

Machine Failure Risk Management in Continuous Production Systems through Failure Mode Identification and Risk Priority Number Evaluation

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Abstract: Machine failure risk management is essential in continuous production systems because unplanned downtime can disrupt production flow, reduce product quality, increase maintenance costs, and create safety risks. **Objective:** This study aims to develop a machine failure risk management framework through Failure Mode and Effects Analysis (FMEA) and Risk Priority Number (RPN) evaluation. **Methodology:** This research uses a qualitative literature study approach. Data were collected from scientific journals, technical standards, and academic publications related to reliability engineering, risk management, predictive maintenance, and production systems. The data were analyzed thematically to identify failure modes, risk assessment parameters, and effective control strategies. **Findings:** The findings show that machine failure risks can be managed through systematic identification of failure modes, evaluation of occurrence, severity, and detection, and prioritization based on RPN values. High-risk failure modes require preventive maintenance, predictive monitoring, redundancy systems, spare parts planning, and structured operator involvement. **Implications:** The proposed framework can assist manufacturing organizations in developing documented, auditable, and proactive maintenance risk management systems to improve machine reliability and reduce unplanned downtime. **Originality:** The originality of this study lies in integrating FMEA, RPN evaluation, predictive maintenance, spare parts management, operator participation, and ERP-based monitoring into a comprehensive framework for continuous production systems.

Keywords: Machine Failure Risk Management; Failure Mode and Effects Analysis; Risk Priority Number; Predictive Maintenance; Continuous Production Systems.

INTRODUCTION

In sustainable production systems, machine reliability becomes the determining factor for operational continuity because every unplanned shutdown can propagate through the entire production chain. Machine failure not only causes economic losses from lost production time but also has the potential to damage other components, disrupt the material supply to subsequent workstations, and create unsafe conditions for operational workers. This condition demands high material management effectiveness to ensure the availability of critical spare parts to minimize the duration of production disruptions (Theodara et al., 2022). Machine failure risk management aims to anticipate scenarios where machine

components lose their function, whether gradually or suddenly ([Santos & Silva, 2024](#)). Traditional approaches relying on routine time-based maintenance have proven inadequate for handling failures that are random or triggered by operational factors such as overloading or electrical voltage fluctuations. This inadequacy underscores the need for more comprehensive manufacturing planning from the early stages of machine development to enhance operational durability ([Anwar et al., 2022](#)).

Modern production systems with high levels of automation have thousands of interconnected components, meaning the failure of a single small sensor can result in reading errors that damage an entire batch of products. World-class manufacturing companies report that costs arising from unexpected machine failures reach twenty to thirty percent of total annual maintenance costs. This figure shows that a reactive approach waiting for a failure to occur before taking action is highly inefficient ([Hansen et al., 2024](#)). Strengthening internal control through integrated information systems is essential for detecting machine performance anomalies early on ([Arifin & Sinambela, 2021](#)). A proactive risk management system is required, where potential failures are identified before they actually occur, evaluated for their severity, and controlled through planned technical interventions. The use of cutting-edge technology can now be relied upon as a rapid solution for producing precise replacement components to maintain mechanical efficiency ([Triono & Darmawan, 2024](#)).

Identification of machine failure risks requires an understanding of the common damage mechanisms occurring in each type of component ([Kim et al., 2025](#)). Bearings, for example, have a characteristic failure pattern starting with an increase in operational temperature, followed by abnormal vibration, and finally a total seizure. Conveyor belts show early signs in the form of micro-cracks on the surface or uneven tension changes. Pneumatic systems experience leaks characterized by a slow drop in pressure or a whistling sound at hose connections. Each of these damage mechanisms has a latent period, which is the time span between the appearance of the first symptoms and the occurrence of functional failure. Material quality analysis is also a key variable in understanding the speed of component degradation ([Djaelani et al., 2022](#)). The latent period varies greatly between component types, from a few minutes for electrical components experiencing a short circuit to several months for mechanical components undergoing material fatigue. Effective risk management must utilize this latent period to perform maintenance interventions before the actual failure occurs. Identification techniques such as periodic

visual inspections, measurement of operating parameters, and lubricant sample analysis can detect early symptoms of damage. Unfortunately, many organizations lack systematic procedures to interpret these symptoms as risk signals that need to be followed up (Tranter, 2016). Consequently, failures that could actually be prevented still occur because warning signs are ignored.

Machine failure risk evaluation is conducted by considering three main dimensions: the frequency of failure occurrence, the severity of consequences, and the detection capability before failure occurs (Magomedov et al., 2022). In addition to technical considerations, this evaluation must also include ethical principles in investment risk management so that maintenance decisions align with the company's financial sustainability (Putra & Arifin, 2023). The frequency of occurrence is estimated from historical damage data of similar components on the same machine or from industrial databases. A pneumatic valve identical to a thousand units operating in another factory might have a failure rate of once every two years, but in a dusty work environment, the frequency could increase to three times per year. The level of consequence severity is assessed based on the impact of failure on production continuity, worker safety, and product quality. The implementation of strict Occupational Health and Safety (K3) programs becomes an important instrument to mitigate the impact of physical injuries that may arise from sudden machine failure (Djaelani & Darmawan, 2016). Failure in a critical machine that serves as a production bottleneck can halt the entire line with losses of millions of rupiah per hour, while failure in a redundant machine that has a backup might only cause a temporary decrease in production speed. Detection capability measures how easily the early symptoms of failure can be observed by operators or automated monitoring systems. Components located in hard-to-reach areas or those whose symptoms only appear at very high frequencies require specialized sensors for early detection. A comprehensive risk evaluation results in the mapping of each component into an intervention priority matrix, ensuring that maintenance resources are allocated to the components with the highest risk values first.

Machine failure risk control covers a broad spectrum of actions, ranging from component design modifications, changes in maintenance schedules, to the provision of redundancy systems (Bao & Zuo, 2018). A systematic risk management approach becomes an absolute prerequisite to ensure the success of maintenance projects amidst a dynamic business environment (da Silva et al., 2022). For high-risk components with failure

frequencies that cannot be reduced, the most appropriate control strategy is to install a backup unit that becomes active immediately when the main component fails (hot standby). The control system can automatically switch to the backup without stopping production at all. For components with a sufficiently long latent period, control is carried out through preventive maintenance scheduled at intervals shorter than the shortest latent period ever recorded. For example, if the minimum latent period for a bearing is three months, then preventive replacement is performed every two months to provide a safety margin. For components whose failures cannot be predicted due to their random nature, control is carried out through corrective maintenance supported by spare parts inventory and a standby repair team. The choice of control strategy must consider the total cost of each option, including spare parts procurement costs, labor costs for repairs, and production downtime costs. Sometimes, a larger initial investment to purchase components with higher reliability is more economical in the long run than continuously repairing cheap components that break frequently. This decision requires a careful life cycle cost analysis of the components.

Sustainable production systems demand a different machine failure risk management approach compared to conventional mass production due to their operational characteristics that never stop over the long term (Wu et al., 2026). Digitalization has reshaped work architectures and task loads in the manufacturing sector, thereby demanding the integration of IoT-based monitoring to manage operational risks more precisely (Triono et al., 2025). Factories with operating schedules of twenty-four hours a day, seven days a week do not have ample time windows to perform major maintenance. Every intervention on the machine must be planned very meticulously so as not to disrupt supplies to customers who expect daily deliveries. This time constraint demands a risk control approach that relies more on accurate prediction than on fixed time-based maintenance (Berrade et al., 2023). Predictive maintenance that uses online sensors to monitor component conditions in real-time becomes very important. Vibration sensors, temperature sensors, electrical current sensors, and fluid flow sensors are installed at critical points on the machine. Data from these sensors is streamed to a central monitoring system that uses algorithms to detect anomalies. The use of these connected digital tools has also become a growing trend to upgrade their production setups (Mardikaningsih & Darmawan, 2025). When parameters approach predetermined thresholds, the system schedules maintenance at a time that is least disruptive to production, such as during shift changes or when production is low due to

seasonal factors. This approach allows sustainable plants to avoid sudden failures without having to halt operations for routine maintenance that is not always necessary. Its implementation requires significant initial investment in sensor infrastructure and data analytic systems, but the return on investment usually occurs within two to three years through the reduction of unplanned downtime.

The main problem in machine failure risk management is the organization's inability to identify all potential failure modes for each component. A simple centrifugal pump has more than twelve different failure modes: mechanical seal leakage, impeller erosion, bearing damage, rotor imbalance, cavitation, motor overheat, starting capacitor failure, suction pipe leakage, clogged strainer, coupling damage, power supply voltage error, and control relay failure. Each failure mode has a different cause, symptom, latent period, and consequence. Maintenance teams lacking adequate technical knowledge often only recognize the three to four most common failure modes, leaving risks from other failure modes unmanaged. Besides technical competence, transparent human resource governance is necessary to ensure the responsibility of each personnel in maintaining organizational justice regarding the distribution of the risk management workload ([Darmawan, 2026](#)). This incompleteness causes companies to feel secure because maintenance reports show no issues, even though certain components are undergoing undetected latent degradation. The method that should be used is Failure Mode and Effects Analysis (FMEA), performed systematically by involving technicians who understand the working principles of each component. This method produces a comprehensive list of all possible failures and their physical causal mechanisms. However, its implementation is time-consuming and requires high documentation discipline, leading many companies to skip this stage and jump straight to evaluation with incomplete data. As a result, control priorities become biased because unidentified failure modes are never evaluated.

Another problem hindering machine failure risk management is the lack of reliable historical data to calculate the frequency of each failure mode. Small and medium-sized enterprises often lack structured damage recording systems. When a component fails and is replaced, technicians only record that the machine jammed and has been repaired, without specifying the broken component, the failure mode, or the operating time prior to failure. These non-detailed records are useless for statistical analysis because they do not distinguish between bearing failure due to material fatigue (wear-out failure) and failure due to dust contamination, even though these two types require very different control

strategies. Failure due to material fatigue requires bearing replacement at intervals based on design life, whereas failure due to contamination requires seal system repair or environmental cleanliness improvements. Without differentiating data, maintenance managers will make incorrect decisions. Digital recording systems with standard failure codes such as ISO 14224 for process industries should be adopted, yet in many general manufacturing sectors, adoption remains very low as it is considered bothersome and requires additional training. This poor recording culture is the root of recurring risk management failures.

In smart factories, production decisions are made automatically by systems based on the availability and reliability of each machine. If the risk management system does not provide accurate information about the probability of a machine failing within the next twenty-four hours, the production control system cannot allocate orders optimally. Consequently, customers may experience delivery delays because the system selects a production path that happens to use a machine with a high risk of failure. Furthermore, undetected machine failures can lead to the production of large quantities of defective goods before the quality control system realizes there is a deviation. The losses from defective production include not only wasted material costs but also re-testing costs, re-shipping costs, and the potential loss of customer trust. Regulations in several countries are beginning to mandate that manufacturing companies have a documented asset risk management system. Companies that do not comply with these regulations face the risk of administrative sanctions or even the revocation of operating licenses. Thus, developing a machine failure risk management system is no longer a strategic choice but an operational and compliance necessity.

The objective of this research is to outline a machine failure risk management framework that includes identifying failure modes through Failure Mode and Effects Analysis, evaluating risks based on frequency, severity, and detectability, and controlling risks through preventive, predictive, and redundancy maintenance strategies. This research provides a theoretical contribution by mapping technical risk management methods into the context of sustainable production systems. Its practical contribution is a step-by-step guide for machine maintenance practitioners to develop a documented and auditable risk management system.

RESEARCH METHOD

This research was conducted as a qualitative literature study aimed at examining risk management approaches for machine failure within sustainable production systems. Shipman (2014) explains that social research in the fields of engineering and operations management often faces limitations in accessing machine failure data, which is frequently classified as corporate secrets. A literature study serves as a valid alternative for developing theoretical propositions without having to rely on primary data that is difficult to obtain (Sridhar, 2020). Adler and Clark emphasize that non-empirical research can still produce valid conclusions as long as the source selection process is conducted transparently and systematically (Adler & Clark, 2011). This research draws on literature from three scientific domains: reliability engineering, risk management, and production systems. The library sources analyzed include technical standards such as ISO 31000 for general risk management, ISO 14224 for reliability data collection, as well as scientific publications from journals such as Reliability Engineering and System Safety and the Journal of Quality in Maintenance Engineering. Lampard and Pole refer to this multi-domain approach as an interdisciplinary literature study that requires the synthesis of concepts from various fields which may use different terminology for similar phenomena (Lampard & Pole, 2015). The use of advanced tracking systems also helps to improve data clarity and build stronger confidence throughout the distribution channel (Mardikaningsih & Darmawan, 2025). The synthesis process is carried out by mapping key concepts from each domain into an integrated framework (Zhu & Newman, 2025). The analysis is conducted thematically by identifying recurring patterns in the literature regarding factors causing machine failure, the risk evaluation methods most widely adopted by industry, and control strategies proven effective in published case studies.

The analysis method in this literature study follows the procedures outlined by Lampard and Pole for qualitative research that does not involve field data collection (Lampard & Pole, 2015). The first stage is the collection of sources from trusted academic databases such as Scopus, Web of Science, and Google Scholar using keywords: machine failure risk, production system reliability, failure mode and effects analysis, risk assessment matrix, predictive maintenance, and continuous operation. The second stage is the screening of sources based on inclusion criteria: publications within the last ten years, case studies from the sustainable manufacturing sector, and the availability of data regarding the effectiveness of risk control strategies. Shipman warns that literature studies relying

solely on secondary sources may lose important nuances that only emerge through direct observation (Shipman, 2014). Therefore, this research also analyzes technical reports from organizations such as the Society for Maintenance and Reliability Professionals as well as standard documents from the International Electrotechnical Commission. The third stage is data extraction from each source into a thematic matrix containing columns for: failure mode, identification method, risk evaluation parameters, control strategy, and operational context. Adler and Clark refer to such a matrix as a tool to compare findings across studies that may use different methodologies (Adler & Clark, 2011). The fourth stage is the synthesis of findings from the matrix to generate propositions regarding best practices in machine failure risk management. The resulting propositions are conditional, meaning the recommendations provided depend on specific characteristics of the production system, such as the level of automation, machine age, and the availability of historical data.

RESULT

The most systematic approach to identifying machine failure risks is Failure Mode and Effects Analysis (FMEA), which is conducted at the individual component level. This method begins with the decomposition of the machine into the smallest functional units that can be replaced or repaired independently (Signoret & Leroy, 2021). This decomposition process must also consider risk mapping within the global supply chain to identify potential disruptions in the availability of critical components (Mardikaningsih et al., 2024). For example, a CNC lathe is decomposed into the main spindle, axis drive system, cooling system, chip removal system, numerical control system, and centralized lubrication system. Each functional unit is then analyzed to answer the question: in what ways can this unit fail to perform its function? For the main spindle, failure modes include: bearing wear, drive belt damage, rotational imbalance, shaft cracking due to material fatigue, position sensor failure, and overheating due to clogged lubricant circulation. Damage characteristics in rotating machinery, such as generators, can also be specifically identified through vibration signal analysis to determine the type of failure occurring (Riyadin & Darmawan, 2023). Each failure mode is then detailed regarding its root causes using the fishbone diagram method. Bearing wear, for instance, can be caused by particle contamination in the lubricant, insufficient lubrication, loads exceeding design capacity, or vibrations from other machines propagating through the production floor. A complete FMEA document can have more than a hundred rows for a machine of moderate

complexity. The team performing the analysis must consist of maintenance technicians who understand the mechanics of damage, machine operators who know daily operation patterns, and process engineers who understand the impact of failure on product quality. Operator involvement is crucial because they often observe early symptoms that are not recorded in automated monitoring systems.

DISCUSSION

The risk assessment of each failure mode requires the assignment of numerical values to three parameters: Occurrence (frequency of occurrence), Severity (severity of consequences), and Detection (detection capability) (Liu et al., 2022). The most commonly used scale is a 1 to 10 scale, where a value of 1 indicates very low risk and a value of 10 indicates very high risk. Occurrence is assessed based on the historical Mean Time Between Failures (MTBF) of similar components. A value of 1 is assigned to failure modes with an MTBF of more than five years, a value of 5 for an MTBF between six months and one year, and a value of 10 for an MTBF of less than one week. Severity is assessed based on the impact of the failure on worker safety, product quality, and production time. Strengthening the culture of occupational safety and health significantly contributes to improved operational performance whilst reducing the severity score resulting from workplace accidents (Djaelani et al., 2021). A score of 1 is assigned if the failure causes only minor inconvenience without halting production. A score of 10 is assigned if the failure has the potential to cause serious injury or even death, and halts the entire production line for more than one day. Detection is assessed based on how easily early signs of failure can be identified before a functional failure occurs. A score of 1 is assigned if automatic sensors immediately detect anomalies and issue a warning with a response time of more than one week. A score of 10 is assigned if no detection methods are available, meaning failures always occur suddenly. The Risk Priority Number (RPN) is calculated as the product of Occurrence \times Severity \times Detection. Failure modes with the highest RPN become the top priority for control actions. However, a very high Severity value (9 or 10) must be addressed immediately regardless of the Occurrence and Detection values due to the potentially fatal consequences (Kumar et al., 2024).

Risk control for failure modes with a high RPN can be implemented through three main approaches: reducing the frequency of occurrence, reducing the severity of consequences, or increasing detection capabilities (Kim et al., 2025). The effectiveness of

these controls depends heavily on compliance with accounting rules and internal controls to prevent deviations in risk reporting (Gardi & Sinambela, 2022). Reducing the frequency of occurrence is achieved by replacing components with more reliable designs or altering operating conditions to be more favorable to the components. For example, the frequency of bearing failure due to contamination can be reduced by installing more effective labyrinth sealing systems or by replacing mineral lubricants with synthetic lubricants that are more resistant to contamination. Reducing the severity of consequences is achieved by installing protection systems that limit the impact of failure if it occurs. For instance, installing a torque limiter on the machine coupling will cause the coupling to slip when the load exceeds the threshold, preventing the shaft from breaking even if the machine jams. Increasing detection capability is achieved by adding sensors that monitor component health parameters in real-time. Vibration sensors on the bearing housing can detect increased vibration amplitude at specific frequencies, which is an early indication of bearing damage. These three approaches are complementary and are often applied simultaneously for the most critical failure modes. The decision on which approach is most suitable must be based on a cost-benefit analysis. Analysis of cost behavior and the categorization of maintenance costs are necessary so that the allocation of risk control resources becomes more accurate (Sinambela & Djaelani, 2022). Investing in sensor systems and early detection may be more expensive upfront but yields long-term savings by preventing more severe damage.

Sustainable production systems with continuous operations require different risk control strategies compared to batch production with periodic stop schedules (Su et al., 2020). Because there is no time for preventive maintenance at fixed intervals, a more suitable strategy is condition-based predictive maintenance using real-time data from sensors to predict the end of a component's life. Calculating production costs using the variable costing method can help managers understand maintenance cost efficiency for each unit of output (Sinambela, Darmawan, & Gardi, 2022). For bearings, the monitored parameters include surface temperature, vibration amplitude in the frequency domain, and the number of metal particles in the lubricant. Machine learning algorithms are trained with historical failure data to recognize patterns preceding a failure. When the algorithm detects a component approaching failure, the system schedules a replacement at the most appropriate time in coordination with the supply chain. For critical components that cannot be stopped for even a moment, an alternative strategy is active redundancy (two identical

components operating in parallel) so that if one fails, the other remains functional. Active redundancy is expensive because it requires double the investment, but for machines with very high hourly downtime costs, the cost of redundancy is smaller than the losses from a total production halt.

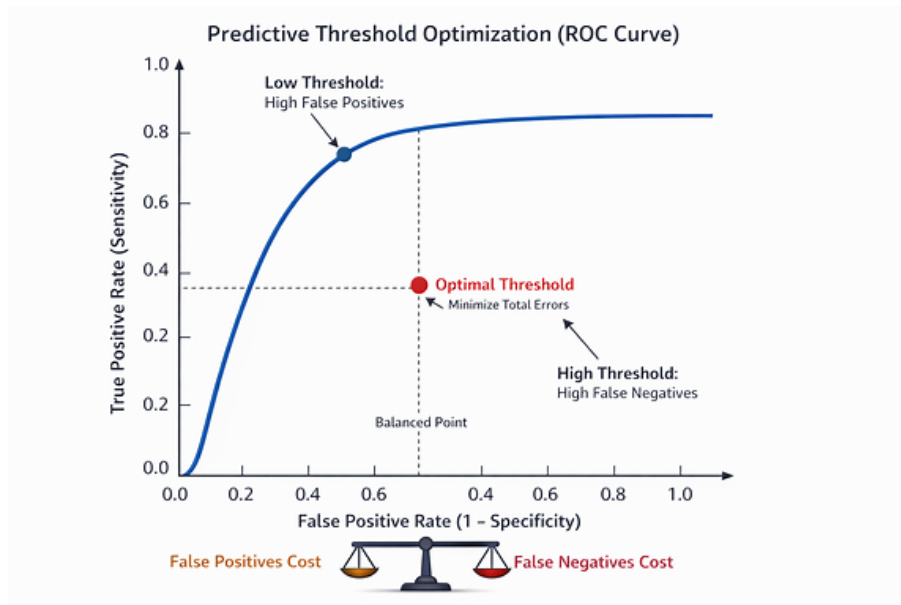


Figure 1. ROC Curve for Predictive Threshold Optimization and Classification Error Balance.

One of the biggest challenges in predictive maintenance is determining the threshold values for each sensor parameter. A threshold that is too low leads to false alarms (false positives) and unnecessary maintenance, which wastes costs and disrupts production. A threshold that is too high causes failures to go undetected until it is too late (false negatives). Establishing an optimal threshold requires statistical data on the distribution of parameters for both healthy and failing components. For new components without historical data, the initial threshold is based on manufacturer recommendations or technical standards such as ISO 10816 for machine vibration. After one to two years of operation, the collected data is used to recalibrate the thresholds using statistical methods like the ROC (Receiver Operating Characteristic) curve, which determines the cutoff point that minimizes total errors. In continuous production, the cost of a false negative is usually much higher because it leads to unplanned downtime; therefore, thresholds are set lower to increase sensitivity despite the increased risk of false positives (Hansen et al., 2024)

As in Figure 1, the ROC Curve in the context of determining sensor thresholds for predictive maintenance illustrates the relationship between the true positive rate and the false positive rate

for various threshold values. When the threshold is set too low, the system becomes highly sensitive and generates many false alarms that trigger unnecessary maintenance. Conversely, a threshold that is too high makes the system less sensitive, causing it to fail to detect impending damage. The optimal point on the ROC curve indicates the best balance between sensitivity and specificity, which is the point where the total number of errors (false positives and false negatives) is minimized. In industrial practice, threshold setting is often adjusted according to the relative cost of each type of error; because the cost of failure (false negative) is typically greater than the cost of a false alarm, the threshold tends to be chosen slightly lower to increase early detection capabilities and maintain production sustainability.

Documentation of machine failure risk management must include a risk map showing the position of each failure mode in a frequency versus severity matrix. This matrix is divided into a green zone (low risk without specific action), a yellow zone (medium risk with periodic monitoring), and a red zone (high risk with immediate control actions). Failure modes in the red zone must have a documented action plan that includes the person in charge, the actions to be taken, deadlines, and success measures (Handani & Uchida, 2024). Action plans for high severity but low occurrence can take the form of emergency response procedures and worker training. Action plans for high occurrence but low severity can involve optimizing preventive maintenance schedules. Good documentation also includes an explanation of the assumptions used in the risk evaluation, such as the assumption that normal machine vibration does not exceed 2 mm per second, which must be verified by actual measurements. Shipman emphasizes the importance of transparency of assumptions in non-empirical research, and the same principle applies to risk management documentation (Shipman, 2014). Documentation must be reviewed at least once a year or whenever significant changes occur in the production process or machine composition.

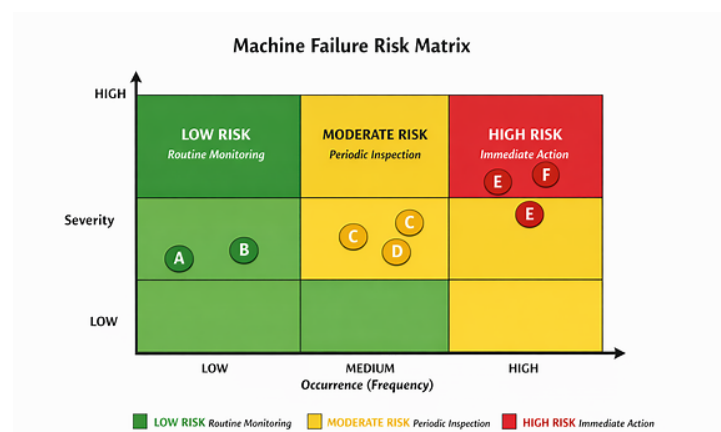


Figure 1. Machine Failure Risk Matrix Based on Severity and Occurrence Frequency

Figure 2 is an image of the machine failure risk matrix showing the relationship between the frequency (occurrence) and severity of each failure mode in the production system. The horizontal axis represents the frequency level from low to high, while the vertical axis shows the severity level from low to high. The matrix is divided into three color zones: green for low risks that only require routine monitoring, yellow for medium risks that require periodic inspections, and red for high risks that demand immediate control actions. Each failure mode is placed according to its position in the matrix; for example, modes in the red zone must have a fully documented action plan including the person in charge, corrective steps, deadlines, and success measures. Modes with high severity but low occurrence are typically handled through training and emergency response procedures, while high occurrence but low severity modes are addressed by optimizing preventive maintenance schedules. This matrix serves as a visual tool to prioritize risks and ensures that risk management documentation is transparent, systematic, and can be reviewed periodically in accordance with changes in operational conditions.

Cost control through break-even point analysis is crucial for determining the investment feasibility of such redundancy systems (Sinambela, Darmawan, Gardi, et al., 2022). The difference in risk management approaches for new versus old machinery is substantial due to the availability of data and technical documentation. For new machines, manufacturers typically provide component reliability data obtained from accelerated laboratory testing (Ayele & Barabadi, 2017). This data is useful for initial Occurrence estimations, but it must be validated with field data after the machine has been operating for several months, as field conditions always differ from laboratory conditions. For old machines that have been operating for decades without adequate documentation, a more realistic approach is to use historical failure data from maintenance records as an estimation basis. However, maintenance records for old machinery are often incomplete due to periods when digital recording systems were not yet in use. In such conditions, the technique used involves interviewing long-tenured technicians to reconstruct major failure events from the past. This method is prone to memory bias but remains better than having no data at all. Another alternative is using data from public industrial databases like OREDA (Offshore Reliability Data), which collects failure data from various companies for standard components like pumps, valves, and compressors. Data from these industrial databases can serve as a rough proxy until the company manages to collect sufficient internal data (Selvik

& Ford, 2017). For unique components with no industrial equivalent, the only path is to perform prospective data collection by recording every failure in detail from this point forward.

Machine failure risk management cannot be separated from spare parts management. Even the greatest risk control strategy will fail if repair parts are unavailable when a component breaks (Chi et al., 2025). The provision of production support facilities, including adequate storage space, must have its requirements evaluated periodically (Priambodo et al., 2022). Determining spare parts inventory levels must be based on failure frequency, procurement lead times, and storage costs. Failure modes with high occurrence require sufficient spare parts in local warehouses to cover the lead time. Failure modes with low occurrence but very high severity require a consignment strategy, where suppliers deliver parts within 24 hours. For critical components that are expensive and rarely fail, the most economical strategy is a maintenance agreement with the manufacturer that guarantees the dispatch of technicians and parts within an agreed timeframe. All inventory decisions must be documented in the risk management system and reviewed periodically due to changes in lead times or failure frequencies caused by machine aging. Continuous production systems cannot tolerate long wait times because every hour of downtime results in losses (Dreyer et al., 2018), so they tend to keep larger inventories as an insurance premium against uncertainty.

Operator training on failure risk management is often overlooked because it is considered the responsibility of the maintenance department, yet operators interact with the equipment daily and can be the primary source of early failure symptoms. The utilization of information technology and high work motivation among employees will improve their performance in detecting machine anomalies (Sinambela & Mardikaningsih, 2022). Effective training teaches operators to recognize five early signs of failure: abnormal noise, vibration, changes in machine casing temperature, burning smells, and fluid leaks. Operators also need training on symptom reporting procedures using a standard format that includes which machine, the suspected component, symptoms, time of appearance, and production status. The implementation of an integrated accounting information system has been proven capable of improving the quality of operational reports through a strong internal control system (Sinambela & Darmawan, 2011). Without a standard format, operator reports tend to be subjective and non-comparable. An example of a good report: lathe number 03, main spindle, high-frequency squeaking sound around 2000 Hz at speeds above 3000 RPM, first

heard March 14 at 09:30, production ongoing with a feed rate reduction of about five percent. The integrity of personnel in reporting data honestly is heavily influenced by the quality of their work life and job satisfaction ([Hariani & Sinambela, 2021](#)). Companies with a culture of operator symptom reporting indicate a decrease in the average failure detection time from several days to a few hours, allowing maintenance to be performed at early stages of damage with lower costs ([Okirie & Ejomarie, 2025](#)).

Integrating the machine failure risk management system with Enterprise Resource Planning (ERP) systems enables a seamless data flow between condition monitoring, maintenance scheduling, and spare parts procurement. This ultimately impacts the stability of corporate performance, which is often reflected through stock prices and dividends in the eyes of investors ([Sinambela & Mardikaningsih, 2021](#)). When sensors detect a component approaching the end of its useful life, the system automatically generates a work order, checks spare parts availability, and, if unavailable, sends a purchase requisition to the supplier. Work orders are scheduled by considering production priorities. This integration requires data communication standards such as OPC Unified Architecture for industrial data communication and ISA 95 for the interface between control and business systems. For older machines without digital interfaces, a possible solution is installing gateways that read data from analog indicator panels using cameras or additional sensors, then converting them into digital signals. While not ideal, this solution is more economical than replacing the machine. Companies with full integration report that the time between symptom detection and repair completion can be shortened by up to seventy percent due to administrative process automation ([Nozari & Szmelter-Jarosz, 2025](#)).

Audits of the machine failure risk management system should be conducted by independent third parties to ensure objectivity in assessment. The integrity and competence of auditors are fundamental factors determining audit quality in providing an accurate assessment of system reliability. Auditors will examine the completeness of FMEA documentation, the consistency between calculated Risk Priority Numbers and the control actions taken, and evidence that control actions were actually implemented according to schedule ([Tang et al., 2025](#)). Furthermore, auditor integrity plays a large role in shaping the organizational commitment to comply with every improvement recommendation provided ([Sinambela & Mardikaningsih, 2021](#)). Auditors will also conduct interviews with operators and technicians to verify that failure symptom reporting procedures are understood and followed. Regularly conducted internal audits are also an obligation to

mitigate the company's legal liability regarding potential operational deviations or negligence (Fajarudin et al., 2024). One common audit finding is that some high-RPN failure modes lack documented control actions because the maintenance team considers them unavoidable risks. The auditor will assess whether the absence of these control actions is caused by technical limitations (e.g., no technology is available to detect that failure mode) or by negligence. If caused by technical limitations, the auditor will accept the reason but still recommend a research plan to find future solutions. If caused by negligence, the auditor will issue a non-conformance finding that must be corrected within a specific timeframe. The quality of the resulting audit will ultimately influence company performance, especially in providing a transparent overview for stakeholders.

Building strong relationship networks and solid team communication inside the workplace is also vital to support long-term quality improvement goals (Darmawan, 2026; Putra & Arifin, 2023) Certification of risk management systems based on standards such as ISO 31000 can increase the trust of customers and other stakeholders in the company's ability to manage operational risks. However, it should be remembered that certification does not guarantee that failures will not occur, but rather guarantees that the risk management process has been implemented according to established procedures.

CONCLUSION

Machine failure risk management in sustainable production systems requires a systematic approach that begins with the identification of all potential failure modes using Failure Mode and Effects Analysis for each component. Risk evaluation is performed by calculating the Risk Priority Number as a product of the frequency of occurrence (Occurrence), the level of consequence severity (Severity), and the detection capability (Detection). Failure modes with very high Severity values must receive control priority regardless of other parameter values due to the potential for fatality. Risk control can be achieved by reducing the frequency of occurrence through more reliable designs, reducing consequence severity through protection systems, or enhancing detection capabilities with online sensors and predictive algorithms. For sustainable production systems without routine maintenance windows, the most suitable strategy is condition-based predictive maintenance supported by redundancy in the most critical components. Setting sensor thresholds must balance the costs of false positives and false negatives, with a tendency toward choosing higher sensitivity because the cost of unplanned downtime is extremely

high. Documentation of risk maps, action plans, and assumptions must be reviewed annually. Spare parts for high-frequency failure modes should be stored in local warehouses, while components with low frequency but fatal consequences require fast-delivery agreements with suppliers. Training operators to recognize and report early symptoms of failure in a structured manner is an equally vital component. Integrating the risk management system with ERP and conducting periodic third-party audits ensures the ongoing effectiveness of the system.

The practical implication of these findings is that organizations must allocate sufficient resources for training cross-functional teams to perform Failure Mode and Effects Analysis correctly, as incomplete identification of failure modes is the most common cause of risk management system failure. The suggestion for industry is to begin implementation on a single pilot production line that has the most complete historical data, then expand to the entire plant once procedures are well-documented and internal auditors have been trained. For future research, empirical studies are recommended to compare the effectiveness of various failure prediction algorithms (logistic regression, random forest, or neural networks) on different machine components, as well as research on the optimal cost of spare parts inventory in production systems that are highly sensitive to downtime. Regulators are advised to develop sectoral guidelines regarding the documentation of machine failure risk management tailored to the technical capacity of small companies, including pre-filled Failure Mode and Effects Analysis templates for commonly used machine types.

REFERENCES

- Adler, E. S., & Clark, R. (2011). *An invitation to social research: How it's done*. Cengage.
- Anwar, M. S., Setiawan, A., Saleh, M., Diba, F. F., Triono, B., & Darmawan, D. (2022). Fabric Expansion Joint Roller Machine Manufacturing Planning. *International Journal of Service Science, Management, Engineering, and Technology*, 1(1), 1-5.
- Arifin, S., & Sinambela, E. A. (2021). Studi tentang kinerja karyawan ditinjau dari keberadaan sistem informasi akuntansi dan pengendalian internal. *Realible Accounting Journal*, 1(1), 58-70.
- Ayele, Y. Z., & Barabadi, A. (2017). Quantitative risk analysis of components under high stress.
- Bao, H., & Zuo, H. (2018). Probability risk analysis and control of aeroengine control system failures. *189*(6), 062049. <https://doi.org/10.1088/1755-1315/189/6/062049>
- Berrade, M. D., Calvo, E., & Badía, F. G. (2023). Maintenance of systems with critical components. Prevention of early failures and wear-out. *Computers & Industrial Engineering*, 181, 109291. <https://doi.org/10.1016/j.cie.2023.109291>

- Chi, G., Tang, X., Zhang, L., & Hu, J. (2025). Calculation of ground backup requirements for aero-engine based on statistical analysis.
- da Silva, B. D. S., Darmawan, D., & Gardi, B. (2022). A Systematic Approach to Risk Management to Enhance Information Technology Project Success in a Dynamic Business Environment. *Journal of Social Science Studies*, 2(2), 213-218.
- Darmawan, D. (2026). Human Resource Risk Management and HR Governance as Predictors of Organizational Justice in Islamic Banking Institutions. *Jurnal Ilmiah Satyagraha*, 9(1), 66-80.
- Djaelani, M., & Darmawan, D. (2016). Studi Tentang Program Keselamatan dan Kesehatan Kerja (K3) serta Kompetensi Lintas Budaya terhadap Kinerja Pekerja Konstruksi. *Jurnal Ekonomi dan Bisnis*, 6(2), 11-17.
- Djaelani, M., Judiono, J., Darmawan, D., & Amri, M. W. (2022). Study of concrete: quality and economic. *Bulletin of Science, Technology and Society*, 1(1), 1-3.
- Djaelani, M., Sinambela, E. A., Darmawan, D., & Mardikaningsih, R. (2021). Strengthening the culture of occupational safety and health as a contributor to the formation of construction project performance. *Journal of Marketing and Business Research (MARK)*, 1(2), 59-70.
- Dreyer, S., Passlick, J., Olivotti, D., Lebek, B., & Breitner, M. H. (2018). Optimizing Machine Spare Parts Inventory Using Condition Monitoring Data. In *A Quarterly Journal of Operations Research* (pp. 459-465). https://doi.org/10.1007/978-3-319-55702-1_61
- Fajarudin, M., Negara, D. S., & Putra, A. R. (2024). Internal Audit Obligations and Corporate Legal Liability for Corruption. *Journal of Social Science Studies*, 4(1), 303-312.
- Gardi, B., & Sinambela, E. A. (2022). Effectiveness of Internal Controls and Compliance with Accounting Rules and its Influence on the Trend of Accounting Fraud. *Studi Ilmu Sosial Indonesia*, 2(1), 1-12.
- Handani, D. W., & Uchida, M. (2024). Development of Maintenance Scheduling Model for the Safety Operational of Ship Machinery. *Kapal*, 21(2), 92-101. <https://doi.org/10.14710/kapal.v21i2.61582>
- Hansen, H. K., K ulahçı, M., & Nielsen, B. F. (2024). A primer on predictive maintenance: Potential benefits and practical challenges. *Quality Engineering*, 1-12. <https://doi.org/10.1080/08982112.2024.2331140>
- Hariani, M., & Sinambela, E. A. (2021). Hubungan Kualitas Kehidupan Kerja, Kepuasan Kerja, dan Integritas Akuntan Publik. *Ekonomi, Keuangan, Investasi dan Syariah (Ekuitas)*, 3(2), 297-301.
- Kim, D. H., Park, H. J., & Yang, S. W. (2025). Analysis of the cause of damage in Aircraft Engine through the Fracture Analysis. *Journal of the Korea Academia Industrial Cooperation Society*. <https://doi.org/10.5762/kais.2025.26.11.107>
- Kumar, M. P., Raju, N. V. S., & Kumar, M. (2024). Prioritizing the risk priority numbers in fmeca – a heuristic approach. In (pp. 191-201). <https://doi.org/10.58532/v3bdme5p2ch7>

- Lampard, R., & Pole, C. (2015). *Practical social investigation: Qualitative and quantitative methods in social research*. Routledge.
- Liu, Y., Chen, B. Q., Dong, Q., Liu, W., Nie, W., & Yang, C. (2022). Failure mode risk assessment methodology for controlling multi-uncertainties in the evaluation process. *Engineering Applications of Artificial Intelligence*, 116, 105470. <https://doi.org/10.1016/j.engappai.2022.105470>
- Magomedov, F. M., Melikov, I. M., Pashtaev, B. D., Bedoeva, S. V., & Kurbakov, I. I. (2022). Methods for determining the probability of failure-free operation of the engine of machines with an electronic control system. *IOP Conference Series: Earth and Environmental Science*, 979(1), 012103. <https://doi.org/10.1088/1755-1315/979/1/012103>
- Mardikaningsih, R., & Darmawan, D. (2025). Analisis Adopsi Teknologi Internet of Things Oleh Industri Manufaktur Skala Kecil dan Menengah. *Jurnal Lima Daun Ilmu*, 5(1), 41.
- Mardikaningsih, R., Halizah, S. N., Nuraini, R., Darmawan, D., & Hardyansah, R. (2024). Manajemen Risiko Pada Penerapan Manajemen Rantai Pasokan Global: Kajian Terhadap Pendekatan Strategis Untuk Mengidentifikasi, Mengevaluasi, dan Mengelola Risiko. *Yos Soedarso Economic Journal (YEJ)*, 6(2), 1-15.
- Nozari, H., & Szmelter-Jarosz, A. (2025). A Predictive Maintenance Approach for Composting Plants Based on ERP and Digital Twin Integration. *Machines*. <https://doi.org/10.3390/machines13121123>
- Okirie, A. J., & Ejomarie, E. K. (2025). Exploring Proactive Maintenance through Fault Detection Techniques for Rotating Machinery. *International Journal of Prognostics and Health Management*, 16(2). <https://doi.org/10.36001/ijphm.2025.v16i2.4424>
- Priambodo, S., Djaelani, M., Jahroni, J., Sinambela, E. A., & Darmawan, D. (2022). Evaluation of the Need for Motorcycle and Car Parking Spaces. *International Journal of Service Science, Management, Engineering, and Technology*, 1(1), 16-19.
- Putra, A. R., & Arifin, S. (2023). Ethical Principles in Corporate Financial Management: A Literature Study on Investment and Risk. *Journal of Social Science Studies*, 3(2), 221-226.
- Riyadin, F., & Darmawan, D. (2023). Experimental Study of 3 KW Generator Damage Types Based on Vibration Signals. *International Journal of Service Science, Management, Engineering, and Technology*, 3(2), 27-31.
- Santos, G. R. D., & Silva, T. K. L. R. D. (2024). Optimization of preventive maintenance in production lines: an approach based on reliability statistics. *Contribuciones a Las Ciencias Sociales*. <https://doi.org/10.55905/revconv.17n.2-129>
- Selvik, J. T., & Ford, E. P. (2017). Down Time Terms and Information Used for Assessment of Equipment Reliability and Maintenance Performance. In. <https://doi.org/10.5772/INTECHOPEN.71503>
- Shipman, M. D. (2014). *The limitations of social research*. Routledge.

- Signoret, J. P., & Leroy, A. (2021). Failure Mode, Effects (and Criticality) Analysis, FME(C)A. In (pp. 165-172). https://doi.org/10.1007/978-3-030-64708-7_10
- Sinambela, E. A., & Darmawan, D. (2011). Analisis Dampak Penerapan Sistem Informasi Akuntansi terhadap Kualitas Laporan Keuangan melalui Sistem Pengendalian Internal Sebagai Variabel Intervening. *Jurnal Ekonomi dan Bisnis*, 1(1), 18-29.
- Sinambela, E. A., Darmawan, D., & Gardi, B. (2022). Production cost calculation analysis using variable costing method. *International Journal of Service Science, Management, Engineering, and Technology*, 1(2), 13-16.
- Sinambela, E. A., Darmawan, D., Gardi, B., & Malaihollo, F. J. (2022). Cost control through break even point analysis. *International Journal of Service Science, Management, Engineering, and Technology*, 1(3), 1-3.
- Sinambela, E. A., & Djaelani, M. (2022). Cost behavior analysis and categorization. *Journal of Social Science Studies*, 2(1), 13-16.
- Sinambela, E. A., & Mardikaningsih, R. (2021). Integritas Auditor dan Peranannya terhadap Pembentukan Komitmen Organisasi. *Jurnal Simki Economic*, 4(2), 112-120.
- Sinambela, E. A., & Mardikaningsih, R. (2022). The Influence of Accounting Information Systems, Work Motivation and Utilization of Information Technology on Employee Performance. *Journal of Science, Technology and Society (SICO)*, 3(2), 35-44.
- Sridhar, M. S. (2020). Importance and Issues of Literature Review in Research. In.
- Tang, Y., Fei, Z., Huang, L., Zhang, W., Zhao, B., Guan, H., & Huang, Y. (2025). Failure Mode and Effects Analysis Method on the Air System of an Aircraft Turbofan Engine in Multi-Criteria Open Group Decision-Making Environment. *Cybernetics and Systems*. <https://doi.org/10.1080/01969722.2025.2468189>
- Theodara, N. A., Darmawan, D., & Putra, A. R. (2022). Material Management Effectiveness. *Bulletin of Science, Technology and Society*, 1(1), 7-10.
- Tranter, J. (2016). Condition monitoring is not enough. *Asset Management & Maintenance Journal*, 29(2), 4.
- Triono, B., & Darmawan, D. (2024). 3D Printing Technology as A Driver of Innovation and Efficiency in Mechanical Engineering. *Journal of Science, Technology and Society (SICO)*, 5(2), 11-20.
- Triono, B., Darmawan, D., Djaelani, M., Safitri, F. S. A., & Masithoh, N. (2025). How Digitalization Reshapes Labor and Task Architecture in the Manufacturing Sector. *International Journal of Service Science, Management, Engineering, and Technology*, 7(2), 11-16.
- Wu, Y., Zhang, H., Li, D., & Lv, Z. (2026). Causal approach to quality-centered risk assessment in multi-machine manufacturing systems. *Reliability Engineering & System Safety*, 267, 111952. <https://doi.org/10.1016/j.ress.2025.111952>
- Zhu, R., & Newman, G. (2025). Synthesizing Insights. In (pp. 266-273). <https://doi.org/10.4324/9781003628064-20>