Quality Control in Crude Palm Oil Processing by Failure Mode and Effect Analysis (FMEA) Method at PT. Kebun Ganda Prima PKS Kembayan

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Abstract
Quality control is a proactive of systematic effort to identify and eliminate the root causes of defects in Crude Palm Oil (CPO) by focusing resources on process points that have the highest risk of failure. The goal is to achieve optimal product quality consistency at PT. Kebun Ganda Prima. The application of the Failure Mode and Effect Analysis (FMEA) method in the processing of oil palm fresh fruit bunch (FFB) into CPO at PT. Kebun Ganda Prima PKS Kembayan can serve as an effective alternative to identify, evaluate, and analyze potential failures that may occur during the production process. This study aims to enhance CPO quality by minimizing product defects and optimizing production efficiency through the tracing of critical points in the process that are susceptible to failure. The results of the FMEA analysis indicate that the highest-risk failure mode occurs at the Fresh Fruit Bunch (FFB) reception stage, specifically poor oil palm fruit quality, with the highest Risk Priority Number (RPN) value of 128.85. This condition is characterized by a high proportion of overripe or rotten fruit, which is the primary cause of the increased Free Fatty Acid (FFA) content in the CPO. Additionally, other potential failures were identified in the form of imperfect stripping (threshing) and malfunction of key equipment, such as the sterilizer and thresher. Based on these findings, quality control efforts should be focused on strict supervision of initial raw material quality and the implementation of preventive maintenance on critical machinery. The proposed recommendations include tightening the Standard Operating Procedures (SOPs) at the FFB reception stage and optimizing the preventive maintenance schedule to ensure that the processing runs consistently and produces CPO that meets quality standards.

1. Introduction

Indonesia is the world's largest producer of crude palm oil (CPO), recording a production of 50.07 million tons in 2023, making it a strategic sector that contributes significantly to national income and community welfare. Despite being the largest supplier, Indonesia's CPO competitiveness in the global market still lags behind Malaysia and Thailand, as indicated by Indonesia's Revealed Comparative Advantage index of 0.98, lower than Malaysia (1.04) and Thailand (1.45). This highlights the importance of strict quality control to produce high-quality CPO that can compete in the international market with increasingly rigorous export standards.

PT. Kebun Ganda Prima-PKS Kembayan in West Kalimantan, with a production capacity of 60 tons/hour, faces critical problems related to the quality of the CPO produced, where the product frequently fails to meet internal quality standards (maximum FFA of 3.50%, moisture content of 0.15%, and dirt contamination of 0.020%). This failure risks reducing competitiveness. The main identified problems include unstable temperature during the sterilization process, contamination by dirt particles during extraction, and lack of maintenance for the centrifuge machine. These issues indicate that the current quality control system is not optimal and requires systematic improvement.

To address quality challenges and enhance product competitiveness, this research proposes using the Failure Mode and Effect Analysis (FMEA) method, which is considered effective for quality control in palm oil mills. FMEA is a risk analysis method that identifies potential failure modes, evaluates their impact, and prioritizes corrective actions based on the Risk Priority Number (RPN = Severity X Occurrence X Detection) value. This study aims to identify the factors affecting CPO quality and formulate alternative strategies for quality control in the CPO production process at PT. Kebun Ganda Prima-PKS Kembayan so that the resulting product can meet expected quality standards and compete in the global market.

The objective of this research is to determine the factors that influence CPO quality at PT. Kebun Ganda Prima-PKS Kembayan and to determine alternative strategies for quality control in the CPO production process at PT. Kebun Ganda Prima-PKS Kembayan.

1.1 Material and Method

1.1.1 Location and Time of Implementation

The research was conducted at the oil palm factory of PT. Kebun Ganda Prima-PKS Kembayan, located in Kedakas Village, Tayan Hulu District, Sanggau Regency, West Kalimantan. The implementation period covered the production data from January to December 2024. Data analysis was performed at the Agro-industrial Management Laboratory, Department of Agricultural Industry Technology, Tribhuwana Tunggadewi University, Malang.

1.1.2 Scope of the Problem

The scope of the problem in this research is intended to focus the objectives to be achieved. The limitations of the problem in this research are: This research is focused on the process of processing oil palm fresh fruit bunches (FFB) into Crude Palm Oil (CPO) at PT. Kebun Ganda Prima-PKS Kembayan, starting from the raw material reception to the oil purification stage (clarification station). Processes outside of this stage (e.g., cultivation, post-harvest, or waste treatment) are not included in the scope of the research.

The data used covers the production period from January to December 2024. The research uses the Failure Mode and Effect Analysis (FMEA) method to identify process failure risks and determine improvement priorities. The quality parameters reviewed are limited to the main CPO indicators according to industry standards, such as Free Fatty Acid (FFA) content, moisture content, and dirt contamination. Secondary quality parameters (e.g., color, odor, or nutritional content) are not the main focus. The data used originates from internal company documents, field observations, and interviews.

2. Research Methods

This research was carried out through a series of methodological stages, beginning with a literature study and preliminary survey to identify and formulate the core problem. Subsequently, data collection was conducted to determine the potential failure modes and the impact of process failures, followed by the development of the FMEA questionnaire and a validity test of the instrument. The verified data was then processed and analyzed using the DMAI (Define, Measure, Analyze, Improve) approach to calculate the risk level (Risk Priority Number/RPN), analyze risk priorities, and design mitigation strategies. The process concludes with the validation and standardization of solutions to ensure the sustainability and effectiveness of the implementation of corrective actions.

3. Result and Discussion

3. 1 Overview of PT. Kebun Ganda Prima-PKS Kembayan

PT. Kebun Ganda Prima is an oil palm plantation and processing company that commenced operations in August 2017. The company is located in Tayan Hulu Estate, precisely in Dusun Mekar Jaya Siran, Kedakas Village, Tayan Hulu Sub-district, Sanggau Regency, West Kalimantan Province. Geographically, the company area is situated at coordinates $110^\circ 20' 21''$ E - $110^\circ 24' 54''$ E and $00^\circ 21' 6''$ N - $00^\circ 24' 40''$ N.

The operational area of PT. Kebun Ganda Prima covers several villages across two sub-districts: Kedakas, Pandan Sembuat, Baratak, Engkasan, and Riyai Villages in Tayan Hulu Sub-district, as well as Sebuduh and Tanap Villages in Kembayan Sub-district. The plantation area is bordered by PT. Karya Mufakat Lestari to the north, Kedakas Village to the south, Tanap and Sebuduh Villages to the east, and Baratak, Janjang, and Kedakas Villages to the west.

The company manages a total area of 10.41 hectares, which is divided into the factory area (4.40 hectares), reservoir (2.00 hectares), and effluent ponds (4.01 hectares). The palm oil mill (PKS) has an installed capacity of 40 tons of Fresh Fruit Bunches (FFB) per hour, equipped with storage facilities of 5,000 tons capacity, consisting of 2 storage units and 1 bisley/silo unit with a capacity of 500 tons.

In terms of human resources, PT. Kebun Ganda Prima is led by Manager Pakkat Antonius Sibarani, with Assistant Head Budi Wahyudi Tanjung. The company employs a total of 66 people, consisting of 7 staff and 59 employees. To meet its raw material needs, the company collaborates with various suppliers, including Tayan Hulu Estate, Kembayan Estate, as well as several cooperatives such as Koperasi Satria Usaha Bersama, Koperasi Sumber Makmur Perkasa, Koperasi Bopakat Cahaya Sawit, Koperasi Usaha Mitra Tani, and the Village-Owned Enterprise (Badan Usaha Milik Desa/BumDes) Karok Jayo.

As one of the CPO (Crude Palm Oil) producers in West Kalimantan, PT. Kebun Ganda Prima PKS Kembayan holds a strategic position in the regional palm oil industry. The company not only focuses on production but also runs Corporate Social Responsibility (CSR) programs and participates in various environmental research, demonstrating a commitment to sustainable development and corporate social responsibility.

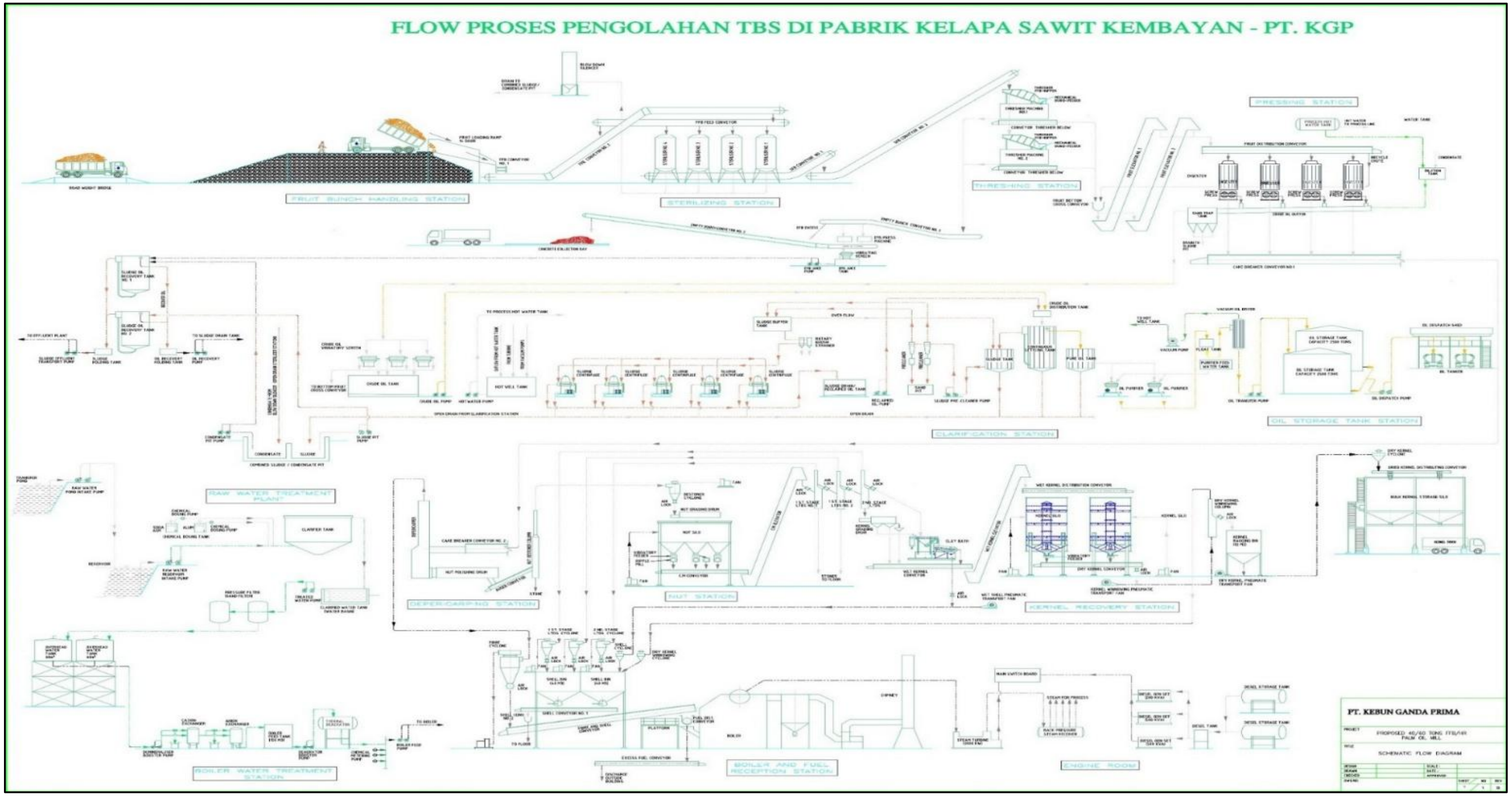

Figure 1.

Processing Fresh Fruit Bunches into Crude Palm Oil

3.2 Data Collection

The data collection stage was carried out through discussions with key personnel and by using questionnaires to comprehensively identify operational risks at PT. Kebun Ganda Prima-PKS Kembayan. The involvement of key personnel is crucial because they possess an in-depth understanding of daily operational dynamics and specific challenges of the palm oil industry that are not documented in standard procedures. This method ensures the accuracy of the Risk Priority Number (RPN) calculation aligns with the company's existing conditions, thereby ensuring that the risk mitigation strategies developed are truly relevant to the operational characteristics of the palm oil mill.

3.3 Risk Identification

Conducting systematic and comprehensive risk identification is a fundamental stage in effective risk management implementation. This process aims to analyze, map, and evaluate various potential threats that could affect the continuity of company operations and impact the achievement of production targets, particularly in the context of identifying operational process risks that encompass the entire series of activities from raw material reception to the final product.

Risk identification was carried out through discussions and interviews with the company's key personnel. Based on the identification results of the operational processes at the Kembayan Palm Oil Mill (PKS), operational risks that are potentially occurring in the area were obtained according to the flow of the palm oil production process. Table 5 shows the results of the operational failure risk identification at the company's palm oil mill, based on the operational process flow starting from the reception of fresh fruit bunches (FFB), sterilization, threshing, oil extraction, up to clarification.

Table 1. Identification of Operational Failure Risks in the Palm Oil Mill

Process	Code	Failure Mode	Effect
FFB Reception			
FFB Reception	R1	Poor quality of fresh fruit bunches (FFB)	Low oil yield, decreased CPO quality, economic loss
Weighing	R2	Error in FFB weighing	Inaccurate production data, financial loss, incorrect production planning
Data Recording	R3	Error in reception data recording	Inaccurate production reports, inventory errors, failed audits
Sterilization			
Sterilization	R4	Imperfect sterilization	Low oil quality, sub-optimal extraction process, microbial contamination
Sterilizer Equipment	R5	Damage/malfunction of the sterilizer	Process halt, production delay, high repair costs
Thresher			
Threshing	R6	Incomplete fruit threshing	Fruit loss, low yield, production loss
Loose Fruit Condition	R7	Damage to loose fruit during threshing	Fruit crushed/destroyed
Thresher Equipment	R8	Malfunction or damage to the thresher	Process halt, downtime, repair costs
Conveyor System	R9	Conveyor jam	Process bottleneck, production delay, material overflow
Oil Extraction			

Extraction	R10	Low oil yield, high losses, decreased production efficiency	Less efficient pressing, sub-optimal parameters
CPO Quality	R11	Contamination of crude oil (CPO)	Decreased CPO quality, buyer rejection, economic loss
Separation	R12	Imperfect separation of oil, water, and sludge	Low oil quality, high water content, excess sludge
Clarification Equipment	R13	Malfunction of main clarification equipment	Process halt, decreased oil quality, downtime
Heating System	R14	Heating system disturbance	Decreased separation efficiency, sub-optimal oil quality

Risk Analysis Using Failure Mode Effect and Analysis (FMEA)

In this stage, risks are analyzed by assessing the scores for Severity (S), Occurrence (O), and Detection (D) to obtain the Risk Priority Number (RPN) value. Severity is the level of seriousness of an impact caused by the risk. Occurrence is the likelihood that the cause of the failure will happen and result in a failure mode during the operational process. Detection is the preventative effort against the operational process that reduces the level of failure in the operational process. Subsequently, the RPN values are sorted to determine the priority scale of the operational risks. The RPN value and the priority scale are directly proportional, meaning that the higher the RPN value, the higher the priority for addressing that risk.

Table 2. FMEA (Failure Mode and Effect Analysis) Results

Process	Code	Failure Mode	Effect	Cause	Current Control	S	O	D	RPN
FFB Reception									
FFB Reception	R1	Poor quality of palm fruit	Low oil yield, decreased CPO quality, economic loss	Over-ripe, under-ripe, rotten, dirty	Visual inspection, manual sorting	7.11	4.93	3.68	**128.85**
Weighing	R2	FFB weighing error	Inaccurate production data, financial loss, incorrect production planning	Inaccurate scale calibration, human error	Periodic calibration, double check	7.14	2.39	2.46	**42.12**
Data Recording	R3	Error in reception data recording	Inaccurate production reports, inventory errors, failed audits	Human error in recording, damaged recording system	Data verification, backup system	6.93	2.68	2.57	**47.72**
Sterilization									
Sterilization	R4	Imperfect sterilization	Low oil quality, sub-optimal extraction, microbial contamination	Under-sterilization, unsuitable temperature/pressure/time	Monitoring process parameters, alarm system	7.39	2.79	2.68	**55.16**
Sterilizer Equipment	R5	Sterilizer damage/malfunction	Process halt, production delay, high repair costs	Autoclave damage, worn components, lack of maintenance	Preventive maintenance, spare parts, backup unit	7.46	3.11	2.64	**61.29**
Thresher									
Threshing	R6	Incomplete fruit threshing	Fruit loss, low yield, production loss	Fruit still attached to empty bunches, improper thresher setting	Inspection of empty bunches, thresher adjustment	7.43	3.43	2.82	**71.86**
Loose Fruit Condition	R7	Damage to loose fruit during threshing	Fruit crushed/destroyed	Fruit still attached to empty bunches, improper thresher setting	Inspection of empty bunches,	7.21	3.11	2.79	**62.44**

					thresher adjustment				
Thresher Equipment	R8	Thresher malfunction or damage	Process halt, downtime, repair costs	Thresher jammed, breakdown, damaged components	Preventive maintenance, condition monitoring	7.43	2.86	2.71	**57.61**
Conveyor System	R9	Conveyor jam	Process bottleneck, production delay, material overflow	Feeding/discharging conveyor jammed, overload	Load monitoring, routine cleaning	7.61	2.50	2.43	**46.19**
Oil Extraction									
Extraction	R10	Low oil yield, high losses, decreased production efficiency	Low oil yield, high losses, decreased production efficiency	Less efficient pressing, sub-optimal parameters	Monitoring parameters, press adjustment	6.86	3.07	2.54	**53.41**
CPO Quality	R11	Contamination of crude oil (CPO)	Decreased CPO quality, rejected by buyer, economic loss	Contamination by impurities, poor cleanliness	Filtering, cleaning procedure	6.82	3.00	2.61	**53.35**
Separation	R12	Imperfect separation of oil, water, and sludge	Low oil quality, high water content, excess sludge	Sub-optimal separation parameters, insufficient settling time	Monitoring parameters, settling time control	7.18	2.82	2.57	**52.08**
Clarification									
Clarification Equipment	R13	Malfunction of main equipment	Process halt, decreased oil quality, downtime	Damage to clarifier, centrifuge, setting tank	Preventive maintenance, spare parts	7.75	2.39	1.68	**31.13**
Heating System	R14	Heating system disturbance	Decreased separation efficiency, sub-optimal oil quality	Damaged heat exchanger, leaking steam pipe	Routine inspection, temperature monitoring	7.61	2.36	1.79	**32.02**

After obtaining the RPN value for each risk identified, the risks are then sorted from the highest RPN value to the lowest RPN value. Table 7 shows the recapitulation of the RPN values for the risks in the FFB to CPO production process at PT. Kebun Ganda Prima-PKS Kembayan.

Table 3. Recapitulation of RPN Values for FFB to CPO Production Process Risks at PT. Kebun Ganda Prima-PKS Kembayan

Risk Code	RPN
R1	128.85
R6	71.86
R7	62.44
R5	61.29
R8	57.61
R4	55.16
R10	53.41
R11	53.35
R12	52.08
R3	47.72
R9	46.19
R2	42.12
R14	32.02
R13	31.13

The primary cause of poor palm fruit quality identified is the condition of the fruit being over-ripe, under-ripe, rotten, or dirty. The over-ripe condition occurs when the palm fruit is harvested too maturely, which increases the Free Fatty Acid (FFA) content and lowers the oil quality. Conversely, the under-ripe condition indicates fruit harvested too early, meaning the oil yield has not yet reached its optimum level. The rotten and dirty conditions can be caused by improper handling during the harvesting process, transportation, or storage before processing at the mill (Zein et al., 2019). The current control system, which consists of visual inspection and manual sorting, has limitations in detecting all fruit conditions that do not meet the standards. Visual inspection relies on the expertise and consistency of the workers, while manual sorting has capacity limitations and is susceptible to human error. Therefore, the control system needs to be improved to increase the effectiveness of detecting and preventing poor palm fruit quality (Nainggolan et al., 2025). The failure mode R1, which is poor quality of palm fruit, has a very significant impact (effect) on the entire production process. The main resulting impacts include decreased oil yield, deterioration of the CPO quality produced, and substantial economic losses for the company. Low oil yield will directly affect the factory's productivity and operational efficiency, while a decline in CPO quality can impact the product's competitiveness in the market and potentially lead to rejection by buyers (Tarigan & Purwanggono, 2022). FFB conditions that are over-ripe, under-ripe, rotten, or dirty can cause low oil yield, decreased CPO quality, and significant economic losses. Given the highest RPN value, the management of PT. Kebun Ganda Prima-PKS Kembayan needs to take comprehensive corrective actions to address risk R1. Recommended improvements that can be implemented include implementing a stricter fruit quality assessment system with clear criteria for separating ripe, unripe, rotten, and dirty fruit. Additionally, it is necessary to install illustrated information boards about fruit quality standards in the reception area so that they are easily understood by all workers. Increasing the frequency and quality of training for sorting workers is also needed to improve their ability to identify fruit conditions that do not meet the standards. Handling this R1 risk requires an integrated approach that involves not only improvements at the mill level but also coordination with supplier plantations to ensure that the quality of the palm fruit received meets the standards from the outset. With the implementation of appropriate improvements, it is expected that the RPN value for risk R1 can be significantly reduced, thereby improving the production efficiency and CPO quality produced by PT. Kebun Ganda Prima-PKS Kembayan.

The Risk Priority Number (RPN) analysis for failure R2 shows a value of 42.12, obtained by multiplying the severity (7.14), occurrence (2.39), and detection (2.46). The high severity (7.14) indicates that the impact of the weighing error is very serious on mill operations. This is logical given that FFB weighing is the starting point that determines the accuracy of all subsequent production data. The relatively low occurrence (2.39) suggests that with the existing control system, the frequency of weighing errors has been reasonably suppressed. However, the low detection (2.46) value indicates that the ability to detect a weighing error when it occurs still needs to be improved. The combination of these three values results in an RPN that falls into the medium category, meaning this risk requires attention and consistent corrective action, although it is not the highest priority. The primary causes of FFB weighing errors can be categorized into two main aspects. The first is the technical factor of inaccurate scale calibration. Scales that are not periodically calibrated or are calibrated with inaccurate standards will produce readings that deviate from the actual weight. This calibration issue can be caused by various factors such as wear on scale components, changes in environmental conditions, or the use of invalid calibration standards (Purbaningtias et al., 2022). The second factor is human error in weighing operations, which can include mistakes in reading the scale display, errors in the weighing procedure, or even errors in recording the weighing results. This human error often occurs due to a lack of operator training, work fatigue, or insufficient attention to detail in the weighing process (Bastian et al., 2023). The effects of FFB weighing errors are diverse and interconnected. The main noticeable impact is the inaccuracy of production data, which affects the entire production planning and control system (Ginting et al., 2022). When weighing data is inaccurate, management will have difficulty making accurate production projections, calculating the yield ratio, and determining optimal production capacity. This leads to financial losses that can occur in various forms, ranging from overpayment to plasma farmers to underestimation of the actual production potential. Furthermore, weighing errors will cause incorrect production planning, where the mill may prepare a capacity that does not match the actual FFB volume, leading to inefficiency in resource use or even a lack of processing capacity (Ginting et al., 2022). The control systems that have been implemented to address this risk consist of periodic calibration and a double-check system. Periodic calibration is a preventive measure carried out on a schedule to ensure scale accuracy remains within established tolerance limits. This process involves using verified calibration standards and is performed by competent personnel (Purbaningtias et al., 2022). Meanwhile, the double-check system serves as a detective control that verifies the weighing results through rechecking or cross-verification with other methods or tools. This system can involve reweighing samples, verification with a backup scale, or visual confirmation of suspicious weighing results. To improve the effectiveness of controlling risk R2, several corrective recommendations can be implemented. First, improving the detection system through the implementation of an automated monitoring system that can detect anomalies in weighing results in real-time. This system can be equipped with an alarm that sounds when a significant deviation from the normal pattern occurs (Buluaro et al., 2025). Second, developing a redundancy system by using multiple weighing systems that can cross-verify the weighing results. Third, increasing operator competency through periodic training and certification to ensure consistency in weighing procedures. Fourth, implementing an integrated digital recording system to reduce human error in data entry and allow for better tracking of the weighing history.

The Risk Priority Number (RPN) analysis for failure R3 shows a value of 47.72, which is obtained by multiplying severity (6.93), occurrence (2.68), and detection (2.57). The relatively high severity (6.93) indicates that the impact of data recording errors has serious consequences for mill operations, particularly concerning the credibility of the information system and compliance with applicable regulations. The moderate occurrence (2.68) suggests that although the existing control system is moderately effective in reducing the frequency of errors, there are still opportunities for human error and system failure that need to be anticipated. The low detection (2.57) value indicates that the ability to detect recording errors when they occur still needs improvement. This may be due to a lack of an automated monitoring system or a delayed verification process that allows errors to go undetected for a long time. The primary causes of reception data recording errors can be identified in two main, interconnected categories. The first factor is human error in recording, which can occur in various forms, ranging from manual data input mistakes, misinterpretation of the data to be recorded, to negligence in following established recording procedures (Nursaada, 2025). This human error is often triggered by factors such as operator fatigue, lack of adequate training, excessive workload, or lack of motivation to maintain accurate records. The second factor is damage to the recording system, which can include hardware malfunction, network connection issues, or backup system failure. System damage can lead to the loss of input data, data duplication, or the system's inability to store data in the correct format. The impacts of reception data recording errors are highly complex and have a domino effect that can spread throughout the entire mill management system. The most significant main effect is the inaccuracy of production reports, which will affect decision-making at the management level (Anggrahini et al., 2023). When FFB reception data is not correctly recorded, daily, weekly, and monthly reports will contain misleading information, making it difficult for management to make sound strategic decisions regarding production planning, resource allocation, and marketing strategies (Harahap et al., 2023). Inventory errors, which are the second impact, will cause an imbalance between recorded stock and the actual physical condition. This can result in unexpected surpluses or difficulties in accurate stock planning. The most critical impact is audit failure, both internal and external, which can lead to regulatory sanctions, loss of certification, and a decrease in stakeholder confidence in the company's credibility (Anggrahini et al., 2023). The control system that has been implemented to address risk R3 consists of two main mechanisms: data verification and a backup system. Data verification functions as a detective control that rechecks the accuracy and completeness of the recorded data. This process can be done through cross-checking with source documents, validation by a supervisor, or comparison with historical data to identify anomalies. The backup system serves as a corrective control that ensures data can still be recovered when a main system failure occurs. This system includes automatic backup scheduling, a redundant storage system, and disaster recovery procedures that allow for data recovery within minimal time (Appy & Wicaksono, 2025).

The Risk Priority Number (RPN) analysis for failure R4 shows a value of 55.16, obtained by multiplying the severity (7.39), occurrence (2.79), and detection (2.68). The high severity (7.39) indicates that the impact of imperfect sterilization is very serious on product quality and mill operations. This is understandable because sterilization is the process that determines the fundamental quality of the palm oil to be produced. The moderate occurrence (2.79) suggests that with the existing control system, the frequency of imperfect sterilization is already reasonably well controlled, although the possibility of errors still exists. The moderate detection (2.68) value indicates that the ability to detect sterilization problems when they occur is reasonably adequate, but can still be improved to provide a faster response to deviations. The primary causes of imperfect sterilization can be identified as several interconnected technical factors. The first cause is under-sterilization or insufficient sterilization, which occurs when the sterilization process fails to reach the necessary conditions to kill microorganisms and deactivate enzymes. This can be caused by the operator's lack of understanding regarding the correct sterilization parameters or pressure to speed up the production process (Julianti et al., 2024). The second cause is unsuitable temperature parameters. Sterilization requires a sufficiently high temperature

The Risk Priority Number (RPN) analysis for failure R5 shows a value of 61.29, obtained by multiplying the severity (7.46), occurrence (3.11), and detection (2.64). The high severity (7.46) indicates that the impact of sterilizer damage is very serious on mill operations, as it can cause a total production halt and significant financial losses. This is understandable given that the sterilizer is a critical piece of equipment that does not have an alternative bypass in the production process. The moderate occurrence (3.11) suggests that even though a preventive maintenance system has been implemented, the sterilizer still has a significant possibility of experiencing damage. This is normal considering the sterilizer operates under harsh conditions with high temperatures and pressure, making its components vulnerable to wear and tear. The low detection (2.64) value indicates that the ability to detect signs of damage before the sterilizer completely fails is reasonably good, but can still be improved to provide a more accurate early warning. The primary causes of sterilizer damage or malfunction can be grouped into several interconnected categories. The first cause is autoclave damage, which is the main component of the sterilizer serving as the high-pressure sterilization chamber. The autoclave can experience damage such as cracks in the wall, leaks in the seal, or damage to the locking system, which can cause pressure loss and disrupt the sterilization process (Winarsih, 2020). The second cause is component wear and tear resulting from intensive use and harsh operating conditions. Components such as valves, gaskets, sensors, and heating elements can experience wear that leads to performance degradation or even total failure. The third cause is lack of maintenance or inadequate maintenance, which can include delays in performing routine care, the use of spare parts that do not meet specifications, or a lack of technical understanding on how to properly maintain the equipment. Inadequate maintenance will accelerate damage and reduce the service life of the equipment. The impacts of sterilizer damage or malfunction are highly detrimental from both an operational and financial perspective. The first and most direct impact is the halt of the entire production process, as the sterilizer is a non-bypassable initial stage in palm oil processing. When the sterilizer is damaged, the entire production flow is disrupted and cannot run normally. The second impact is a production delay that can last for hours or even days, depending on the severity of the damage and the availability of necessary spare parts. This production delay not only affects daily production targets but can also lead to the accumulation of FFB, which potentially degrades in quality if not processed immediately. The third impact is high repair costs, as the sterilizer is complex and expensive equipment. These repair costs include the cost of spare parts, technician labor costs, and the cost of lost production during the repair period. In cases of severe damage, major component replacement may be required, which demands a very large investment (Wahyudi et al., 2024).

The potential for sterilizer damage or malfunction to cause a process halt and high repair costs means that the existing preventive maintenance system needs to be strengthened. Based on the FMEA, a weakness gap was identified in the sterilization system that could potentially lead to process failure and compromise product sterility. Therefore, the implementation of systematic alternative improvement solutions is necessary to close this weakness gap and increase the reliability of the sterilization system. The control system that has been implemented to address risk R5 consists of three main components: preventive maintenance, spare parts, and backup units. Preventive maintenance is a system of scheduled preventative care carried out to avoid damage before components reach the end of their useful life. This system includes routine inspection, lubrication, replacement of worn components, and calibration of measuring instruments. Good preventive maintenance must be performed according to a determined schedule and use a comprehensive checklist to ensure all aspects of the equipment are carefully checked. Spare parts are a critical component of the control system because the timely availability of the correct spares will determine the speed of repair when damage occurs. Good spare parts management includes planning needs, an appropriate storage system, and monitoring stock levels to ensure the availability of critical parts. The backup unit functions as a temporary substitute when the main sterilizer is damaged, allowing production to continue, albeit potentially at a limited capacity (Amalia et al., 2022).

This high RPN value indicates that failure mode R6 requires priority attention in the improvement and prevention program. Although control systems are already implemented, it appears that further improvements are needed to reduce the frequency of occurrence and enhance early detection capabilities. Improvements can be made through upgrading thresher machine technology, optimizing operating parameters, providing better operator training, or implementing a more sophisticated monitoring system to detect incomplete threshing in real-time. The root causes of incomplete threshing problems generally stem from two main factors. The first is the condition of the fruit still firmly attached to the empty bunches, which can occur due to sub-optimal fruit maturity levels or the physical condition of the bunches not matching the ideal parameters for the threshing process. The second is improper thresher machine settings, where parameters such as rotation speed, pressure, or threshing time are not suitable for the characteristics of the fruit being processed. To control this risk, a control system consisting of empty bunch inspection and thresher adjustment has been established. Empty bunch inspection is performed to ensure that the threshing process has run properly and to identify if any fruit is left behind. Meanwhile, thresher adjustment is carried out to optimize the machine's operating parameters to suit the condition of the processed fruit (Nabila, 2024). The impact of this failure is highly significant on the productivity and profitability of the palm oil mill. When threshing is incomplete, there is a loss of fruit whose oil could actually still be extracted. This condition directly causes low oil yield because not all available fruit is successfully processed. Consequently, a production loss occurs, which not only affects the output volume but also reduces the overall efficiency of the production process (Syahputri et al., 2025). Incomplete fruit threshing is the second priority risk with an RPN of 66.67. Fruit still attached to the empty bunches causes significant yield loss and production losses. Failure mode R6 is one of the critical issues in the palm oil production process that occurs at the threshing stage. This problem is characterized by the condition where palm fruit does not detach completely from the empty bunches during the threshing process, resulting in a large amount of fruit still attached to the bunches after passing through the thresher machine.

Based on the Risk Priority Number (RPN) analysis, failure mode R7 has an RPN value of 62.44, which is obtained by multiplying severity (7.21), occurrence (3.11), and detection (2.79). The high severity (7.21) indicates that the impact of this failure is very serious on the mill's productivity and profitability. The occurrence (3.11) value indicates that this problem happens with a sufficiently concerning frequency in daily operations. Meanwhile, the detection (2.79) value shows that the system's ability to detect this problem still needs improvement. Although the RPN value for R7 (62.44) is lower than R6 (71.86), this issue still requires serious attention because it relates to the quality of the final loose fruit (brondolan) which will affect subsequent processes. The suggested improvements—through daily visual checks and checklist implementation—are a more proactive and structured step compared to the current control system. This approach allows for early detection and faster corrective action, which is expected to reduce the frequency of occurrence and minimize the production losses caused by incomplete fruit threshing. The primary causes of the problem with loose fruit damage during threshing are identical to the general threshing problems. Damaged loose fruit can cause oil cells to rupture and crude oil to prematurely escape before the pressing process. The first factor is the condition of the fruit still firmly attached to the empty bunches, which can occur for various reasons such as non-uniform fruit ripeness levels, excessively hard physical condition of the bunches, or a sub-optimal prior sterilization process that failed to sufficiently soften the bond between the fruit and the bunch. The second factor is improper thresher machine settings, where operating parameters such as rotation speed, pressure, threshing duration, or angle of inclination are not suitable for the characteristics of the fruit being processed. The impact of this failure is highly detrimental to the palm oil mill's operations. Imperfect loose fruit during threshing will result in kernel fragments or fibers being carried into the oil. This condition directly causes an increase in Free Fatty Acid (FFA) content and an increase in dirt content. Consequently, significant production losses occur, where the mill misses the opportunity to produce the amount of oil that should have been achievable from the available raw material (Smed & Athaillah, 2023). Failure mode R7 is a problem related to the condition of the loose fruit in the palm oil production process, specifically damage to the loose fruit during threshing. Loose fruit (brondolan) is the term referring to the palm fruits that have detached from their bunches after the threshing process. This problem indicates that the threshing process is not operating optimally, resulting in some fruit being damaged due to impact during the threshing process. The control system implemented to address this issue includes empty bunch inspection and thresher adjustment (Susanti et al., 2023). Empty bunch inspection is performed to verify the effectiveness of the threshing process by checking if any fruit remains attached to the bunches. Thresher adjustment is carried out to optimize the machine's operating parameters so that it can work with maximum efficiency according to the condition of the fruit being processed. However, based on the available alternative improvements, a more systematic approach is needed: performing a daily visual inspection of loose fruit quality and creating a daily checklist to ensure no fruit is wasted.

Based on the Risk Priority Number (RPN) analysis, failure mode R8 has an RPN value of 57.61, which is obtained by multiplying the severity (7.43), occurrence (2.86), and detection (2.71). The high severity (7.43) indicates that the impact of thresher damage is very serious because it can halt the entire production process. The occurrence (2.86) value suggests that although this problem does not happen too frequently, it still needs to be closely monitored. The detection (2.71) value indicates that the ability to detect early signs of damage still needs improvement.Although the RPN value for R8 (57.61) is not among the highest in the entire process, this issue still requires serious attention because it is critical to production continuity. Thresher damage can cause very significant losses, not only in terms of repair costs but also from lost production during downtime. Therefore, the implementation of a routine and consistent maintenance schedule and the provision of adequate spare parts are very important strategies to minimize this risk. This approach is expected to reduce the frequency of damage and speed up the repair time when a problem occurs. The primary causes of thresher malfunction or damage can be categorized into several factors. The first is a thresher jam, which usually occurs due to foreign material entering the machine or excessive accumulation of material. Additionally, damage to the beater blades or grates on the thresher drum often occurs due to continuous impact from the palm fruit bunches during the separation process. The second is a breakdown or sudden failure, which can be caused by excessive workload, old age, or operating conditions that do not match the machine's specifications. The third is damage to critical components such as bearings, gears, drive motors, or hydraulic systems that are worn out or damaged due to intensive use.Inadequate maintenance is also a key cause of thresher damage. When the preventive maintenance program is not executed properly, machine components will experience excessive wear and ultimately lead to failure (Amalia et al., 2022). This could actually be prevented if there were a regular maintenance system and continuous machine condition monitoring. The impact resulting from thresher damage or malfunction is highly detrimental to the palm oil mill's operations. When the thresher experiences a disruption, the production process will either stop completely or experience prolonged downtime (Marpaung et al., 2021). This condition causes a delay in production because the entire sequence of processes after threshing cannot proceed without input from this stage. Furthermore, the repair costs required to fix thresher damage are usually quite high, especially if the damage involves major machine components with high investment value (Rompas et al., 2021).

In terms of risk assessment, conveyor jam has a Severity (S) level of 7.61, which indicates that the impact of this problem is quite serious on production operations. However, the Occurrence (O) level is relatively moderate with a value of 2.50, suggesting that the problem does not happen too frequently if the system is well managed. The Detection (D) level is 2.43, which shows that this problem can be detected relatively easily through visual observation or a monitoring system. With a calculated Risk Priority Number (RPN) of 46.19, this risk falls into the medium category and requires appropriate control measures. Based on the Failure Mode and Effect Analysis (FMEA) conducted, the issue of conveyor jam in the material transport system at the palm oil mill is one of the operational risks that deserves serious attention. This conveyor jam can occur in both the feeding conveyor and the discharging conveyor, commonly caused by an excessive load on the transport system (Syahputri, 2022). The impact of a conveyor jam is highly significant on the overall production operation. When a conveyor jams, it creates a bottleneck or obstruction in the production flow that should otherwise run smoothly. Consequently, a production delay occurs, which can disrupt the daily operational schedule. Furthermore, this jam also causes material buildup in certain areas, which not only hinders work efficiency but can also create unsafe working conditions for the operator (Syahputri, 2022). To address the conveyor jam problem, a control strategy focused on prevention and maintenance has been established. The main strategies include routine monitoring of the conveyor load to ensure capacity is not exceeded, and periodic conveyor cleaning to avoid the accumulation of dirt or residual material that could impede movement. In addition, load monitoring also helps the operator to identify potential overloads before a jam occurs, allowing preventive actions to be taken immediately (Syahputri, 2022). The implementation of this control system is vital for maintaining the smooth flow of production operations and preventing greater economic losses. With the consistent application of monitoring and regular maintenance, the risk of conveyor jams can be minimized, thus keeping the palm oil mill's productivity optimal and achieving production targets as planned (Naibaho, 2024).

The risk assessment shows a Severity (S) level of 6.86, an Occurrence (O) of 3.07, and a Detection (D) level of 2.54, resulting in a Risk Priority Number (RPN) of 53.41. The moderately high severity (6.86) indicates that the impact of this failure is very serious on mill operations, as it can lead to decreased oil quality, production loss, and disruption in the separation process, which is a critical stage in CPO extraction. The moderate occurrence (3.07) suggests that with the current maintenance system, the frequency of low oil yield issues is still quite frequent and requires an enhancement of the preventive maintenance program. Meanwhile, the low detection (2.54) value indicates that the ability to detect the early signs of equipment malfunction is reasonably good, but can still be improved through the implementation of a real-time equipment condition monitoring system and an increase in operator competence in identifying abnormal symptoms in clarification equipment. This issue is caused by several interconnected technical factors. The main factor is less efficient pressing, where the press machine fails to maximally extract oil from the fruit flesh. This can happen because operational parameters such as pressure, temperature, and pressing time are not adjusted to the optimal conditions (Anoraga, Wijanarti & Sabarisman, 2018). Furthermore, unsuitable machine settings also cause the processing results to be sub-optimal. This occurs because each batch of palm fruit has different characteristics, depending on the ripeness of the fruit and how it was stored (Syahrullah & Izza, 2021). The impact of low oil yield is significantly detrimental economically. In addition to resulting in losses or high product loss, this problem also causes a sharp decrease in production efficiency (Priyatama & Supriyanto, 2023). In the long term, this can affect the company's competitiveness because the production cost per unit of oil becomes higher than the industry standard. In the palm oil extraction process, the problem of low oil yield is one of the main challenges that can significantly impact production efficiency and profitability. Low oil yield means the percentage of oil successfully extracted from the palm fruit does not reach the optimal target, leading to waste of raw materials and resulting in economic losses (Priyatama & Supriyanto, 2023). To address this problem, the established control strategies include continuous monitoring of process parameters and adjustment of the press machine according to the condition of the material being processed. Parameter monitoring involves supervising pressure, temperature, speed, and process time to ensure optimal conditions are achieved. Additionally, routine adjustment of the press tool is performed to accommodate different types of fruit. Alternative solutions that can be implemented are setting the pressure and speed of the press machine according to the fruit condition, and periodically monitoring the extraction results and recording them to determine the optimal pattern.

The risk assessment for CPO contamination shows a Severity (S) of 6.82, an Occurrence (O) of 3.00, and a Detection (D) of 2.61, with an RPN of 53.35. The high severity (6.82) indicates that the impact of CPO contamination is very serious on the final product quality, as it can cause a decrease in selling value, product rejection by buyers, loss of quality certification, and potentially lead to significant financial losses for the company. The moderate occurrence (3.00) suggests that with the current quality control system, the likelihood of contamination still occurs quite frequently in daily operations, thus requiring an enhancement of sanitation procedures and stricter process control. Meanwhile, the low detection (2.61) value shows that the ability to detect contamination at an early stage is reasonably good through laboratory testing and visual inspection, but can still be improved through the implementation of an online monitoring system and an increase in the frequency of quality parameter testing to ensure the CPO product meets established standards. The source of CPO contamination generally originates from impurities entering during the processing. Contamination can be in the form of unwanted solid particles, water, or chemical substances (Azzahro et al., 2022). The main causal factor is poorly maintained cleanliness during the production process. This can occur due to a lack of equipment maintenance, sub-optimal cleaning procedures, or inadequate quality control in preceding stages (Azzahro et al., 2022). The impact of CPO contamination is very serious because it directly affects the final product quality. When CPO is contaminated, the product will experience a grade reduction and potentially be rejected by buyers (Hidayati et al., 2024). This rejection not only causes direct losses from unsold products but can also damage the company's reputation and affect long-term business relationships with buyers. Crude Palm Oil (CPO) contamination is a highly critical quality issue in the palm oil processing industry. Contaminated CPO will experience a significant decline in quality, failing to meet the standards set by buyers. This can lead to product rejection by the buyer, which will certainly cause substantial economic losses for the company (Hidayati et al., 2024). The established control system to address CPO contamination focuses on filtering and cleaning. The filtering process is carried out in stages using specialized filters to capture dirt or foreign objects that could enter the oil (Sundari et al., 2021). Furthermore, all equipment must be cleaned regularly and thoroughly to maintain cleanliness and prevent becoming a source of contamination, thereby preserving the quality of the resulting palm oil (Amalia et al., 2022). As an alternative improvement solution, installing additional filters and replacing them periodically can be done to ensure filtering effectiveness remains optimal. Saturated or damaged filters must be replaced immediately to prevent a decline in filtering quality. Additionally, implementing stricter and scheduled cleaning procedures can help reduce the risk of contamination from the start of the process (Kurniawan, 2022).

Based on the risk analysis conducted, failure mode R12 (Imperfect separation of oil, water, and sludge) has a Severity (S) value of 7.18, indicating that the resulting impact of this failure is quite serious on product quality and the production process. The Occurrence (O) value of 2.82 suggests that the likelihood of this failure is relatively low to moderate, meaning that with the existing control system, this failure does not happen too often but still needs to be anticipated. The Detection (D) value of 2.57 shows that this failure can be detected quite well using the existing monitoring system, indicating that the implemented control and monitoring system is reasonably effective in detecting the separation failure. The resulting RPN (Risk Priority Number) is 52.08, which suggests that although this risk is not in the highest category, it still requires consistent attention and preventive action. In the palm oil processing, the clarification stage is a critical process that determines the quality of the resulting crude palm oil. At this stage, the separation of oil, water, and sludge is vital to produce high-quality CPO. However, as identified in the FMEA analysis, this separation process can experience failure that significantly impacts the final product quality (Nainggolan et al., 2025). Failure mode R12 describes the condition where the separation between oil, water, and sludge is not perfectly accomplished during the clarification process. Under normal conditions, these three components should separate effectively based on their specific gravity differences and physical characteristics. Oil, with the lightest specific gravity, will be in the top layer; water in the middle; and sludge, with the heaviest specific gravity, will settle at the bottom. When separation is imperfect, these three components will be mixed and difficult to separate, resulting in sub-optimal oil quality (Tarigan, 2023). Based on the analysis, the primary cause of this separation failure is sub-optimal separation parameters. These parameters include temperature, pressure, and flow rate within the clarification system (Nainggolan et al., 2025). When these parameters are not set correctly, the gravity separation process cannot proceed effectively. A temperature that is too low can cause the oil's viscosity to increase, making separation more difficult, while a temperature that is too high can cause oil quality degradation (Saukani et al., 2025). Another equally important cause is inadequate settling time. The gravity separation process requires sufficient time to allow the three components to separate according to their specific gravities. If the settling time is too short, separation will be imperfect because the components have not had enough time to separate naturally. Conversely, too long a settling time can cause production inefficiency and potential oil quality degradation due to prolonged exposure to high temperatures (Nabila, 2024). To prevent system failure R12, the company uses an automated surveillance system that continuously monitors machine conditions such as temperature, pressure, and flow rate in real-time. Modern sensor equipment is used to provide accurate data and updates on process conditions so operators can make necessary adjustments quickly. Additionally, the settling time in the separation process is automatically regulated according to the type of material being processed, and personnel perform visual checks to ensure the separation results meet established standards (Nur & Alya, 2024). The imperfection in the separation process leads to several serious impacts on product quality and production efficiency. The main impact is the decrease in the quality of the crude palm oil produced because the oil that should be pure becomes contaminated with water and sludge that are not properly separated. The water content in the oil will increase above the allowable standard, which can cause problems in storage and further processing (Noriega, 2024). Another impact is excess sludge in the final product, which not only degrades quality but can also cause problems in the downstream process (Cahyono & Yuliastuti, 2020). High sludge content can accelerate oil deterioration and reduce the product's selling value, thus causing significant financial losses because the resulting product may not meet the quality standards set by buyers or applicable regulations (Cahyono & Yuliastuti, 2020). To make the separation system work better and reduce the possibility of failure, several things need to be done. First, all measuring and control tools must be checked and maintained regularly to always provide accurate data. Second, use a smarter automated control system that can directly adjust settings according to the condition of the material being processed. Third, operators must be continuously trained to understand how the separation process works and what to do when problems arise. Finally, create complete and detailed work guidelines that cover monitoring methods, troubleshooting, and corrective steps for various situations, ensuring everyone works in a consistent manner. Failure mode R12 concerning the imperfect separation of oil, water, and sludge is one of the important risks in the crude palm oil production process. Although it does not have the highest RPN value, the impact on product quality is significant and requires serious attention. By implementing the right control system, consistent monitoring, and continuous improvement, this risk can be minimized to ensure the production of high-quality and efficient crude palm oil. Success in controlling this risk depends not only on the technology and equipment used but also on the management's commitment and the operators' skills in running the process well (Nainggolan et al., 2025). Investment in better control systems and personnel training will provide a positive return in the long term through increased product quality and operational efficiency (Simbolon et al., 2023).

4.4. Analysis of Calculation Results

Based on the Failure Mode and Effects Analysis (FMEA) of the palm oil processing, 14 potential failures that can affect product quality and operational efficiency have been identified. The obtained Risk Priority Number (RPN) values range from 31.13 to 128.85, indicating a variation in risk levels that require different attention in the effort to improve the production system. The following are the most influential risks requiring priority attention:

Priority Risks

The problem requiring the most immediate attention is poor palm fruit quality at the FFB reception stage with an RPN of 128.85. This issue is crucial because it directly impacts oil yield and the quality of the resulting CPO (Crude Palm Oil). Fruit that is over-ripe, under-ripe, rotten, or dirty will significantly reduce the quality of the final product and cause major economic losses. Although a system of visual inspection and manual sorting is in place, this control appears to be insufficient given the high Severity (7.11) and Occurrence (4.93) values. This indicates that the fruit reception and selection system requires fundamental improvements, both in terms of technology and operational procedures. Incomplete fruit threshing at the thresher stage shows an RPN of 71.86, indicating significant fruit loss because the fruit remains attached to the empty bunches due to improper thresher settings. This problem directly impacts yield and production losses, which can reduce operational profitability. The condition of sub-optimal loose fruit with an RPN of 62.44 indicates a similar problem in the threshing system that leads to decreased production efficiency. Both issues are related and show that the overall threshing system requires in-depth evaluation and adjustment of operational parameters.

Damage or malfunction of the sterilizer with an RPN of 61.29 is an important concern because it can halt the entire production process. Damage to autoclave components and a lack of preventive maintenance are the main causes of this problem, necessitating a more intensive and systematic maintenance program. Thresher malfunction with an RPN of 57.61 also contributes to a significant loss of production efficiency, especially when component jams or damage cause production downtime. Imperfect sterilization with an RPN of 55.16 can lead to microbial contamination and low oil quality, which ultimately affects the product's market acceptance. This issue occurs due to temperature, pressure, or sterilization time parameters not meeting the standard. In the extraction stage, low oil yield with an RPN of 53.41 indicates that the pressing process is not yet optimal, resulting in too much oil being wasted or not perfectly extracted. CPO contamination with an RPN of 53.35 is caused by impurities and inadequate cleanliness, which can degrade product quality and lead to rejection by the buyer. Imperfect separation of oil, water, and sludge with an RPN of 52.08 results in low oil quality with high water content and excess sludge.

Error in reception data recording with an RPN of 47.72 can cause inaccurate production reports and audit problems, despite existing verification and backup systems. Human error in recording and damaged recording systems are the main causes of this problem. Conveyor jams with an RPN of 46.19 can cause a process bottleneck and production delays due to overloaded or stuck conveyors. FFB weighing errors with an RPN of 42.12 result in inaccurate production data and potential financial loss due to inaccurate scale calibration and human error. Heating system disturbance with an RPN of 32.02 can reduce separation efficiency and lead to sub-optimal oil quality due to damaged heat exchangers or leaking steam pipes. Clarification equipment malfunction with an RPN of 31.13 is the lowest priority problem but still has the potential to halt the process and lower oil quality when damage occurs to the clarifier, centrifuge, or setting tank. Although the Severity of both issues is quite high, the low Occurrence and Detection values indicate that the current control systems are relatively effective.

4. Conclusions

To address the various identified problems, a comprehensive approach is needed, starting with strengthening the fruit quality control system at the reception stage. Implementing automatic sorting technology or intensive training for sorting personnel can help reduce the Occurrence level of fruit quality issues. The preventive maintenance program needs to be strengthened, especially for the sterilizer and thresher, coupled with the optimization of process parameter settings to increase threshing and extraction efficiency. Real-time monitoring systems for critical parameters such as process temperature, pressure, and time are highly recommended for earlier deviation detection. Continuous training for operators and standardization of operational procedures will help reduce the human error that causes many of the identified problems. The implementation of corrective actions should be carried out in stages based on the RPN value sequence, while maintaining already effective control systems, thus achieving sustainable improvement in quality and production efficiency. Based on the results of the FMEA, the potential failure modes in the process of processing fresh fruit bunches into Crude Palm Oil can be identified. The main and most urgent risk to address is R1, poor quality of palm fruit at the FFB reception stage, which yields the highest Risk Priority Number (RPN) of 128.85. The second highest high risk is R6, incomplete fruit threshing, yielding an RPN of 71.86. The third highest risk is R7, damage to loose fruit during threshing (crushed and destroyed loose fruit), yielding an RPN of 62.44. The fourth risk is R5, sterilizer malfunction damage, yielding an RPN of 61.29. The fifth risk is R8, thresher equipment malfunction or damage, yielding an RPN of 57.61. The higher the resulting Risk Priority Number (RPN) value, the higher the priority for implementing improvements before process failures occur.

5. References

Afrizal, Y., Dewi, E., & Zamhari, M. 2022. Pengolahan Crude Palm Oil (CPO) Menjadi Minyak Sawit Merah (MSM) Menggunakan Filter Batuan Zeolit, Membran Keramik dan Cartridge Filter. *Kinetika*, *13*(03), 11-19.

Al Maududy, M. M., Mardianto, K., & Susanto, A. 2021. Pemanfaatan Berbagai Sensor dalam Manajemen Perkebunan Kelapa Sawit. *WARTA Pusat Penelitian Kelapa Sawit*, *26*(2), 117-123.

Alfianto, Y. (2019). Analisis Penyebab Kecacatan Produk Weight A Handle Menggunakan Metode Fault Tree Analysis dan Failure Mode and Effect Analysis sebagai Rancangan Perbaikan Produk. *JIEMS (Journal of Industrial Engineering and Management Systems)*, *12*(2), 71-80.

Amalia, W., Ramadian, D., & Hidayat, S. N. 2022. Analisis Kerusakan Mesin Sterilizer Pabrik Kelapa Sawit Menggunakan Failure Modes and Effect Analysis (FMEA). *Jurnal Teknik Industri*, *8*(2), 369-377.

Anastasya, A., & Yuamita, F. 2022. Pengendalian kualitas pada produksi air minum dalam kemasan botol 330 ml menggunakan metode failure mode effect analysis (FMEA) di PDAM Tirta Sembada. *Jurnal Teknologi dan Manajemen Industri Terapan*, *1*(I), 15-21.

Andriana, A. N., & Wulandari, C. 2023. Dinamika Harga Minyak Goreng Serta Dampaknya Terhadap Pengukuran Standar Kualitas Produk. *EKUITAS (Jurnal Ekonomi dan Keuangan)*, *7*(1), 62-80.

Andry, M. A. Z. S., Syachputra, D., Fauzan, H. Z., & Prastyo, Y. 2025. Literatur Review: Pemanfaatan Artificial Intelligence Dalam Predictive Maintenance Untuk Meningkatkan Keandalan Industri. *Journal of Management and Innovation Entrepreneurship (JMIE)*, *2*(4), 2384-2395.

Anggrahini, T., Widyastuti, S., & Sihite, M. 2023. Pengaruh Internal Kontrol, Organization Behaviour Dan Digitalisasi Terhadap Kinerja Perusahaan. *Jurnal Locus Penelitian dan Pengabdian*, *2*(11), 1079-1093.

Anoraga, S. B., Wijanarti, S., & Sabarisman, I. (2018). Pengaruh suhu dan waktu pengepresan terhadap mutu organoleptik bubuk kakao sebagai bahan baku minuman coklat. *Jurnal Pertanian Cemara*, *15*(2), 20-28.

Appy, F. N., & Wicaksono, P. A. 2025. Analisis Pengendalian Kualitas Produksi Crude Palm Oil (CPO) Dengan Metode Six Sigma (Studi Kasus: PT Sampoerna Agro Tbk). *Industrial Engineering Online Journal*, *14*(3).

Ariyanto, E., Alqorni, M. F., & Mardwita, M. 2024. Efisiensi Thermal Alat Economizer pada Pre-Treatment Section dalam Pengolahan Crude Palm Oil (CPO). *Eksergi*, *21*(1), 48-54.

Assauri, S. 2016. *Manajemen Operasi Produk*si. Jakarta: PT Raja Grafindo Persada.