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Research Article

Strategy for Implementing Reliability Centered Maintenance to Improve Productivity in the Cajuput Oil Production Process at PT. Eagle Indo Pharma

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Abstract: One of the objectives of this study is to identify and analyze problems that have an impact on increasing productivity in cajuput oil production. The method used Reliability Centered Maintenance (RCM) is used to determine the most effective maintenance approach based on system reliability, using the Failure Mode and Effects Analysis (FMEA), Fault Tree Analysis (FTA), and Logic Tree Analysis (LTA) approaches in order to overcome ambiguity and uncertainty in risk assessment. The results of the study using the Failure Mode and Effect Analysis (FMEA) method, there are failures that are a priority for improvement based on the risk priority number (RPN) value. The highest RPN values are Labeling Machines, Filling Machines, Capping Machines with RPN values of 294, 288 and 252 in the high criticality category. The maintenance carried out is routine checks after and before using the tool or machine, carrying out Checks and maintenance according to the Cleaning, Inspection, Lubrication, Tighting (CILT) checksheet. The downtime rate from July to August 2024 decreased by 4.72%, previously the weekly downtime rate was 19.09% after 2 weeks the downtime rate dropped to 14.37%. Shows that the selection of the maintenance model has been successful in increasing the reliability, efficiency and overall performance of the system.

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1. Introduction

The pharmaceutical industry consists of companies in the form of legal entities that are licensed to carry out activities related to the production or utilization of production resources, distribution of medicines, medicinal ingredients, and phytopharmaceuticals, as well as education and training, and/or research and development (Regulation of the Minister of Health of the Republic of Indonesia No. 26 of 2018). According to data from the Ministry of Health of the Republic of Indonesia, as of 2021, there are 241 pharmaceutical industries, including 17 drug ingredient industries, 132 traditional medicine industries, and 18 natural product extraction industries. In Indonesia, the pharmaceutical industry is a promising sector (Jose et al., 2019). Between 2015 and 2021, there was an increase in the number of medical device manufacturers, from 193 to 891 companies. In the last five years, the domestic medical device industry has grown by 361.66 percent or around 698 companies. Indonesia exports pharmaceutical and medical device products to several countries, namely the

Netherlands, the United Kingdom, Poland, Nigeria, Cambodia, Vietnam, the Philippines, Myanmar, Singapore, South Korea, and the United States (Mahmood, Evenye, & Athanasios, 2019).

The development of the pharmaceutical industry in Indonesia will influence economic growth, which will absorb a large workforce, especially skilled workers in the pharmaceutical field (Wolniak, 2019). This will open up a wide range of job opportunities for pharmacy graduates. The Ministry of Health continues to encourage the independence of the domestic pharmaceutical and medical device industries. "Currently, the number of vaccines, raw materials for medicines, and medical devices produced domestically has increased, and it has been noted that in 2023, this independence will begin to take effect, with domestic spending on medical devices reaching 9.8 trillion on July 23, 2023" (Aziz et al., 2019).

The chemical, pharmaceutical, and traditional medicine industries are among the sectors prioritized for development, making them key contributors to national economic growth and significant foreign exchange earnings. In the fourth quarter of 2023, exports from the chemical, pharmaceutical, and traditional medicine industries reached US$543.7 million. This figure increased by 8.78 percent compared to the same period the previous year. "Based on the determination of priority industries, the herbal or natural products industry and herbal preparations are a priority for development in 2020-2035" (Ahmed et al., 2020).

Indonesia is one of the fastest growing pharmaceutical markets in Asia, and the local pharmaceutical industry meets around 90 percent of Indonesia's pharmaceutical product needs. However, this industry is still limited in the development of new and innovative high-value drugs. The Natural Medicine Industry (OBA) or traditional medicine has enormous potential for further development, especially since Indonesia is very rich in biodiversity and natural resources, including medicinal plants. Currently, there are several components of the natural medicine industry in Indonesia, namely Small Traditional Medicine Businesses (UKOT), Micro Traditional Medicine Businesses (UMOT), Natural Ingredient Extract Industry (IEBA), and Traditional Medicine Industry (IOT), which have produced 17,000 herbal medicines, 79 types of standardized medicines, and 22 types of phytopharmaceuticals. (Ming et al., 2021).

The focus on increasing added value is carried out through the processing of derivative commodities, such as medicinal plants and spices, the development of geographical indications for herbal or medicinal plants, and the standardization of processes and natural medicine products. The chemical, pharmaceutical, and traditional medicine industries have proven to be one of the significant contributors to the economy. In 2023, the export value for pharmaceutical industry products, chemical medicines, and traditional medicines increased by 8.78 percent compared to 2022 in the fourth quarter, with an export value of 543.7 million US dollars (Mahmood, Evenye, & Athanasiou, 2019).

Based on data from Bank Indonesia (BI), the volume of industry in the BI Prompt Manufacturing Index (PMI-BI) in the chemical, pharmaceutical, and traditional medicine industries shows an optimistic value above the 50 percent threshold, with a PMI-BI value in the fourth quarter of 2023 at 52.50 percent, indicating a phase of expansion (Choi & Shin, 2024). The global market for natural medicines reached US$200.95 billion in 2023 and is expected to continue to grow. Moreover, this opportunity is supported by the use of natural medicines, especially herbal medicines. The trade sector continues to record positive results. The Central Statistics Agency (BPS) reported that Indonesia's trade balance in January 2022 had a surplus of US$930 million. The surplus occurred because last month's export volume reached US$19.16 billion, while imports amounted to US$18.23 billion (Niu et al., 2024).

The best performing non-oil and gas industries include the transportation equipment industry, which grew by 17.82 percent, followed by the basic metals industry at 11.50 percent, and the machinery and equipment industry at 11.43 percent. In addition, the chemical, pharmaceutical, and traditional medicine industries continued their positive trend with growth of 9.61 percent . One of the leading companies in the pharmaceutical sector in Indonesia is PT. Eagle Indo Pharma, which produces eucalyptus oil. The national demand for eucalyptus oil has increased from year to year, as can be seen from the percentage of sales of eucalyptus oil products in the Top Brand Indonesia data table in the eucalyptus oil subcategory (Destro & Barolo, 2022).

PT. Eagle Indo Pharma is a pharmaceutical company that produces traditional medicine products, one of which is caplang eucalyptus oil. Eucalyptus oil is produced under strict standards and is certified by the Indonesian Food and Drug Administration (BPOM). However, there are issues with productivity in the production process that are not yet as expected. One of the ongoing processes is the primary packaging of white camphor oil, which takes place on the filling machine. Based on data obtained from the production department, data was collected over the last 5 years, from 2019 to 2023. It was found that the average downtime of the filling machine was 34,919 minutes or 22.85 percent, which had an impact on productivity, which was still at 77.15 percent, with the production process running for 16 hours per day (A. J. Hadi et al., 2022).

The average machine downtime from 2019 to 2023 reached 22.85 percent, indicating that downtime has become a serious problem faced by companies. Downtime that occurs in the eucalyptus oil production process is caused by various failures and disruptions to production machine components, resulting in damage to the eucalyptus oil production machine system.

The downtime value is still high, with an average of 22.85 percent per year. To overcome this problem, a machine maintenance system analysis was carried out using the Reliability Centered Maintenance (RCM) method through the Failure Mode and Effect Analysis (FMEA) approach, a structural procedure to identify and prevent failures by determining the qualitative factors of critical components and calculating the Risk Priority Number (RPN) value. According to Anthony M. Smith, 1992 (Ming et al., 2021), research using the Reliability Centered Maintenance (RCM) method is generally divided into two types: qualitative and quantitative. This study uses qualitative analysis using the Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA), and Logic Tree Analysis (LTA) approaches. The recommended maintenance actions and plans based on the Reliability Centered Maintenance (RCM) method are to conduct routine checks, make redesigns to reduce failures, and provide training to the Maintenance department on maintenance concepts.

Previous studies have highlighted several research gaps that require deeper examination, particularly in the application of maintenance strategies to enhance productivity and reliability. Based on the observed phenomena, this study identifies gaps aligned with earlier findings. Research conducted by Alfredo & Moisés (2022) demonstrates that the application of RCM and FMEA can improve operational performance through maintenance system enhancement, yet the study does not provide a detailed discussion on failure risk reduction as a driver of productivity improvement. Similarly, the study by Yixin et al. (2019) reports a significant reduction in the average failure rate of type A filling machines from 11 percent to 4.2 percent through the integration of Autonomous Maintenance and the FMEA-RCM method. This research does not sufficiently address the practical barriers encountered during Autonomous Maintenance implementation. Findings from Khusainah et al. (2021) indicate that the development of an RCM strategy effectively minimizes crane failures, while also revealing that existing preventive maintenance practices remain inconsistent and ineffective.

Several studies further reveal unresolved gaps related to the practical implementation of integrated maintenance methodologies. Research conducted by Mahmood, Evenye, & Athanasios (2019) demonstrates the effectiveness of combining Fault Tree Analysis, Failure

Mode and Effect Analysis, and combinatorial risk analysis techniques, particularly in improving risk prioritization outcomes. However, this study does not provide an in depth discussion of the challenges or constraints faced during the implementation of such combined maintenance models within organizational settings. Meanwhile, a study by examines the application of Reliability Centered Maintenance in expedition truck maintenance management through a structured seven step process, including system definition, asset and functional block diagram development, failure identification, FMEA, Logic Tree Analysis, and maintenance policy determination. Although the study offers a comprehensive procedural framework, it emphasizes the need for post implementation evaluation. Specifically, it does not quantitatively assess the impact of RCM implementation on maintenance cost efficiency, leaving an important empirical gap for further investigation.

Research conducted by Aulia et al. (2019) concludes that the Failure Mode and Effect Analysis applied by the company was not effective, largely due to significant maintenance costs. The study identifies maintenance policies for 16 components across five main truck systems using the Reliability Centered Maintenance approach, including time directed, condition directed, failure finding, and run to failure strategies. The authors emphasize the need for post implementation evaluation to measure the impact of RCM on maintenance cost efficiency. The study by Wolniak (2019) finds that FMEA implementation was unsuccessful, also influenced by high associated costs. The findings suggest that FMEA is only effective when conducted by experienced personnel with extensive knowledge of production processes, technology utilization, and quality management tools. In contrast, research by Alfefy et al. (2019) demonstrates that RCM implementation significantly reduced corrective and preventive maintenance downtime by 55.77 percent and 52.17 percent, respectively, resulting in substantial cost savings. Nevertheless, this study does not thoroughly discuss implementation challenges within integrated maintenance systems.

Based on the aforementioned previous research, the Reliability Centered Maintenance (RCM) approach using Failure Tree Analysis (FTA), Failure Mode and Effect Analysis (FMEA), and Logic Tree Analysis (LTA) is expected to be able to resolve the problems occurring in the maintenance sector of the pharmaceutical industry in Indonesia.

2. Literature Review

Producitivity

Productivity is simply defined as the ratio between output and input. In other words, productivity is the output produced per unit of input. Productivity values also indicate how effective the production process is in increasing output and how efficiently input resources have been conserved (Santoso, 2011). According to Kotler & Keller (2012), productivity is defined as the ratio between output obtained and input used. Productivity is "the ratio between output (results) and input (inputs). If productivity increases, this is only possible due to improvements in the efficiency (time, materials, labor) of the work system, production techniques, and the increased skills of the workforce" (Hasibuan, 2018).

Productivity is a measure of a company's performance that shows how well inputs are converted into outputs. Inputs can come from Man (labor), Machine (machinery), Material (materials), Utility (energy), Capital (capital), and others. A transformation process will occur, namely the production process that can produce products or services, which are called outputs. The output may include successful products or services, as well as unsuccessful ones, which are called waste.

Reliability Centered Maintenance (RCM)

Reliability Centered Maintenance (RCM) is an approach to developing maintenance programs for preventive maintenance that focuses more on system functions than on individual components. This approach focuses maintenance on components that are critical to system function. This makes maintenance programs more efficient with lower costs. Reliability Centered Maintenance (RCM) is defined as a method for developing, selecting, and implementing maintenance strategy alternatives based on operational, economic, and safety criteria (AIfefy et al., 2019). The main objective of RCM is to maintain system functionality by identifying failure modes and prioritizing the importance of failure modes, then selecting effective preventive maintenance actions (Alfefy et al., 2019).

Risk management is a systematic process designed to identify and mitigate risks that could affect performance and the life of critical assets. Unlike traditional maintenance practices that follow a fixed schedule or reactive approach, RCM focuses on analyzing the function and failure modes of equipment to develop a tailored maintenance strategy. By identifying potential failures and their consequences, RCM enables organizations to prioritize maintenance efforts effectively and allocate resources where they are most needed. (Hussain, 2023)

Failure Mode Effect Analysis (FMEA)

Failure Mode Effect Analysis (FMEA) is a method for evaluating the likelihood of a failure occurring in a system, design, process, or service in order to make improvements (Wolniak, 2019). In FMEAI, each possible failure is quantified to determine the priority of improvement. In this study, FMEAI was used to identify risks that may occur in the operations and activities of the company. This method produces three results that help determine the level of risk: Severity This determines the severity, which is determined by how serious the damage is that results from the occurrence of a failure in the maintenance process and the operational activities of the factory; Frequency (occurrence) Dailaim determines that this occurrence can be determined as a good indicator of the frequency of occurrence of a particular operational activity in the factory; Detection Level Dailaim determines the detection level, which is determined by how well the event is known before it occurs. The detection level is also influenced by the quality of the controls that regulate the process. The better the control and procedures that regulate the operational system and the operational activities of the factory, the higher the detection level of the activities.

Fault Tree Analysis (FTA)

Fault Tree Analysis (FTA) is a logical and graphical model consisting of several combinations of failures created using a tree diagram, in which several combinations of failures (faults) are created in parallel and in sequence, which are called undesired events (Riadi, 2024). which are then analyzed with environmental and operational conditions to find all possible causes that may lead to the occurrence of these undesired events. FTAI is used to assess the reliability of a product and to identify the causal relationship between one event and another.

Fault Tree Analysis was first developed in 1962 by H.S. Waitson at Bell Telephone Laboratories in connection with a study on the safety evaluation of a minute missile launch system. FTAI is a technique used to identify risks that play a direct role in the occurrence of failures. This method is carried out using a top-down approach, which begins with the assumption of a failure or loss from the top event and then details the causes of the top event until it reaches the root cause.

Logic Tree Analysis (LTA)

The purpose of compiling the Logic Tree Analysis (LTA) is to prioritize each mode of failure and observe the functions and malfunctions so that the status of the mode of failure is not overlooked. The priority of a fault mode is determined by the importance of the factors provided in this LTA. Criticality analysis places each fault mode into one of four categories. The four important aspects of critical analysis are as follows: Evident, meaning that the operator is aware of the normal conditions and has experienced the production system; Safety, meaning that this failure mode causes a safety hazard; Outaige, meaning that this failure mode causes the entire machine to stop; Caitegory, meaning the categorization obtained after considering the proposed criteria.

3. Proposed Method

This qualitative research was influenced by the research instrument method and the data collection process (Sugiyono, 2022). The research methods used are RCM (reliability centered maintenance), FTAI (Fault Tree Analysis), LTA (Logic Tree Analysis), and qualitative data collection related to the results of observations, interviews, and documentation. After the data was collected, it was further processed to determine the Downtime weight.

In this study, the data sources were selected purposively and snowball sampling was used. The data sources for this study were determined in order to find out the causes of downtime that occurred in each production process, as well as to obtain the information needed to find out the causes of downtime. This data can be obtained through library studies, observation, interviews, and documentation. In this study, the researcher wants to identify and analyze the implementation strategy of Reliability Centered Maintenance to increase the productivity of the white oil production process using qualitative research methods, so that the researcher collects data using observation, data collection, and documentation (Sekaran & Bougie, 2017).

Triangulation strengthens credibility by integrating multiple data collection techniques and sources. Technique triangulation uses different methods to examine the same source, while source triangulation applies one method across diverse sources (S. Hadi, 2016). The goal of triangulation focuses on deepening researcher understanding rather than determining absolute truth. You gain stronger analytical insight through systematic comparison and integration of evidence.

4. Results and Discussion

Downtime Production Data

Production downtime for the last 5 weeks from week 26 to week 30 of 2024, with production downtime reaching 19.09%.

Table 1. Downtime Procution Data.

Weeks	Downtime (Min)						Total Downtime	Total Work-time	Down-time Per-cent-age
	Bottle Arranging Machine	Filling Machine	Cap-ping Ma-chine	Label-ling Ma-chine	Cod-ing Ma-chine	Penge-mas Ma-chine			
26	81	121	110	119	2	10	442	2344	18.87%

27	82	93	112	84	6	10	386	1504	25.69%
28	97	106	156	147	3	15	525	2989	17.58%
29	47	99	138	125	4	13	425	2485	17.12%
30	80	145	146	178	4	19	571	3526	16.19%
Rata-rata Downtime									19,09%

RPN Value on FMEA Calculation

The FMEAI method aims to determine the level of risk for each type of failure so that appropriate corrective action can be taken. The most important factor in determining FMEAI is the Risk Priority Number (RPN). The RPN value is calculated based on the severity value, occurrence value, and detection value..

Table 2. RPN Value on FMEA Calculation.

Failure Mode	Effect of Failure Mode	Cause of Failure Mode	S	O	D	RPN	Criticality Level
Raw material or packaging material rejected	Inventory becomes unstable and production may stop	Raw material or packaging specifications do not meet standards	2	3	1	6	Very Low
Delay in raw material transfer	Production stops	Transfer pump failure	1	2	2	4	Very Low
Delay in packaging material delivery	Waiting for materials and potential production stoppage	Forklift failure	3	5	3	45	Low
Delay in packaging material delivery	Waiting for materials and potential production stoppage	Worker absence due to emergency	1	2	4	8	Very Low
Buffer tank unable to transfer	Oil does not flow and production may stop	System error or pump failure	4	3	3	36	Low
Bottle arranging machine stops	Bottles fall on conveyor	Bottle neck guide too wide	5	4	3	60	Low
Filling machine stops	Bottles jammed	Star wheel loosened	6	6	8	288	High
Filling machine stops	Bottles fall on screw	Screw misalignment	3	4	5	60	Low
Filling machine stops	Bottles become wet	Nozzle leakage	5	6	6	180	Medium
Filling machine stops	Volume below standard	Nozzle blockage	7	5	7	245	High
Capping machine stops	Cap descends slowly	Reversed cap position	6	5	6	180	Medium

Failure Mode	Effect of Failure Mode	Cause of Failure Mode	S	O	D	RPN	Criticality Level
Capping machine stops	Cap stuck on rail	Cap opens during transfer	6	6	7	252	High
Labelling machine stops	Label folds on bottle body	Uneven sponge surface	6	6	8	288	High
Labelling machine stops	Label breaks	Unstable machine speed	6	6	8	288	High
Labelling machine stops	Double label applied	Sensor error or incorrect positioning	6	7	7	294	High
Packaging machine	Packaging material replacement	Packaging material depleted	2	3	1	6	Very Low
Delivery not on schedule	Insufficient product stock	Production machine failure	2	2	2	8	Very Low
Manual transfer required	Forklift malfunction	Forklift failure	2	2	1	4	Very Low

Failure Tree Analysis (FTA) Downtime Filling Machine

There are two factors that cause Failure Tree Analysis (FTA) downtime in filling machines, namely machine factors and material factors. Machines are an important factor in the production process of white oil, because if the machines are not functioning properly, the production of white oil will also be affected and productivity will decrease. The cause of this machine factor is that bottles often get stuck in the stairwheel transfer. This is because the stairwheel is unstable and loose, causing the bottles to easily get stuck.

Material (bottles) that is not properly cleaned causes downtime in the production machine, resulting in rejected production and loss of production because the bottle filling process becomes slow and the bottle volume is insufficient. This has a significant impact on production output and productivity.

Failure Tree Analysis (FTA) Downtime Capping Machine

There are two factors that cause Failure Tree Analysis (FTA) Downtime of the Capping Machine, namely machine factors and human factors. The Caipping machine functions as a bottle capping machine, so if this machine breaks down, the product will not be able to be capped and the bottles will not be able to be closed. Downtime that occurs due to the capping machine is caused by the cap getting stuck on the transfer rail and the cap falling. The cap gets stuck on the rail because the transfer rail is narrow, causing the cap to fall and get stuck on the side of the transfer rail. The hopper body is not level, causing the hopper to tip over and fall.

In addition to the machine, human error is a factor that greatly affects the production process, especially when humans are involved in the production process. In this case, the downtime of the caipping machine has a significant impact caused by the main factor, namely the operator. The cause of the operator's mistake is the operator's carelessness in putting the caip (lid) into the hopper, which is too much so that the hopper machine does not work properly.

Failure Tree Analysis (FTA) DowntimeLabelling Machine

The downtime of the Laibelling machine is caused by machine factors. The Laibelling machine functions as a machine for applying/attaching labels to the body of bottles. The downtime of this machine is caused by other factors in the labeling process. These problems occur when the labels are torn, broken, or the bottle is not labeled. Labels curling up is caused by the machine's sponge being worn out, so that the labels are not applied perfectly to the bottles and curl up. The label tears because the machine speed is too fast and the label is not aligned, causing the label roll to pile up. The labels were torn off the bottles because the sensor position was not stable and the labels were dirty.

Logic Tree Analysis (LTA) Filling Machine

The Logic Tree Analysis for the filling machine focuses on evaluating failure consequences and determining suitable maintenance actions based on operational impact. The analysis identifies bottle jamming, nozzle leakage, and filling volume deviation as the main failure modes. These failures are evident because they are directly observable and immediately disrupt production activities. Bottle jamming increases downtime, nozzle leakage causes material loss and hygiene issues, and volume deviation leads to product nonconformity with quality standards. From the LTA perspective, these failures are operationally significant due to their effects on productivity, cost, and product quality, even though they do not involve direct safety risks. LTA indicates that corrective maintenance alone is insufficient to manage these conditions. Preventive and condition based maintenance are therefore prioritized, including routine inspection of star wheel alignment, monitoring nozzle performance, and periodic calibration of filling volume. This structured logic supports improved reliability and operational stability of the filling machine within the Reliability Centered Maintenance framework.

Logic Tree Analysis (LTA) Copping Machine

The Logic Tree Analysis for the capping machine examines failure consequences to support appropriate maintenance decision making based on operational and quality impacts. The analysis identifies delayed cap descent and caps sticking on the guide rail as the dominant failure modes. These failures are evident during operation and directly interfere with the sealing process, leading to line stoppages and inconsistent cap application. Delayed cap descent increases cycle time and disrupts production continuity, while caps sticking on the rail can cause misalignment and improper sealing. From the LTA perspective, these failures are operationally significant because they compromise product integrity and increase the risk of rework and quality rejection, although they do not present immediate safety hazards. LTA indicates that relying solely on corrective maintenance is inadequate to control these failures. Preventive and condition based maintenance actions are therefore required, including routine inspection of cap orientation, guide rail alignment, and torque adjustment mechanisms. Through this logic, LTA links failure characteristics with targeted maintenance strategies, enabling you to reduce downtime, maintain sealing consistency, and enhance the reliability of the capping machine within the Reliability Centered Maintenance framework.

Logic Tree Analysis (LTA) Labelling Machine

The Logic Tree Analysis for the labelling machine focuses on assessing failure consequences that affect operational continuity and product quality. The analysis identifies label folding, label breakage, and double label application as the primary failure modes. These failures are evident during operation and directly influence labeling accuracy and visual product conformity. Label folding and breakage disrupt the labeling process and increase material waste, while double label application results in quality defects that require rework or product rejection. From the LTA perspective, these failures are operationally significant because they affect production efficiency, increase operational costs, and reduce overall process reliability, even though they do not pose direct safety risks. LTA indicates that corrective maintenance alone is insufficient to manage these failures effectively. Preventive and condition based maintenance actions are therefore prioritized, including regular inspection of sensor accuracy, stabilization of machine speed, and adjustment of contact surfaces such as sponges and rollers. This logical framework enables you to align failure consequences with appropriate maintenance strategies, supporting consistent labeling performance and enhancing the reliability of the labelling machine within the Reliability Centered Maintenance framework.

5. Comparison

The findings of this study demonstrate consistency with previous research on the application of Reliability Centered Maintenance in manufacturing systems, while also presenting contextual differences. Similar to prior studies, the results confirm that RCM supported by FMEA, FTA, and LTA effectively reduces downtime and improves equipment reliability through structured failure identification and targeted maintenance actions. However, this study provides a more detailed comparison by emphasizing machine specific Logic Tree Analysis for filling, capping, and labelling machines, which is less frequently elaborated in earlier research. The observed reduction in downtime after RCM implementation aligns with empirical evidence from pharmaceutical and process industries, yet this study highlights a stronger integration between failure consequences and maintenance decision logic. This integration strengthens maintenance prioritization and supports more sustainable productivity improvement within the production system.

6. Conclusions

The findings demonstrate that the application of RCM provides measurable improvements in machine reliability and production performance. Analysis of Mean Time Between Failure shows the lowest value on the capping machine at 19.40 minutes, indicating a short interval between consecutive failures, while the highest MTBF is observed on the coding machine at 681.63 minutes, reflecting superior operational reliability. Mean Time To Repair analysis reveals that the filling machine records the lowest MTTR at 17.63 minutes, indicating faster recovery time, whereas the labelling machine has the highest MTTR at 34.37 minutes. Failure Tree Analysis identifies downtime causes originating from machine, human, and material factors. Failure Mode and Effect Analysis further confirms that the labelling machine, filling machine, and capping machine exhibit the highest Risk Priority Number values of 294, 288, and 252, respectively, placing them in the high criticality category. Downtime data from July and August 2024 indicate a significant reduction, where the average weekly downtime decreased from 19.09 percent to 14.37 percent after two weeks of RCM implementation, confirming its effectiveness. To sustain this improvement, the study emphasizes routine maintenance based on the Cleaning, Inspection, Lubrication, and Tightening checksheet through regular machine component inspections. These results show that structured RCM implementation strengthens maintenance effectiveness, reduces downtime, and supports stable productivity improvement at the operational level..

Following the evaluation of production downtime and its reduction through the application of Reliability Centered Maintenance supported by Failure Mode and Effect Analysis, Fault Tree Analysis, and Logic Tree Analysis, this study proposes a set of actionable recommendations. Regular inspections before and after machine operation are necessary to identify early failure symptoms and prevent escalation. Maintenance activities should follow a structured approach using the Cleaning, Inspection, Lubrication, and Tightening checksheet to maintain consistency and procedural control. Critical components need replacement prior to the end of their service life to avoid sudden breakdowns and minimize corrective maintenance. Prompt execution of improvement actions is required to reduce the likelihood of recurring failures. Coordination with the procurement unit is essential to ensure the selection of higher quality spare parts that meet technical specifications. These measures reinforce preventive maintenance, improve equipment reliability, and support stable production performance..

References

Ahmed, F., Hossain, M. J., & Tareque, M. (2020). Investigating the roles of physical infrastructure, financial development, and human capital on economic growth in Bangladesh. *Journal of Infrastructure Development, 12*(2), 154–175. https://doi.org/10.1177/0974930620961479

Alfefy, I. H., El-Karmash, A. M., & Mahmoud, M. A. (2019). A new framework of reliability centered maintenance. *Jordan Journal of Mechanical and Industrial Engineering, 13*(3), 1–10.

Alfredo, C., & Moisés, M. (2022). Application of RCM and FMEA methodology to improve industrial maintenance management: A case study of fibers for mattresses. *International Journal of Engineering and Technology, 12*(1). https://doi.org/10.7176/IEL/12-1-04

Aulia, I., Khairita, S., Asfriyati, & Hansen, N. (2019). Quality control with Six Sigma DMAIC and grey failure mode effect analysis (FMEA): A review. *IOP Conference Series: Materials Science and Engineering, 505*(1), 012057. https://doi.org/10.1088/1757-899X/505/1/012057

Aziz, N. A., Shamsudin, S. N., Yusoff, M. S., & Samat, H. A. (2019). Conceptual analysis and survey of total productive maintenance and reliability centered maintenance relationship. *IOP Conference Series: Materials Science and Engineering, 530*(1), 012050. https://doi.org/10.1088/1757-899X/530/1/012050

Choi, Y., & Shin, H. K. (2024). Adverse events associated with herbal medicine products reported in the Korea Adverse Event Reporting System from 2012 to 2021. *Frontiers in Pharmacology, 15*, 1378208. https://doi.org/10.3389/fphar.2024.1378208

Destro, F., & Barolo, M. (2022). A review on the modernization of pharmaceutical development and manufacturing: Trends, perspectives, and the role of mathematical modeling. *International Journal of Pharmaceutics, 620*, 121715. https://doi.org/10.1016/j.ijpharm.2022.121715

Hadi, A. J., Riman, E. Y., Sudarman, S., Manggabarani, S., Ahmad, H., Ritonga, N., Antoni, A., Ishak, S., Rate, S., Simamora, F. A., Hidayah, A., Napitupulu, M., & Sani, H. A. (2022). Socio-family culture against stunting risk: A cross-sectional population-based study. *Natural Volatiles & Essential Oils Journal, 9*(1), 1301–1311.

Hadi, S. (2016). Pemeriksaan keabsahan data penelitian kualitatif pada skripsi. *Jurnal Ilmu Pendidikan Universitas Negeri Malang, 22*(1), 1–9. http://journal.um.ac.id/index.php/jip/article/download/8721/4194

Hasibuan, M. S. P. (2018). *Manajemen: Dasar, pengertian, dan masalah*. PT Raja Grafindo Persada.

Jose, M. M. A., Leite, A. F. C. S. M., Costa, M. B., Lopes, A., Rodrigues, E. F., & Osiris, C. (2019). A multi-criteria approach for FMEA in product development in Industry 4.0. *Applied Intelligence, 50*(3), 1–15. https://doi.org/10.3233/AITDE200090

Khusainah, R., Sodikin, I., Penirewo, A. P., Rachmad, B., & Pratama, N. A. (2021). Reliability centered maintenance effect on plant availability and downtime loss. *IOP Conference Series: Materials Science and Engineering, 1072*(1), 012054. https://doi.org/10.1088/1757-899X/1072/1/012054

Kotler, P., & Keller, K. L. (2012). *Manajemen pemasaran* (Edisi ke-13). Erlangga.

Mahmood, S., Evenye, E., & Athanasiou, K. (2019). An integrated FTA–FMEA model for risk analysis of engineering systems: A case study of subsea blowout preventers. *Applied Sciences, 9*(6), 1192. https://doi.org/10.3390/app9061192

Ming, B., Zhang, M., Zhang, H., Pan, L., Jie, Z., & Chu, Y. (2021). An error compensation method for surgical robot based on RCM mechanism. *IEEE Access, 9*, 139246–139256. https://doi.org/10.1109/ACCESS.2021.3117350

Niu, J., Rosales, O., Oluyomi, A., Lew, S. Q., Winkelmayer, W. C., Chertow, G. M., & Erickson, K. F. (2024). The use of telemedicine by US nephrologists for in-center hemodialysis care during the pandemic: An analysis of national Medicare claims. *Kidney Medicine*, 100798. https://doi.org/10.1016/j.xkme.2024.100798

Riadi, M. (2024). *Fault tree analysis (FTA): Fungsi, metode, simbol, dan langkah pembuatan*. Kajian Pustaka. https://www.kajianpustaka.com

Santoso, S. (2011). *Structural equation modeling (SEM): Konsep dan aplikasi dengan AMOS 18*. PT Elex Media Komputindo.

Sekaran, U., & Bougie, R. (2017). *Metode penelitian untuk bisnis*. Salemba Empat.

Sugiyono. (2022). *Metode penelitian kualitatif, kuantitatif, dan R&D*. Alfabeta.

Wolniak, R. (2019). Problem of use of FMEA method in industrial enterprise. *Production Engineering Archives, 23*, 12–17. https://doi.org/10.30657/pea.2019.23.02

Yixin, S., Junyang, Y., Bohan, L., Han, L., Xin, H., Jinjiang, W., & Rui, Z. (2019). RCM: A remote cache management framework for Spark. *Applied Sciences, 12*(22), 11491. https://doi.org/10.3390/app122211491