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Proposed Scheduling of Preventive Maintenance on Co_2 Welding Machines Based on Reliability Analysis and FMEA Methods at PT. Sub Automotive

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Abstract

As the industry increases its dependence on production machinery, machine maintenance is a vital aspect in ensuring the smooth operation of the company. PT. Sub Automotive, as a dump truck carousel manufacturer, faces the problem of high downtime in CO_2 welding machines caused by component damage. This research aims to design an appropriate preventive maintenance schedule to reduce the frequency of damage and increase machine availability. The methods used include Mean Time Between Failure (MTBF), Mean Time To Repair (MTTR), and Overall Availability (Ao) analysis, as well as the Failure Mode and Effect Analysis (FMEA) approach to identify critical components based on the Risk Priority Number (RPN) value. The results showed an average machine availability value of 97%, exceeding the global standard of 90%. The components with the highest RPN values, namely the Control PCB (180), Nozzle (168), and Contact Tip (126), were identified as the main contributors to downtime. Based on these results, preventive maintenance recommendations were prepared focused on these components to improve the overall reliability of the system.

***Keywords**: Preventive maintenance, MTBF, MTTR, Availability, FMEA, RPN, Welding Machine co_2*

Introduction

Today, companies are increasingly relying on machines to run their production processes. Machines as physical assets require regular maintenance so that the company's productivity is maintained [1]. Damage to the machine can be caused by a variety of factors, such as overuse, lack of maintenance, component wear, design errors, as well as other factors. Some common forms of damage include mechanical faults, electrical, overheating, corrosion, material fatigue, lubrication problems, human error, improper design, and the lifespan of components [2]. Therefore, maintenance is required to ensure the reliability, availability, and ability of the machine to operate optimally. An effective and efficient maintenance program will directly contribute to increasing the productivity of the production system [3]

PT. Sub Automotive is a national company engaged in the manufacturing of carousels, especially for truck types. In its operations, PT. Sub Automotive focuses on dump truck production. The high market demand for these products encourages companies to adopt advanced technology and apply it consistently to produce superior products, the production process consists of several stages supported by the use of various machines, such as shearing, bending, compressor, cutting, and co_2 welding [4].

Damage to one of the machines can have a major impact on the company's production activities. Currently, the company is facing problems with welding machines that are experiencing operational disruptions. [5]. Since the welding machine has a vital role in the process of making dump trucks, the implementation of proper maintenance procedures should be the main focus of the industry. This effort is made to reduce the possibility of downtime due to engine damage [6].

Based on data from PT. Sub Automotive there is a high breakdown on the welding machine. PT. Sub Automotive uses a corrective maintenance system on welding machines that experience breakdown, which is maintenance and maintenance carried out when the equipment is damaged so that it cannot function optimally. To reduce the impact of the damage, it is necessary to plan preventive maintenance on a regular basis [7]. According to [6], preventive maintenance is a maintenance activity that is carried out periodically, including inspection, repair, component replacement, cleaning, lubrication, adjustment, and equalization to keep the performance of the equipment in ideal condition.

The purpose of preventive maintenance is to prevent or minimize the occurrence of failures, detect if failures occur, find hidden failures, increase the reliability and availability of these components to prevent failures, so that maintenance intervals are scheduled. [8] Identification of potential failures is carried out by assigning a score or score for each failure mode based on the level of occurrence, severity, and detection level.

Here, the researcher describes and determines how the Preventive Maintenance schedule on Welding machines is effective and the extent of Preventive Maintenance on Welding machines with the Mean Time Between Failure, Mean Time Between Failure (MTBF) and Mean Time to Repair (MTTR) methods is an important indicator in an effort to suppress breakdowns and reduce downtime. MTBF is used to calculate the average time between breakdowns, which is from the time the engine is repaired until it is damaged again. Meanwhile, MTTR is used to measure the average time required by technicians from the beginning to the completion of repairs [9].

Failure Mode and Effect Analysis (FMEA) is a qualitative method commonly used to assess the reliability of a system by identifying potential failures, their causes, and their impacts. The impact of failure was analyzed from three levels, namely the component level, the system, and the overall plant. In FMEA, the risk of failure is assessed using the Risk Priority Number (RPN), which is calculated based on three main aspects: Severity (severity), Occurrence (likelihood of occurrence), and Detection (the ability to detect failure), to determine the priority of risk management [10].

Meanwhile, Preventive Maintenance is a form of maintenance that is carried out on a scheduled basis before the engine is damaged. This strategy aims to prevent unexpected downtime and maintain optimal engine performance [11].

Theoretical Foundations

Maintenance Definition

According to (Pasaribu, 2021), Maintenance is a series of activities that aim to keep equipment or production facilities in a ready-to-use condition and function optimally [12]. Actions taken in the maintenance process include efforts to maintain, repair, and return the system to its ideal condition. This activity has an important role in ensuring product quality, work safety, cost efficiency, and production capacity, so that its implementation is a vital aspect in the company's operations.

According to [13], it is argued that maintenance is a combination of technician and administrative activities to restore a system so that it can perform the requested functions with good performance.

The purpose of maintenance itself is as follows:

1. Ensure system functions such as system availability, efficiency, system and product quality.
2. Ensuring system life
3. Ensuring safety
4. Ensuring human welfare.

System damage in the company can cause production disruptions, decrease in capacity, and lead to a decrease in revenue. Often, companies do not perform routine maintenance due to hight cost considerations. However, research shows that the implementation of planned preventive care can significantly reduce downtime and treatment costs [14].

Maintenance Type

Preventive maintenance is a form of periodic maintenance that is carried out before damage to the system occurs. This activity includes a number of actions such as inspection, cleaning, lubrication, repair, component replacement, adjustment of settings, and calibration. The main goal of preventive maintenance is to maintain the reliability of the system so that the production process can take place on schedule, with cost efficiency, and optimal output achievement [15].

The main advantage of preventive maintenance is to keep the condition of the machine or equipment optimal. By performing regular maintenance, including inspections, replacement of components that are nearing the end of their useful life, and other maintenance measures, the possibility of sudden damage can be reduced. This of course increases operational efficiency, reduces downtime, and reduces potential losses due to production disruptions [16].

In addition, preventive maintenance helps companies in extending the life of machines and optimizing investment in fixed assets. When maintenance is carried out regularly and in a timely manner, the possibility of severe wear and tear or major damage can be suppressed. This also makes budget planning easier, as maintenance costs can be predicted and allocated in a planned manner, compared to the unexpected costs that often arise in sudden breakdowns [17].

Preventive maintenance is very important because it can prevent engine damage before it occurs. By performing routine maintenance such as inspections, parts replacement, and cleaning, the machine can continue to work optimally. This obviously helps reduce sudden damage that could stop production. In addition, regular maintenance can also extend the life of the machine and save costs in the long run, because we can plan the maintenance budget better and not have to spend large costs suddenly when the machine breaks down [18].

Corrective Maintenance

Corrective maintenance is carried out when there is a functional disturbance in the system, such as production results that do not meet standards in terms of quality, quantity, or process time. This activity includes repairing or replacing damaged components [19].

Corrective maintenance offers several significant advantages in asset maintenance management. This approach allows for a more efficient allocation of resources, as maintenance is only carried out when damage occurs, avoiding unnecessary expenditure on preventive maintenance. Additionally, corrective maintenance provides flexibility in scheduling, allowing for quick response to issues that arise without significant disruption to other operations. By focusing on repairs after failures, this approach also provides valuable insights into equipment reliability and performance, which can be used to improve future maintenance strategies [20].

However, the lack of corrective maintenance is also very significant, especially in the context of operations that require high reliability, when equipment is damaged suddenly, the production process can be disrupted, even stopped completely, which of course causes large losses. Additionally, sudden repairs tend to be more expensive because they can involve overtime costs, urgent parts shipments, or even additional damage that arises from an initial breakdown that isn't addressed immediately. Occupational safety risks can also increase if damage occurs to equipment that is directly related to human operations [21], [22], [23], [24].

Corrective maintenance has advantages that should be considered, especially in terms of cost efficiency and ease of implementation in the short term. This approach is indeed suitable for systems or equipment that are not too crucial to the continuity of the production process, as they do not require a complex routine maintenance schedule. However, I also realized that this strategy is not always ideal, especially in an operational environment that demands high reliability and continuity [25], [26], [27], [28].

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Methodology

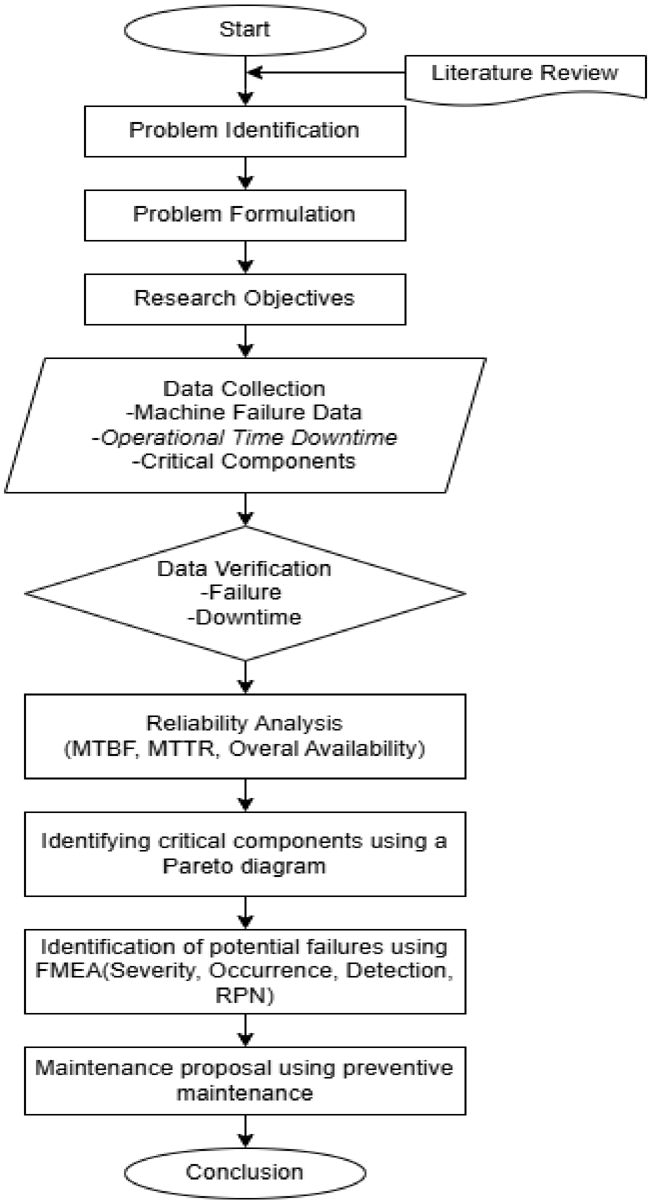

Figure 1 Research Flow.

Data Collection Techniques

The data collection methods that will be used in this study are:

a. Field observation

Field observation was carried out by directly visiting the production area to obtain factual data on real conditions at the location. This activity includes observation of the repair process of the welding machine, including the type of damage that occurs, how to handle it, and the maintenance procedures applied.

b. Interview

The interview process is carried out directly with related parties, namely the head of production, head of spare parts, and head of maintenance, who are authorized in the preparation of welding machine maintenance procedures at PT. Sub Automotive

Data Processing Techniques

The steps in processing data to determine preventive maintenance activities are as follows:

1. Create a pareto diagram to determine the most critical machines and components
   a. Pareto charts are used to identify the types of machine or component failures that occur most frequently, making it easier to determine the most critical parts to be repaired.
   b. Prepare and collect data on machine breakdowns that have occurred in a given period.
   c. Each type of damage is calculated in frequency, then compared to the total total damage event.
   d. The percentage calculation is done with the formula (amount of damage of a certain type / Total damage) x 100%
2. Data processing analysis using MTBF, MTTR, and Overall Availability (Ao)
   a. Calculates the Mean Time Between Failures (MTBF) to determine the average operating time of the machine between two failures. This calculation gives an idea of how long the machine can operate normally after it is repaired before it breaks down again.

$$MTBF = \frac{Total\ Operational\ Time\ -\ Downtime}{Number\ of\ Failure}$$

   b. Mean Time to Repair (MTTR) is a parameter used to determine the average time required in the engine repair process until the machine can return to operation

$$MTTR = \frac{Downtime}{Number\ of\ Failure}$$

   c. Overall Availability (Ao) is an indicator to assess the extent to which the machine is available for use, taking into account the entire downtime, whether planned or not. Downtime due to the absence of production demand is not included in this calculation. Based on the World Class Standard, the ideal availability level is ≥ 90%.

$$Overall\ Availability = \frac{MTBF}{MTBF + MTTR}\ x\ 100\%$$

3. Perform Failure Mode and Effect Analysis (FMEA) calculations to determine the damage value of critical components. Source [29], [30].

   FMEA Calculation

   The main formula in FMEA: Risk Priority Number or (RPN)

   RPN = S x O x D

   Where:
   S (Severity) = The severity of a failure (scale 1-10)
   O (Occurrence) = Frequency of failure (scale 1-10)
   D (Detection) = Ability to detect failures before reaching customers or systems (scale 1-10)

   The higher the RPN, the higher the priority of the risk to be immediately corrected or followed up.
4. Proposed Maintenance with preventive maintenance

Results and Discussion

Diagram Pareto

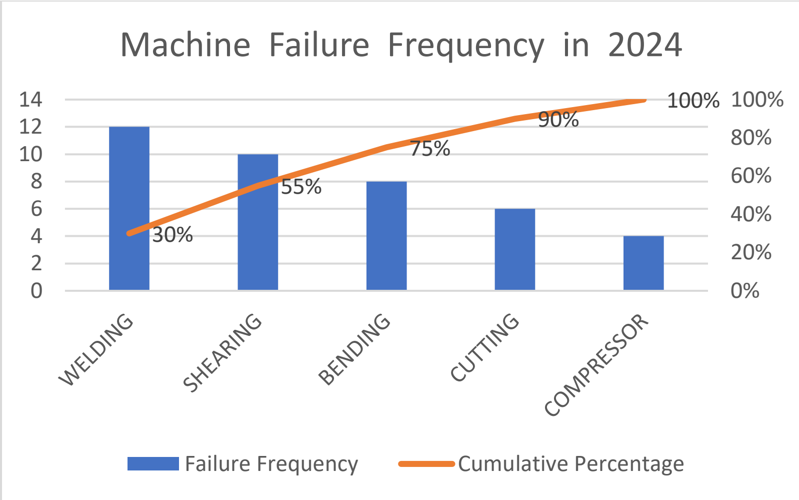

Figure 2 Data on Damage to Production Machinery of PT. Sub Automotive, 2024

The Pareto diagram above shows the frequency of engine breakdowns at PT. Sub Automotive in 2024. The machine with the highest damage rate was Welding co₂. 12 times (30%), and then only focused on the welding co₂ machine. Historical data from several cases of damage to Welding Machine components at PT. Sub Automotive from January to June in 2024 as follows:

Table 1 Frequency of Welding Machine Breakdowns for 6 Months in 2024

Incident Hours	Date	Moon	Component	Downtime (hours)	Total Frequency Component
8:30	1/8/2024	January	Nozzle	1.5	3
13:15	1/18/2024	January	Nozzle	1.0	3
10:45	1/25/2024	January	Welding Cable	1.0	1
9:20	2/10/2024	February	Regulator Gas CO_2	2.0	2
14:10	2/22/2024	February	Regulator Gas CO_2	1.5	2
8:00	3/5/2024	March	Contact Tip	1.0	4
11:30	3/12/2024	March	Contact Tip	1.5	4
15:40	3/22/2024	March	Roller Feeder	2.0	1
16:10	3/28/2024	March	Contact Tip	1.5	4
9:00	3/31/2024	March	Contact Tip	1.0	4
7:50	4/3/2024	April	Switch On/Off	1.0	2
13:05	4/18/2024	April	Switch On/Off	0.5	2
14:25	5/9/2024	May	Cooling Fan	3.0	1
10:00	6/2/2024	June	PCB Control	6.0	1
11:15	6/15/2024	June	Grounding Cable	1.0	2
16:50	6/28/2024	June	Grounding Cable	1.0	2

Based on the results of the recapitulation of welding machine downtime data at PT. Sub Automotive for 6 months in 2024, a total downtime of 27.5 hours was recorded from 9 cases of damage to various engine components. The component that most often experienced damage was the Contact Tip, which was recorded to have 2 types of damage with a total frequency of 4 times and an accumulated downtime of 5 hours. This damage indicates that the component is one of the vulnerable points in the control system of the welding machine co₂.

Table 2 Summary Data on Damage to Welding Machine Components for 6 Months in 2024

Component	**Types of Damage**	**Damage Description**	**Frequency**	**Total Downtime (hours)**
Nozzle	Mechanical Breakdown	Aus, clogged	3	2.5
Contact Tip	Mechanical Breakdown	Aus, loose	4	5.0
Roller Feeder	Mechanical Breakdown	Slip, per aus	1	2.0
Welding Cable	Electrical Damage	Short circuit	1	2.0
Grounding Cable	Electrical Damage	Loose, sagging	2	2.0
Switch On/Off	Electrical Damage	Unresponsive, stuck	2	1.5
PCB Control	Electronic Component Damage	Control system error	1	6.0
Regulator Gas CO_2	Electronic Component Damage	Leaky seal, unstable pressure	2	3.5
Cooling Fan	Cooling System Breakdown	Fan motor dead	1	3.0

Based on data on damage to co_2 welding machine components , there are various types of damage that occur in several main components such as nozzles, contact tips, roller feeders, welding cables co_2 and grounding cables. The types of damage recorded include mechanical damage such as wear, clogging, and slipping, as well as electrical damage such as short circuits and joint looseness.

Results of Machine Availability Analysis Based on MTBF, MTTR, and Overall Availability (Ao)

Table 3 Reliability Analysis Data of Welding Machines for 6 Months

Number	Moon	Machine Operating Time	Number Of Failure	Downtime (Hours)	MTBF (Hours)	MTTR (Hours)	Overall Availability (%)
1	January	172.50	3	3.50	57.50	1.17	98%
2	February	172.50	2	3.50	86.25	1.75	98%
3	March	169.00	5	7.00	33.80	1.40	96%
4	April	174.50	2	1.50	87.25	0.75	99%
5	May	173.00	1	3.00	173.00	3.00	98%
6	June	168.00	3	8.00	56.00	2.67	95%
				Average			97%

The results of the analysis show that the highest MTBF value occurred in May, which was 173.00 hours, while the lowest MTBF value was recorded in March with 33.80 hours. In addition, it is known that the overall availability of the machine during the observation period is in the range of 95% to 99%. On average, the Overall Availability (Ao) value reaches 97%, which means that the engine's performance has exceeded the World Class Standard threshold of >90%.

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Welding Machine Damage Analysis Using Pareto

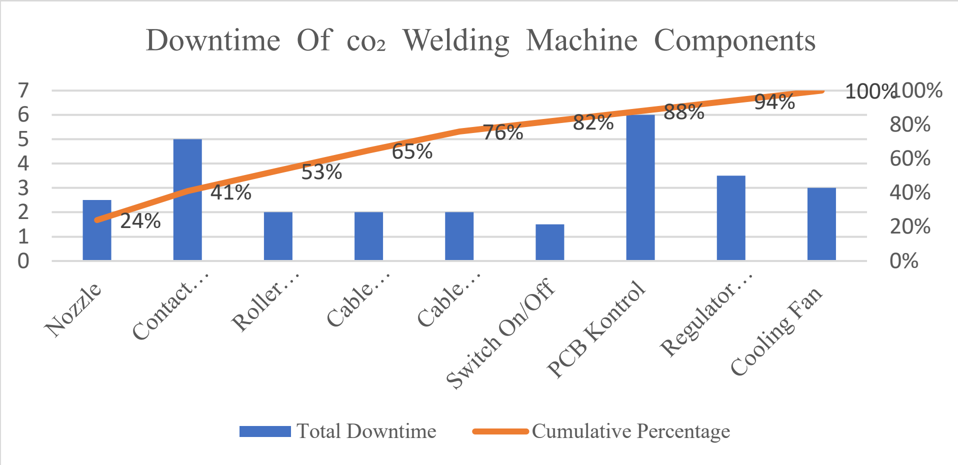

Figure 3 Welding Machine Breakdown Diagram CO_2 2024

Based on the graph above, it shows the analysis of the downtime of welding machine components for 6 months in 2024. The component with the highest contribution to total downtime is the Control PCB, accounting for about 24% of downtime with a low but high-impact breakdown frequency. Followed by Contact Tip and Nozzle, the top three components account for up to 76% of total cumulative downtime, suggesting that improved focus on those components will have a significant impact on lowering downtime.

Table 4 Results of Risk Priority Number (RPN) Value Analysis

Welding Machine Components	Function	Types of Damage	Effects of Failure	Severity	Occurrence	Detection	RPN
Nozzle	Delivering shielding gases to the welding area	The nozzle is clogged by spatter or dirt	Gas flow is obstructed welded to become porous/deformed	6	7	4	168
Contact Tip	Transmitting current electricity to welding wire	A hole in the wall, Wear Surface Tip	Unstable current, uneven weld	7	6	3	126
Switch On/Off	Turning the machine on and off	Contacts are broken, switches are stuck	The machine cannot be turned on the welding process cannot be done	8	5	2	80
Roller Feeder	Moving the wire Weld stably	Roller wear, insufficient pressure, jammed	Immobile wire Welding can't done/disconnected-disconnected	7	6	3	126
Welding Cable	Conducting electrical current from machine to torch	Broken cable, torn insulation	Disrupted current, unstable weld results/risk of sting	7	6	3	126
Grounding Cable	Channeling current to the ground to avoid short circuit	Broken cable, loose connector	Ground not working engine not turning on/risk of electric shock	8	4	2	64

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PCB Control	Controlling the working system of the machine (current, time, and operation settings)	Circuit damage, short circuit, burn	The welding system does not run normally, the machine fails to work	9	5	4	180
Regulator Gas CO_2	Regulating the pressure of the CO_2 shielding gas to the nozzle	Regulator leaking/jamming /imprecision	Unstable gas pressure due to defective welding	6	6	3	108
Cooling Fan	Cooling the internal components of the machine during operation	Motor fan is broken/fan is dead/Propeller stuck	Engine overheating Risk of damage Internal components	8	4	3	96

The table above shows the results of FMEA analysis on welding machine components to identify potential failures, causes, and impacts. The RPN value is used to determine the level of risk of each failure mode, so that appropriate handling priorities can be set in prevention and improvement efforts.

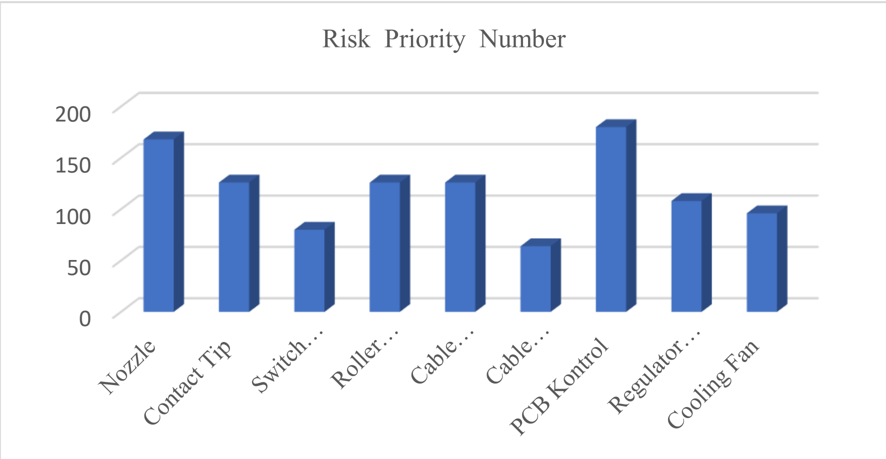

Figure 4 Graph of Risk Priority Number Values

The table and graph above show that each component of the welding machine has a high RPN value, which indicates a critical condition. Therefore, priority handling is needed to prevent engine damage at PT. Sub Automotive.

Table 5 Job Activity Scheduling Preventive Maintenance Welding Machine Co_2

Job Activity	July				August				September				October				November				December			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Nozzle																								
Contact Tip																								
Switch On/Off																								
Roller Feeder																								
Welding Cable																								
Grounding Cable																								
PCB Control																								
Gas Regulator co_2																								
Cooling Fan																								

Conclusion

Based on the results of the research during the period from January to July 2024, the following can be concluded: Based on the results of the analysis for 6 months, the Welding co_2 machine at PT. Sub Automotive shows an average Availability of 97%, exceeding the world class standard (≥ 90%). The most critical component is the Control PCB with the highest RPN value (180), followed by the Contact Tip and Nozzle which have a high frequency of damage. The main causes of damage come from mechanical and electrical factors, such as wear, short circuits, and loose joints. The application of MTBF-MTTR analysis and the FMEA method is very effective in identifying priority components and developing a targeted preventive maintenance schedule. Preventive maintenance scheduling has been systematically prepared and focused on a periodic basis (weekly, monthly, quarterly) based on damage data and risk level for each component.

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