

**IMPROVING ENGINE COOLING SYSTEM TO PREVENT OVERHEATING
IN MOTOR GRADER USING IOT**

By

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STATEMENT BY THE AUTHOR

I hereby declare that this submission is my own work and to the best of my knowledge, it contains no material previously published or written by another person, nor material which to a substantial extent has been accepted for the award of any other degree or diploma at any educational institution, except where due acknowledgement is made in the thesis.



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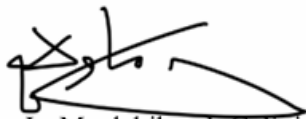


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ABSTRACT

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Overheating of the Komatsu GD825A-2 motor grader in the mining area is mainly caused by dust accumulation on the radiator fins and the absence of a real-time temperature and pressure monitoring system. This study designs an automatic radiator washing system integrated with IoT-based monitoring using temperature and pressure sensors with delta analysis as the main feature. The method used is Define–Measure–Analyze–Improve–Control (DMAIC), starting from identifying the root cause through Focus Group Discussions (FGD), interviews, and field observations, then analyzed using fishbone diagrams and Failure Mode and Effects Analysis (FMEA). The implementation results show a significant reduction in the Risk Priority Number (RPN), namely the radiator tube from 392 to 96 (~75%) and the radiator fin from 336 to 84 (~75%). In addition, downtime due to overheating in the engine was successfully reduced from 30.3 hours to 0 hours. The implementation of this system has been proven to increase inspection and maintenance efficiency, reduce the risk of overheating, and support the reliability and productivity of heavy equipment in tough mining working conditions.

Keywords: Overheating, Radiator, IoT, FMEA, DMAIC



DEDICATION

I dedicate this works for my parents, my wife, and my children.



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All praise and gratitude I offer to Allah Subhanahu Wa Ta'ala for all His abundant grace, guidance, and strength, enabling me to successfully complete this thesis. Without His will, the preparation and completion of this scientific work would not have been possible.

With the utmost respect and love, I express my deepest gratitude to my beloved wife and children, who have been a source of encouragement, patience, and motivation throughout this study. I also express my deepest gratitude to my parents for their constant prayers, moral support, and affection that have always accompanied my every step.

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May all the good deeds you have received be rewarded with value in the sight of Allah Subhanahu Wa Ta'ala. Finally, I realize that this thesis is far from perfect, and I am open to any form of input for future improvements.

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CHAPTER 1 - INTRODUCTION

1.1 Background

The mining sector has continued to grow in recent decades. PT. XYZ is one of the mining companies that provides mining contractor services, hauling services, and port operator services. Figure 1 shows that currently, PT. XYZ has 11 jobsites with 7 coal mining jobsites, 1 gold mining jobsite, 1 nickel mining jobsite, 1 coal hauling jobsite, and 1 port operator jobsite. PT.XYZ's head office is located in East Jakarta. As a company that focuses on the mining sector, PT. XYZ is committed to maintaining the company's assets including the units it owns. This is important to do in order to keep the unit in optimal condition so that the company's operational processes can run effectively and efficiently. Therefore, the aspect of equipment maintenance is one of the things that requires special attention.

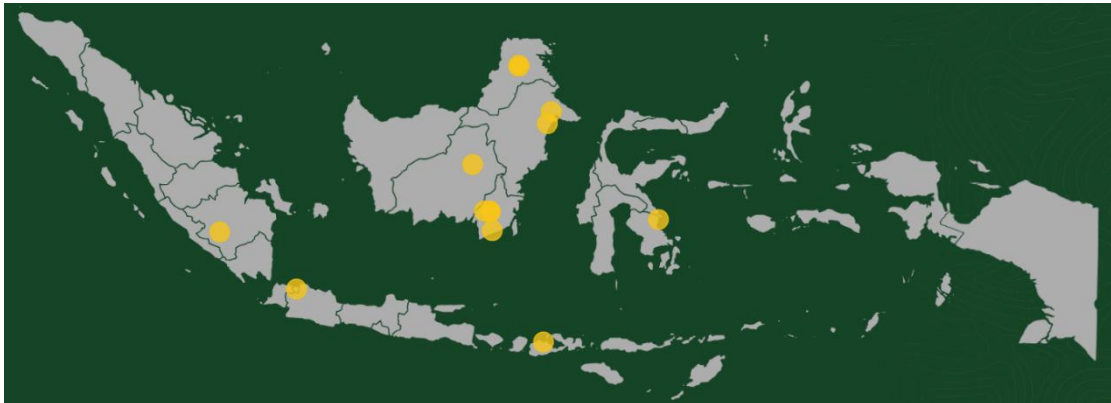


Figure 1 Location of PT. XYZ
(PT. XYZ, 2025)

The jobsite where this research was conducted is a port operator jobsite located in South Kalimantan. In addition, beside a port operator, this jobsite is also responsible for the maintenance of a 32-kilometer hauling road. One of the units that plays an important role in hauling road maintenance activities is the motor grader as shown in Figure 2.

Motor grader are equipped with blade attachments on the front and rippers on the rear as shown in Figure 2 to carry out their functions such as to leveling the ground or road after spreading the material, forming water channels and drainage, making road sides, and forming and tidying up embankments on the hauling road. If the motor grader is damaged, then various processes will experience obstacles. Hauling roads that are not properly maintained will experience damage such as holes and undulations. This causes the coal hauling process to the port to be disrupted and dangerous in terms of safety.

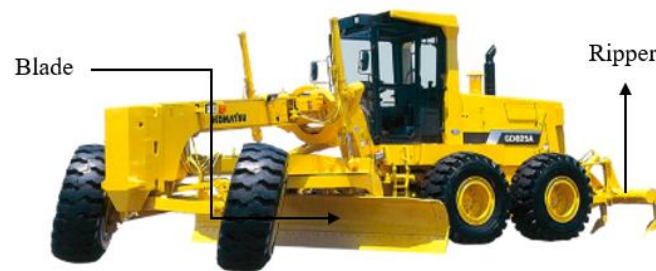


Figure 2 Attachment of GD825A-2 Komatsu
(United Tractors, 2025)

Motor grader consists of several systems and many components to be able to carry out their functions. One of the main components of its drive is the engine. The engine functions to convert chemical energy into mechanical energy. Figure 3 shows that the engine will transmit power to the next component, namely the joint, hydroshift transmission, drive shaft, final drive, and tandem drive. The rotation of the engine is also used to drive the hydraulic pump so that the motor grader can move its attachments, namely the blade at the front and the ripper at the rear.

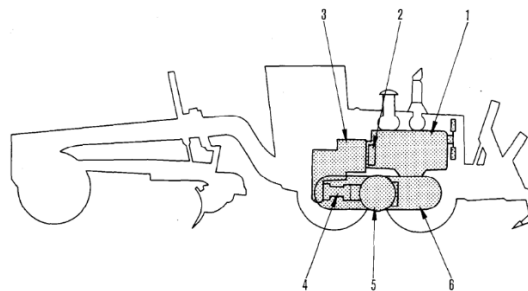


Figure 3 Power Train of Motor Grader GD825A-2
(Komatsu, 2001)

The working principle of a 4-stroke engine consists of intake stroke, compression stroke, power stroke, and exhaust stroke. When the combustion process occurs in the combustion chamber, precisely in the compression stroke, the temperature reaches 400~500°C (Yuni, 2021). Working environment conditions with air temperatures above 30 degrees celsius coupled with exposure to dust on the hauling road are challenges that must be faced in the field. In such conditions, the cooling system on the motor grader engine often have problems that trigger overheating due to dust accumulation, especially in the radiator area as show in the Figure 4.



Figure 4 Dusty Radiator

If the GD825A-2 motor grader unit overheats, only the operator can see the temperature gauge in the cabin, so it is very important for the operator to always check the display monitor in the cabin. Based on the Operation & Maintenance Manual of the unit, if overheating occurs, the engine rpm must be lowered (it cannot be turned off immediately). After the coolant temperature drops gradually, the engine is turned off (Komatsu, 2010b). If the operator does not perform this procedure, it will cause further damage to the engine. If the operator does not turn off the unit when the temperature gauge is on, it will damage the seal, gasket, hose, etc. Meanwhile, if the operator turns off the engine immediately, the flow of coolant and oil will stop immediately so that friction between components will be greater. The cooling system that is not monitored in real time plus the distance from the workshop to the hauling road maintenance location where the motor grader unit is located is quite far, causing maintenance to be less than optimal.

At the jobsite where this research was conducted, the performance of the GD825A-2 unit was still not up to the standards set by management. Figure 5 shows that the average percentage of unscheduled maintenance was 26.1% of the maximum target of 10%.

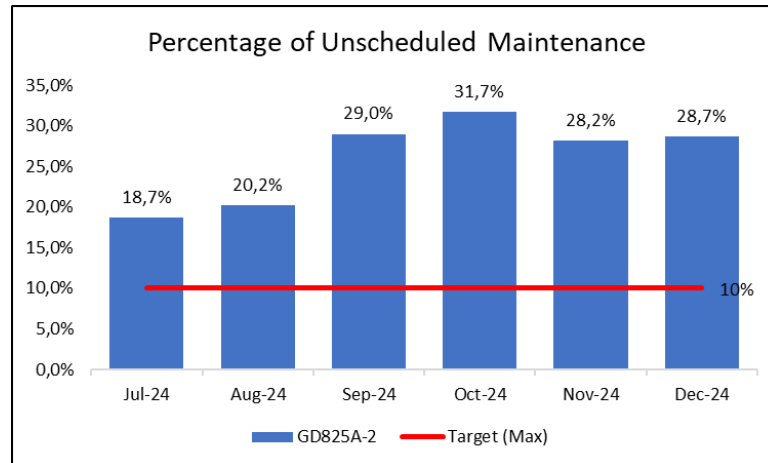


Figure 5 Percentage of Unscheduled Maintenance

Along with the development of technology, the application of the internet of things (IoT) is becoming increasingly relevant, including in the mining industry. IoT allows real-time monitoring of unit parameters as shown in Figure 6 so that damage that will occur can be prevented. By using this technology, not only operators can know the condition of the unit, but also mechanics and people related to the maintenance department. The implementation of real-time monitoring also helps in carrying out predictive maintenance, so that existing maintenance is not only based on time intervals, but also based on the actual condition of the motor grader unit in the field.

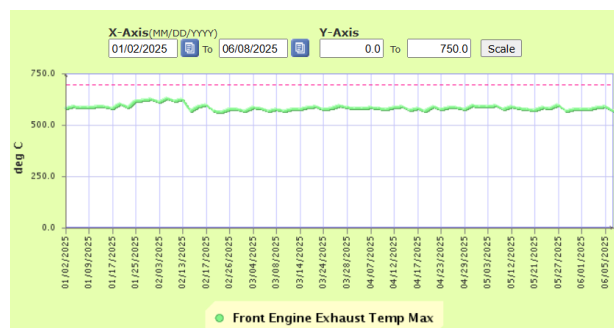


Figure 6 Utilization of IoT
(Komatsu, 2010)

This study aims to develop a system for automatic radiator washing enhanced with IoT-based monitoring system on the GD825A-2 motor grader engine to reduce the risk of overheating and improve the operational efficiency of heavy equipment in mining environments, especially in the hauling road maintenance process. With this system, it is expected that downtime and frequency due to cooling problems can be minimized, so that heavy equipment productivity can be maintained. In addition, this study also contributes to the development of technology-based monitoring systems in the mining industry, which can be a reference for wider implementation on various types of other heavy equipment.

1.2 Research Problem

The cooling system performance on the GD825A-2 motor grader tends to decline due to dust buildup on the radiator and the absence of a direct temperature and pressure monitoring system equipped with delta temperature and pressure data. This condition increases the possibility of overheating and operational disruptions. In addition, radiator washing which is still done manually and unscheduled also worsens the situation. For this reason, the development of an automatic washing system that is integrated with IoT-based monitoring is needed to maintain cooling performance and support the smooth operation of the equipment in the coal hauling area.

1.3 Research Objective

The objectives of this research is as follows:

1. Identify critical failure points that cause overheating
2. Design and implement automatic washing radiators equipped with a real-time temperature and pressure monitoring system and its delta
3. Conduct evaluations related to automatic washing and IoT-based systems

1.4 Research Questions

The questions of this research is as follows:

1. What are the critical failure points in the cooling system of the Komatsu GD825A-2 motor grader unit that significantly contribute to the increased risk of overheating during operations in the coal hauling area?
2. How to design and implement an automatic radiator washing system integrated with real-time radiator temperature and transmission pressure monitoring, including delta analysis?
3. How effective is the IoT-based monitoring system and automatic washing in improving cooling system performance and operational efficiency in the coal hauling area?

1.5 Hypothesis

The hypothesis of this research is as follows:

1. Infrequent radiator cleaning and lack of monitoring are among the causes of failures in the GD825A-2 motor grader cooling system, significantly contributing to an increased risk of overheating during operation in coal hauling areas,
2. The design and implementation of an automatic radiator washing system integrated with real-time temperature and pressure monitoring, including delta analysis, can be done with an IoT-based approach and electric actuators,
3. IoT-based monitoring system and automatic washing have a positive impact on reducing the frequency of overheating and increasing the operational efficiency of heavy equipment in the coal hauling area.

1.6 Significance of Study

This research contributes to improving the reliability of the motor grader cooling system through the development of an automatic radiator washing system integrated with IoT-based temperature and pressure monitoring. The results of the study are expected to support the operational efficiency of heavy equipment in mining environments and become a reference in the application of data-based monitoring technology for preventive maintenance on similar equipment.

1.7 Research Scope

The scope of this research is as follow:

1. This study focuses on the cooling system of the Komatsu GD825A-2 motor grader engine used in hauling road maintenance activities in coal mining areas,
2. The scope of the study includes identifying failure points in the cooling system that could potentially cause overheating during operation,
3. The research includes the design and implementation of an automatic radiator washing system, limited to the radiator components without discussing the washing system in other parts of the engine,
4. The developed system is equipped with real-time temperature and pressure monitoring, as well as temperature delta and pressure delta analysis as indicators of engine cooling performance,
5. Evaluation was carried out on the performance of the cooling system before and after repairs, taking into account real conditions in the field.

1.8 Research Limitations

The limitation of this research is as follow:

1. This study did not include testing on other types of heavy equipment besides the Komatsu GD825A-2, so the results cannot be generalized to all types of units,
2. Electrical and mechanical aspects that are not directly related to the cooling system were not discussed in this study
3. This study did not evaluate the fuel consumption efficiency, emissions, or environmental impact of the system as a whole.,
4. The design was carried out on a prototype scale with components that are accessible in the field, so the effectiveness of the system may differ if implemented in a mass production version,
5. The application notification is blocked on Samsung devices.

CHAPTER 2 - LITERATURE REVIEW

2.1 Theoretical Perspectives: Diesel Engine

Diesel engines are engines that are included in the internal combustion engine group. Diesel engines are widely chosen because of their advantages (Julianto, 2020). In the mining industry diesel engines are widely used for heavy equipment including motor graders. The working principle of a diesel engine is to convert chemical energy into mechanical energy. Chemical energy comes from fuel in the form of hydrocarbons. This energy is then released through the combustion process. When fuel is injected at high pressure, it will produce heat. The combustion gas produces high pressure that pushes the piston down. This movement converts heat energy into mechanical energy in the form of reciprocating piston movement. The diesel engine on the GD825A-2 motor grader has several components and systems used to carry out its functions. Figure 7 is the generic structure of a diesel engine.

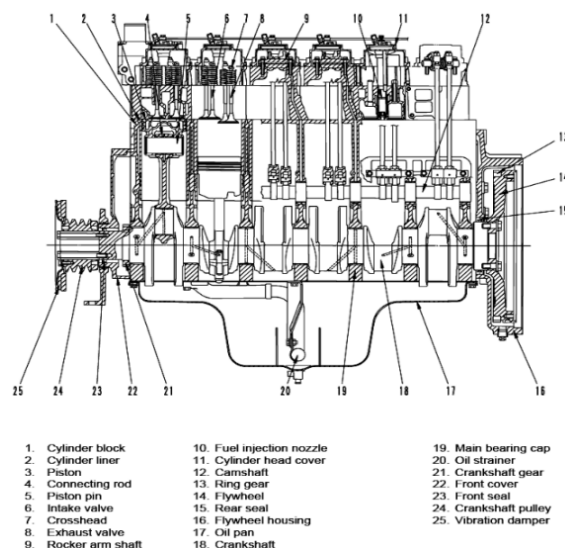


Figure 7 Component of Diesel Engine
(Yuni, 2021)

In the mining industry, the Komatsu GD825A-2 motor grader relies on a diesel engine as its primary power source. This type of internal combustion engine is known for its ability to produce high torque at low revs while maintaining good thermal efficiency. These advantages make it suitable for heavy-duty work with long operating durations. However, field use often faces challenges such as high ambient temperatures, continuous dust exposure, and extreme workloads, all of which have the potential to trigger excessive engine temperatures. These conditions make cooling system performance a key factor in maintaining engine reliability and operational life. Therefore, diesel engines in mining areas require a responsive and efficient cooling system. This research not only discusses the general concept of cooling operation but also examines the use of Internet of Things (IoT) technology to monitor and regulate temperatures directly in the field, so that potential overheating can be prevented before it disrupts productivity.

Recent studies have shown that due to increasingly sophisticated technological advances, achieving effective thermal efficiencies of up to 55% and even exceeding 60% in internal combustion engines is now very possible (Dahham, Wei and Pan, 2022), lower fire hazard as the fuel's flash point is relatively higher, no need for an ignition device or carburator, can produce significant power at low speeds are some advantages of diesel engine. Diesel engines that require 4 piston strokes or 2 crankshaft rotations to produce one combustion are 4-strokes diesel engines. Each piston stroke is an intake stroke, compression stroke, expansion/power stroke, exhaust stroke.

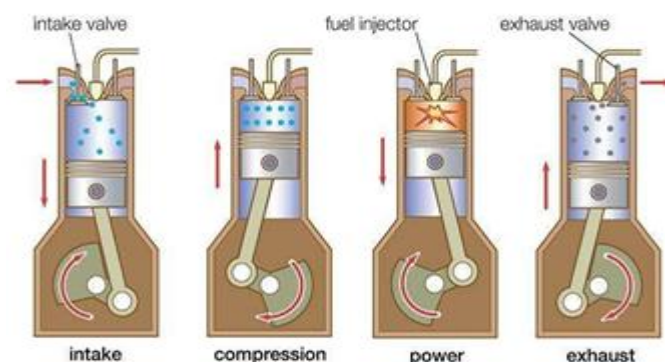


Figure 8 Working Principle of a Four-Stroke Engine
(Alturki, 2017)

Figure 8 shows that during the stroke process, the piston moves from Top Dead Center (TDC) to Bottom Dead Center (BDC) two times for each cycle (Li, 2024). The exhaust valve is open and the exhaust valve remains closed, so that pure air enters the cylinder. The next process is the compression stroke where the air in the cylinder is compressed by the piston moving from Bottom Dead Center (BDC) to Top Dead Center (TDC). In this process, the intake valve and exhaust valve are both closed which causes the pressure to increase to 30-40 kg/cm², and the air temperature to increase to 400-500°C. The next step is the power/power stroke. In this stroke, both the intake valve and the exhaust valve are still closed. The fuel particles injected by the nozzle mix with the high-pressure and high-temperature air, causing combustion that produces power (Gonçalves and Carvalheira, 2024). As a result, the pressure increases to 80-110 kg/cm², and the temperature increases to 600-900°C. And finally, there is the exhaust stroke where the exhaust valve opens just before the piston reaches Bottom Dead Center (BDC), allowing the combustion gases to start coming out. The piston then moves from (Bottom Dead Center) BDC to (Top Dead Center) TDC, which causes the exhaust gas to escape completely.

To move the piston when it first runs, the engine is equipped with an electrical system. Electrical power from the battery will be forwarded to the starting motor where the starting motor will then move the pinion to rotate the flywheel. To recharge the battery, the engine is equipped with a charging system. Another system in a diesel engine is the fuel system. The fuel system functions to store, filter, and inject fuel into the combustion chamber. The fuel that enters the combustion chamber will be mixed with air which is then compressed to produce an explosion that will move the piston. This process is supported by the intake and exhaust system in the engine. In addition to these 2 systems, the engine is also equipped with a lubricating system that is useful for lubricating engine components to prevent wear. Finally, there is a cooling system that functions to maintain the working temperature so that it remains at the optimal. The engine cooling system consists of several main components such as the radiator, water pump, thermostat and oil cooler. The engine can be said to overheat if the coolant reaches a temperature of 102±3°C (Komatsu, 2001). Table 1 shows the detail specification of GD825A-2 engine.

Table 1 Komatsu GD825A-2 Engine Specification

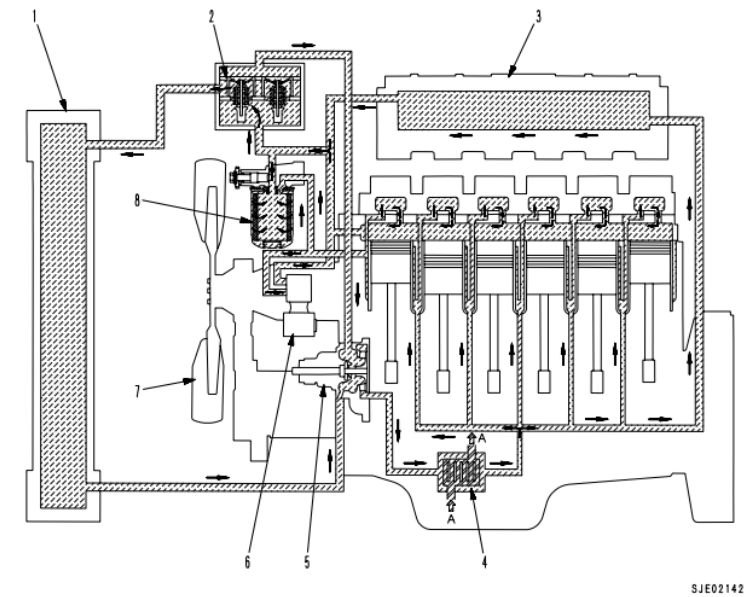
Description	Unit	Spesification
Model	-	S6D140E-2
Number of cylinder – Bore x Stroke	mm	6 – 140 x 165
Total piston displacement	L (cc)	15.2 (15,240)
Firing order	-	1-5-3-6-2-4
Overall length	mm	1,593
Overall width	-	895
Overall height	mm	2,060
Flywheel horsepower	kW (HP)/rpm	209 (280)/2,100
Maximum torque	Nm (kgm)/rpm	1,230 (125)/1,400
High idling speed	rpm	2,300 – 2,400
Low idling speed	rpm	650 – 700
Min. fuel consumption ratio	g/kWh (g/HPh)	208 (155)
Dry weight	kg	1,506
Fuel injection pump	-	BOSCH PE-P (PS3S) type
Governor	-	BOSCH RSV centrifugal all speed control type
Lubricating oil (refill capacity)	Liter	38 (34)
Coolant amount	Liter	23
Alternator	-	24 V, 50 A
Starting motor	-	24 V, 11 kW
Battery	-	12 V 200 Ah x 2
Turbocharger	-	KOMATSU KTR110 type
Air compressor	-	ZEXEL Reciprocation, 1- cylinder type

2.2 Engine Cooling System

As previously mentioned, the function of the cooling system is to maintain the optimal working temperature. The optimal engine working temperature is 70-90°C. Very low working temperatures cause the optimal combustion chamber temperature not to be achieved so that combustion becomes imperfect which triggers the formation of carbon deposits on the piston. In addition, the engine requires more fuel to achieve the same power. Low temperatures also cause the oil to thicken so that lubrication becomes less good. On the other hand, if the temperature is too high it will cause pre-ignition, thus triggering knocking in the engine. In addition, high temperatures also cause the oil viscosity to become thinner so that lubrication becomes less good. Deformation of the components is also possible. Overheating also causes the turbocharger to fail and shortens the life of the seal, gasket, or o-ring.

To be able to perform its function, the cooling system is equipped with several components. The following are the components found in the Komatsu GD825A-2 motor grader cooling system.





- 1. Radiator
- 2. Thermostat
- 3. Water-cooled aftercooler (SA6D140-2)
- 4. Oil cooler
- 5. Water pump
- 6. Air compressor
- 7. Cooling fan
- 8. Corrosion resistor
- A. Oil inlet and outlet

Figure 9 Cooling System of Engine S6D140E-2
(Komatsu, 2005)

Figure 9 shows some of the main components found in the S6D140E-2 engine cooling system such as the radiator, water pump, thermostat, and corrosion resistor. Here is a brief explanation of each of these components.

1. Radiator

The radiator is one of the main components in the cooling system for internal combustion engines. The working principle of the radiator is to transfer heat from the engine coolant to the surrounding air. After the coolant circulates in the system by passing through the engine block, the coolant will enter the radiator.



Figure 10 Radiator

Figure 10 shows that this component is equipped with aluminum fins. This significantly increases the surface area for the cooling process using the help of a fan that is rotated by the engine using a belt. The efficiency of this heat-exchange process relies considerably on radiator design, material selection, and coolant composition, each influencing the radiator's ability to effectively absorb and disperse heat from the engine (Habeeb *et al.*, 2020).

2. Water Pump

One of the components in the diesel engine cooling system is the water pump. This component functions to circulate coolant from the radiator to the engine block and back to the radiator. The water pump on the GD825A-2 is driven using a belt connected to the crankshaft. When the engine is operating, the water pump continuously circulates coolant, so that the heat generated from the combustion process can be absorbed and then released through the radiator so that the engine working temperature can be maintained to prevent the risk of component damage due to overheating. The water pump can work because there is an impeller in its housing which creates centrifugal force so that the coolant can flow throughout the cooling path. Figure 11 shows that the water pump used by the GD825A-2 is a centrifugal type with a ratio of 1.56 to engine speed and a capacity of 800 liters per minute.

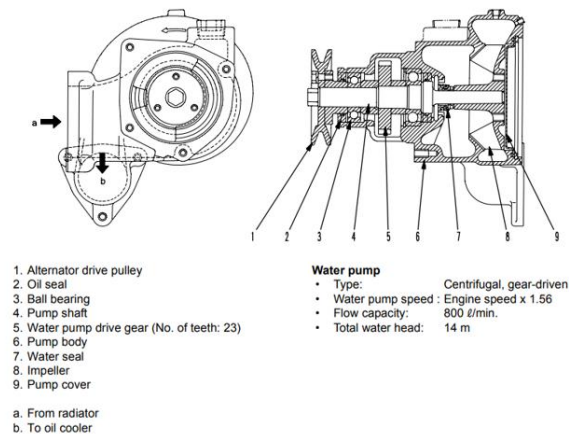


Figure 11 Water Pump for S6D140E-2
(Komatsu, 2005)

3. Thermostat

Thermostat is a component in the diesel engine cooling system that functions to regulate the opening and closing of the flow to the radiator so that the working temperature is maintained at 70-90°C. This component is important to prevent engine overheating and helps to accelerate the engine to reach its working temperature. Figure 12 show that if the temperature has reached the opening temperature of the radiator (74.5-78.5°C) then the expander will begin to expand and push the piston up. Because the piston is one with the valve, the channel to the radiator will begin to open. The size of the flow entering the radiator depends on the size of the valve that is open. The valve will open fully at a temperature of 90°C.

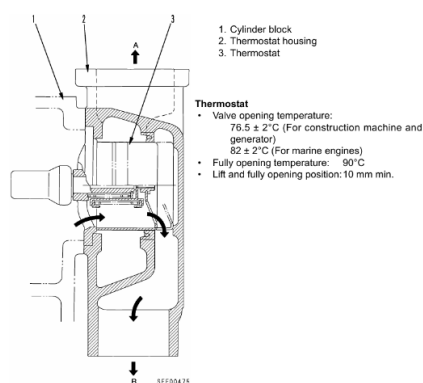


Figure 12 Thermostat
(Komatsu, 2005)

4. Corrosion Resistor

The corrosion resistor functions to prevent the formation of deposits and rust that could cause blockages in the cooling channels. Figure 13 shows that the corrosion resistor used by the GD825A-2 has a filtration area of 0.13 m².

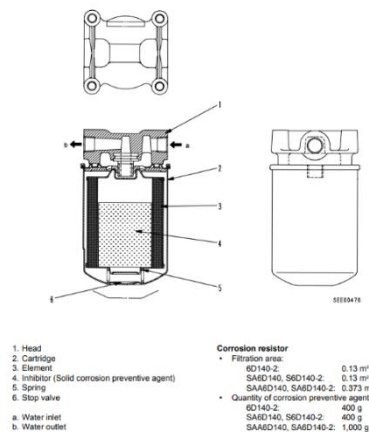


Figure 13 Corrosion Resistor

(Komatsu, 2005)

Figure 14 shows that Komatsu GD825A-2 motor grader is equipped with a panel monitor that makes it easier for operators to know the condition of the unit. The indicator related to the cooling system on the panel monitor is the coolant temperature (number 1). The indicator is in the form of a lamp and how high the coolant temperature is. The sensor is connected to a wiring harness that gets power from the battery.

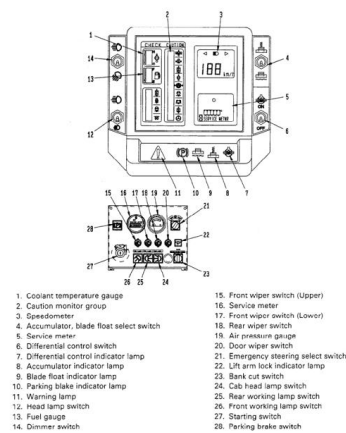


Figure 14 Komatsu Motor Grader GD825A-2 Panel Gauge

(Komatsu, 2010)

In mining environments, diesel engine cooling systems operate under conditions far more demanding than those encountered in general applications. The coolant flow, driven by a water pump, circulates through the cylinder block to absorb heat generated by combustion, and is then directed to the radiator to dissipate this heat into the surrounding air. The efficiency of heat transfer in the radiator is significantly influenced by the design of the aluminium fins, the composition of the coolant, and the airflow rate produced by the engine fan.

Air quality in mining areas constitutes one of the primary limiting factors in cooling performance. Dust particles carried by the airflow tend to accumulate on the radiator fins, obstructing air passage and reducing heat dissipation capacity. A study conducted by (Habeeb *et al.*, 2020) demonstrated that dust accumulation on radiator fins can lower heat dissipation efficiency by up to 30%, ultimately increasing coolant temperature and elevating the risk of overheating.

Research by (Yuni, 2021) on heavy equipment revealed that when airflow is disrupted due to dust and debris buildup, coolant temperature can rise sharply in less than fifteen minutes under full load. Such conditions frequently trigger power reduction (derating) or emergency engine shutdowns to prevent damage to critical components such as seals, gaskets, and O-rings. Considering the dynamic interaction between coolant flow, heat transfer processes, and air quality, the implementation of Internet of Things (IoT)-based monitoring becomes highly relevant. The use of temperature and pressure sensors connected to an Arduino platform enables early warning before damage occurs, and can also activate an automatic radiator cleaning system to restore airflow to optimal conditions.

2.3 Engine Overheating

When the unit is operating, the engine will produce a lot of heat from the combustion process. The cooling system in the engine will circulate coolant from the water pump to the cylinder block and continue until it is recirculated by the water pump. During this process, the coolant will absorb heat from the engine to then be released when passing through the radiator. The cooling system is useful for maintaining the engine's working temperature at an optimal temperature. If the temperature is too low, it will cause

imperfections in the combustion process. On the other hand, if the temperature is too high, it can cause damage to the seal, gasket, o-ring, etc. components. An engine that runs hotter than normal can be said to be overheating (Momin et al., 2016). Engine overheating can occur because the cooling system fails to function. Component damage, system leaks, or the wrong choice of coolant are some examples of the causes. To prevent this, monitoring the cooling system is important (Ghufron and Prayogi, 2023).

As a preventive measure against overheating in the Komatsu GD825A-2 diesel engine, several key parameters must be consistently monitored. These include the coolant temperature, which serves to detect any rise above the manufacturer-specified safe limit of 102 ± 3 °C; coolant pressure, where a decrease may indicate leakage or failure of the water pump; the temperature differential between the radiator inlet and outlet (delta temperature), where an unusually small difference may signify reduced heat dissipation capacity due to dust blockage or fan malfunction; and engine vibration, which, if excessive, can impair the performance of the pump, cooling fan, and other components in the cooling system.

In field practice, operators often overlook the early signs of overheating because available indicators are only displayed on the cabin panel and are not recorded for further analysis. As a result, early symptoms are frequently ignored until the coolant temperature reaches a critical level. Manual monitoring, which relies on periodic inspections, has a fundamental drawback: the data are not collected continuously, causing the resulting actions to be reactive. In contrast, IoT-based real-time monitoring enables parameter readings to be obtained directly from the mining site or remotely, supported by early warning systems and historical data logging. This approach allows potential failures to be identified at an earlier stage, even before they significantly affect engine performance.

S-14 Water temperature becomes too high (overheating)

General causes why water temperature becomes too high

- Lack of cooling water (deformation, damage of fan)
- Drop in heat dissipation efficiency
- Defective cooling circulation system
- Rise in oil temperature of power train
- ★ Carry out troubleshooting for chassis.

Legend

- : Possible causes (judging from Questions and check items)
- △ : Most probable causes (judging from Questions and Check items)
- ◇ : Possible causes due to length of use (used for a long period)
- : Items to confirm the cause.

		Causes											
		Broken water pump	Clogged, crushed radiator fin	Clogged radiator core	Defective thermostat (does not open)	Defective water temperature gauge	Insufficient cooling water	Fan belt slipping, worn fan pulley	Clogged, broken oil cooler	Defective pressure valve	Broken head, head gasket	Damaged liner, O-ring, holes made by pitting	Rise in torque converter oil temperature
Questions	Confirm recent repair history												
	Degree of use												
	Condition of overheating												
	Water temperature gauge												
	Radiator water level sensor lights up												
	Fan belt whines under sudden load												
	Cloudy white oil is floating on cooling water												
	Cooling water flows out from overflow hose												
	Excessive air bubbles inside radiator, water spurts back												
	Engine oil level has risen, oil is cloudy white												
Check items	There is play when fan pulley is rotated												
	Radiator shroud, inside of underguard are clogged with dirt or mud												
	When light bulb is held behind radiator, no light passes through												
	Water is leaking because of cracks in hose or loose clamps												
	Belt tension is found to be slack												
	Power train oil temperature enters red range before engine water temperature												
Troubleshooting	Temperature difference between top and bottom radiator tanks is excessive												
	Temperature difference between top and bottom radiator tanks is slight												
	When water filler port is inspected, the core is found to be clogged												
	When a function test is carried out on the thermostat, it does not open even at the cracking temperature												
	When water temperature is measured, it is found to be normal												
	When oil cooler is inspected directly, it is found to be clogged												
	When measurement is made with radiator cap tester, set pressure is found to be low												
	When compression pressure is measured, it is found to be low												
	Remove oil pan and check directly												
		Remedy	Replace	Repair	Repair	Replace	Replace	Add	Repair	Replace	Replace	Replace	Replace

Figure 15 Overheating Troubleshooting Chart for Komatsu Motor Grader GD825A-2
(Komatsu, 2001)

Figure 15 explains the causes of engine overheating, linking issues like poor cooling, circulation defects, or heat dissipation failure with symptoms such as rising temperature and sensor alerts. It outlines inspection points, troubleshooting methods like checking radiator temperature differences and thermostat function, and concludes with corrective actions (repair, replacement, or fluid adjustment) to restore cooling efficiency.

2.4 Basic Concepts of IoT with Arduino

IoT uses small microcontroller-based devices such as Arduino to collect environmental and machine condition data. The Arduino platform supports a variety of sensors and connections, and is easy to program, making it ideal for prototyping mechanical and thermal monitoring systems. A paper by Chaudhari et al. (2023) uses Arduino for construction equipment management, providing benefits such as real-time condition monitoring and predictive maintenance using integrated sensors.

2.5 Arduino Based Sensor & Data Logger Architecture

Arduino Mega 2560 can be developed as a modular data logger to record various parameters: temperature, pressure, vibration, and exhaust gas. Hernández-Rodríguez et al., 2023 describe the creation of a low-cost data logger in various applications, including monitoring diesel generator exhaust gas, demonstrating Arduino's ability for accuracy and field durability.

The proposed engine cooling monitoring system architecture in this study is designed to integrate Internet of Things (IoT) technology with a focus on operational reliability in mining environments. The system comprises a set of sensors that measure air quality human activity, motion, and exhaust gas monitoring. All sensors are connected to an Arduino Mega 2560, which functions as the main controller as well as a data logger.

The selection of the Arduino Mega 2560 is based on several strategic considerations. This device offers high operational reliability in the field, relatively low implementation costs that make large-scale deployment feasible, and modular flexibility that facilitates the integration of various sensor types and iterative prototype design modifications. Furthermore, its extensive community support and comprehensive technical documentation simplify development, maintenance, and future repair processes.

Nevertheless, the deployment of Arduino in mining environments is not without limitations. Continuous exposure to high vibrations may affect the stability of physical connections between components and the accuracy of sensor readings. Extreme ambient temperatures at mining sites may impair the performance of electronic components, while dust and high humidity can cause corrosion or short circuits in the

circuitry. Therefore, the system design also incorporates physical protection measures such as a dust-proof enclosure and vibration dampening mechanisms to ensure long-term device durability.

The proposed monitoring and recording system directly addresses the gap in real-time cooling performance data acquisition for the Komatsu GD825A-2. By leveraging integrated sensors and the Arduino platform, the collected data are not only displayed visually on the dashboard but also analyzed to detect trends in rising temperature or declining coolant pressure. In addition, the system can trigger automatic radiator cleaning when certain parameters exceed predefined thresholds, thereby preventing a reduction in cooling capacity before overheating occurs.

1. Arduino-Based Diesel Generator Monitoring System

The implementation of monitoring systems on diesel engines, especially generators, is very important to maintain operational performance and reliability in various industrial environments, including mining. Arduino is an attractive choice in IoT implementation due to its ease of configuration, flexibility of sensor integration, and affordable price. In a study by Oladoyin & Ogunsola (2023), an Arduino-based system was developed to perform real-time monitoring of diesel generators in a maritime environment. This system uses Arduino Uno together with a GSM communication module to send operational parameter data such as engine temperature, engine speed (RPM), fuel level, and voltage status periodically to a mobile application. The system has proven effective in providing direct engine condition reports, reducing the risk of unscheduled downtime due to mechanical failures, and facilitating predictive and preventive maintenance scheduling. This study shows that the integration of Arduino with a GSM/Wi-Fi communication module is an effective solution in monitoring the operational conditions of diesel engines remotely and in real-time (Emmanuel Oladoyin and Ogunsola, 2023).

2. Data Analysis Method with Arduino in IoT Systems

The direct collection and processing of sensor data (on-device) that Arduino is capable of doing makes it an effective tool for the initial analysis process before data is sent to the cloud.

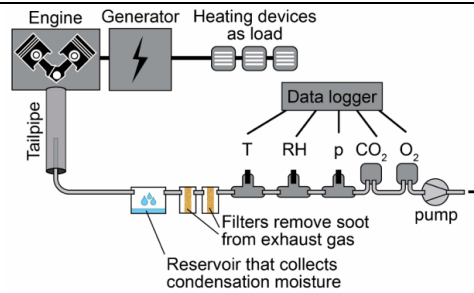


Figure 16 Schematic Representation of the Setup to Monitor Exhaust Gases Emitted
by a Diesel Generator
(Hernández-Rodríguez *et al.*, 2023)

Hernández-Rodríguez *et al.* (2023) says that Arduino functions as a data recording tool that records many parameters shown in Figure 16 such as relative humidity of exhaust gas in diesel engines, pressure, temperature, and gas flow. The collected data is then processed using simple local analysis methods, such as observing changes in data patterns and signal filtering. This method can be used as early detection of machine abnormalities during operation, such as increased vibration or abnormal temperatures that even tend to be high which indicate a problem. This data analysis method allows the relevant team to make decisions faster in the field so that the potential for more serious damage can be prevented.

2.6 IoT Based Predictive Maintenance Concept

The development of modern technology such as the Internet of Things (IoT), sensor technology, and artificial intelligence has caused a shift in maintenance strategies from Reactive Maintenance (RM) to Preventive Maintenance (PM), and finally to Predictive Maintenance (PdM).

- a. Reactive Maintenance (RM) is carried out only after damage occurs to the equipment. If this happens, it is more difficult to return the equipment to its operational condition. This approach causes serious delays, high repair costs, and the potential for long work downtime due to unplanned spare part requirements.
- b. Preventive Maintenance (PM) is carried out based on a planned schedule, both based on time and process cycles, with the aim of preventing damage.

Determining when equipment is in the wear out phase is typically based on theoretical failure rates, rather than the actual condition of the equipment. This often results in expensive maintenance that is performed too early (before a problem occurs) or too late, after a potentially catastrophic failure has occurred. In addition, this approach results in more planned downtime and requires more complex inventory management. If equipment fails before its expected wear out time, it must be repaired using Reactive Maintenance (RM) methods. Studies show that the cost of reactive maintenance (after a failure occurs) is typically three times more expensive than scheduled maintenance.

- c. Predictive Maintenance (PdM) aims to achieve an optimal balance between Reactive Maintenance (RM) and Predictive Maintenance (PM) by estimating the health condition of the equipment online and in real time. This approach allows intervention and prevention before failure occurs, reduces the frequency of unnecessary maintenance, and prevents expensive emergency repairs. If the trend is towards a failure that can be detected early, appropriate action can be taken immediately.

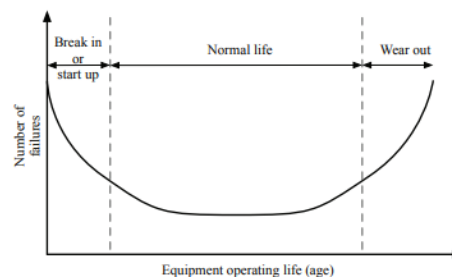


Figure 17 Bathtub Curve

(Alvarez-Alvarado and Jayaweera, 2018)

The Bathtub (shown in Figure 17) curve is an important concept in reliability theory because it measures the probability of a component surviving beyond a certain time (Breznická *et al.*, 2023). With this curve, component availability can be estimated, so that reliability analysis can be performed. However, in reliability models for repairable components, the formulation becomes more complex because in addition to the Bathtub curve, the repair rate pattern must also be taken into account. The literature divides the Bathtub curve into three main stages: infant mortality, useful life, and wear out (Chen,

Lin and Sheu, 2018). Most studies focus on the useful life stage, where the failure rate is assumed to be independent of time, so that the availability value becomes constant. However, this assumption can ignore component degradation due to aging, which can potentially cause inaccuracies in realistic reliability evaluations (Alvarez-Alvarado and Jayaweera, 2018).

2.7 Challenges and Obstacles to Arduino-Based IoT Implementation

Although Arduino offers several advantages in IoT implementation, there are some major challenges in its use in industrial environments. According to a study by Pratiksha Vilasrao Chaudhari et al. (2023) some of these obstacles include the limited durability of the device to extreme conditions such as high temperature, dust, and humidity, which are commonly found in mining environments. In addition, limited battery power and energy consumption are challenges, considering that Arduino devices require effective power management strategies to be able to operate for a long time without frequent maintenance. Other challenges are the interoperability between various sensors and communication modules that must be compatible with each other and the challenges in managing large data generated by the monitoring system continuously. The study suggests that modular design solutions, the use of appropriate sensors, and efficient power and communication management techniques are the keys to the successful implementation of Arduino on an industrial scale.

2.8 Previous Studies

The Komatsu GD825A-2 diesel engine is highly dependent on the performance of its cooling system to maintain optimal operating temperatures as explained in the previous sub-chapter. Various components such as radiators, water pumps, thermostats, and IoT-based monitoring systems using Arduino play an important role in preventing overheating that can potentially damage internal engine components. Many recent studies have begun to integrate real-time monitoring and sensor technology in order to improve maintenance efficiency, engine reliability, and as a step towards predictive maintenance.

Previous studies in the Table 2 have shown the effectiveness of using Arduino and IoT-based systems in monitoring the operational conditions of heavy equipment in various

industrial fields. Research by Yuni (2021), Hernández-Rodríguez et al., (2023), Emmanuel Oladoyin and Ogunsola (2023), Pratiksha Vilasrao Chaudhari, Kadam and Sabi Huddin (2023), and Sembiring et al. (2019) generally emphasize the main benefits of direct monitoring and early warning of potential machine failures. In addition, preventive maintenance becomes more optimal, and operational efficiency increases thanks to the application of IoT technology. However, several studies suggest further development, especially in terms of system resilience, periodic performance evaluation, and large-scale implementation in the field so that long-term benefits can be achieved optimally.

Table 2 Previous Studies

No	Author (Year)	Title	Objective	Method	Findings	Recommendation
1	Yuni et al. (2021)	Monitoring Heavy Equipment Coolant Temperature to Prevent Engine Overheat Using IoT	Monitor coolant temperature and fan speed to prevent overheating	Development of IoT-based monitoring	Successful real-time monitoring of coolant temperature, volume, and fan speed	Further implementation for enhanced system stability and operator responsiveness
2	Hernández-Rodríguez et al. (2023)	Reliability Testing of a Low-Cost, Multi-Purpose Arduino-Based Data Logger	Evaluate reliability of a multi-purpose Arduino data logger	Short-term monitoring campaigns	Data logger is versatile and reliable across multiple scenarios (air quality, human activity, motion, exhaust gas)	Need for continuous evaluation and periodic engineering adjustments for long-term use
3	Oladoyin et al. (2023)	Design and Construction of IoT Based Generator Monitoring System	Monitor diesel generator parameters remotely using IoT	Design and implementation	Effective real-time monitoring of generator parameters (oil level, battery, stability) via mobile app	Further development for improved operator alert and diagnostic capabilities
4	Chaudhari et al. (2023)	Use of Arduino in IoT for Construction Equipment Management and Maintenance	Investigate IoT's impact on construction equipment management	Surveys, interviews, data analytics	IoT significantly improves equipment uptime, operational efficiency, and safety through predictive maintenance	Encourage wider IoT adoption with emphasis on overcoming integration and operational risks
5	Sembiring et al. (2019)	Design and Simulation of Engine Operation Temperature Monitor and Control System Using IoT	Develop a real-time engine temperature monitoring system using IoT	Simulation and prototype testing	Real-time engine temperature monitoring with alerts on abnormalities successfully demonstrated	Further testing and application to actual heavy equipment for reliability
6	Samudra (2025)	Improving Engine Cooling System to Prevent Overheating in Motor Grader Using IoT	To design and implement automatic washing radiator with a real-time monitoring of temperature and pressure	Prototyping, device development, and testing	-	-

The research gap in this study compared to the previous five studies is in the development of an automatic radiator washing system equipped with real-time temperature and pressure monitoring by utilizing IoT, especially for heavy equipment motor grader GD825A-2 in the hauling road area. Previous studies have focused more on monitoring engine conditions and general parameters, such as engine speed, temperature, or fuel conditions. However, no one has specifically equipped the monitoring system with an automatic washing mechanism to prevent overheating in the radiator, especially in heavy equipment units operating in mining environments. Therefore, this study contributes by presenting a new solution in the form of a prototype of an automatic radiator washing system equipped with IoT sensors to improve maintenance efficiency and reduce downtime due to overheating more effectively.

The developed system has several main design requirements. In the temperature monitoring section, the maximum temperature limit of the upper radiator tank is set at 105 °C, with a temperature difference (ΔT) between the upper and lower tanks in the range of 8–15 °C. The sensor used has an accuracy of ± 2 °C and works in an ambient temperature range of 23–35 °C. For pressure monitoring, the maximum pressure limit on the after-transmission filter side is set at 34 bar, with a maximum pressure difference tolerance (ΔP) of 4 bar. Furthermore, the automatic radiator washing system is designed with an activation mechanism via a push button, using a spray pressure of around 0.2 bar, and a maximum washing cycle of 10 minutes. From the IoT monitoring system side, the system uses a Wi-Fi communication protocol, with a data transmission frequency of every 1 minute, as well as dual data storage on a local SD card (for areas with weak signals) and a cloud server (for areas with good signals). As for the operational aspect, the system is designed to be easy to maintain through the use of standardized components.

CHAPTER 3 - RESEARCH METHODS

3.1 Research Framework

To achieve the objectives that have been set effectively, this study requires a systematic approach. Because of this, it is necessary to prepare a clear research framework so that it can be used as a guide to describe the entire process flow starting from problem identification, data collection, to the evaluation stage and the preparation of recommendations. All steps taken in this study can be explained in a structured manner through this framework in Figure 18 making it easier to understand the relationship between existing problems, solutions provided, and the impact on improving the performance of the cooling system on the Komatsu GD825A-2 motor grader.

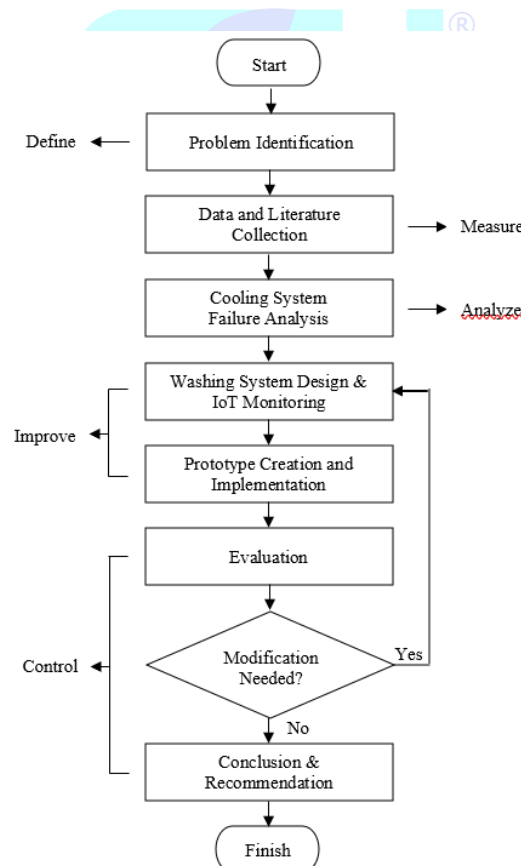


Figure 18 Research Flowchart

This research was compiled using the DMAIC (Define, Measure, Analyze, Improve, Control) approach which is widely used in improving data-based management, engineering systems and improving quality (Rodriguez, Medini and Wuest, 2022). This approach was chosen because it can provide a systematic and measurable flow in solving technical problems in the field, which in this study is about the GD825A-2 motor grader engine cooling system.

3.2 Define

The cooling performance of the Komatsu GD825A-2 motor grader is frequently compromised by the accumulation of dust on radiator fins and the absence of real-time monitoring tools. These issues often trigger overheating and unplanned maintenance shutdowns, especially in mining environments with high dust intensity, where cleaning is manually performed only after clogging becomes visible. To mitigate this recurring problem, this study proposes the development of an automatic radiator washing system that is integrated with a monitoring platform capable of tracking temperature and pressure in real time, including differential (delta) analysis. Chaudhari et al., (2023) highlight the potential of Arduino-based IoT systems for managing and maintaining construction machinery efficiently. Furthermore, Hernández-Rodríguez et al., (2023) demonstrated that affordable microcontroller-based data loggers can reliably capture environmental parameters, making them suitable for field applications requiring continuous performance monitoring. This solution follows the trend of IoT utilization which has proven effective in reducing sudden failures in industrial equipment (Prosper, 2025).

The workflow included in the define is problem identification. To map the process in general, the SIPOC (Supplier, Input, Process, Output, Customer) approach is used which describes the flow starting from the cooling system input to the output in the form of performance data and notifications as shown in the Figure 19.

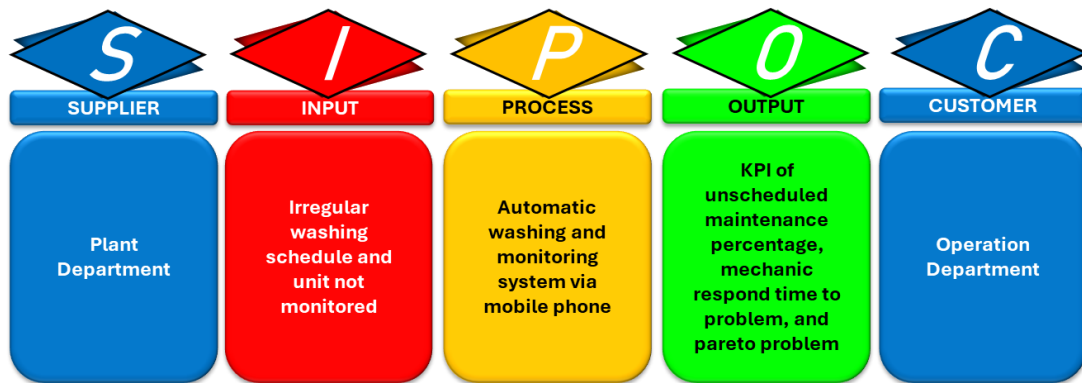


Figure 19 SIPOC

The scope of the study is limited to the radiator system of the GD825A-2 unit, without covering other systems or different units. The main focus is on the design, installation, and evaluation of the automatic washing system and temperature-pressure monitoring implemented in the field.

3.3 Measure

The Measure phase involved an acquisition of baseline data to evaluate the initial condition of the engine cooling system prior to implementing improvements. Data collection was carried out through a combination of manual inspections, field observations, and sensor-based monitoring. Temperature sensors were placed at both the upper and lower radiator tanks to capture the thermal differential (delta temperature), while pressure sensors were installed before and after the transmission filter to assess flow resistance through delta pressure. Variables measured included engine temperature, pressure readings, and duration of unscheduled maintenance due to overheating. Delta temperature thresholds 8-15°C and pressure drops across the filter greater than 4 bar were used as indicators of system performance. The threshold for delta temperature was determined through field trials, whereas the reference value for delta pressure was obtained from the Komatsu GD825A-2 shop manual. These metrics provided a quantitative basis to identify performance gaps and validate the severity of recurring cooling failures.

As a support, literature was collected from the latest scientific journals to strengthen the theoretical basis of the diesel engine cooling system, thermal efficiency, and the

implementation of Arduino-based sensors and IoT monitoring. One of the references is research conducted by (Daniel, Comfort Chinaza and Stanley, 2023), which shows the effectiveness of an IoT-based temperature monitoring and alarm system.

3.4 Analyze

The analysis phase focuses on identifying the primary causes of excessive downtime due to overheating in the Komatsu GD825A-2 unit. Data collection was conducted using a combination of structured interviews, Focus Group Discussions (FGD), and direct field observations. The Pareto diagram was created based on historical unscheduled maintenance records between July–December 2024, allowing for the quantification and ranking of dominant failure components. Meanwhile, the fishbone diagram was constructed using insights gathered during FGDs held with experienced mechanics, group leader, maintenance instructor, and plant engineers who had directly dealt with engine overheating issues. These discussions, combined with supporting interview data, helped classify potential root causes into the 5M1E framework. FMEA was then performed to evaluate and prioritize failure modes using severity, occurrence, and detection scores. The findings confirmed that the cooling system—particularly issues in the radiator—was the most significant contributor to downtime. Therefore, improvement efforts were directed toward implementing an automatic radiator washing system and integrating real-time monitoring of temperature and pressure parameters.

3.4.1 Pareto Problem of GD825A-2

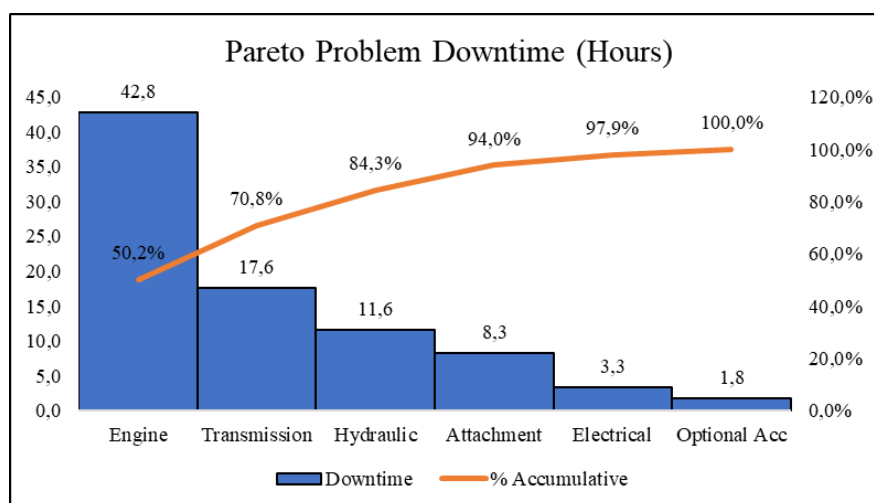


Figure 20 Pareto of Component Downtime July – December 2024

Figure 20 is obtained from daily report data. It can be seen that the most downtime was caused by the engine, which was 42.8 hours, so that this component contributed more than 50% of the total downtime on the motor grader GD825A-2. Other components—hydraulic (11.6 hours), attachment (8.3 hours), electrical (3.3 hours), and additional accessories (1.8 hours), contributed the rest gradually. This confirms the Pareto 80/20 law, namely that most problems (downtime) come from a few main causes (Egbe *et al.*, 2024). This method is commonly used in maintenance to prioritize corrective actions—as shown by a study by Bialy & Beno (2016) on mining equipment, which combines Pareto analysis with RCA to determine a more efficient maintenance strategy.

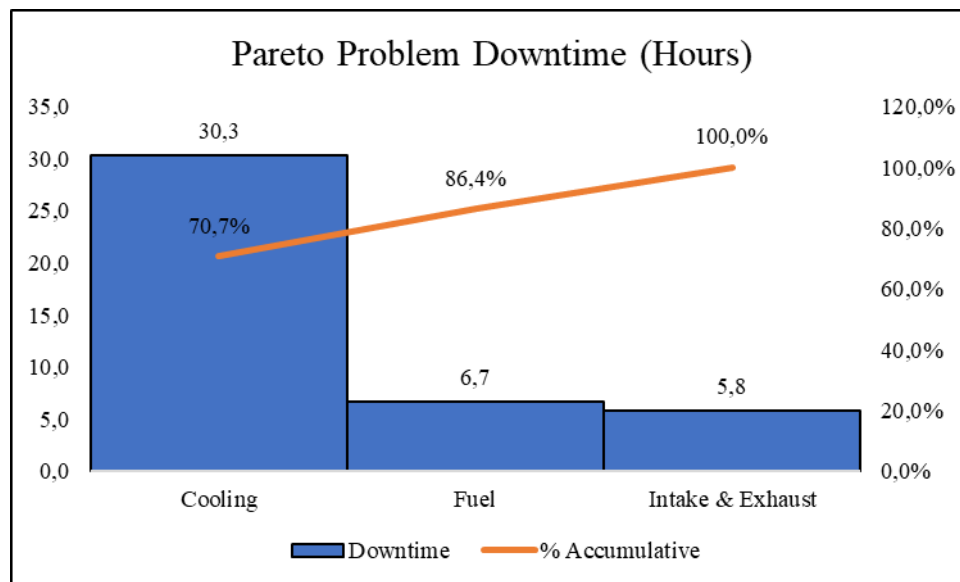


Figure 21 Pareto of Sub Component Downtime July – December 2024

Based on the Pareto downtime graph based on subcomponents shown in Figure 21, it is known that the cooling system is the largest contributor to downtime, which is 30.3 hours, or around 70.7% of the total recorded downtime. Other subcomponents such as the fuel system and intake & exhaust each contributed 6.7 hours and 5.8 hours, so that cumulatively the three cover all downtime (100%). This shows that the main problem in the engine system is focused on the cooling sector. With such a concentration of downtime, improvements and optimization of the cooling system will have the most significant impact in reducing unit downtime. The Pareto principle strengthens this finding, where most effects come from a small number of causes, so that the

justification for focusing on improvements to the cooling system becomes stronger and more focused.

3.4.2 Field Data Collection

This stage is focused on collecting field data to map actual problems in the cooling system of the Komatsu GD825A-2 motor grader unit. This process is carried out through the Focus Group Discussion (FGD) method, structured interviews, and direct observation in the work area (Mwilongo, 2025). The FGD was carried out during the period April to May 2025 in the workshop meeting room, involving one group leader with 13 years of experience, five senior mechanics who have worked for more than 5 years, and one maintenance instructor with 7 years of service. One plant engineer with 3 years of experience as moderator. All of them has directly handled causes of engine overheating. The FGD aims to explore technical understanding and identify possible root causes (Tümen Akyildiz and Ahmed, 2021) of the decline in cooling system performance.

To validate the reliability of the qualitative data gathered through Focus Group Discussions (FGDs), triangulation was applied by cross-verifying results from structured interviews, direct field observations, and supporting maintenance documentation. This method helped ensure consistency and reduce subjectivity in the identification of failure modes. Furthermore, technical insights obtained from the FGD were corroborated with secondary references and internal service records to reinforce their credibility. The combined approach ensured that the problem mapping was not solely dependent on anecdotal input, but was grounded in both field evidence and historical performance data.

Each participant in the FGD was selected based on their practical experience and direct involvement with engine maintenance. Table 3 presents a summary of the roles of each participant and the specific data or insights they contributed. The information obtained was then structured using the 5M1E classification—Man, Machine, Method, Material, Measurement, and Environment—to build a comprehensive fishbone diagram. This visualization served as a foundational tool for identifying critical factors contributing

to the recurring overheating problem and guided the direction of technical improvements.

Table 3 Summary of FGD Participants, Data Contribution, and Validation Method

No	Participant Role	Experience (Years)	Data or Insights Contributed	Validation Method
1	Group Leader	13	Common overheating cases, constraints in cleaning intervals, historical downtime	Cross-checked with maintenance logs and interview transcript
2	Senior Mechanic 1	7	Practical failure modes on radiator fins and water pump	Verified via field observation on radiator physical condition
3	Senior Mechanic 2	6	Thermostat malfunction during heavy load operations	Compared with recorded daily activity report
4	Senior Mechanic 3	8	Fan belt slippage, clogging impact on airflow	Triangulated with daily checklist
5	Senior Mechanic 4	5	Issues on coolant quality and refill practices	Confirmed by used coolant sampling data and interview
6	Senior Mechanic 5	6	Sensor placement inefficiency, lack of delta temperature readings	Validated using wiring diagram and monitoring log gaps
7	Maintenance Instructor	7	Inconsistency in inspection routines and SOP adherence	Matched with monthly inspection
8	Plant Engineer (Moderator)	3	System integration insight, need for automated cleaning and real-time monitoring	Synthesized and reviewed with site engineering records

3.4.3 Failure Mode and Effects Analysis

In this study, Failure Mode and Effects Analysis (FMEA) was used to complement the root cause analysis of overheating problems after previously using the fishbone diagram. With this method, a systematic risk assessment can be carried out to detect each potential failure such as a clogged radiator, leaking seal, or fan not rotating by calculating the risk priority number (RPN) based on severity, occurrence, and detection (Amanuel Daya and Joel Leonard, 2025). These three aspects are assessed on a scale of 1 to 10 for each failure mode, then multiplied to produce a Risk Priority Number (RPN) as a reference in determining the priority of corrective actions. To ensure consistency and objectivity of the assessment, a scale guideline is used that has been adjusted to the operational context of the cooling system on heavy equipment. The description of each scale can be seen in the following tables.

Table 4 Severity Rating Scale

Rank	Functional Impact	Explanation of Severity
10	System completely fails or creates danger	The issue leads to system breakdown or threatens operator safety
9	Critical function becomes unusable	The equipment is no longer able to carry out a vital operation
8	Function still works but performance suffers	The operation continues with major performance deterioration
7	System runs inefficiently	Core processes work but at poor or unstable performance levels
6	Moderate process interference	System shows partial issues but can still operate under limited conditions
5	Slight degradation in performance	Minor drop in system quality with no serious consequences
4	Barely noticeable impact	The problem has a very limited effect on the operation
3	Disruption rarely felt	The failure is subtle and hardly affects daily activity
2	No operational relevance	Failure occurs but has no link to actual functional output
1	Absolutely no effect	The problem doesn't influence any aspect of the system

Table 4 is used to assess how much impact a failure will have on system performance or safety. Each rating indicates the severity of the possible consequences, ranging from no impact to causing a total failure or hazardous situation. Next is the table related to occurrence.

Table 5 Occurrence Rating Scale

Rank	Failure Likelihood	Explanation of Occurrence
10	Very high	The fault arises frequently and cannot be controlled easily
9		The failure pattern is observed nearly every working day
8	High	Appears consistently about once a week
7		Happens occasionally but still noticeable
6	Moderate	Irregular yet recorded in system history
5		Uncommon but not improbable
4	Low	Seldom occurs under typical conditions
3		Occurs in rare or exceptional scenarios
2	Very low	Has barely ever happened, extremely unlikely
1		No record of the failure, with virtually zero expectation

Table 5 shows the occurrence scale that is used to measure how likely a failure mode is to occur during system operation. The rating is based on the frequency of occurrence that has occurred or is likely to occur under normal or extreme conditions. The higher the number, the more often the failure is predicted to occur. This assessment helps in identifying risks that need to be anticipated immediately. After knowing the possibility of failure, the next step is to assess how likely the failure can be detected before it impacts the system, which is explained in the following detection table.

Table 6 Detection Rating Scale

Rank	Probability of Being Detected	Explanation of Detection
10	Cannot be identified before failure	The issue is invisible until consequences appear
9	Almost impossible to notice	Detection before failure is highly unlikely
8	Very difficult to find	Only detailed investigation might catch it
7	Typically missed in standard checks	Frequently passes through inspections undetected
6	May or may not be discovered	Depends on the scenario; it could remain unnoticed
5	Only visible with special checks	Detection is possible but not within normal procedures
4	Usually detected	Will likely be identified in regular inspections
3	Easily flagged with routine evaluation	Detection is simple using standard protocols
2	Rarely goes unnoticed	Inspection methods almost always reveal the problem
1	Always identified	System monitoring ensures immediate recognition of the issue

Table 6 shows the detection scale that is used to assess how likely a failure is to be detected before it causes a significant impact. The detection rating indicates the effectiveness of the inspection system or procedure in identifying potential damage. The higher the number, the less likely the failure is to be detected in time. This assessment is important to determine the reliability of the monitoring and prevention system implemented. After all aspects of severity, occurrence, and detection have been evaluated, the next step is to calculate the Risk Priority Number (RPN) value to determine the priority of risk handling, which will be detailed in chapter 4.

3.4.4 Architecture Diagram

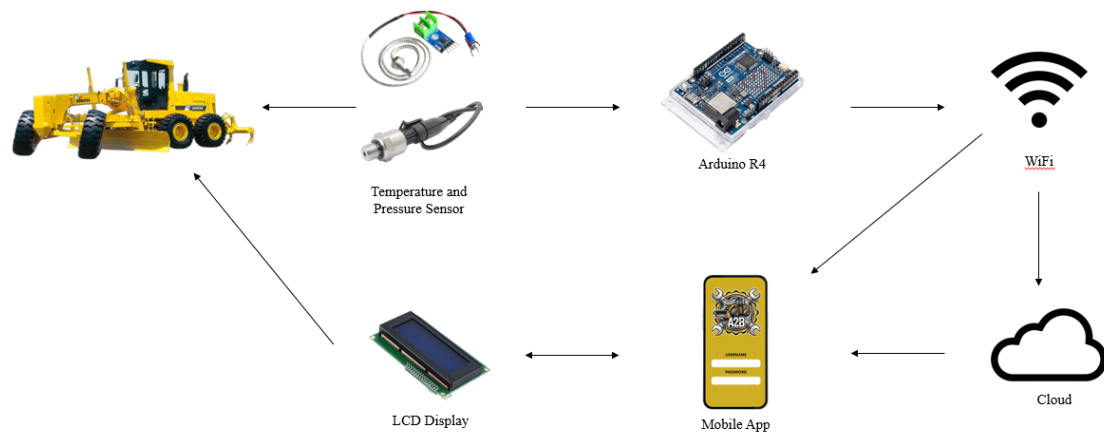


Figure 22 Architecture Diagram

The system architecture in Figure 22 illustrates the integration of IoT-based components designed to monitor the temperature of the cooling system and the pressure of the motor grader transmission system in real time. The temperature and pressure sensors are connected to the Arduino R4 microcontroller, which functions as the main processor. Data received from the sensors is sent via a Wi-Fi connection to the cloud platform for further storage and analysis. This information can be accessed via a mobile application that allows users to monitor system conditions remotely. In addition, data readings are also displayed via an LCD display as a direct interface for operators in the field. This system supports responsive and accurate monitoring, so it can minimize the risk of overheating and support the operational efficiency of heavy equipment.

In the implementation of this IoT system, the wireless network utilizes a domestic telecommunications service provider with a 2.4 GHz operating frequency, chosen because it has a wider range and is stable for mining area conditions. The MiFi device is placed inside the motor grader unit cabin to protect the panel and electronic components from exposure to dust, vibration, and extreme environmental conditions. With this configuration, data transmission requirements are relatively small because only temperature and pressure parameters are used, so the provided bandwidth capacity far exceeds actual needs, and the main challenge focuses more on signal stability in the field.

3.4.5 Use Case Diagram

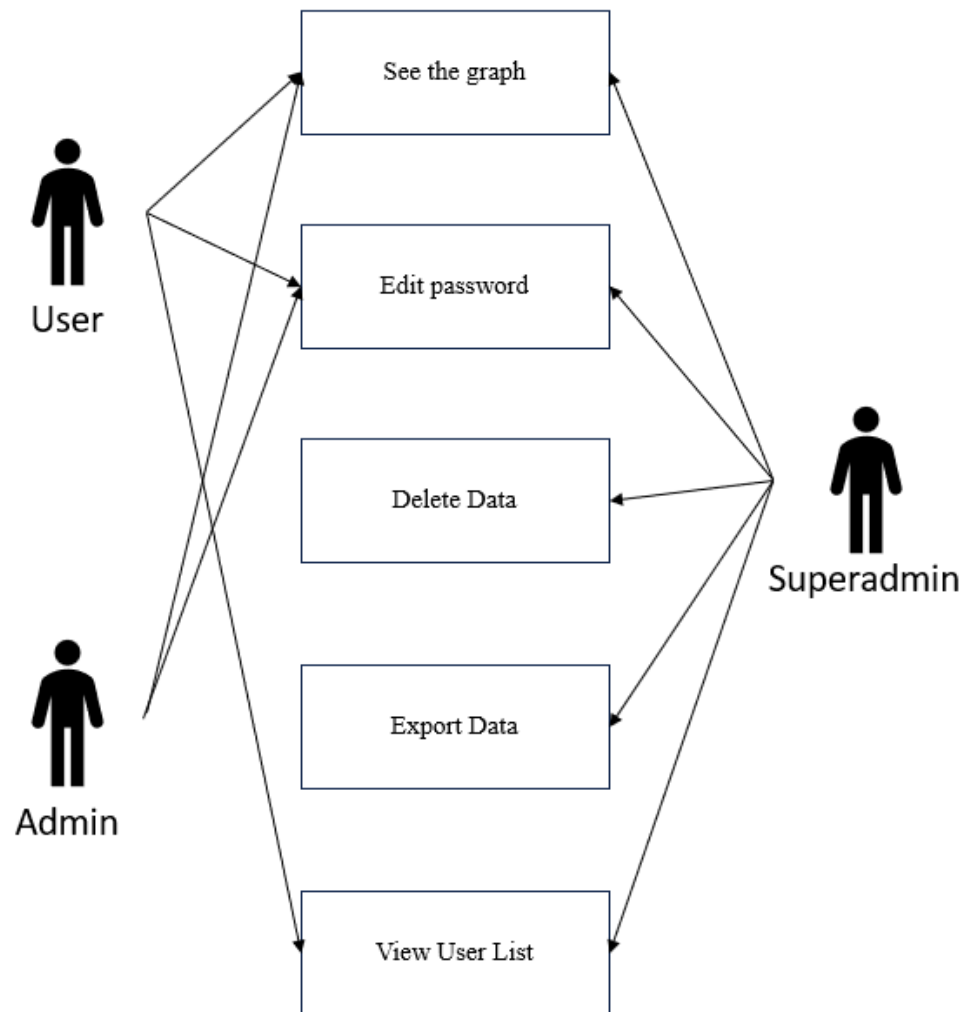


Figure 23 Use Case Diagram

The use case diagram shown in Figure 23 illustrates the interaction between users and the IoT-based engine coolant monitoring system. This system includes five main functionalities: real-time monitoring of coolant temperature and transmission pressure, password management, data deletion, data export for further analysis, and user list viewing. User access is tiered to ensure data integrity and system security. Superadmins have full access to all features, including setting and modifying threshold values for temperature and pressure alerts. Admins can monitor graphs, export data, manage passwords, and oversee user activity, but cannot modify threshold parameters. Regular users have the most limited access—restricted to viewing monitoring graphs, updating their own passwords, and seeing registered users—without the ability to alter system

configurations or sensitive data thresholds. This role-based access control helps safeguard the system from unauthorized changes and ensures each user operates within their scope of responsibility.

3.4.6 Activity Diagram

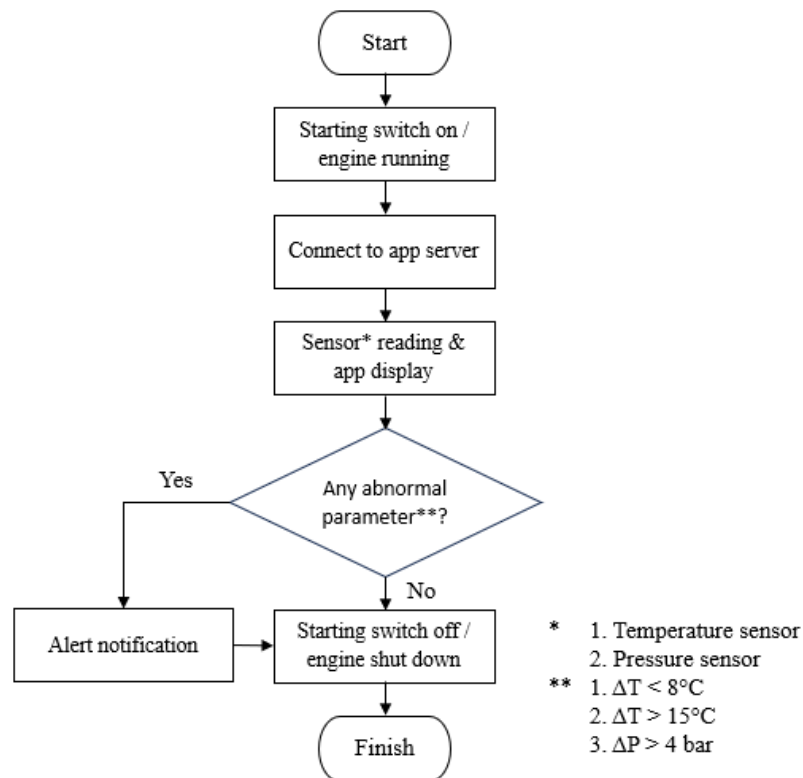


Figure 24 Activity Diagram

The activity diagram in Figure 24 explains the workflow of the temperature and pressure monitoring system on the engine using IoT-based sensors. The process begins when the operator activates the starting switch, which indicates that the engine is starting to operate. After that, the system will connect to the application server. The sensor will read data from the temperature sensors on the upper and lower radiator tanks and the pressure on the before and after transmission filters, which are then displayed via the LCD display in the cabin and application. Furthermore, the designed system will automatically check whether there are parameters that deviate from the predetermined limits, such as a temperature delta of less than 8°C or more than 15°C , or a pressure delta exceeding 4 bar. If one of these conditions is met, the system will send a warning notification to the user. Conversely, if no anomalies are found, the system will continue

running until the engine is turned off and the monitoring process ends. This diagram illustrates how the system works automatically to detect and respond to abnormal conditions that have the potential to cause overheating.

3.4.7 Entity Relationship Diagram

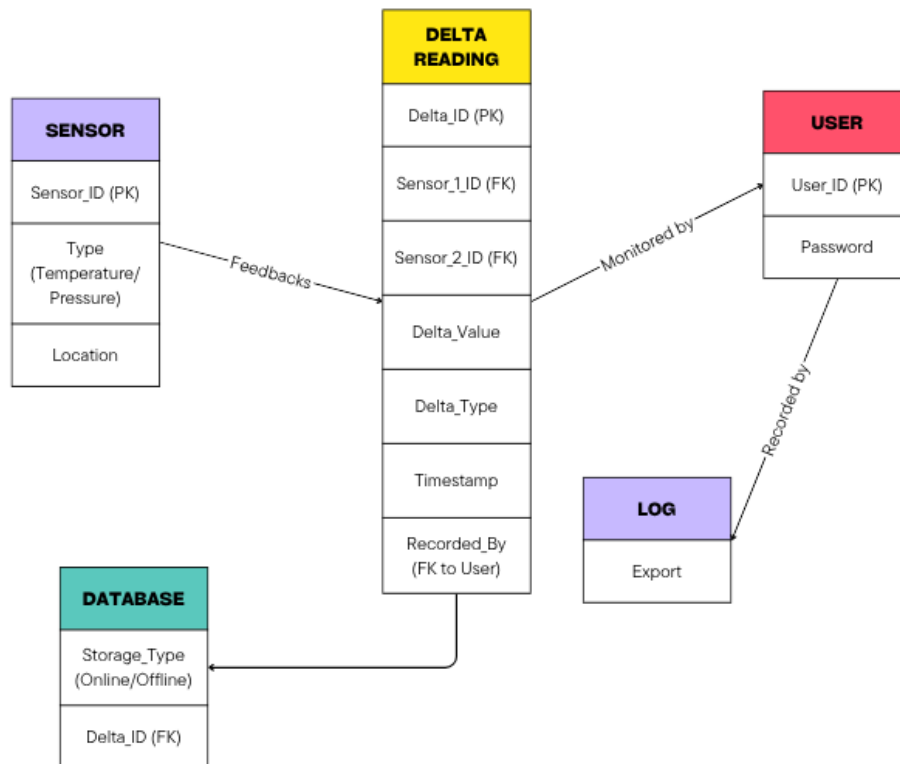


Figure 25 Entity Relationship Diagram

The Entity Relationship Diagram (ERD) on Figure 25 illustrates the database structure in an IoT-based temperature and pressure monitoring system. The main entity in the system is the sensor, which consists of a temperature and pressure sensor. Each sensor has attributes such as type and installation location. Readings from two different sensors are processed into Delta Reading, which records the difference value (delta), measurement type (temperature or pressure), recording time, and is recorded by an authorized user through the User entity. Each delta result is then stored in the Database, either locally (offline) or via a cloud server (online). The data export process is recorded in the Log entity, which is directly connected to the user who performs the export process. The relationship between entities is visualized with a foreign key relationship to ensure data connectivity and referential validity between tables. To safeguard data

integrity and security, the system enforces role-based access controls and implements logging mechanisms that monitor critical activities. This structured approach ensures not only relational coherence among entities through foreign key constraints but also supports privacy by limiting access to sensitive operations and maintaining a detailed audit trail of user interactions.



CHAPTER 4 - RESULTS AND DISCUSSIONS

4.1 Improve

4.1.1 Downtime Percentage of GD825A-2

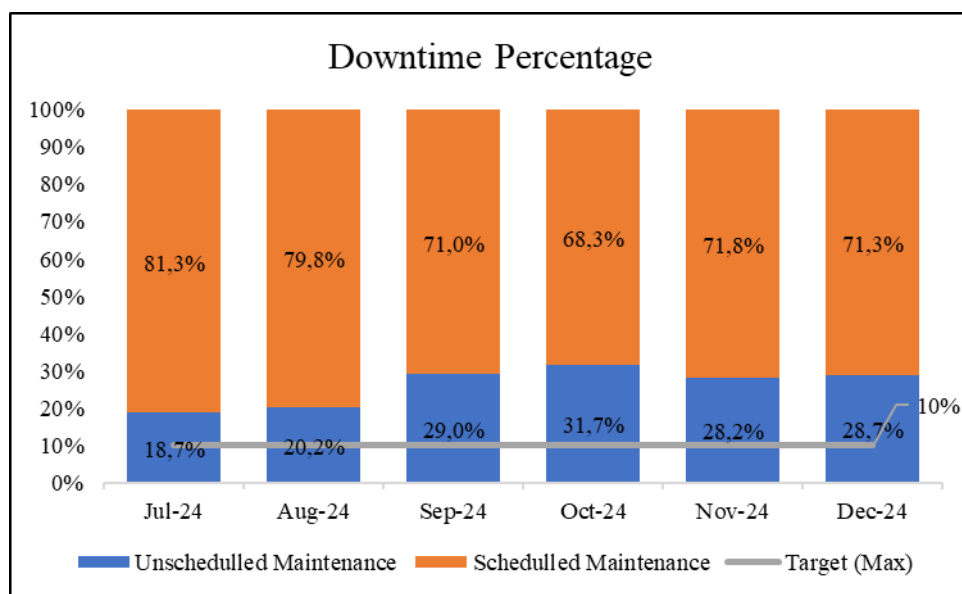


Figure 26 Performance of GD825A-2 July - December 2024

Based on the performance data of the Komatsu GD825A-2 at PT. XYZ as shown in Figure 26, it is known that the average downtime due to unscheduled maintenance reached 26.1%, far exceeding the maximum target limit set at below 10%. The data was obtained from the monthly KPI report. This high figure indicates a significant disruption to the unit's reliability, especially from the cooling system side which causes overheating. The irregularity of the radiator cleaning schedule and the absence of a real-time temperature and pressure monitoring system are suspected to be the main factors triggering this condition. Therefore, further data collection and analysis are needed to formulate a technology-based solution that can reduce the percentage of downtime to approach or even exceed the predetermined performance target. Downtime data from

each component and subcomponent is collected for further analysis using the Pareto approach.

4.1.2 FGD, Interview, and Observation

PT. XYZ		NAME		COMPANY		SIGN	
Minutes of Meeting		Group Leader	XYZ	1.		2.	
DATE	05-Feb-25	Instructor	XYZ				
TIME	09:00	Engineer	XYZ	3.		4.	
AGENDA	KONVENSI 2025	Mechanic 1	XYZ				
CATEGORY	QUALITY CONTROL CIRCLE	Mechanic 2	XYZ	5.		6.	
SUB-CATEGORY	TECHNIQUE	Mechanic 3	XYZ				
SECTION	A2B - WHEEL	Mechanic 4	XYZ	7.		8.	
		Mechanic 5	XYZ				

No	Category	Problem	Check
1	Data Validation & Field Condition	Are the failure modes listed in the table consistent with actual incidents in the field?	Yes
2		Are there any other failure modes not listed that significantly contribute to overheating?	No
3		Does the recorded Severity rating accurately reflect the actual risk level?	Yes
4		Does the Occurrence frequency in the field match the value shown in the table?	Yes
5		Is the current Detection capability realistic based on daily inspection procedures?	Yes
6	Technical Analysis of Overheating Causes	Is scale buildup in the radiator tubes a primary cause of overheating?	Yes
7		Is installing the temperature sensor only on one side of the engine sufficient for detecting anomalies?	No
8		Is radiator fin cleanliness currently well maintained according to the cleaning schedule?	No
9		Does the existing warning system provide timely alerts?	No
10		Do fan belt and pulley systems frequently experience loosening or significant wear?	No
11	Evaluation of Proposed Improvements	Will installing additional sensors (upper and lower tank) significantly reduce the RPN value?	Yes
12		Will AFNAC coolant effectively reduce the risk of overheating?	Yes
13		Will implementing automatic radiator washing at set intervals effectively prevent debris buildup?	Yes
14		Is a stricter maintenance schedule for the fan system feasible without disrupting operations?	No
15		Should the delta temperature alert be integrated into the IoT monitoring system?	Yes
16	Implementation Readiness & Resources	Are the personnel (mechanics and operators) ready to carry out the new procedures after improvements are applied?	Yes
17		Can the budget cover the cost of installing sensors, auto-washing systems, and coolant replacement?	Yes
18		Are there any technical challenges in installing pressure sensors before and after the transmission filter?	No
19		Is it necessary to revise the SOP for inspection and maintenance of the cooling system after the improvements?	Yes
20		Is additional training required to improve early failure detection capabilities among mechanics?	No

Figure 27 FGD Minutes of Meeting

Based on the data in the Figure 27, the Data Validation & Field Conditions stage indicates that the list of failure modes used aligns with actual field events. Assessments of severity, occurrence, and detection capability were also deemed relevant to daily operating conditions. However, no indications of additional failure modes significantly contributing to the overheating problem were found.

During the Technical Analysis of Overheating Causes stage, scale buildup in the radiator pipes was identified as a primary cause of engine temperature increases. However, the use of temperature sensors installed on only one side of the engine was deemed inadequate to detect all potential anomalies. Furthermore, radiator fin cleanliness was not optimally maintained according to the maintenance schedule, the early warning system was unable to provide timely notifications, and fan belt and pulley components rarely experienced significant loosening or wear.

Evaluation of the Proposed Improvements demonstrated a positive response to most of the proposed improvements, such as the addition of sensors to the upper and lower tanks, the use of AFNAC coolant, and the implementation of an automatic radiator flushing system at specific intervals. Integration of delta temperature alerts into the IoT monitoring system was also deemed essential. However, implementing a stricter fan maintenance schedule is considered potentially disruptive to operational schedules and is therefore not recommended in a rigid format.

The Implementation Readiness & Resources phase demonstrates personnel readiness, budget adequacy, and the feasibility of implementing additional devices. However, technical challenges were identified in installing pressure sensors before and after the transmission filter, and additional training for early failure detection is not a current priority. Changes to the SOP for cooling system inspection and maintenance are deemed necessary to accommodate the agreed-upon corrective measures.

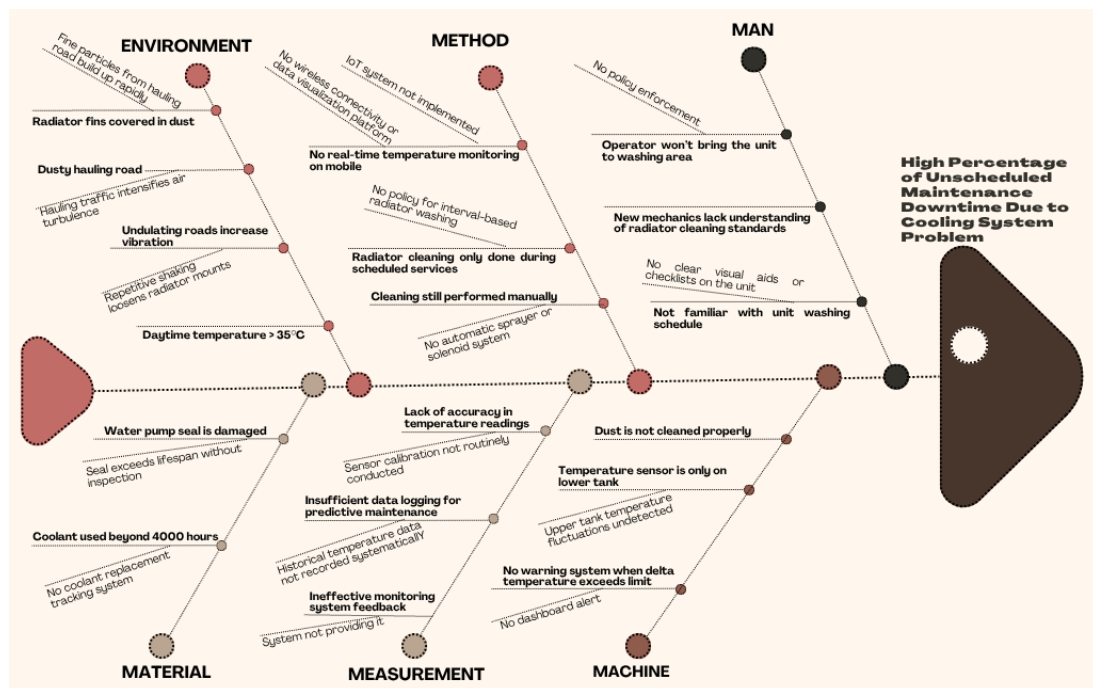


Figure 28 Fishbone Diagram

Based on the fishbone diagram analysis referring to the 5M1E approach in Figure 28, it was found that the high frequency of downtime due to cooling system problems was closely related to the accumulation of dust on the radiator fins and the absence of real-

time temperature and pressure monitoring. In terms of the environment, the dusty and rocky hauling road conditions caused the radiator to quickly become covered in fine particles. In terms of the method, the radiator washing process is still carried out manually and only when the unit is scheduled for service, without an automatic interval system. This is exacerbated by the lack of temperature measurement accuracy due to only one active sensor point (right side of engine) and the absence of a warning system when the temperature delta exceeds the threshold. Therefore, a solution is needed in the form of an automatic radiator washing system that can be activated directly by the operator, as well as the integration of an IoT-based monitoring system that allows real-time temperature and pressure readings from two different points (upper and lower tank of radiator, before and after the transmission filter). These two steps are expected to reduce the risk of overheating and increase the effectiveness of preventive unit maintenance. These findings are then used as a basis for compiling a Failure Mode and Effects Analysis (FMEA) in the next sub-chapter.

The results of this study align with previous findings shows that dust buildup on radiator fins significantly reduces cooling effectiveness and leads to overheating in heavy-duty units. For example, Gangisetty & Zevenhoven, (2023) highlighted the importance of keeping radiator surfaces clean of contaminants to prevent thermal resistance. The automated cleaning method proposed in this study conceptually extends and strengthens this idea by providing a straightforward solution in dusty operational environments. The integration of real-time temperature and pressure monitoring also expands on concepts from previous research suggesting that IoT sensor-based monitoring can identify cooling failures early and improve system reliability (Erişen, 2023). Thus, these results not only confirm the observed phenomenon but also extend its technical applications through IoT-based automation and monitoring systems.

4.1.3 FMEA

To identify components in the cooling system that have the highest risk of failure, an FMEA analysis is conducted based on items that have been found through field observations and mapping using a fishbone diagram. Each failure mode is assessed based on three main aspects, namely the severity of the impact (severity), the chance of failure (occurrence), and the level of difficulty in detecting it (detection). These three

factors are used to calculate the Risk Priority Number (RPN) value, which is the basis for determining the priority of corrective actions systematically.

After each potential failure is assessed based on severity, occurrence, and detection, the next step is to calculate the RPN value. This assessment is arranged in a table to determine the priority of targeted repairs.

Table 7 Result of Failure Mode Effect Analysis

No.	Component	Sub-component	Failure Mode	Effect Analysis	S	O	D	RPN	Priority
1	Radiator	Tube	Internal coolant passages clogged	Blockage inside the core restricts coolant flow, resulting in fast engine temperature escalation.	8	7	7	392	High
2	Temperature Sensor	—	Installed only in right side of the engine	Temperature at the upper tank is not monitored, leaving overheating risk unnoticed.	8	6	7	336	High
3	Radiator	Fin	Bent or obstructed fins or clogged	Airflow becomes limited, which causes a major drop in the radiator's ability to dissipate heat.	7	8	6	336	High
4	Warning System	—	Missing delta temperature alert	No indication when temperature difference exceeds normal levels, delaying critical intervention.	8	6	6	288	Medium
5	Fan System	Belt & Pulley	Slippage or excessive wear	Inadequate airflow due to belt issues, reducing cooling efficiency and raising engine temp.	8	7	5	280	Medium
6	Coolant Supply	—	Insufficient volume or poor quality	Coolant fails to absorb heat effectively, raising the likelihood of boiling or corrosion.	9	6	5	270	Medium
7	Thermostat	—	Stuck closed	Coolant fails to circulate to the radiator at high temperatures, leading to rapid overheating.	9	6	4	216	Medium
8	Cylinder Block	Liner/O-ring	Worn or pitted	Coolant and oil may internally mix, compromising lubrication and leading to higher engine risk.	9	4	4	144	Low
9	Pressure Valve	—	Malfunction	Unstable pressure leads to coolant leaks or vapor formation, affecting cooling performance.	7	4	5	140	Low
10	Power train	—	Rising oil temperature	Transmission loses efficiency due to thermal load, increasing the chance of overheating failures.	8	4	4	128	Low
11	Oil Cooler	—	Clogged or cracked	Overheated oil impairs engine lubrication, increasing wear and mechanical failure risks.	8	4	4	128	Low
12	Water Pump	—	Mechanical failure	Complete loss of coolant circulation, severely increasing engine temperature and risk of damage.	10	4	3	120	Low

Based on the results of the Risk Priority Number (RPN) evaluation shown in the Table 7, the three components with the highest risk are the radiator core that is blocked in the internal coolant channel (RPN = 392), the temperature sensor that is only installed on the right side of the engine so that it does not detect the temperature in the upper tank (RPN = 336), and the radiator fins that are covered in dust or in a bent condition (RPN = 336). All three directly affect the effectiveness of the heat release process and early detection of increased engine temperature. In addition, the differential temperature warning system is not available (RPN = 288), wear on the fan belt (RPN = 280), and inadequate coolant volume or quality (RPN = 270) also have high risk values and require attention. These findings indicate that the main failure in the cooling system does not only come from mechanical damage, but also due to limitations in the monitoring and maintenance system. Therefore, the repair strategy is directed at installing temperature and pressure sensors that are able to monitor delta in real time, as well as implementing an auto washing system to maintain the cleanliness of the radiator fins and support optimal cooling performance.

4.1.4 Radiator Automatic Washing

An automatic radiator washing system was created and deployed on the Komatsu GD825A-2 motor grader unit to address the issue of diminished cooling system performance caused by dust accumulation on the radiator fins. This innovation aims to facilitate the radiator cleaning process by the operator directly from the cabin, without having to dismantle components or wait for routine maintenance schedules. This development was motivated by the results of the FMEA analysis and field findings which showed that clogged radiator fins were one of the main causes of increased engine working temperature. This sub-chapter describes the system design, working mechanism, and implementation results of auto washing as a technical solution to reduce the risk of overheating.

1. Automatic Washing System Design

The automatic radiator cleaning system is designed using several main components, including a support frame, push button, limit switch, stepper motor driver, water pump, spray nozzle, and water reservoir tank. The working mechanism begins when the

operator performs a daily inspection and finds a buildup of dust or dirt on the radiator fins. The operator then presses the push button available in the cabin, so that the system will automatically activate the pump and direct the water spray to the radiator surface area. The nozzle movement follows a zigzag pattern, starting from the lower right corner and moving up until it reaches the upper right corner. When it touches the limit switch at the top, the nozzle will shift to the right, then go down slightly and move in the opposite direction. This pattern repeats until the entire radiator surface is thoroughly cleaned. Figure 29 shows the block diagram. Fuse are used for safety reasons.

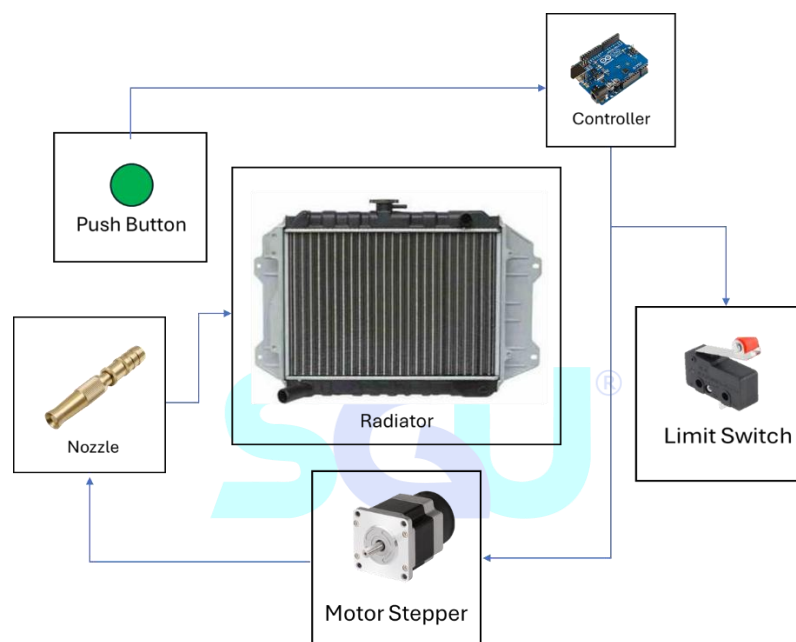


Figure 29 Block Diagram

2. Implementation

The creation of an auto washing system is carried out through several main stages, namely: design, fabrication, assembly, and testing.

a. System Design

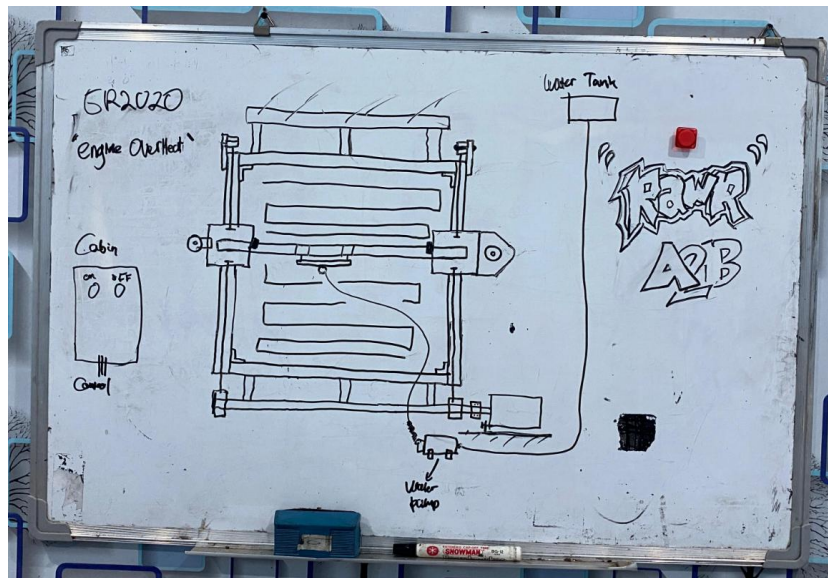


Figure 30 Draft of System Design

Figure 30 shows draft of the system design. The initial stage begins with creating a system design plan to determine the frame dimensions, nozzle position, and spray path. The system control diagram is designed to ensure that the interconnection between the push button, stepper motor driver, pump, and limit switch can work according to the desired logic flow. This system is designed to operate semi-automatically with a single control point from inside the cabin.

b. Mechanical Component Fabrication

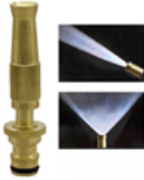
Pict	Desc	Qty	Pict	Desc	Qty
	Kepala Semprotan Selang Air Lurus Kuningan Water Gun Nozzle Adjustable	1pcs		Timing Belt HTD3M Pitch 3mm width 10mm Dust Proof per meter	4m
	V Slot Aluminium Profile Extrusion Rail 2020 Black OX CNC Frame	6,5M		Openbuilds V Slot Plate Kit 20mm With Solid Wheel POM Bearing 625rs	3

Figure 31 Main Mechanical Component

Figure 31 shows main mechanical component of the system. The system frame is made of aluminium material because it is lightweight and resistant to corrosion. The motor mount, nozzle track rail, and limit switch mounting points are fabricated according to the design specifications. The water tank is installed above the engine hood because this point is a safe and easily accessible location for refilling.

c. Electrical and Mechanical System Assembly



Figure 32 Electrical Component

Figure 32 shows the electrical component. At this stage, the stepper motor is attached to the track rail to move the nozzle horizontally and vertically. Limit switches are installed at each track limit point to detect the final position of the nozzle and change its direction of motion. The water pump is connected to a hose from the water tank, and connected to the nozzle. The push button is installed inside the cabin and connected to the controller system via a heat-resistant cable.

d. Integration and Initial Testing



Figure 33 Nozzle

After all components are installed, functional testing is carried out to ensure that all parts work in sequence: from pressing the push button, activating the pump, moving the nozzle according to a zig-zag pattern, to the response of the limit switch. Figure 33 shows the nozzle after getting installed. Testing is carried out several times to evaluate the effectiveness of cleaning the radiator fins and the system's resistance to water and vibration.

e. Finalization



Figure 34 Final Design

Figure 34 shows the final design. After initial testing, adjustments are made to the nozzle position and motor speed to ensure even spray coverage. The system is tidied up, electrical connections are secured using cable protectors (conduits), and technical documentation is carried out as part of the standardization of system implementation.

3. Discussion

The design of the automatic radiator cleaning system is strategically focused on mitigating a failure mode which is clogged radiator fins, as identified in the earlier FMEA analysis. This particular failure mode was previously assigned an RPN of 336 and it falls in the category of high risk that leads to overheating. It would fully and systemically spray water in a programmed nozzle movement mechanism whereby blockage due to dust or other dirt gets significantly reduced. Quantitative data on how much engine temperature has come down or on how much the air flow rate has increased after this system is put in place is not available, but logically, this step directly acts as a preventive measure against damages due to blockages. Thus, this auto washing

implementation will not only be a technical solution for the primary cause of failure but also risk severity reduction and overall system cooling reliability enhancement. Table 8 Number of Testingshows the result of testing.

Table 8 Number of Testing

<i>No. of Testing</i>	Nozzle Coverage	Cleaning Time	ΔT Before	ΔT After
1	50%	00:04:40	12°C	13°C
2	75%	00:07:13	8°C	12°C
3	100%	00:09:35	10°C	13°C
4	100%	00:09:35	11°C	13°C

4. Advantages and disadvantages of the system

This automatic radiator cleaning system provides an efficient way to deal with the problem of cooling fin clogging which usually happens in mining work environments where there is lots of dust. By using a simple control mechanism in the form of a push button and systematic nozzle movement, this system can help keep dirt at bay. Also, its use helps condition-based maintenance since it is only turned on when visual indicators show a blockage. This might just make the cooling process even more effective, lengthen component life, and cut way down on possible downtime from overheating.

On the other hand, this system is still plagued with several limitations, particularly in its dependence on the operator's decision to activate it. In the absence of an automatic sensor for detecting the level of clogging, the effectiveness of the system becomes largely dependent on how consistent daily inspections are conducted. This has a mechanical design that requires periodic maintenance, especially on the limit switch, motor, and nozzle components for optimal movement and water spray accuracy. Thus integration with an automatic monitoring system and the addition of fail-safe features are further steps in development.

4.1.5 Mobile Application

This Android-based application developed using the Flutter framework is designed to facilitate the process of monitoring the condition of the cooling system on motor graders

in real time. The main goal is to provide fast and flexible access for users, especially the maintenance team—in observing crucial temperature and pressure parameters, such as radiator temperature delta and transmission filter pressure delta. With monitoring that can be done directly via mobile devices, this system is expected to be able to improve early detection of overheating symptoms, so that the maintenance process can be carried out more timely and efficiently.

1. Application Feature



Figure 35 Features of Application

This application is designed to support comprehensive cooling system monitoring by providing crucial features that focus on temperature and pressure parameters like shown in the Figure 35. Among them are temperature monitoring on the upper and lower radiator tanks accompanied by delta temperature calculations as an indicator of the effectiveness of the cooling process. The system also facilitates monitoring of pressure before and after the transmission filter, allowing delta pressure calculations as an early signal of decreased performance or blockage of the lubrication system. The automatic warning function will be activated when the parameter reaches a potentially dangerous threshold value. In addition to these technical features, this application is also equipped with administrative functions, such as user access management, password changes, deletion and export of data, and display of user lists. All of these features are integrated

to improve the accuracy of monitoring and decision making in the IoT-based maintenance process.

2. User Interface

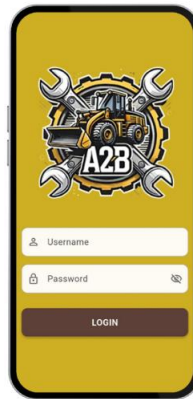


Figure 36 Login Page

The login page on this application is designed as the main gateway for user authentication to ensure secure access to cooling system monitoring data as shown in the Figure 36. The login interface displays two input columns, namely username and password, which are protected by a password visibility feature to minimize input errors. The visual design on this page also carries the identity of the heavy equipment brand through a logo depicting mining heavy equipment and a maintenance symbol, thus reflecting the main function of the application in supporting a technology-based maintenance system. The existence of this authentication is the first step in setting user access rights according to their respective roles in unit management.



Figure 37 Main Page

Figure 37 shows the main page of application. Users will be forwarded to the main page if they have successfully logged in. The main page consists of several menus. On this page, users can select the heavy equipment unit to be monitored, such as a wheel loader or motor grader. The two options are visualized in the form of images for easier recognition. In addition to the monitoring feature, there is also a feature for exporting data, changing passwords, and viewing a list of user accounts. The layout of the various features is made as simple as possible so that users find it easy to access the functions they need without having to move from page to page.

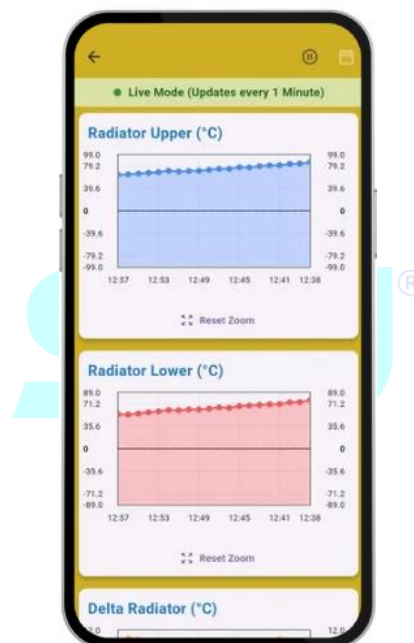


Figure 38 Page of Temperature Monitoring

This display is used to monitor the radiator temperature condition directly as shown in the Figure 38. It contains a graph showing the temperature values in the upper and lower radiator tank, as well as the temperature difference between the two. The data displayed is updated periodically every few seconds, so users can see changes that occur in real-time. With this visualization, technicians can more easily observe whether there is a temperature difference that is too high which could indicate a problem with the cooling system. A display like this is very helpful in daily monitoring of units in the field without having to carry out manual checks continuously.

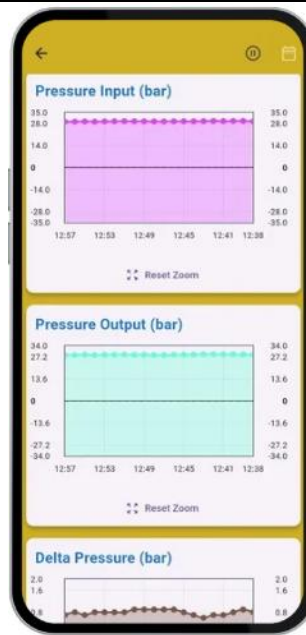


Figure 39 Page of Pressure Monitoring

Figure 39 shows fluid pressure graphs in the transmission system that can be accessed after scrolling the screen from the temperature monitoring menu. The first graph shows the pressure value before passing through the transmission filter, while the second graph records the pressure after. The difference between the two is displayed as delta pressure to help identify possible flow restrictions or blockages in the filter. Data updates occur periodically and automatically, so users can monitor pressure changes in real time. This display is important to support faster and more accurate maintenance decisions based on real conditions that are taking place in the field.

The application is designed to support offline data logging, ensuring that sensor readings and user activities continue to be recorded even in areas with limited network connectivity. Once the device is reconnected to the internet, all stored data will be automatically synchronized with the central server, preserving data continuity and integrity. Looking ahead, the user interface is planned to undergo enhancements such as adaptive layout compatibility for tablet devices, enabling better visualization of charts and controls on larger screens. These improvements aim to provide a more responsive and user-friendly experience across various device types and operational conditions.

3. Unit Testing

Unit testing is performed to ensure that each system component performs according to its individually designed function. At this stage, testing focuses on the accuracy of sensor data readings compared to manual measurements as a validation benchmark.

Table 9 Sensor Test

<i>No.</i>	<i>Sensor (°C)</i>	<i>Termogun (°C)</i>	<i>Difference</i>	<i>Percentage</i>
1	25,25	25,1	0,15	0,6%
2	24,75	24,8	-0,05	-0,2%
3	24,50	24,6	-0,10	-0,4%
4	25,50	25,3	0,20	0,8%
5	25,00	25,0	0,00	0,0%
6	25,25	25,4	-0,15	-0,6%
7	24,50	24,5	0,00	0,0%
8	24,25	24,2	0,05	0,2%
9	23,75	23,8	-0,05	-0,2%
10	25,75	25,9	-0,15	-0,6%

Table 9 shows that the temperature sensor readings had an average deviation within the allowable tolerance of ± 2 °C. The tests were conducted indoors before installation to minimize external disturbances and to simulate the sensor's protected position inside the radiator. Overall, the sensor's performance met the acceptance criteria, making it suitable as a primary component in the IoT monitoring system for the motor grader.

4. Functionality Testing

Functional testing was conducted to ensure that every feature in the temperature monitoring system functioned according to its designed specifications. This test included verifying the accuracy of sensor readings, real-time data update speed, delta calculation accuracy, and data export results. These test results served as the basis for assessing system readiness before moving on to the next testing phase.

Table 10 Feature Test

No	Tested Features	Test Scenario	Testing Steps	Test Data	Expected Results	Actual Results	Status (Pass/Fail)
1	Dashboard Display	Open the main dashboard	Login → Select the Dashboard menu	Actual sensor data	All temperature and pressure values are displayed in real-time according to sensor data.	Data displayed as shown	Fail
2	Delta Temp Alarm	$\Delta T > 15^{\circ}\text{C}$ or $< 8^{\circ}\text{C}$	The moment when the upper-lower tank is outside the threshold	Upper: 95°C , Lower: 75°C ($\Delta T=20^{\circ}\text{C}$)	A notification appears with smartphone data.	Alarm displayed as shown	-
3	Delta Pressure Alarm	$\Delta P > 4$ bars	The moment when the before-after filter is outside the threshold	Before: 30 bars, After: 25 bars ($\Delta P=5$ bars)	A notification appears with smartphone data.	Alarm displayed as shown	-
4	Data Export	Export to Excel	Click the "Export" button	—	The Excel file is downloaded in the correct format.	File format as shown	Pass

Table 10 shows the feature tested. Test results showed that sensor reading was generally quite accurate when compared to manual measurements using a thermogun. However, there were obstacles at several points on the hauling route that experienced signal interference, especially around kilometers 6–7, 12–13, 16–17, 21–22, and 25–26, which resulted in less-than-optimal data transmission quality. Furthermore, in the temperature delta alarm test, the measured values never exceeded the predetermined threshold, so this condition did not trigger an alarm according to the planned test scenario.s

5. User Acceptance Test

User Acceptance Testing (UAT) is conducted to ensure that the developed system meets the needs and expectations of end users. This process focuses on testing the system's functionality, appearance, and usability from a user perspective. UAT results serve as the basis for determining whether the system is fully suitable for use in an operational environment shown in the Table 11.

Table 11 User Acceptance Test

No	Test Description	Acceptance Criteria	Test Results	Status
1	Displays upper tank, lower tank, and delta temperature parameters	All parameters are clearly displayed	94%	Accepted
2	Displays pre-filter, post-filter, and delta pressure parameters	All parameters are clearly displayed	94%	Accepted
3	Historical data can be accessed for at least 3 months	Data is accurate and complete	100%	Accepted
4	The system remains functional in areas with weak signal levels	Data is still sent even with delays	53%	Not Accepted
5	The system's display and navigation are easy for mechanics to understand	Mechanics can operate without special training	100%	Accepted
6	The system does not interfere with maintenance SOPs	Maintenance processes remain smooth	88%	Accepted

Based on the results of the User Acceptance Test (UAT) involving 17 respondents, most of the system's features met the established acceptance criteria. Parameters such as upper tank temperature, lower tank temperature, temperature delta, and pressure before and after the filter were clearly displayed, each achieving a 94% success rate and being declared acceptable. Access to historical data for at least three months achieved 100% accuracy, demonstrating the completeness and reliability of the data. The system's ease-of-use feature also received maximum marks, allowing mechanics to operate the system without special training. Furthermore, system integration with maintenance procedures was smooth, with an acceptance rate of 88%. However, there were still challenges with the stability of the system's function in areas with weak signals, which only achieved a 53% success rate and did not meet acceptance standards. The IoT system was enhanced with a temporary storage capability through local data logging utilizing a microSD module. This mechanism ensures that, in the event of a connectivity interruption, the operational parameters—such as temperature and pressure—are continuously recorded. Once the network connection is reestablished, the stored information is automatically transmitted, thereby maintaining data integrity and minimizing losses caused by unstable wireless coverage.

4.2 Control

4.2.1 Pareto Problem

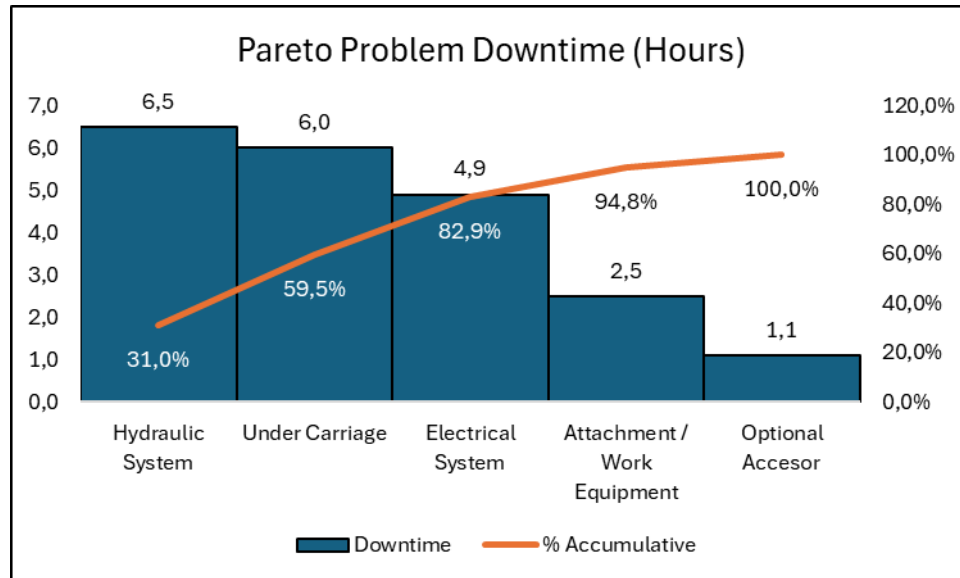


Figure 40 Pareto of Component Downtime March-May 2025

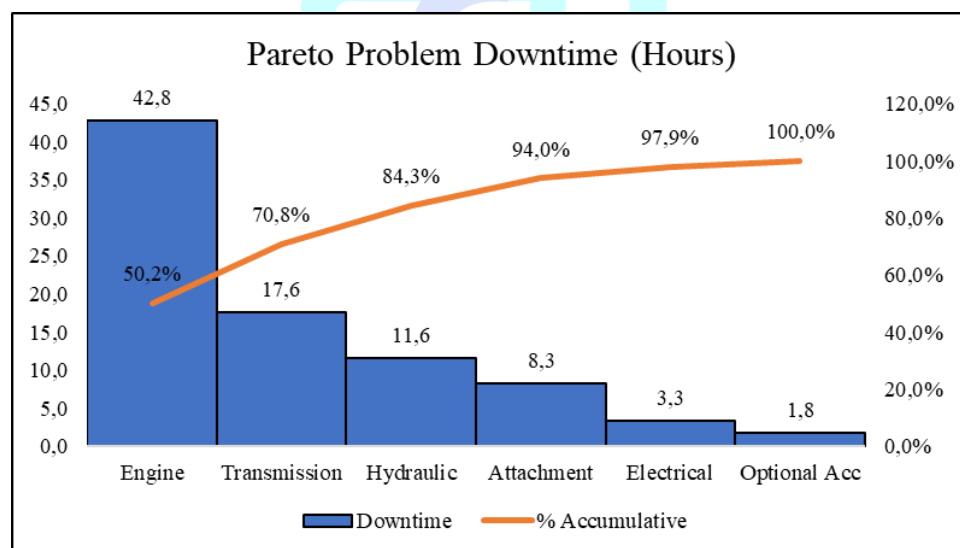


Figure 41 Pareto Problem Before (Jul-Dec 24)

Table 12 Comparison Before vs After

<i>No</i>	<i>Component</i>	<i>Before (Hours)</i>	<i>After (Hours)</i>
1	Engine (Cooling System)	30.3	0
2	Transmission	17.6	0
3	Hydraulic	11.6	6.5
4	Attachment	8.3	2.5
5	Electrical System	3.3	4.9
6	Optional Acc	1.8	1.1
7	Undercarriage	0	6.5

From the Pareto chart of unscheduled maintenance downtime for the periods of July–December 2024 and March–May 2025 shown in Figure 40 and Figure 41 and summarized in Table 12, a noticeable change in the pattern of contributions to component damage is observed. In the last period, the engine component is the largest cause of downtime, in the amount of 42.8 hours, or approximately 50.2% of the total downtime. In the March–May 2025 timeframe, engine faults no longer emerged as prominent in the distribution of downtime. This variation in the risk factors means that the countermeasures that have been introduced, including the new auto-washing radiator system and the temperature/pressure-monitoring system based on IoT, have successfully addressed the primary cause of the high ratio of overheating.

This significant reduction is also consistent with the analysis of the previous FMEA investigation, which showed that blockages in the radiator fins and undetected temperature spikes due to limitations in the monitoring system had high RPN values. By means of an automatic spraying system driven by cabin buttons and a mobile application for real-time visualization, both failure modes were effectively controlled, resulting in minimized risk of overheating and longer operational life of the engine. These results show that a data-driven and technology-based approach can make a serious difference in motor grader cooling reliability

4.2.2 Impact on KPI

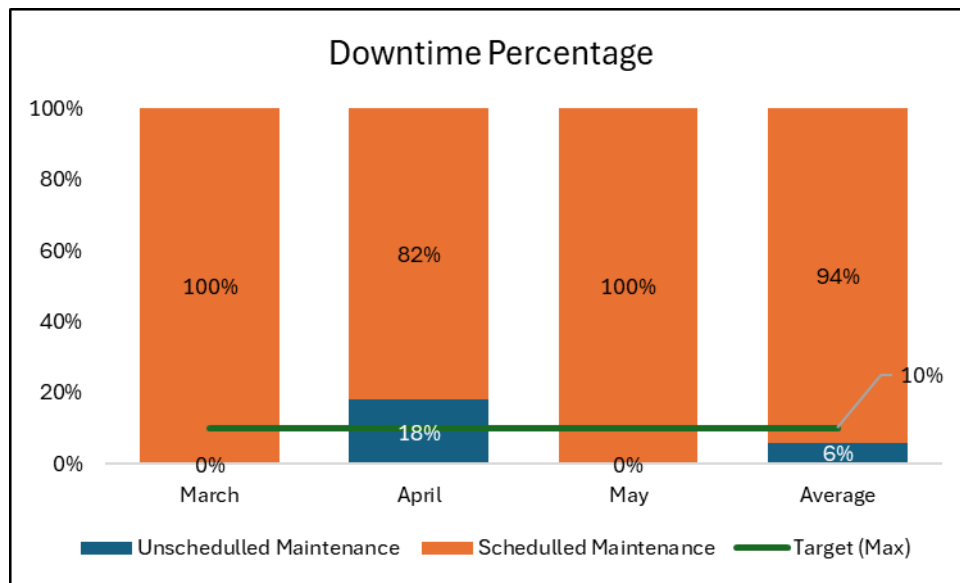


Figure 42 Downtime Percentage March – May 2025

Based on the comparison of the downtime percentage graph between the July–December 2024 (Figure 26) and March–May 2025 (Figure 42) periods, there is a significant decrease in the portion of downtime caused by unscheduled maintenance. Previously, the average percentage of unplanned downtime ranged from 18.7% to 31.7%, with values that consistently exceeded the maximum target threshold of 10%. However, in the March–May 2025 period, this proportion decreased drastically, even reaching 0% in March and May, and only 6% on a quarterly average.

This change shows that the technical interventions carried out, such as the implementation of an auto radiator washing system and IoT-based temperature and pressure monitoring, have succeeded in reducing the incidence of sudden damage. This finding is also in line with the FMEA results, which place problems with radiator fins and temperature detection systems as high priorities (RPN > 300), which have now been addressed with a data-based solution approach and automation. Thus, the decrease in unplanned downtime is not only an indicator of technical success, but also validation of the effectiveness of the risk analysis-based improvement strategy that has been implemented.

4.2.3 Impact on FMEA

To determine the effectiveness of the proposed system, a comparative analysis of the Risk Priority Number (RPN) values was conducted using the FMEA method before and after implementation. This analysis aims to assess the extent to which the system is able to reduce the risk of potential failures, which were previously the main cause of overheating. The results of the RPN calculation are shown in Table 13. which shows a significant reduction in most components after the IoT-based autowashing and monitoring system was implemented.

Table 13 Impact on FMEA (RPN)

No.	Component	Sub-component	Before				After			
			S	O	D	RPN	S	O	D	RPN
1	Radiator	Tube	8	7	7	392	8	3	4	96
2	Temperature Sensor	—	8	6	7	336	8	5	3	120
3	Radiator	Fin	7	8	6	336	7	3	4	84
4	Warning System	—	8	6	6	288	8	3	5	120
5	Power Train	—	8	4	4	128	8	3	3	72

From the FMEA evaluation results in Table 13, it can be seen that the implementation of the system has a real impact on reducing the Severity (S), Occurrence (O), and Detection (D) values in most components. For example, the RPN value of the radiator tube dropped drastically from 392 to 96, which was influenced by a decrease in the occurrence rate from 7 to 3 and detection from 7 to 4. In the radiator fin, the RPN value also decreased from 336 to 84, along with a decrease in occurrence from 8 to 3 and detection from 6 to 4. Similarly, in the temperature sensor and warning system, the RPN value decreased from 336 to 120 and from 288 to 120, respectively, with the largest contribution coming from improvements in the occurrence and detection aspects. Meanwhile, the power train showed a decrease in RPN from 128 to 72, which was also produced by a decrease in occurrence (4 to 3) and detection (4 to 3).

4.2.4 Sustainability and Preventive Control Strategy

In an effort to ensure the sustainability of the implementation of the repair system on the GD825A-2 cooling system, hardware standards have been prepared to support the two main repair initiatives, namely the radiator auto washing system and the IoT-based temperature and pressure monitoring system. These standards include specifications for temperature and pressure sensors, controller types, actuator systems and pumps for spraying, and the type of connectivity used. The determination of these specifications is intended to ensure component availability, ease of maintenance, and consistency of performance in the long term, while also supporting the system replication process to similar units in other work areas.

To ensure that the operation of the auto washing system continues to run according to its function and prevent system failure due to negligence, a task specific procedure (TSP) has been prepared in the form of technical steps and safety controls in carrying out daily inspections and system activation. Meanwhile, for the use of the mobile monitoring application, work instructions have been prepared in the form of an interactive guide that explains the login process, access to temperature and pressure graphs, and steps to export data or verify temperature and pressure anomaly notifications.

As part of the preventive and long-term control strategy, this system change is also accompanied by a change management document that will be approved by the Maintenance Group Leader and Maintenance Department Head. This document contains the technical justification for the changes, the implementation plan, the impact on work schedules and training, and an initial evaluation of the system's performance after implementation. Thus, the improvement steps that have been developed are not just temporary solutions but can be formally integrated into the maintenance department's work system on an ongoing basis. It is hoped that in the future this system can be applied to all A2B units. Work instruction of this system shown in the Figure 43.

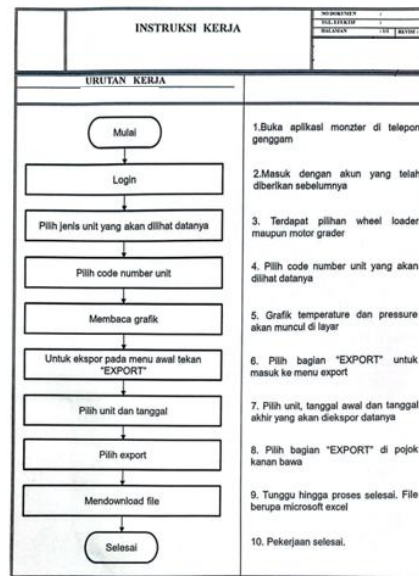


Figure 43 Application Work Instruction

4.2.5 Summary of Improvements and Financial Impact

To evaluate the effectiveness of the proposed IoT-based automatic radiator washing system, several key performance indicators were measured and compared with the previous manual approach. The analysis focused on aspects such as response time, equipment downtime, and monitoring reliability, which are critical for ensuring operational continuity in mining activities. A summary of these findings is presented in Table 14.

Table 14 Summary of Improvement

Parameter	Before Implementation	After Implementation	Improvement Impact
Respond Time To Problem	~ 60 minutes	~ 15 minutes	Reduced respond time
Average Downtime Per Month	5.05 hours	0 hours	Reduced equipment downtime
Monitoring Method	Manual (operator-based)	Automatic (real-time IoT)	Faster and more accurate data acquisition
Data Availability	Delayed, risk of loss	Continuous with local buffering	Higher data reliability
Preventive Maintenance Response	Reactive (after failure)	Proactive (early detection)	Improved system reliability

The implementation of a radiator washing system combined with IoT-based monitoring has significantly improved equipment performance and maintenance practices. As outlined in Table 14, the average response time to issues has decreased from approximately 60 minutes to 15 minutes, while 5.05 hours of monthly downtime has been eliminated. Furthermore, the transition from manual, operator-based monitoring to an automated, real-time IoT system allows for faster data collection. The offline storage system allows for data retention during network downtime. These improvements support the shift from reactive maintenance to a proactive strategy, thereby strengthening the overall system reliability.

Table 15 Estimated Financial Benefit

Description	Value
Total trips in 25 days	9,946 trips
Estimated trips in 90 days	35,806 trips
Total tonnage ($35,806 \times 29$ tons)	1,038,362 tons
Road damage equivalent (30 hrs BD = 8 km not maintained)	8 km
Hauling speed (loaded)	40 km/h
Hauling speed (empty)	60 km/h
Hauling speed (damaged road, loaded/empty)	25 km/h
Travel time (loaded: 8 km damaged + 24 km good)	0.92 hours
Travel time (empty: 8 km damaged + 24 km good)	0.72 hours
Total cycle time with 8 km damaged road	1.64 hours
Total cycle time with 100% good road	1.33 hours
Hauling efficiency ratio (good vs. damaged road)	0.813
Effective tonnage with 30 hrs BD ($0.813 \times 1,038,362$ tons)	844,102 tons
Lost tonnage due to road damage	194,260 tons
Financial impact ($194,260 \times \text{IDR } 21,156/\text{ton}$)	IDR 4,109,764,560
Gross profit margin	35%
Estimated gross profit impact	IDR 1,438,417,596

From a financial perspective, Table 15 shows that the system also provides significant economic benefits. The system prevented potential gross losses of IDR 4,109,764,560. With a gross profit of 35%, the averted amount is IDR 1,438,417,596. These results highlight that the proposed solution not only improves technical reliability but also delivers measurable economic value to mining operations.

CHAPTER 5 - CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The FMEA results show that the critical points causing overheating in the Komatsu GD825A-2 are internal radiator blockage (RPN 392), temperature sensor installation on only one side (RPN 336), and bent/dust-clogged radiator fins (RPN 336). Other factors are the absence of a delta temperature alarm (RPN 288). In addition, although the increase in power train oil temperature has a lower RPN (128), it is still considered critical because limited spare parts can extend downtime when a disruption occurs.

The study successfully designed and implemented an automatic radiator washing system integrated with IoT-based monitoring of radiator temperature and transmission pressure. By installing sensors at both the upper and lower tanks, delta temperature values were obtained, while pressure sensors before and after the filter provided delta pressure analysis. The system was further enhanced with a MiFi-based network to ensure real-time data transmission, with the device strategically placed inside the cabin to protect it from contamination.

The analysis showed that the implementation of FMEA-based RCM significantly reduced the RPN value, for example, from 392 to 96 radiator tubes (a 75% decrease), and reduced cooling system downtime from 30.3 hours to 0 hours. Furthermore, the average monthly unscheduled maintenance frequency decreased from 26.1% to just 6%. Overall, this strategy proved effective in reducing failure risk while increasing unit reliability and availability.

As a follow-up, a development roadmap was developed aimed at expanding monitoring capabilities. The focus will include integrating predictive analytics and real-time dashboards to support more optimal preventive maintenance. Furthermore, further research will be aimed at developing the system for implementation on previous-generation units, using a concept similar to Komatsu's EQPcare monitoring system.

5.2 Recommendations

In order for the system that has been designed to continue to provide positive impacts sustainably, the author recommends the following:

1. Integration to the Company Maintenance System: The temperature and pressure monitoring system should be directly connected to the internal database so that anomaly data can be directly linked to the maintenance schedule and unit failure history,
2. Software Improvement: The mobile application needs to be further developed to adapt to different screen sizes (e.g. tablets),
3. Expansion to Other Units: Considering the significant results obtained, this system can be replicated for other types of units that have similar cooling systems, such as wheel loaders or dozers,
4. Explore the integration of predictive analytics and machine learning for more accurate failure prediction and maintenance optimization, as well as assess the economic, energy efficiency, and long-term reliability impacts of the system,
5. Consider implementing LoRa-based communication to ensure more reliable long-distance data transmission in mining environments where Wi-Fi connectivity is unstable.

REFERENCES

- Akther Momin, M., Golam Kader, M., Roy, P., Hasan, M. and Mufrid Zuhane, M. (2016) 'Automatic Signal and Alarming System to Avoid Engine Overheating', *International Journal of Research*, 3(13), pp. 962–966. Available at: <https://edupediapublications.org/journals>
- Alturki, Eng.W. (2017) 'Four-Stroke and Two-Stroke Marine Engines Comparison and Application', *International Journal of Engineering Research and Applications*, 07(04), pp. 49–56. Available at: <https://doi.org/10.9790/9622-0704034956>.
- Alvarez-Alvarado, M.S. and Jayaweera, D. (2018) 'Bathtub curve as a Markovian process to describe the reliability of repairable components', *IET Generation, Transmission and Distribution*, 12(21), pp. 5683–5689. Available at: <https://doi.org/10.1049/iet-gtd.2018.5505>.
- Daya, A. and Leonard, J. (2025) 'Maintenance plan improvement using failure mode effect and criticality analysis: A case study on mining equipment', *Engineering Science & Technology Journal*, 6(3), pp. 86–103. doi:10.51594/estj.v6i3.1879.
- Bialy, W. and Beno, P. (2016) 'Application of quality engineering in assessment of mining technical equipment failure', *MM Science Journal*, 2016(OCTOBER), pp. 1127–1133. Available at: https://doi.org/10.17973/MMSJ.2016_10_201682.
- Breznická, A., Kohutiar, M., Krbat'a, M., Eckert, M. and Mikuš, P. (2023) 'Reliability Analysis during the Life Cycle of a Technical System and the Monitoring of Reliability Properties', *Systems*. Multidisciplinary Digital Publishing Institute (MDPI). Available at: <https://doi.org/10.3390/systems11120556>.
- Chen, T.Y., Lin, W.T. and Sheu, C. (2018) 'A dynamic failure rate forecasting model for service parts inventory', *Sustainability (Switzerland)*, 10(7). Available at: <https://doi.org/10.3390/su10072408>.
- Dahham, R.Y., Wei, H. and Pan, J. (2022) 'Improving Thermal Efficiency of Internal Combustion Engines: Recent Progress and Remaining Challenges', *Energies*, 15(17), p. 6222. Available at: <https://doi.org/10.3390/en15176222>
- Daniel, O.C., Comfort Chinaza, O. and Stanley, O.I. (2023) 'An automobile temperature monitoring and alert system using Internet of Things (IoT)'.
- Egbe, G.O., Arinze, S.N., Ebebuwa, S.H., Obi, E.R. and Nwajana, A.O. (2024) 'Maintenance Resources Optimization Using Pareto Analysis: Instrumentation Air Compressor in Oredo, Nigeria', *International Journal of Manufacturing, Materials, and Mechanical Engineering*, 13(1). Available at: <https://doi.org/10.4018/IJMMME.353392>.
- Oladoyin, A.E. and Ogunsola, T. (2023) 'Design and construction of Internet of Things (IoT) based generator monitoring system', *International Journal of Innovative Science and Research Technology*. Available at: <https://www.researchgate.net/publication/380345116>.
- Erişen, S. (2023) 'A Systematic Approach to Optimizing Energy-Efficient Automated Systems with Learning Models for Thermal Comfort Control in Indoor Spaces', *Buildings*, 13(7). Available at: <https://doi.org/10.3390/buildings13071824>.

- Gangisetty, G. and Zevenhoven, R. (2023) ‘A Review of Nanoparticle Material Coatings in Passive Radiative Cooling Systems Including Skylights’, *Energies*. MDPI. Available at: <https://doi.org/10.3390/en16041975>.
- Ghufron, S. and Prayogi, S. (2023) ‘Cooling System in Machine Operation at Gas Engine Power Plant at PT Multidaya Prima Elektrindo’, *RIGGS: Journal of Artificial Intelligence and Digital Business*, 1(2), pp. 25–29. Available at: <https://doi.org/10.31004/riggs.v1i2.21>.
- Gonçalves, P.A.C. and Carvalheira, P.F.V. (2024) ‘Cycle assessment of a four-stroke spark-ignition ethanol fueled engine’, *Sustainable Energy Technologies and Assessments*, 65. Available at: <https://doi.org/10.1016/j.seta.2024.103722>.
- Habeeb, H.A., Mohan, A.E., Norani, N.A.M., Abdullah*, M.A. and Harun, M.H. (2020) ‘Analysis of Engine Radiator Performance at Different Coolant Concentrations and Radiator Materials’, *International Journal of Recent Technology and Engineering (IJRTE)*, 8(6), pp. 2664–2669. Available at: <https://doi.org/10.35940/ijrte.F7866.038620>.
- Hernández-Rodríguez, E., González-Rivero, R.A., Schalm, O., Martínez, A., Hernández, L., Alejo-Sánchez, D., Janssens, T. and Jacobs, W. (2023) ‘Reliability Testing of a Low-Cost, Multi-Purpose Arduino-Based Data Logger Deployed in Several Applications Such as Outdoor Air Quality, Human Activity, Motion, and Exhaust Gas Monitoring’, *Sensors*, 23(17). Available at: <https://doi.org/10.3390/s23177412>.
- Julianto, E. (2020) ‘ANALISIS PENGARUH PUTARAN MESIN PADA EFISIENSI BAHAN BAKAR MESIN DIESEL 2DG-FTV INFO ARTIKEL ABSTRAK’, *Jurnal Penelitian dan Pengabdian Kepada Masyarakat UNSIQ*, 7(3), pp. 225–231.
- Komatsu (2001) ‘GD825A-2-SN11001and-UP’. [Shop Manual]. Komatsu Ltd.
- Komatsu (2005) ‘Diesel engine 00-2 6D140-2 series (10)’. [Shop Manual]. Komatsu Ltd
- Komatsu (2010) *EQPCare Komatsu JP*. Available at: <https://eqp-care.komatsu.co.jp/eqpc/init.do> (Accessed: 15 August 2025).
- Komatsu (2010) ‘OMM GD825A-2_PEN00357-02’.
- Li, Z. (2024) ‘Analysis of the Principle and Applications of Four-stroke Engines in Transportation’, *Applied and Computational Engineering*, 98(1), pp. 195–202. Available at: <https://doi.org/10.54254/2755-2721/98/2024FMCEAU0113>.
- Mwilongo, N. (2025) ‘Focus Group Discussions in Qualitative Research: Dos and Don’ts’, *Eminent Journal of Social Sciences*, 1(1), pp. 1–16. Available at: <https://doi.org/10.70582/7fmpzs58>.
- Pratiksha Vilasrao Chaudhari, M., Kadam, T.D. and Sabi Huddin, P. (2023) ‘Use of Arduino in IoT for Construction Equipment Management and Maintenance’, *International Journal of Scientific Research and Engineering Development*, 6(3), pp. 1041–1045. Available at: www.ijrsred.com.
- Prosper, J. (2025) Smart thermal monitoring systems: IoT-enabled temperature sensing for rotating equipment. Available at: <https://www.researchgate.net/publication/390233231>
- Rodriguez, R.D., Medini, K. and Wuest, T. (2022) ‘A DMAIC Framework to Improve Quality and Sustainability in Additive Manufacturing—A Case Study’, *Sustainability (Switzerland)*, 14(1). Available at: <https://doi.org/10.3390/su14010581>.

- Sembiring, J.D., Baskoro, G. and Berchmans, H.J. (2019) 'Design and Simulation of Engine Operation Temperature Monitor and Control System by Using Internet of Things', *Proceedings of Conference on Management and Engineering in Industry (CMEI)*, pp. 9–15. Swiss German University
- Tümen Akyildiz, S. and Ahmed, K.H. (2021) 'An Overview of Qualitative Research and Focus Group Discussion', *International Journal of Academic Research in Education*, 7(1), pp. 1–15. Available at: <https://doi.org/10.17985/ijare.866762>.
- United Tractors (2025) *Product*. Available at: <https://products.unitedtractors.com/en/product/komatsu/motor-grader/gd825a-2/> (Accessed: 15 August 2025).
- Yuni, R.T. (2021) Monitoring heavy equipment coolant temperature. [Master's thesis]. Swiss German University.



CURRICULUM VITAE



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I am a Mechanical Engineer specializing in heavy equipment maintenance with experience in performance analysis, reliability improvement, and equipment monitoring. Skilled in technical diagnostics, failure analysis, and implementation of corrective and preventive actions, I also have hands-on experience in the manufacturing industry, enabling me to integrate practical engineering solutions with reliability and efficiency improvements.

Work Experience

Plant Engineer, PT. XYZ (May 2022 – Now)

- Perform technical and performance analysis of heavy equipment, covering breakdowns, MTBS, physical availability, and abnormality trends from programs such as PAP, PPM, and PPA.
- Prepare weekly and monthly PICA reports while coordinating with mechanics and planners to support reliability improvement initiatives.
- Monitor and ensure the implementation of corrective and preventive actions to minimize repeat failures and reduce downtime.

Production Foreman, PT. Wilmar Nabati Indonesia (May 2021 – May 2022)

- Supervised and monitored production processes to ensure compliance with SOPs and production targets & conducted end-of-shift evaluations and reported operational issues to supervisors
- Participated in weekly meetings for production monitoring and evaluation; identified operational bottlenecks and proposed solutions
- Ensured coordination between departments to maintain smooth shift transitions and minimize production delays

Education

D4 Mechanical Engineering – Production and Maintenance, Politeknik Negeri Malang (2016 – 2020)

- GPA: 3.68
- Thesis: Effect of Fiber Layer Number and Resin Type on the Bending Strength of Jute Fiber-Reinforced Composite

S2 Mechanical Engineering, Swiss German University (2024-2025)

Organizational Experience

Head of Education Division, Ikatan Mahasiswa Ronggolawe Polinema (2017 – 2018)

- Designed and developed a one-year work program in coordination with the association's president
- Organized team meetings and coordinated with other divisions to support academic development

Hardskill / Certificate / Training

- Basic Leadership Program (June 2022)
- Basic Mechanic Course (Heavy Equipment Maintenance – September to November 2022)
- QC For Leader (QCC, QCP, Suggestion System – December 2022)
- Plant Staff Menengah 2 (Metalurgi, Welding Inspector, Non-Destructive Test – August 2023)
- Pengawas Operasional Pratama (September 2023)
- Overhaul Komatsu Engine (December 2023)
- Plant Staff Dasar 2 (Technical Analysis, CMI – May 2024)
- Condition Monitoring (Vibration & Oil Analysis – July 2024)
- Design Thinking (December 2024)
- Advance Komatsu Engine (May 2025)
- Calibration Certification of Tools (Weighing Scales, Temperature Equipment, Dimensional Instruments, Force Equipment – July to August 2025)