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Damage Analysis of Caterpillar C9 Acert Machine Using Root Cause Analysis Method at PT. XYZ

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***Abstract* - Since the occurrence of the first industrial revolution in the 18th century, machines have become a part of human life. Like humans, machines also need treatment to keep running their activities as described, the treatment carried out on machines is often referred to as maintenance. Maintenance is an activity that can restore the function of a system or a system to the initial function. Machine maintenance can be broadly classified into two types namely unplanned maintenance and planned maintenance; planned maintenance can be further classified as preventive maintenance and predictive maintenance while breakdown maintenance is considered as unplanned maintenance. At PT. XYZ a maintenance has been carried out on the Caterpillar C9 Acert engine, and after the field team carried a diagnosis, it was found that several parts of the engine were damaged, which would result in damage to the Caterpillar C9 Acert engine. This study uses the RCA (root cause analysis) method assisted by 5 whys analysis and fishbone diagrams. The results of the 5 whys analysis show the facts causing the damage in a structured manner, and the results from the fishbone diagram show the factors causing the damage which include human factors, machines, materials, and methods, making it easier to find the basic causal factors. This study aims to identify the cause of the damage so that preventive measures can be taken to minimize the recurrence of this damage in the future. The results of the two methods of analysis can be concluded that the main cause of the damage suffered by the machine is the occurrence of human error on the part of the company that owns the machine, therefore more precise decisions and policies are needed from the company so that the damage does not occur again in the future.**

Keywords: whys analysis, diagnosis, fishbone diagram, maintenance, root cause analysis.

I. INTRODUCTION

Since the first industrial revolution in the 18th century, machines have become a part of human life. Like humans, machines also need maintenance so that they can carry out their activities as they should; the maintenance carried out on these machines is often referred to as maintenance. Maintenance is all activities carried out to maintain facilities and equipment so that they function properly so that the system can function properly [1]. The purpose of doing maintenance is to reduce the number of equipment failures and to avoid damage that can cause interruptions during operation [2]. Determining critical components in an industry is one of the most important tasks performed by maintenance personnel to choose the best maintenance policy [3]. If the treatment policy chosen is inappropriate or inappropriate, then failure will definitely occur. Failure and damage found in components can hamper the productivity of a company; therefore proper maintenance is needed at the right time [4]. Failure and damage to equipment so that it cannot be operated causes downtime. Downtime refers to periods of inactivity on the machine, where the machine is not productive or not ready to carry out its duties, downtime is also closely related to the productivity and business profitability of a company [5]. Poor maintenance quality and inappropriate maintenance practices have a negative impact on the economic, environmental and social sectors. The economic impact is mainly related to costs, downtime, breakdown, waste, low performance, waiting times and disability. Inappropriate maintenance practices also cause several environmental impacts, such as harmful emissions, and inefficient use of energy. The social impact concerns human health and safety, poor maintenance practices can also cause accidents, incidents, and unhealthy and unsafe working conditions [6].

Machine maintenance can be broadly classified into two types, namely unplanned maintenance and planned maintenance; planned maintenance can be further classified as preventive maintenance and predictive maintenance [7], while breakdown maintenance is considered as unplanned maintenance. Preventive maintenance is a scheduled maintenance action that is planned with the aim of preventing damage and failure, preventive maintenance is maintenance that occurs while the system is still operating. All actions taken in preventive maintenance attempt to maintain an item under certain conditions by carrying out systematic inspections, detection and prevention of failures [8]. Predictive maintenance has similarities with preventive maintenance but is not scheduled regularly, predictive maintenance implies that

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the remaining useful lifetime (RUL) of components or systems can be predicted [9]. Breakdown Maintenance is maintenance that is carried out when the machine is damaged so that the machine cannot operate normally [10]. Breakdown maintenance means that heavy equipment will be maintained when there is a failure during operation [11]. Problem solving can only be achieved when the cause of the breakdown is identified. Breakdown is not only possible because of the system itself but skills and behavioral factors can affect the performance of the equipment [12].

Breakdown maintenance is carried out on the Caterpillar C9 Acert machine due to a failure during operation where the machine dies or breaks down when used and cannot be restarted, therefore breakdown maintenance is carried out on the machine which aims to repair the damage found on the machine and return the machine to its original condition. Available for the machine to operate again. The Caterpillar C9 Acert engine can experience damage due to the duration of use and maintenance intervals that are not quite right or not suitable for the machine. This is usually done by the owner of the machine to maximize production and minimize costs or costs required to carry out periodic maintenance. This is of course included in the high risk - high reward spectrum, where on the one hand productivity and profits can increase, the risks involved will also increase as productivity and profits increase. Everything actually returns to the policy of the machine owners, whether they want to take a higher risk of a breakdown.

The Caterpillar C9 Acert engine is a machine produced by the company Caterpillar Inc. distributed by PT. Main Trakindo. PT. Trakindo Utama is an authorized dealer of heavy equipment for Caterpillar products, a leading manufacturer of heavy equipment in the world from America, covering the mining, oil and gas, construction, forestry and agriculture industries, as well as power systems [13]. Figure 1 shows the Caterpillar C9 Acert engine when it arrives at the workshop where the machine will be carried out for maintenance, the condition of the machine is damaged and cannot be started and it can also be seen that the machine looks dirty and looks like it has not been maintained for a long time.

Figure 1: Caterpillar C9 Acert engine before the maintenance process

Whereas Figure 2 shows the Caterpillar C9 Acert engine which has completed the maintenance process on its components, and is working as it should. It can be seen in the picture that the machine has been cleaned and repainted using an air brush with a special paint color for Caterpillar machines, namely Caterpillar yellow. Figure 2 was taken just before the machine was packed to be sent back to the client.

Figure 2: Caterpillar C9 Acert engine after maintenance process

The damage that occurred to the Caterpillar C9 Acert engine resulted in the unit not being able to operate, and this certainly affected the company's productivity. Based on this, observations were made to find out what damage was found in the engine components, and the main causes of the damage. The diagnosis is made on the machine by directly carrying out the overhaul process. Overhaul is a procedure carried out to restore engine performance to factory standard specification values and provide second age or second life with worn component conditions referring to instructions for spare parts that can be reused according to factory standards [14]. What is meant by second age here is when a maintenance procedure is performed on a component that is already worn out, and it turns out that the component can still be used or is still reusable, so there is no need to replace the component with a new one. Overhaul includes efforts to check, detect, maintain or replace engine components in order to maintain engine performance at a certain level. However, the drawback of overhauling is that to overhaul equipment requires a lot of manpower, funds and materials, and the operating time of the equipment after overhauling is limited by the remaining life of the equipment [15]. Therefore, careful consideration is needed regarding the policy of when to overhaul a machine.

The purpose of this research is to identify the main causes of engine damage from the Caterpillar C9 Acert so that preventive measures can be taken to minimize future damage [16]. This research is expected to assist companies in making more precise decisions and policies. That way, the results of the maintenance carried out will be of higher quality and the Caterpillar C9 Acert engine can have a longer use life.

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II. METHODOLOGY

Data processing in this study uses the RCA (Root Cause Analysis) method with the help of 5 whys analysis and fishbone diagrams. The 5 whys analysis method will be used to find the common thread that causes the damage, which component causes the sequence of damage events to occur until the machine breaks down. While the fishbone diagram will be used to find and classify additional factors from outside the machine that contribute to or influence the occurrence of damage to the machine. The following is the definition and explanation of each method.

2.1 Research Flow

The research process began with a literature review, followed by interviews with engineers, and finally by collecting data on physical damage to the Caterpillar C9 Acert engine and crankshaft measurements. Following the collection of damage data and measurements, an analysis procedure employs two methods: Whys Analysis and Fishbone Diagram Analysis. The cause of the damage to the Caterpillar C9 Acert Engine can be determined based on the results of this analysis.

If the data collected from the damage or measurement is insufficient, the data collection is repeated until a full analysis can be carried out.

2.2 Data Retrieval Method

The data needed for writing is taken using several methods, the first is the observation method, this method is carried out by making observations and recording everything that happens in the field. Then the interview method, which is carried out by conducting discussions and asking questions to supervisors and technicians to obtain the necessary data. And finally there is a literature study, which is carried out by collecting information, data, and references from manual books and literature related to the practical work being carried out.

2.3 Explanation of the Root Cause Analysis Method

In the world of science and engineering, root cause analysis (RCA) is a problem solving method that is used to identify the root cause or root cause of a damage or problem. Another definition of root cause analysis (RCA) is a method that has been developed to identify the main causes of accidents and to prevent the same accidents from reoccurring [17].

The RCA method can be broken down into 4 steps starting with clearly identifying and describing existing problems, then establishing a timeline from before the problem or damage occurred until the problem or damage started, then distinguishing between the root causes and other causal factors, and finally making or establish a graph between the root cause and the problem.

The RCA method is widely used in both IT operations, telecommunications, industrial process control, accident analysis (e.g. aviation, rail transport, nuclear plants), medicine (for medical diagnosis), healthcare industry (e.g. for epidemiology), etc. [18]. Root Cause Analysis is a method used to help answer the questions 'what happened?', 'how did it happen?', and 'why did it happen?'. The main aim of this technique is to determine the root cause of the problem by repeating the question "why"? Each answer forms the basis of the next question. The 5 in its name comes from an anecdotal observation on the number of iterations needed to solve the problem [19].

Figure 3 shows an example of a root cause analysis method, namely a tree diagram. Tree diagrams are used to display all the possible outcomes of an event and are used to summarize the probabilities associated with a sequence of random events. The branches originating from a given starting point represent all possible outcomes [20]. This tree diagram method is not used in data processing in this study.

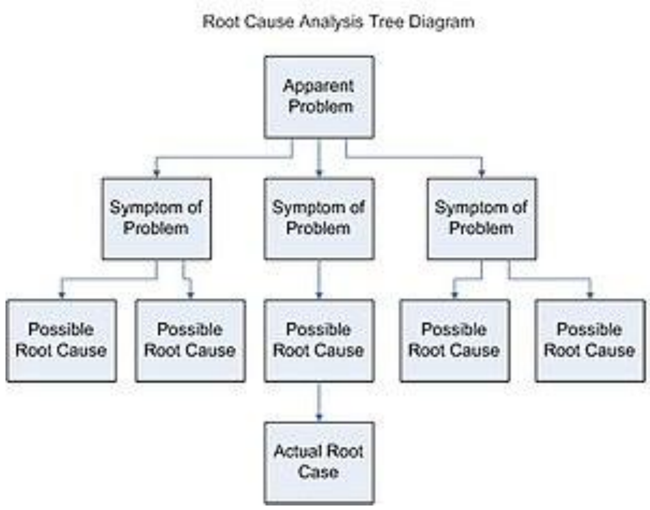

Figure 3: An example of the root cause analysis method (tree diagram) [18]

2.4 Explanation of the 5 Whys Analysis Method

Basically 5 whys analysis is a logic diagram that describes causal relationships to find root causes and produce temporary or final solutions. 5 whys analysis is an iterative and interrogative technique used to find causal relationships that underlie a particular problem. The aim of this technique is to determine the root cause of a disability by repeating the question "why" or "why?". Each answer forms the basis of the next question [21].

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Figure 4 is an example of a worksheet or worksheet from 5 whys analysis. Starting with problem determination and followed by the question "why did this happen?", then the question is continued with the question "why?" which is repeated many times until the root cause or main problem of all is found.

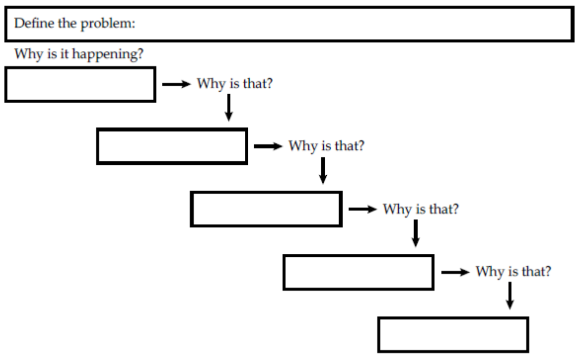

Figure 4: The 5 whys worksheet [22]

5 whys analysis is related to the basic principles of systematic problem solving, namely without the intent of the principle, the technique can only be a shell of the process. Therefore, there are three key elements that are used so that the 5 whys analysis can be used effectively. The first key element is an accurate and complete statement of the problem, the second is complete honesty in answering questions, and the last is the determination to get to the bottom of the problem and solve it [23].

According to his genealogy, the Toyota Production System (TPS), which was created by Sakichi Toyoda for the Toyota Industries Company, is where the "5 Whys" got its start. The first stage in the "5 Whys" study is to identify the issue, then "why did this happen?" on a Caterpillar C9 Acert engine to determine the cause of the issue. When identifying problems and their causes, data on machine measurements and damage are documented in a diagram or table. For each cause that has been discovered, the question "why did this happen?" is asked again, and the cause is then again identified.

If, 5 repeats of the query "why?" no logical root cause is found, the questioning is repeated until the root cause is located. After determining the main cause of the problem, it is able to be evaluated to choose a solution that will minimize damage to the Caterpillar C9 Acert engine.

2.5 Fishbone Diagram

Fishbone diagrams (also called Ishikawa Diagrams or cause-and-effect diagrams) are a graphical technique used to show the multiple causes of a specific event or phenomenon. In particular, a fishbone diagram (the name comes from its shape which resembles a fishbone skeleton) is a technique often used to perform causal analysis to identify complex causal interactions for a specific problem or an event in management science [25]. Fishbone diagrams use illustrative representations of cause and effect, and can be a very effective tool for a specific case [26]. Fishbone diagram was first proposed by Kaoro Ishikawa in 1960 to show cause and effect in the context of the continuous development of industrial processes [27].

There are several basic functions used from the Fishbone Diagram to analyze damage to the Caterpillar C9 Acert engine, the first is to categorize various potential causes of a problem or subject matter in a neat way, the second is to analyze what actually happens in a process, and the last is to teach inform teams and individuals about current or new processes and procedures.

Fishbone diagram can show the factors that cause damage to the Caterpillar C9 Acert engine in a structured way. Figure 5 shows an example of the shape of a fishbone diagram that can be used. There are several causes that lead to the main effect which are grouped into factors according to the type of cause, for example the grouping of causes A, A1, A2 in factor A. Examples of factors used to group various kinds of causes are, for example, human factors, machines , material, method or process, environment and measurement.

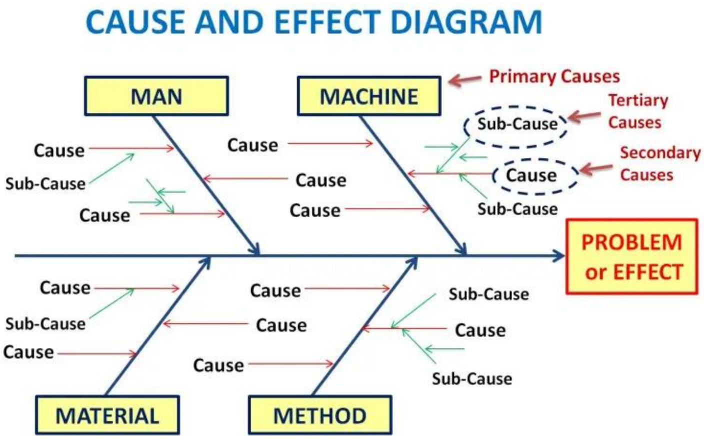

Figure 5: Fishbone diagram [16,25]

III. RESULTS AND DISCUSSION

Interviews were conducted with the engineer responsible for repairing the Caterpillar C9 Acert engine, and it was found that initially before carrying out the diagnostic process on the engine, some information was obtained from the company which might be able to help in finding the main cause of the damage. Information or data obtained from the company can be seen in the following table.

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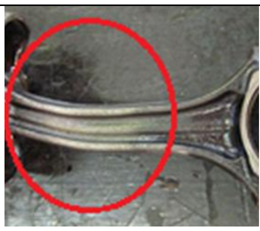
Table 1: Data Interview [16]

No	Information or data from the company
1	At first strange noises were heard from the engine before it stalled and would not start again;
2	The exhaust gas released by the engine changes color;
3	Approximately 30 seconds after the colored smoke comes out of the exhaust, the engine turns off and cannot be started again.

3.1 Physical Damage Data

Damage analysis was performed on the Caterpillar C9 Acert engine. From the information obtained, a direct diagnosis is made on the engine by directly disassembling the engine, in order to find which components or parts are damaged or must be replaced and also to find the main cause of the damage.

Table 2: Physical Damage Data [16]

No	Component		
	Name	**Damaged**	**Damage description**
1	*Crankshaft*	 **Figure 6: Crankshaft**	A measurement procedure must be carried out on the crankshaft due to damage to the connecting rod of one of the pistons (Caterpillar C9 Acert has 6 pistons) to ensure that there is no fatal damage to the crankshaft. The measurement is carried out by opening the main bearing on the crankshaft, and measuring the density using a plastigauge between the main bearing and the crankshaft to ensure that there is no fatal damage to the crankshaft and the crankshaft is still centered. Measurement data using plastigauge can be seen in Table 3 below.
2	*Connecting rod*	 **Figure 7: broken connecting rod [28]**	The damage found in the connecting rod of one of the pistons is in the form of buckling, buckling can occur in the connecting rod due to congestion in the piston ring inside the cylinder liner, buckling occurs when the crankshaft pushes the connecting rod above the dead point to make a stroke but the piston and piston rings hampered the movement due to experiencing jams or traffic jams, so it was stuck and unable to move above the dead point. The buckling load is on the connecting rod arm, when the oscillating movement of the small end and big end pin shafts [29]. Buckling instability is a critical problem that causes catastrophic failure in engineering structures that are subjected to pressure loads, this is due to the compressive stress at the point of failure being smaller than the ultimate compressive stress of the materials used to make the structure [30].
3	*Piston*	 **Figure 8: Scratch on piston**	The damage found in the piston is in the form of a jam in the cylinder liner which is usually called the clock piston. This damage is caused by the occurrence of thermal expansion caused by overheating. Overheating is a condition where the engine temperature exceeds the allowable working limit. The main cause of engine overheating is an abnormal occurrence in the engine cooling system [31]. Overheating has major consequences, if an engine is allowed to overheat even for a short period of time (say it can be a matter of minutes) it can cause the piston and piston rings to expand to the point where they are too big and tight inside the cylinder liner [32]. This can cause friction between these components to leave damage in the form of scratch marks. In Figure 8 it can be seen that there is a scratch on the piston body caused by friction between the piston and the piston ring in the cylinder liner.
4	*Cylinder liner*	 **Figure 9: Scratch on cylinder liner**	As with the piston, damage to the cylinder liner is in the form of scratches caused by friction between the piston and the piston ring inside the cylinder liner. Figure 9 shows the installation of the cylinder liner which has been installed with new O-rings which are being inserted into the cylinder block. O-rings are one part of a cylinder liner which is attached to the cylinder liner before the cylinder liner is inserted into the cylinder block. O-rings are made of rubber and are one of the most commonly used sealing structures in mechanical systems [33].

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5	*Water pump*	 **Figure 10: Damaged Impeller**  **Figure 11: Broken mechanical seals**	In Figure 10 and 11 you can see the components of the water pump in the form of an impeller and a mechanical seal which have exhausted their lifetime or have been worn out. We can see this from the physics of each component, for the impeller it can be seen that there is a roughness on the surface which indicates cavitation and it can also be seen from the color of the component which has changed to a blackish brown color from its original color which is silver (silver in color because it is made of cast material). irons). If the suction pressure drops below vapor pressure, air bubbles will form from localized boiling and these air bubbles will eventually cavitate the impeller, and cause a decrease in the efficiency and flow rate of the water pump. In Figure 10 and Figure 11, you can see a comparison between mechanical seals that have been damaged and mechanical seals that are still good, damage to mechanical seals on average is caused by long-life (lifetime is up) and good maintenance is not carried out, in other words, mechanical seals should have long been replaced with a new mechanical seal. Damage that occurs in the mechanical seal causes disturbances in the bearings and damage to the water pump housing, where disturbances in the bearings cause the impeller rotation to be disrupted and as a result the impeller does not rotate on the axis it should be, resulting in friction between the impeller body and the water pump housing. This friction, of course, affects the rpm of the water pump and is one of the reasons why there is a decrease in flow in the water pump. Damage that occurs to the components of the water pump causes a decrease in the flow released from the water pump so that the cooling system cannot work properly to cool the engine.

3.1.1 Measurement on the crankshaft

Root cause analysis (RCA) is a structured approach method that is used to determine the factors that influenced one or more past events so that they can be used to improve performance (Corcoran, 2004). By using Root Cause Analysis, we can easily trace the factors that affect performance. The root cause is a subset of several factors (events, conditions, organizational factors) that give rise to possible causes and are followed by undesirable effects. In this case, root cause analysis is used to identify problems with the Caterpillar C9 Acert engine. The use of root causes on the Caterpillar C9 Acert machine is by identifying problems, explaining the causes of problems that occur, identifying the causal factors of these problems, identifying root causes, designing and determining improvement plans, and the last thing to do is to measure the results of repair evaluations. Table 3 shows the parts of the Caterpillar C9 Acert engine that were damaged and their consequences. Based on Table 3, it can be identified the root cause of the problem and the improvement plan that will be carried out in the future.

Table 3: Plastiguge measurement on crankshaft main bearings [16]

Main Bearing	Measurement Figures	Density (mm)	Status (tolerance 0.050mm – 0.076mm)
Main bearing 1	 **Figure 12: Measurement of main bearings 1**	0.063	Still within tolerance
Main bearing 2	 **Figure 13: Measurement of main bearings 2**	0.063	Still within tolerance

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Main bearing 3	 **Figure 14: Measurement of main bearings 3**	0.063	Still within tolerance
Main bearing 4	 **Figure 15: Measurement of main bearings 4**	0.076	Still within tolerance
Main bearing 5	 **Figure 16: Measurement of main bearings 5**	0.063(2.5 Inch)	Still within tolerance
Main bearing 6	 **Figure 17: Measurement of main bearings 6**	0.076	Still within tolerance
Main bearing 7	 **Figure 18: Measurement of main bearings 7**	0.063	Still within tolerance

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3.2 Engine Damage Analysis Using 5 Whys Analysis

In this study, an analysis was carried out using the 5 whys analysis method to draw common threads and connect the damage that occurred to the Caterpillar C9 Acert engine based on the physical damage table above. In Figure 19 you can see a 5 whys analysis diagram which links the damage and its Figures sequentially, the order of the damage is then discussed in Table 4. The 5 whys analysis starts with questions followed by answers until the root cause is found. From the diagnostics that have been carried out, it was found that there were several engine parts that were damaged. Damage can be found in several engine parts such as the crankshaft, connecting rod, piston, cylinder liner and water pump.

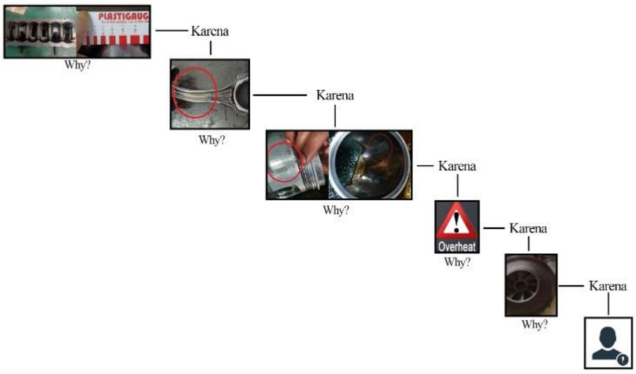

Figure 19: 5 whys diagram [16]

Table 4: 5 Whys Analysis of damage [16]

Why	Answer
1st *why* Why can the crankshaft be damaged?	Because the connecting rod was damaged in the form of buckling which caused density measurements to be carried out on the crankshaft and main bearing to ensure that the density between the crankshaft and main bearing was still within tolerance, the crankshaft was still centered and there was no fatal damage.
2nd *why* Why can the connecting rod experience buckling?	Because there is damage to the piston and piston ring, namely the occurrence of jamming of the piston and piston ring in the cylinder liner, this event is commonly referred to as jamming or piston jam.
3rd *why* Why do pistons and piston rings experience jamming?	Due to overheating of the system which causes thermal expansion of the piston and piston rings, the result is that the piston and piston rings rub against the cylinder liner and leave friction marks in the form of scratches.
4th *why* Why can overheating occur in the engine?	Because the water pump is damaged, the engine cooling system cannot work properly.
5th *why* Why can the water pump be damaged?	Due to human error in the form of making inappropriate policies or decisions on the part of the company regarding the replacement of parts that have expired, in this case the water pump. We can know this from looking at the physical condition of the components in the water pump which look like they haven't been maintained for a long time.
Root cause	**Inappropriate decision making by the company regarding maintenance policies.**
Corrective action	A component will not break down without cause if good maintenance is carried out on the component. If the company carries out maintenance procedures according to the manufacturer's recommendations, this damage will not occur. Of course, the company understands this risk and continues to exercise its right to establish maintenance policies that are not in accordance with standard operating procedures. The concept of risk is a very complex and rich concept, with different approaches and nuances, the concept of risk is key in all scientific, economic and productive sectors [37]. The company in the future must be even wiser in making decisions regarding the maintenance of a component in an engine by considering the existing risks.

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3.3 Machine Damage Analysis Using Fishbone Diagram

Figure 20 discusses the fishbone diagram of the damage that occurred to the Caterpillar C9 Acert. This diagram groups the causes into several main categories to identify the overall source variations that lead to the main effect, namely engine damage in the form of engine breakdown. From Figure 20 we can see that the fishbone diagram has grouped several main factors of damage and their causes and in Table 5 further discussion is carried out.

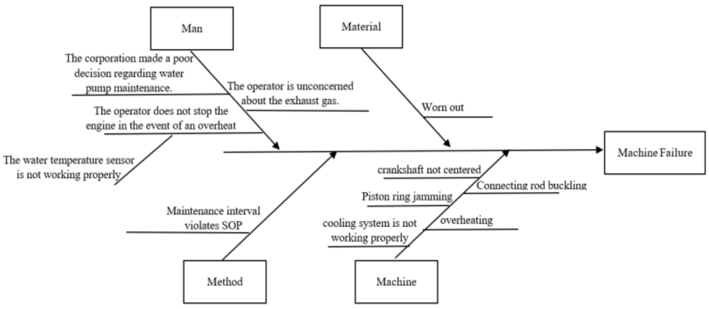

Figure 20: Fishbone diagram of the damage [16]

Table 5: Discussion of fishbone diagram of engine damage [16]

Category	Information
Man	In the human factor, there is an unwise decision making on the part of the company regarding water pump maintenance. We can find this out by looking at the physical condition of the components contained in the water pump, where it is seen that it has not been carried out for a long time or maintenance on these components. There is also a human error from the unit operator, namely not paying attention to the exhaust gas coming out of the unit, and not turning off the unit when overheating occurs, this can occur due to damage to the water temperature sensor on the unit so that the unit monitor does not show that the temperature in the unit is abnormal or has overheating occurs.
Method	In the method factor, it is found that the maintenance interval of the water pump violates the standard operating procedure recommended by the manufacturer. We know this from looking at the physical condition of the components in the water pump, which looks like it hasn't been maintained for a long time. One of the reasons a company does not carry out maintenance or maintenance according to the recommended maintenance intervals from the manufacturer is a policy to reduce the budget or allocation of funds, so that the maintenance that should have been carried out on a component is delayed.
Material	Regarding the material factor, as we know, the components in the water pump have worn out or their lifetime has expired. This can be seen from the physical conditions, for example in the impeller component where one of the characteristics that the component has its lifetime is up is the color change from the color of the initial material, namely silver because it is made of cast iron material until it has become a blackish brown color. In the mechanical seal component we can also see that the physical component looks worn out and it can also be seen that the head has been separated from the spring.
Machine	In the engine factor there are damages that have been discussed in the 5 whys diagram. Starting from the damage in the cooling system, more specifically the water pump, which causes overheating of the engine, followed by jamming or jamming of the piston, then buckling of the connecting rod which ultimately causes the measurement of the density between the crankshaft and the main bearing on the crankshaft.

3.4 General Recommendations

To achieve an optimal operating system, scheduled maintenance is carried out at fixed intervals. The specific interval at which a component will fail is estimated and maintenance intervals are set to replace or overhaul a component to minimize maintenance expenditure while maximizing the performance of that part or component [38]. A good maintenance interval has actually been estimated and determined by the manufacturer of the component, which we can see from the machine maintenance manual. Therefore, the importance of predetermined maintenance intervals must be considered in the maintenance organization. Accurate maintenance intervals optimize treatment results and reduce costs. The advice given to maintenance management is to periodically monitor or inspect systems and components [39].

Based on the results of the damage analysis, a maintenance interval recommendation can be taken or maintenance as a form of preventive maintenance that can be carried out by the company so that similar damage to the engine can be avoided in the future, this recommendation is obtained from the machine maintenance manual and also from interviews conducted with an

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engineer based on his experience in handle similar things, to complete the table. The following are recommended maintenance intervals that can be given:

Table 6: Maintenance interval [16, 40]

Interval	*Maintenance*	Information
321,869 Km (200,000miles) or 3,000 *Service Hours* or 3 tahun	*Cooling system coolant* (DEAC) - *Change*	If the engine uses DEAC (Diesel Engine Antifreeze Coolant) coolant when changing the coolant, also inspect the water pump and water temperature regulator after the cooling system is drained. This is a good opportunity to replace the water pump components if needed.
208,000 L *fuel* or 5,000 *Service Hours*	*Water Pump - Inspect*	Inspect the water pump, if leaking is observed, replace the water pump seal or water pump components that are no longer usable. Carry out an overall inspection to determine which components must be replaced in the water pump.
965,606 Km (600,000miles) or 6,000 *Service Hours* or 6 years	*Cooling system coolant* (ELC) - *Change*	If the engine uses ELC (Extended Life Coolant) coolant when changing the coolant, also inspect the water pump and water temperature regulator after the cooling system is drained. This is a good opportunity to replace the water pump components if needed.
340,000 L *fuel* or 10,000 *Service Hours*	*Water Pump - Inspect*	Carry out an overall inspection to determine which components must be replaced in the water pump.
25,000 *Service Hours*	*Water Pump - Change*	Do a complete water pump replacement.

IV. CONCLUSIONS

From the results of the analysis carried out on the Caterpillar C9 Acert machine at PT. XYZ, it was found that the root cause or root cause of breakdown or failure of the engine when it was operating was human error in the form of policy making or maintenance decisions from the company that were not right for the water pump component. The damage found in the Caterpillar C9 Acert engine is caused by overheating which occurs because the engine cooling system is not working properly, in this case the damage to the cooling system occurs in the water pump component. There are also several engine parts that are damaged due to overheating, such as the piston, piston ring, cylinder liner, connecting rod, and crankshaft. The company is expected to reconsider its policy for scheduling maintenance that must be carried out on the engine cooling system or more specifically on the engine water pump component in order to minimize the occurrence of similar damage in the future.

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