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Risk Mitigation Strategy for CNC Plasma Cutting Machine Damage Using The House of Risk Method and Root Cause Analysis

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Abstract

PT XYZ as a national strategic industrial company has a high dependence on the reliability of production machines, one of which is the CNC Plasma Cutting machine. Damage problems that occur on the machine can disrupt the smooth production process and pose a significant operational risk. In 2024, this machine experienced 35 breakdowns which resulted in a decrease in plate cutting output from the target of 1560 tons to 1417 tons. This study aims to identify the risk of machine failure and formulate mitigation strategies using the House of Risk (HOR) and Root Cause Analysis (RCA) methods. HOR is used to identify risk events, risk agents, and determine mitigation priorities based on the Aggregate Risk Potential (ARP) value, while RCA is used to find the main root cause of selected risks. The results showed that there were 5 mitigation actions that could potentially increase the cutting output by 8.8%, from 1417 tons to 1542 tons in 12 months. The combination of the HOR and RCA methods provides a comprehensive approach to risk mitigation, supporting the achievement of the slaughter output target.

Introduction

The manufacturing industry is one sector that relies heavily on machine reliability in carrying out its production processes. In fierce global competition, companies need to maximize the use of resources, including machinery and production equipment, because optimal machine performance affects quantity, product quality, and operational costs (Maharani et al, 2022; Ullah et al., 2023; Oteri te al., 2023; Khosroniya et al., 2024). The machines used must work optimally to produce efficient production and quality output. Machine breakdowns can reduce production, increase repair costs, and damage the company's reputation. Machine breakdowns can occur due to various factors, such as overuse, inadequate maintenance, worn components, design errors, and many more (Pamungkas et al, 2023; Jain et al., 2022). The growing technology and complexity of modern machines demand more careful risk management to maintain their reliability. One of the efforts that can be made to prevent damage to the machine is to prevent the risk of failure of the machine. The design of mitigation strategies needs to be done as a preventive measure to reduce the occurrence of risk agents (Noerdyah et al, 2020). The purpose of defining a mitigation strategy is to minimize the occurrence of a risk, reduce its frequency or by reducing its impact where the selection of strategic alternatives is based on the source of risk felt directly by the company (Rohimmah et al., 2020; Settembre-Blundo et al., 2021; Senathirajah & Palanisami, 2023).

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PT. XYZ is a company in the shipyard industry sector, shipyards are companies that provide services for building new ships and repairing ships (Oryza, 2023). PT XYZ is currently producing X type warships using various production machines and equipment, including CNC Plasma Cutting machines. Computer Numerical Control (CNC) is a machining method that begins with designing objects through Computer-Aided Design (CAD) software, followed by the production stage utilizing Computer-Aided Manufacturing (CAM) software. This approach involves the use of computer programs and machinery to streamline and automate the manufacturing process (Setyarto et al., 2023; Ajiga et al., 2024; Chukwunweike et al., 2024). There are 2 CNC Plasma Cutting machines used, namely CNC Plasma Cutting machines A & B. CNC Plasma Cutting Machine A which is 10 years old often experiences damage. In 2024 this machine was repaired 35 times, one type of damage that occurred repeatedly was damage to water cooling with a frequency of occurrence of 5 times which caused production delays in 2024 with cutting results reaching 1417 tons, with a target of 1560 tons. The company makes repairs only after damage occurs, without any mitigation or prevention steps. Therefore, a risk analysis is needed to identify and mitigate damage to the machine.

In an effort to identify and manage the risk of CNC Plasma Cutting machine damage, the House of Risk (HOR) and Root Cause Analysis (RCA) methods can be used. House of Risk is a framework for developing FMEA and QFD methodologies (Defriyanti et al, 2021; Santoso te al., 2024; Meilina, 2024). The House of Risk (HOR) method is a proactive risk management approach in which risk agents, identified as the sources of potential risk events, are addressed by prioritizing them according to the severity of their potential impact (Gulo et al, 2020; Ma & Wong, 2018; Partiwi et al., 2023; Nyoman Pujawan & Geraldin, 2009; Hasanah et al., 2025). The HOR model has two stages in dealing with risks that occur. The first is HOR phase 1, where risks will be identified first, then the second stage is HOR phase 2, where risks that have been identified will be handled by taking appropriate precautions (Tri, 2021). This model is based on the need for risk management that focuses on preventive measures to determine which risk factors are prioritized, then given mitigation or countermeasures (Rosadi et al, 2022 Senić et al., 2025; Hallegatte & Rentschler, 2015). So that it can help companies determine more effective mitigation strategies.

While the Root Cause Analysis (RCA) method is a method used to determine the failure of a system or machine (Haqi & Purba, 2020; Viveros et al., 2014; Sharma et al., 2007). Root Cause Analysis (RCA) is used to explore the root causes of machine breakdowns that occur. The principles of RCA can be applied to ensure that the true root cause is identified to initiate appropriate corrective action (Sahoo, 2023). With an organized method, RCA makes it easy to find the exact source of the problem, aiding the implementation of efficient solutions (Brawijaya et al, 2024). One of the most famous RCA techniques is called Five Whys (Paterson, 2023), with the 5 Why Analysis technique, RCA can help identify the main factors causing problems and provide more in-depth and sustainable solutions.

So in this study using a combination of HOR and RCA methods because it provides a comprehensive approach in mitigating the risk of damage to the CNC Plasma Cutting Machine. Thus, the potential for machine damage can be minimized.

Methods

This research uses a descriptive quantitative approach that aims to identify, analyze, and formulate mitigation strategies for the potential risk of CNC Plasma Cutting machine damage at PT. XYZ. The main method applied in this research is the House of Risk (HOR) combined with Root Cause Analysis (RCA). The selection of this method is based on the need to manage risks systematically, from initial identification to the preparation of preventive and measurable mitigation strategies. In the data collection process, researchers used primary data

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through interviews and questionnaires, Questionnaires were distributed to 3 respondents consisting of 2 maintenance staff with 13 years of work experience and 5 years of work experience and 1 CNC Plasma Cutting machine operator with 27 years of work experience with a Likert scale of 1-10 to measure the severity of the Risk Event, the occurance of the Risk Agent, and the correlation of the Risk Event with the Risk Agent, Although respondents have high competence, risk assessment remains subjective and can reflect personal biases based on their respective experiences and work positions, but calibration discussions were held among the three respondents after the initial completion of the questionnaire. Final scores were agreed upon through a consensus approach to reduce extreme differences in perception. As well as secondary data collection from company documents. The problem limitations in this study are the collection of CNC Plasma Cutting machine damage data with a period of 1 year from the beginning of January 2024 to the end of December 2024, the study does not discuss costs, the study was conducted on CNC Plasma Cutting machine A in the plate cutting process at PT XYZ, the research conducted only up to the process of proposing risk mitigation strategies and proposing estimates of plate cutting output after risk mitigation was carried out.

The collected data is then analyzed using the HOR phase 1 stage to identify risks and their causative agents, followed by calculating the Aggregate Risk Potential (ARP) value obtained from the multiplication of severity, occurrence and correlation values. After the risk with the highest ARP value is known, a root cause analysis is carried out using the RCA method with the 5 Whys Analysis Technique from the results of interviews with maintenance staff who often handle cases of CNC Plasma Cutting machine damage to formulate preventive measures against the main risks. For example, one of the risk events, namely 'Unstable water cooling pump', is analyzed using the 5 Why approach. Why is the water cooling pump unstable? Because the capacitor is weak. Why is the capacitor weak? Because the quality of the components is poor and cannot withstand the workload of the machine. Why is the quality of the components poor and cannot withstand the workload of the machine? Because the capacitor used is non-standard. Why is the capacitor used non-standard? because the procurement process does not involve technicians in verifying technical specifications. Why does the procurement process not involve technicians in verifying technical specifications? Because there are no regulations to involve technicians in technical verification during the component procurement process. So the main root cause after being identified is not having regulations to involve technicians in technical verification during the component procurement process. The last stage is HOR phase 2 which is used to design a mitigation strategy based on the Effectiveness to Difficulty Ratio (ETD) value. With this methodology, the study aims to provide the right risk mitigation solution to improve the operational reliability of CNC Plasma Cutting machines. Although this study was conducted on a single machine in a single company, the House of Risk approach and root cause-based mitigation principles can be applied to similar production machines in other manufacturing industries with adjustments to the specific operational context.

Results and Discussion

House of Risk phase 1

Based on the Maintenance division's damage report, In the period from January 2024 to December 2024, there were 35 damage reports from the Maintenance department. Of the 35 reports, the types of damage that occurred were:

Table 1. Frequency and Type of CNC Plasma Cutting Machine Damage Data

Month	Damage	Amount
January 2024	Improper current regulation	1
	Torch sensor broken	1
	Scoring on the drive motor shaft	1

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February 2024	Water cooling circulation pump is unstable	1
	Broken engine filter	1
	Improper current regulation	1
March 2024	Torch sensor broken	1
	Gear motor does not work	1
	Broken engine filter	1
April 2024	Water cooling circulation pump is unstable	2
	Torch cannot descend automatically	1
May 2024	V-belt on motor is loose	1
	Engine drive wheels are not optimized	1
	Gear motor does not work	1
	Broken engine filter	1
June 2024	Cracked gas fitting connection	1
	Faulty power supply	1
	Engine drive wheels are not optimized	1
July 2024	Torch cannot descend automatically	1
	Improper current regulation	1
August 2024	Torch sensor broken	1
	Gear motor does not work	1
	Torch cannot descend automatically	1
September 2024	Scoring on the drive motor shaft	2
	Water cooling circulation pump is unstable	1
October 2024	V-belt on motor is loose	1
	Torch current is too large	1
November 2024	Water cooling circulation pump is unstable	1
	Cracked gas fitting connection	1
	Faulty power supply	1
December 2024	Engine drive wheels are not optimized	1
	Gear motor does not work	1
	Torch sensor broken	1

Source : Damage report of Maintenance division of PT. XYZ

At this stage, the risk event will be assessed by 3 experts based on the severity value, then the risk agent based on the occurance value, and the correlation value between the risk event and risk agent. The following are the results of interviews and questionnaires related to severity, occurance, and correlation on the PT XYZ CNC Plasma Cutting machine :

Table 2. Severity Value Recap Result

Risk Event	**Ei**	***Severity***
Torch current is too large	E1	6
Torch sensor broken	E2	7
Scoring on the drive motor shaft	E3	5
Gear motor does not work	E4	8
Broken engine filter	E5	4
Water cooling circulation pump is unstable	E6	7
Engine drive wheels are not optimized	E7	6

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V-belt on motor is loose	E8	6
Cracked gas fitting connection	E9	7
Torch cannot descend automatically	E10	6
Faulty power supply	E11	9

Table 3. Occurance Value Recap Result

Risk Agent	**Ai**	***Occurance***
Improper current regulation	A1	5
Loose sensor cable	A2	6
There is a bearing problem	A3	4
Gear motor wear	A4	8
Filter clogged with dust	A5	7
The service life of the component has expired	A6	6
Weak capacitor	A7	9
Dirty coolant water	A8	7
Misalignment of wheels	A9	3
Improper V-Belt Installation	A10	7
Improper Gas Pressure Setting	A11	3
Damage to PCB	A12	4
Overheating of the power supply	A13	8

Table 4. Correlation Value Recap Result

Risk Event	**Ei**	**C**	**Ai**	**Risk Agent**
Torch current is too large	E1	3	A1	Improper current regulation
		3	A11	Improper Gas Pressure Setting
		1	A7	Weak capacitor
Torch sensor broken	E2	3	A2	Loose sensor cable
		3	A6	Masa pakai komponen sudah habis
Scoring on the drive motor shaft	E3	9	A3	There is a bearing problem
		9	A4	Gear motor wear
Gear motor does not work	E4	9	A4	Gear motor wear
		3	A3	There is a bearing problem
		1	A7	Weak capacitor
		3	A13	Overheating of the power supply
broken engine filter	E5	3	A5	Filter clogged with dust
		9	A6	The service life of the component has expired
Water cooling circulation pump is unstable	E6	9	A7	Weak capacitor
		1	A8	Dirty coolant water
Engine drive wheels are not optimized	E7	9	A9	Misalignment of wheels
		3	A10	Improper V-Belt Installation
		3	A7	Weak capacitor
		3	A13	*Overheating* pada *power supply*
Risk Event	**Ei**	**C**	**Ai**	**Risk Agent**
V-belt on motor is loose	E8	9	A10	Improper V-Belt Installation
		3	A6	The service life of the component has expired
Cracked gas fitting connection	E9	9	A11	Improper Gas Pressure Setting

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		1	A6	The service life of the component has expired
Torch cannot descend automatically	E10	9	A12	Damage to PCB
		3	A10	Improper V-Belt Installation
		1	A7	Weak capacitor
		3	A13	Overheating of the power supply
Faulty power supply	E11	9	A13	Overheating of the power supply
		3	A7	Kapasitor lemah

Once the values for severity, occurrence, and correlation have been identified, the next step is to calculate the aggregate risk potential. This calculation is intended to identify which risks should be prioritized for treatment or mitigation. The formula used to determine the aggregate risk potential (ARP) is as follows:

ARPj $= Oj \sum Si\ Rij$

ARP_{A1} = 5 x [(3x6)]

= 5 x [18]

= 5 x 18

= 90

After calculating ARP on all risk agents, there is a matrix table containing the ranking of risk agents that will be prioritized to provide mitigation strategies for these risks. The following is the phase 1 house of risk table:

Table 5. House of Risk Matrix phase 1

Risk Event	**Risk Agent**													Si
	A1	**A2**	**A3**	**A4**	**A5**	**A6**	**A7**	**A8**	**A9**	**A10**	**A11**	**A12**	**A13**	
E1	3						1				3			6
E2		3				3								7
E3			9	9										5
E4			3	9			1						3	8
E5					3	9								4
E6							9	1						7
E7							3		9	3			3	6
E8						3				9				6
E9						3					9			7
E10							1			3		9	3	6
E11							3						9	9
Oi	5	6	4	8	7	6	9	7	3	7	3	4	8	
ARP	90	126	276	936	168	576	1.161	49	270	602	243	216	1.096	
Pj	12	11	6	3	10	5	1	13	7	4	8	9	2	

After calculating the Aggregate Risk Potential (ARP), the next step is to evaluate the risk. At this stage, a ranking process is carried out by identifying the most frequently occurring risk agents, using a pareto analysis approach. This evaluation prioritizes the cumulative ARP value based on the Risk Agent ranking, which is then used as the basis for compiling a pareto diagram. The following is a pareto diagram showing the most dominant risk agents:

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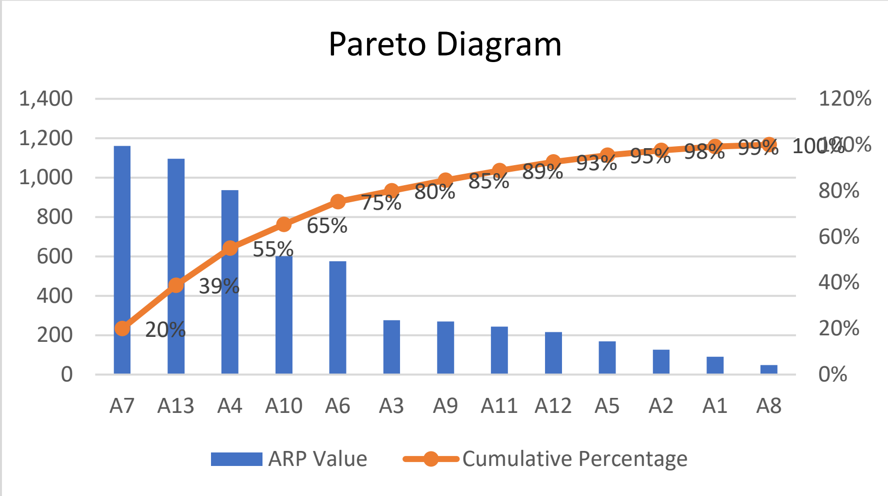

Figure 1. Pareto Diagram

Referring to the pareto diagram above, several of the most dominant risk agents can be addressed. A total of five key risk agents identified from the diagram can be managed by developing targeted risk mitigation strategies. According to the pareto principle, 38.5% of the primary risk agents are expected to account for a 75% reduction in the impact of other risks. These five dominant risk agents are A7, A13, A4, A10, and A6.

Root Cause Analysis

After obtaining the aggregate risk potential (ARP) value along with the most dominant risk agent, the next step is to conduct a root cause analysis, namely by identifying the cause of the risk of damage to the CNC Plasma Cutting machine. From the results of interviews with maintenance staff who often handle cases of CNC Plasma Cutting machine damage.

Table 6. Root Cause Analysis of CNC Plasma Cutting Machine Damage

Ai	Issue	Why 1	Why 2	Why 3	Why 4
A7	Weak capacitor	The quality of the components is poor and cannot withstand the workload of the machine.	The capacitors used are non-standard.	The procurement process does not involve technicians in verifying technical specifications.	There is no regulation to involve technicians in technical verification during the component procurement process.
A13	*Overheating on the power supply*	The cooling system inside the power supply is not working properly.	Internal vents are clogged with dust and dirt.	There is no routine cleaning of the power supply area by technicians.	There is no regular cleaning schedule for the power supply area.
A4	Wear on Motor Gears	Too much friction on the gears	Lubrication is not done routinely	Technicians do not know the routine lubrication schedule for	There is no regular lubrication schedule for motor gears.

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				motorcycle gears.	
A10	V-Belt Installation That Isn't Appropriate	Technician installed using inappropriate method	Technicians do not know how to install V-belts according to engine standards.	There are no clear technical guidelines or SOPs available.	There are no technical standards for the installation and adjustment of V-Belts for CNC Plasma Cutting machines.
A6	The component's service life has expired	Components were not replaced for a long time	It is not known that the component is due for replacement.	Component life data is inaccurate in the manual book.	No usage history analysis was performed to revalidate the actual service life data with reference to the manual book.

House Of Risk phase 2

After conducting Root Cause Analysis and knowing the root cause of the problem of each dominant risk, the next stage is to conduct the House of Risk phase 2 process to then find out which mitigation actions will be prioritized in risk management to reduce the impact of the risk. In determining the mitigation strategy, it is determined based on interviews with maintenance staff and only determines the actions and does not discuss any costs. The following is a draft mitigation strategy that will be implemented and is expected to minimize the occurrence of risk agents.

Table 7. Draft Risk Mitigation Strategy

Ai	Risk Agent	Root causes	PAi	Mitigation Strategy
A7	Weak capacitor	There is no regulation to involve technicians in technical verification during the component procurement process.	PA1	Create a verification form that must be filled out by maintenance staff containing the component name, technical specifications, OEM standards, and the purpose of using the component and approved by the head of the maintenance division before the procurement process..
A13	*Overheating of the power supply*	There is no regular cleaning schedule for the power supply area	PA2	Set a cleaning schedule for the power supply area. Once a week, carried out by a technician on the weekend. The cleaning process is carried out when the machine is off and cold, using a low-pressure blower, and an antistatic brush to clean fine dust.
A4	Gear motor wear	There is no regular lubrication schedule for motor gears.	PA3	Setting a schedule for lubricating the motorcycle gear. Every two weeks, carried out by a technician at the end of the working week. The lubrication process is carried out when the engine is off, using a type of lubricant that is in accordance with the manufacturer's specifications.
A10	Improper V-Belt Installation	There are no technical standards for the	PA4	Prepare illustrated technical SOP for installation and adjustment of V-Belt on

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		installation and adjustment of V-Belts for CNC Plasma Cutting machines.		CNC Plasma Cutting machine clearly (work steps, tightening torque, & tension measuring tool) and Conduct technician training including direct installation trial under the supervision of the chief technician.
A6	Component life has expired	No usage history analysis was performed to revalidate the actual service life data with reference to the manual book.	PA5	Performing a recap of historical component damage data in the last 12 months. The data is correlated with actual machine working hours. The analysis results are used to create a revised table of actual service life, which is then set in the technical documentation system as a guide for future maintenance.

After designing the mitigation strategy, the next step is to determine the correlation value between the risk mitigation strategy and the risk agent. This correlation determination uses the same respondents and scale as the correlation value between the risk event and the risk agent.

Table 8. Correlation between Risk Agents and Mitigation Strategies

Ai	Risk Agent	Root causes	PAi	Mitigation Strategy	ejk
A7	Weak capacitor	There is no regulation to involve technicians in technical verification during the component procurement process.	PA1	Create a verification form that must be filled out by maintenance staff containing the component name, technical specifications, OEM standards, and the purpose of using the component and approved by the head of the maintenance division before the procurement process..	9
A13	*Overheating of the power supply*	There is no regular cleaning schedule for the power supply area	PA2	Set a cleaning schedule for the power supply area. Once a week, carried out by a technician on the weekend. The cleaning process is carried out when the machine is off and cold, using a low-pressure blower, and an antistatic brush to clean fine dust.	9
A4	Gear motor wear	There is no regular lubrication schedule for motor gears.	PA3	Setting a schedule for lubricating the motorcycle gear. Every two weeks, carried out by a technician at the end of the working week. The lubrication process is carried out when the engine is off, using a type of lubricant that is in accordance with the manufacturer's specifications.	3
A10	Improper V-Belt Installation	There are no technical standards for the installation and adjustment of V-Belts for CNC Plasma Cutting machines.	PA4	Prepare illustrated technical SOP for installation and adjustment of V-Belt on CNC Plasma Cutting machine clearly (work steps, tightening torque, & tension measuring tool) and Conduct technician training including direct installation trial under the supervision of the chief technician.	9
A6	Component life has expired	No usage history analysis was performed to revalidate the actual service life data with reference to the manual book.	PA5	Performing a recap of historical component damage data in the last 12 months. The data is correlated with actual machine working hours. The analysis results are used to create a revised table of actual service life, which is then set in the technical documentation system as a guide for future maintenance.	9

After obtaining the mitigation design and weighting the value of the correlation between mitigation strategies and dominant risk agents obtained from interviews with experts. Calculation of Total Effectiveness of Action (TEk) of each mitigation strategy is carried out.

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The calculation of Total Effectiveness of Action (TEk) is obtained from the accumulation of the results of multiplying the aggregate risk potential (ARP) of each risk agent with its correlation value :

TEk $= \sum ARPj.\ Ej$k

TE_1 = ARP_{A7} x Ejk

= 1161 x 9 = 10.449

Table 9. Correlation between Risk Agents and Mitigation Strategies

PAi	Mitigation Strategy	tek
PA1	Create a verification form that must be filled out by maintenance staff containing the component name, technical specifications, OEM standards, and the purpose of using the component and approved by the head of the maintenance division before the procurement process..	10.449
PA2	Set a cleaning schedule for the power supply area. Once a week, carried out by a technician on the weekend. The cleaning process is carried out when the machine is off and cold, using a low-pressure blower, and an antistatic brush to clean fine dust.	9864
PA3	Setting a schedule for lubricating the motorcycle gear. Every two weeks, carried out by a technician at the end of the working week. The lubrication process is carried out when the engine is off, using a type of lubricant that is in accordance with the manufacturer's specifications.	2808
PA4	Prepare illustrated technical SOP for installation and adjustment of V-Belt on CNC Plasma Cutting machine clearly (work steps, tightening torque, & tension measuring tool) and Conduct technician training including direct installation trial under the supervision of the chief technician.	5418
PA5	Performing a recap of historical component damage data in the last 12 months. The data is correlated with actual machine working hours. The analysis results are used to create a revised table of actual service life, which is then set in the technical documentation system as a guide for future maintenance.	4590

After obtaining the Total Effectiveness of Action (TEk) value for each mitigation strategy, a weighting of the level of difficulty in implementing the action (Dk) will be carried out based on the same source, where the Dk value indicates the level of difficulty in implementing the mitigation action:

Table 2. Dk Value of Each Mitigation Action

PAi	Mitigation Strategy	tek	dk
PA1	Create a verification form that must be filled out by maintenance staff containing the component name, technical specifications, OEM standards, and the purpose of using the component and approved by the head of the maintenance division before the procurement process.	10.449	3
PA2	Set a cleaning schedule for the power supply area. Once a week, carried out by a technician on the weekend. The cleaning process is carried out when the machine is off and cold, using a low-pressure blower, and an antistatic brush to clean fine dust.	9864	4
PA3	Setting a schedule for lubricating the motorcycle gear. Every two weeks, carried out by a technician at the end of the working week. The lubrication process is carried out when the engine is off, using a type of lubricant that is in accordance with the manufacturer's specifications.	2808	4
PA4	Prepare illustrated technical SOP for installation and adjustment of V-Belt on CNC Plasma Cutting machine clearly (work steps, tightening torque, & tension measuring tool) and Conduct technician training	5418	5

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	including direct installation trial under the supervision of the chief technician.		
PA5	Performing a recap of historical component damage data in the last 12 months. The data is correlated with actual machine working hours. The analysis results are used to create a revised table of actual service life, which is then set in the technical documentation system as a guide for future maintenance.	5184	4

Next, the Effectiveness To Difficulty of Ratio (ETDk) value is calculated. This ETDk value expresses the ratio between the effectiveness value of mitigation actions and the difficulty level of each mitigation action. The formula used to determine the difficulty ratio value is as follows:

ETDk = TEk/Dk

ETD_1 = TE_1 / Dk

= 10.449/ 3

= 3483

All calculation results from phase 2 of the HOR will be presented in Table 10 below as the final step of this phase. The HOR phase 2 matrix table integrates various variables, including data on the most dominant risk agents, the aggregate risk potential (ARP) values of those agents, degree of difficulty information, as well as calculations of total effectiveness and the ETDk. These variables are used to determine the priority order for risk mitigation. The HOR phase 2 matrix table is shown below:

Table 3. House of Risk Matrix phase 2

Risk Agent	**Preventive Action**					**ARP**
	PA1	PA2	PA3	PA4	PA5	
A1	9					1.161
A2		9				1.096
A3			3			936
A4				9		602
A5					9	576
Total Effectiveness of Action	10.449	9864	2808	5418	5184	
Degree of Difficulty	3	4	4	5	4	
Effectiveness to Difficulty Ratio	3483	2466	936	1806	1296	
Pj	1	2	5	3	4	

Based on table 10 of the phase 2 House of Risk Matrix above, the mitigation strategy with the highest Effectiveness to Difficulty Ratio value is PA1, namely Creating a verification form that must be filled in by technicians before component procurement. And the lowest Effectiveness to Difficulty Ratio value is PA3, namely Implementing a production scheduling system based on machine capacity.

Table 11. Risk Mitigation Priority Ranking

ranking	**Strategi Mitigasi**	**PAi**	**etdk**
1	Create a verification form that must be filled out by maintenance staff containing the component name, technical specifications, OEM standards, and the purpose of using the component and approved by the head of the maintenance division before the procurement process.	PA1	3483

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2	Set a cleaning schedule for the power supply area. Once a week, carried out by a technician on the weekend. The cleaning process is carried out when the machine is off and cold, using a low-pressure blower, and an antistatic brush to clean fine dust.	PA2	2466
3	Setting a schedule for lubricating the motorcycle gear. Every two weeks, carried out by a technician at the end of the working week. The lubrication process is carried out when the engine is off, using a type of lubricant that is in accordance with the manufacturer's specifications.	PA4	1806
ranking	**Strategi Mitigasi**	**PAi**	**etdk**
4	Prepare illustrated technical SOP for installation and adjustment of V-Belt on CNC Plasma Cutting machine clearly (work steps, tightening torque, & tension measuring tool) and Conduct technician training including direct installation trial under the supervision of the chief technician.	PA5	1296
5	Performing a recap of historical component damage data in the last 12 months. The data is correlated with actual machine working hours. The analysis results are used to create a revised table of actual service life, which is then set in the technical documentation system as a guide for future maintenance.	PA3	936

Comparison of Production Ouput

Comparison of production output is to compare the production results achieved in two different conditions. This comparison of production output uses a comparison before risk mitigation and after risk mitigation. Comparison of production output before and after risk mitigation aims to assess the success of the mitigation strategy carried out to improve the efficiency of the CNC plasma cutting machine. The following is a table of historical data related to plate cutting output and downtime on CNC plasma cutting machines in the period January 2024 to December 2024 before risk mitigation is carried out.

Table 12. Total Cutting Output Produced Due to Machine Malfunction

Month	Cutting (tons)	Downtime (Hours)
January 2024	121	15
February 2024	120	16
March 2024	117	20
April 2024	116	22
Mei 2024	113	25
June 2024	116	21
July 2024	124	10
August 2024	116	22
September 2024	118	18
October 2024	125	10
November 2024	114	24
December 2024	117	21
Total	**1417**	**234**

Source: CNC Plasma Cutting Machine Report A

After research using the House of Risk method and Root Cause Analysis, a solution to the problem of CNC Plasma Cutting machine damage is obtained in the form of a proposed prevention or mitigation strategy which is expected to increase the output of cutting with an estimated total cutting output for 12 months as follows. The following is an estimate of downtime based on maintenance staff.

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Table 13. Total downtime when performing risk mitigation

Mitigation Strategy	Downtime Estimation (hours)
Create a verification form that must be filled out by maintenance staff containing the component name, technical specifications, OEM standards, and the purpose of using the component and approved by the head of the maintenance division before the procurement process.	8
Mitigation Strategy	**Downtime Estimation (hours)**
Set a cleaning schedule for the power supply area. Once a week, carried out by a technician on the weekend. The cleaning process is carried out when the machine is off and cold, using a low-pressure blower, and an antistatic brush to clean fine dust.	10
Prepare illustrated technical SOP for installation and adjustment of V-Belt on CNC Plasma Cutting machine clearly (work steps, tightening torque, & tension measuring tool) and Conduct technician training including direct installation trial under the supervision of the chief technician.	15
Performing a recap of historical component damage data in the last 12 months. The data is correlated with actual machine working hours. The analysis results are used to create a revised table of actual service life, which is then set in the technical documentation system as a guide for future maintenance.	13
Setting a schedule for lubricating the motorcycle gear. Every two weeks, carried out by a technician at the end of the working week. The lubrication process is carried out when the engine is off, using a type of lubricant that is in accordance with the manufacturer's specifications.	10
Total	**56**

Normal working hours per year : 2112 hours – 56 hours = 2056 hours/year

Cutting Output per year : 2056 hours x 0,75 hours (45 minute) = 1542 ton/year

Estimated Deductions per Month : (1542 ton)/(12 month) = 128,5 ton / month

Table 14. Total Estimated Output Cuts When Mitigating Risks

Month	Cutting (tons)
Januari	128,5
Februari	128,5
Maret	128,5
April	128,5
Mei	128,5
Juni	128,5
Juli	128,5
Agustus	128,5
September	128,5
Oktober	128,5

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November	128,5
Desember	128,5
Total	**1542**

By knowing the estimated output of Cutting after risk mitigation, we can compare the two Cutting outputs as follows.

Increased production = $\left(\frac{\text{Cutting After Mitigation} - \text{Cutting Before Mitigation}}{\text{Cutting Before Mitigation}}\right)$

Improved Cutting = $\left(\frac{1542-1417}{1417}\right)$ x 100 = 8,8%

Table 4. Comparison of Cutting Output before and after risk mitigation

Condition	Cutting (tons)	Percentage increase
Before mitigation	1417	-
After Mitigation	1542	8,8%

It can be seen in table 13 that after risk mitigation of the cnc plasma cutting machine, the percentage of cutting increased by 8.8% from before risk mitigation was carried out which resulted in cutting the cnc plasma cutting machine to 1542 tons which was previously only 1417 tons.

Advancing Predictive Risk Governance in CNC Machinery Reliability through HOR-RCA Integration

By combining the House of Risk approach and Root Cause Analysis into this research, the importance of this study is that a considerable development of predictive maintenance approaches of the manufacturing system can be observed. The reason this approach is especially applicable in the case of CNC Plasma Cutting machines is that they are the core of PT XYZ shipyard production facility operations. The fact that breakdowns were reported so frequently in the course of 2024, and especially that 35 instances of failure were registered, demonstrates how crucial it was to switch to proactive maintenance systems, leaving the reactive ones behind. The study differs in the sense that it does not just treat the symptoms but rather quantitatively addresses the severity and frequency with which failures occur and the manner in which it occurs due to cause and effect. More recent research in the engineering field has demonstrated that anticipatory models that merge risk prioritization and root tracing of failures result in a much higher machine availability, low levels of planned maintenance, and significant prediction capabilities in operations (Amalia et al., 2022; Maharani et al., 2022; Pamungkas et al., 2023). The present study continues that trend by relying on a dual-layered approach, as it will not only enable us to identify the high-risk components but, as well, will comprise a formulation of root-level preventive strategies, which will be employable both in a scalable and context at once.

The results concerning Aggregate Risk Potential highlight a common concern in contemporary manufacturing failure agents not simply being too many but even when they do interact, frequently in too interlocking, a way. The communicated risks agents have the highest ranks of rankings in this study including weak capacitors, overheating of power supplies, wear of gear motors, incorrectly installed V-belt, and main parts of the life. These agents do not signify mere technical failures that seem to be isolated but also indicating a major structural gap in the integration of machines, assuring quality of its components, and the scheduling maintenance. The prevalence of weak capacitors and the problem of overheating is also related to the literature as it has been pointed out that electrical failures of the component level are the most common stopping issues of the machine in plasma-based machines because of the thermal loads and high operational requirements (Setyarto et al., 2023; Sahoo, 2023). On top of this, the interdependencies of these risk agents in general is

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the one that makes them more critical and the HOR methodology proves to capture such interdependencies by synthesizing expert-assigned severity and occurrence values. This multidimensional approach to analysis will enable this study to go beyond the list of risks; instead, this analytical segmentation produces a dynamic, prioritized picture of the risk relevance, which is highly encouraged in the modern risk modeling systems (Gulo et al., 2020; Noerdyah et al., 2020; Defriyanti et al., 2021).

The use of Root Cause Analysis in the form of the Five Whys will introduce the depth that the risk prioritization process needs. As one may suggest, having identified the absence of involvement of the technicians in procurement as the cause of substandard capacitors, one may tell about a more general organizational weak point. This information confirms the results of recent studies of engineering management that claim that a disintegration of the technical sphere in procurement processes can trigger the cascade of malfunctions in a capital-intensive production system (Paterson, 2023; Haqi and Purba, 2020; Brawijaya et al., 2024). Instead of just being limited to technical hardware-related faults, the present study also uses the domain of institutional practices as a prism of their diagnosis and demonstrates how at the level of processes a design-related fault can emerge as mechanical fault in the factory. The proposed remedial measure of instituting a verification form checked by technicians is a long-term solution as opposed to a short-term one. The applicability of this strategy is testified by systems reliability research findings, which have indicated that mitigation of the gap between maintenance and procurement functions in terms of the standard operating protocols go a long way in minimizing machine downtime and enhancement of part compatibility (Djamaris and Asmi, 2024; Hilman Rosadi et al., 2022).

In this study, the structure of mitigation strategies is also balanced between the objectives of technical effectiveness and the possibilities of legal implementation. This is because the prioritization mechanism is not arbitrary but is based on the calculation of the Effectiveness to Difficulty Ratio. Through this decision-making matrix, there is a rational allocation of engineering resources in efforts that will have the greatest operational pay off. One example of such is the top-ranked strategy that involves the use of verification forms in that it is the most effective and yet shows little complexity of implementation. The same situation was observed in the past in comparisons of maintenance-optimizing interventions with high-cost and low-impact capital upgrades; those with low costs and high impact were demonstrated to outperform the capital-intensive upgrades (Maharani et al., 2022; Rosadi et al., 2022). There is also the introduction of regular cleaning of power supply machines and regular lubrication of gears which shows tendency towards total productive maintenance practices. Such strategies not only increase the lifespan of the machines but also enforces maintenance duties into the daily operations processes. Here, this reflects the best practices in industrial reliability engineering, where the focus now increasingly shifts towards routine checks integrated in the standard operations instead of depending on emergency maintenance (Tri, 2021; Gulo et al., 2020).

This entails the planned reduction of cutting output measured in tons already estimated to drop by 1417 tons to 1542 tons as a result of the mitigation strategies put in place which gives quantitative values to the success of the framework. The increase of 8.8 percent is not only statistically significant but also economically significant in the perspective of the production of the shipyards. One ton is a step more into the desired output unit, one percentage point is an hour of avoided downs and saved capital. This increased performance is backed by previously conducted research which shows that systematic risk reduction programs and effort lead to efficiency increases that grow over time with the program effort and duration (Sahoo, 2023; Setyarto et al., 2023; Brawijaya et al., 2024). It is also worth noting that the number of hours of downtime that is estimated on the basis of this study and the modeling process indicates the importance of proactive maintenance scheduling. Instead of failure events to be

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manifested and respond to them, the study implements a planning style where the historical evidence of the machines is used to forestall the failure events. This aligns with the trend in predictive maintenance systems technology based on time-series data and past failure records to guide specific remedial actions (Maharani et al., 2022; Pamungkas et al., 2023; Amalia et al., 2022).

Another significant finding of this research is that, its methods can be replicated to fit other industrial scenarios. Though the investigation is related to particular case of PT XYZ and its CNC Plasma Cutting machine A the fundamental principles of the House of Risk and Root Cause Analysis can be applied to other systems of machines in other manufacturing operations. The winning aspect of this strategy is that it is modular. It starts with context based risk identification and goes through a standard process of quantifying, diagnosing and mitigating it. This level of flexibility allows its usage in industries as diversified as automotive manufacturing and electronics and heavy equipment. The other recent applications of the HOR framework in various other settings revealed patterns similar in improving the view of risk and the optimization of maintenance interventions (Defriyanti et al., 2021; Noerdyah et al., 2020; Gulo et al., 2020). Specifically, the capacity of this method to generate prioritized and evidence-based action plans renders it useful to the engineering managers who are interested in going beyond the plane of depending on intuition in maintenance planning.

Conclusion

Based on the research that has been conducted at PT XYZ, it is concluded that the proposed risk mitigation strategies given to be able to increase the number of cuts from the CNC Plasma Cutting machine based on the root causes of the problem and its priorities Create a verification form that must be filled out by maintenance staff containing the component name, technical specifications, OEM standards, and the purpose of using the component and approved by the head of the maintenance division before the procurement process, Set a cleaning schedule for the power supply area. Once a week, carried out by a technician on the weekend. The cleaning process is carried out when the machine is off and cold, using a low-pressure blower, and an antistatic brush to clean fine dust, Prepare illustrated technical SOP for installation and adjustment of V-Belt on CNC Plasma Cutting machine clearly (work steps, tightening torque, & tension measuring tool) and Conduct technician training including direct installation trial under the supervision of the chief technician, Performing a recap of historical component damage data in the last 12 months. The data is correlated with actual machine working hours. The analysis results are used to create a revised table of actual service life, which is then set in the technical documentation system as a guide for future maintenance, and Setting a schedule for lubricating the motorcycle gear. Every two weeks, carried out by a technician at the end of the working week. The lubrication process is carried out when the engine is off, using a type of lubricant that is in accordance with the manufacturer's specifications. The proposed mitigation strategies should be followed by periodic evaluation, SOP updates, and mitigation effectiveness audits need to be implemented to ensure continuous improvement.

After obtaining a mitigation strategy for CNC Plasma Cutting damage, it is known that the estimated cutting output on the CNC Plasma Cutting machine after implementing the proposed risk mitigation strategy is 1542 tons during the 12-month period which previously amounted to 1417 tons during the 12-month period, which means there is a significant increase in cutting output of 125 tons or 8.8%.

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