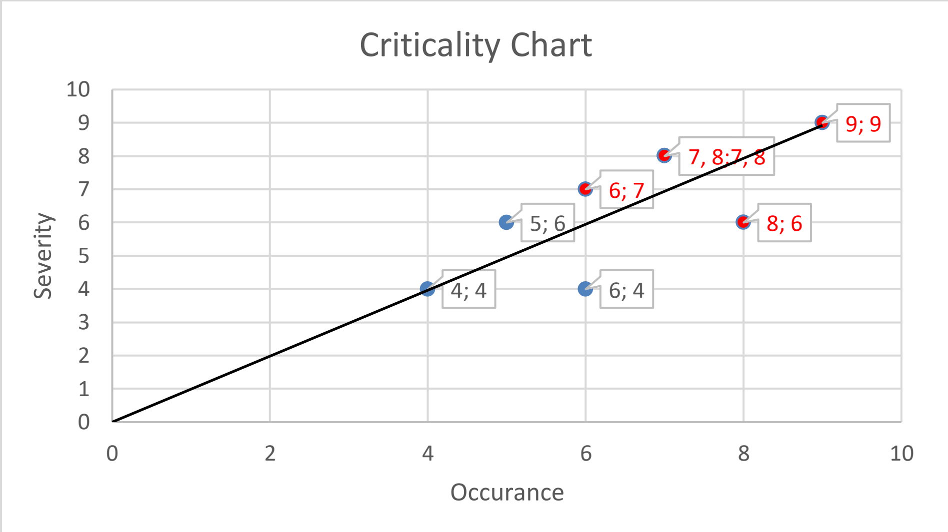

Figure 3. Criticality Chart

Using the Pareto diagram and criticality matrix, the prioritization of failure modes can be determined as follows: Raw materials experiencing physical damage, assembly control tool not functioning, machine frequently jamming due to excessive dust, raw materials colliding with each other, and excessive accumulation of production items.

Table 4. Priority of Failure Modes Based on the Criticality Chart Results

Num	Failure Mode	RPN
2.2	Excessive accumulation of production items.	192
2.3	The assembly control tool is not functioning.	168
3.1	The raw materials are colliding each other.	162
3.2	The raw materials got physical damage.	112
3.4	The machine frequently jams due excessive dust.	56

The next step is to perform an analysis to identify the causes leading to the failure modes depicted in the criticality chart using the fishbone diagram technique. Based on the criticality matrix results, the highest priority is the excessive accumulation of production items, which occurs during the packing process. In this process, the use of cardboard or cartons often results in the accumulation of production items, causing the canned products to become damaged or dented due to being pressed against each other. Furthermore, this accumulation in the packing process can hinder production as it must wait for the packing process to clear the excess items before continuing production, significantly delaying the overall process. The fishbone diagram, also known as the Ishikawa diagram or cause-and-effect diagram, is a visual method used to illustrate the various causes of a particular event or phenomenon. During the fishbone diagram analysis, the researcher examines several factors, specifically: materials, procedures, people, and machines. Below is the fishbone diagram illustrating the failure mode: Overaccumulation of manufacturing resources.

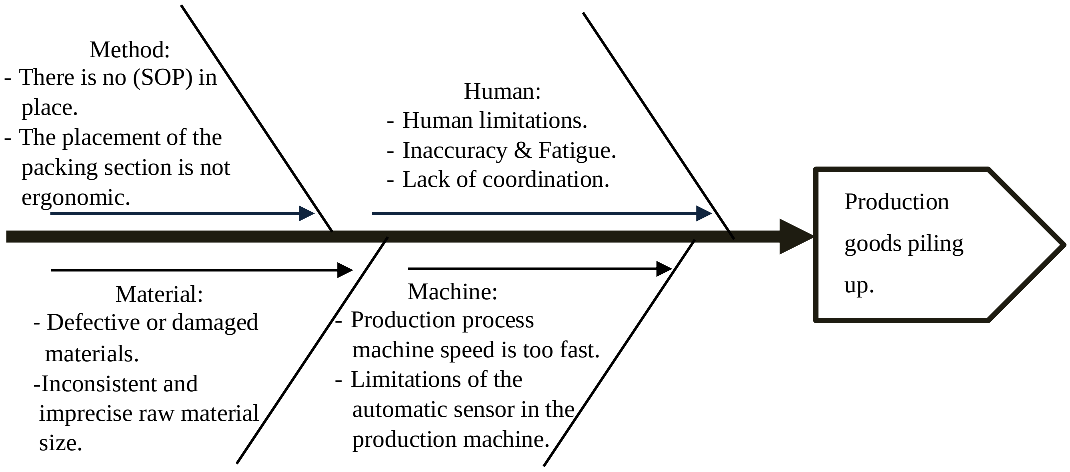

Figure 4. Fishbone Diagram for Excessive Accumulation of Production Items

After identifying the priority failure points through the use of the criticality matrix and Pareto diagram, the next step is to formulate recommendations for PT. XYZ using the 5W+1H method. Analyzing issues using the 5W+1H approach, the main problems in production can be identified, and the questions "what, when, where, who, why, and how" can be answered.

Table 5. 5W+1H Recommendations for SOP on Excessive Accumulation of Production Items

No	Movement	Problem
1	**What**	“**What the purpose of mitigation?** Create SOP for Production Goods Piling.
2	**Why**	**Why improvements are made?** To maintain and produce good products while minimizing product defects in accordance with the company's expectations.
3	**Where**	**Where the action plan will be implemented?** This improvement will be implemented in the packing production process.
4	**When**	**When improvements will be made?** This improvement will be implemented as soon as possible due to the frequent occurrence of damaged products caused by excessive accumulation of production goods, as well as the lack of efficiency in the production process.
5	**Who**	**Who is going to do it?** The production department and operators, in particular, are expected to become more skilled in performing their tasks.
6	**How**	**How will it be implemented?** a. Management and the QC department will have full control over every defect that occurs. b. Management improves the product quality starting from the raw materials by selecting high-quality materials, thereby reducing damaged raw materials caused by accumulation c. Tighter supervision to ensure that workers carry out their tasks more seriously, without any distractions or jokes during work d. Providing training for workers who are considered to have difficulty performing their tasks

		e. Re-evaluating the production process machines if they are considered too heavy or burdensome during production

CONCLUSION

Based on the findings and analysis of the research conducted, it can be concluded that the researchers have identified five failure modes as priorities, namely: excessive accumulation of production goods, malfunctioning assembly control tools, raw materials colliding with each other, raw material physical damage, and machines frequently jamming due to excessive dust. The main factors contributing to product defects in the can production process are the lack of a standardized SOP, poorly ergonomically placed packing areas that hinder production processes, inattention and fatigue experienced by employees, and the production machines being too fast for the human workforce to keep up. To eliminate excessive accumulation of production goods, it is necessary to provide training for workers who find their tasks difficult, re-evaluate the production machines if they are deemed too burdensome in the production process, improve product quality starting from the raw material selection by choosing high-quality materials, and implement full control over each defect. By using the FMECA method, one can proactively mitigate potential failures and establish a foundation for further strategy development. By utilizing the FMECA method, we can assess how well the end-to-end waste management goals have been achieved.

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REFERENCES

[1] Ahmed, S. and Gu, X. (2020). Accident-based FMECA study of Marine boiler for risk prioritization using fuzzy expert system. *Results in Engineering*, 6, 100123. https://doi.org/10.1016/j.rineng.2020.100123.

[2] Canivell, J., Martín-del-Río, J. J., Falcón, R. M., & Rubio-Bellido, C. (2020). Rammed earth construction: A proposal for a statistical quality control in the execution process. *Sustainability*, 12(7), 2830

[3] Coccia, M. (2020). Fishbone diagram for technological analysis and foresight. *International Journal of Foresight and Innovation Policy*, *14*(2-4), 225-247.

[4] Di Bona, G., Silvestri, A., Forcina, A., & Petrillo, A. (2018). Total efficient risk priority number (TERPN): A new method for risk assessment. *Journal of Risk Research*, *21*(11), 1384-1408.

[5] Elbadawi, I. A., Ashmawy, M. A., Yusmawiza, W. A., Chaudhry, I. A., Ali, N. B., & Ahmad, A. (2018). Application of Failure Mode Effect and Criticality Analysis (FMECA) to a Computer Integrated Manufacturing (CIM) Conveyor Belt. *Engineering, Technology & Applied Science Research*, *8*(3).

[6] Gong, J., Luo, Y., Qiu, Z., & Wang, X. (2022). Determination of key components in automobile braking systems based on ABC classification and FMECA. *Journal of Traffic and Transportation Engineering (English Edition*), *9*(1), 69-77. https://doi.org/10.1016/j.jtte.2019.01.008

[7] Goo, B., Lee, J., Seo, S., Chang, D., & Chung, H. (2019). Design of reliability critical system using axiomatic design with FMECA. *International Journal of Naval Architecture and Ocean Engineering*, *11*(1), 11-21.

[8] Halisa, N. N. (2020). Peran Manajemen Sumber Daya Manusia Sistem Rekrutmen, Seleksi, Kompetensi dan Pelatihan Terhadap Keunggulan Kompetitif: Literature Review. *ADI Bisnis Digital Interdisiplin Jurnal*, *1*(2 Desember), 14-22.

[9] Hasan, S., Sahiri, E., Suprayitno, S., & Hartanto, E. T. (2019). Analysis Of Determining Critical Components Using FMECA Method In Seawater Pump Of Diesel Generator Caterpillar 3412. *Journal Asro*, *10*(3), 124-130.

[10] M. Catelani, L. Ciani, D. Galar and G. Patrizi, (2020). Risk Assessment of a Wind Turbine: A New FMECA-Based Tool With RPN Threshold Estimation, in IEEE Access, vol. 8, pp. 20181-20190, 2020, doi: 10.1109/ACCESS.2020.2968812.

[11] Nurkholiq, A., Saryono, O., & Setiawan, I. (2019). Analisis pengendalian kualitas (quality control) dalam meningkatkan kualitas produk. *Jurnal Ekonologi Ilmu Manajemen*, *6*(2), 393-399.

[12] Perdana, S., & Rahman, A. (2020, December). Waste Analysis in the Painting Process of Doll Houses Using Value Stream Mapping (VSM). In *1st International Conference on Folklore, Language, Education and Exhibition (ICOFLEX 2019)* (pp. 113-118). Atlantis Press.

[13] Peyghami, S., Davari, P., Firuzabad, M. F., & Blaabjerg, F. (2019). Failure Mode, Effects and Criticality Analysis (FMECA) in Power Electronic based Power Systems. In Proceedings of 2019 21st European Conference on Power Electronics and Applications (EPE '19 ECCE Europe) (pp. 1-9). Article 8915061 IEEE Press. https://doi.org/10.23919/EPE.2019.8915061

[14] Piumatti, D., Sini, J., Borlo, S., Sonza Reorda, M., Bojoi, R., & Violante, M. (2020). Multilevel simulation methodology for FMECA study applied to a complex cyber-physical system. *Electronics*, *9*(10), 1736.

[15] RahmanA., & FahmaF. (2021). Use Of The Method FMECA (Failure Modes Effects Criticality Analysis) In The Identification Of Critical Point In Industrial Packaging. *Jurnal Teknologi Industri Pertanian*, *31*(1), 110-119. https://doi.org/10.24961/j.tek.ind.pert.2021.31.1.110

[16] Rizqika , A. Q., & Mahbubah, N. (2022). Evaluating Breakdown of Wheel Loader Heavy Equipment Using Failure Mode and Effect Critical Analysis Method. *JKIE (Journal Knowledge Industrial Engineering)*, *9*(3), 148-158. https://doi.org/10.35891/jkie.v9i3.3544

[17] Romadhani, A., Saifi, M., & Nuzula, N. F. (2020). Pengaruh profitabilitas, ukuran perusahaan dan kebijakan dividen terhadap nilai perusahaan. *Profit: Jurnal Administrasi Bisnis*, *14*(2), 71-81.

[18] Royer, M., Libessart, M., Dubaele, J. M., Tourneux, P., & Marçon, F. (2020). Controlling risks in the compounding process of individually formulated parenteral nutrition: use of the FMECA method (failure modes, effects, and criticality analysis). *Pharmaceutical Technology in Hospital Pharmacy*, *4*(3-4), 105-112.

[19] Shiyamy, A. F., Rohmat, S., Sopian, A., & Djatnika, A. (2021). Analisis Pengendalian Kualitas Produk Dengan Statistical Process Control. *Komitmen: Jurnal Ilmiah Manajemen*, *2*(2), 32-44.

[20] Suhardi, B., Anisa, N., & Laksono, P. W. (2019). Minimizing waste using lean manufacturing and ECRS principle in Indonesian furniture industry. *Cogent Engineering*, *6*(1), 1567019.

[21] Suharjo, B. A. M. B. A. N. G., Suharyo, O. S., & Bandono, A. (2019). Failure mode effect and criticality analysis (FMECA) for determination time interval replacement of critical components in warships radar. *Journal of Theoretical and Applied Information Technology*, *97*(10), 2861-2870.

[22] Wijaya, R. A., Qurratu'aini, N. I., & Paramastri, B. (2019). Pentingnya Pengelolaan Inovasi Dalam Era Persaingan. *Jurnal Manajemen dan Bisnis Indonesia*, *5*(2), 217-227.

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