

CHAPTER 2 - LITERATURE REVIEW

2.1 Maintenance Management

Maintenance systems are one of the methods used in activities to conduct planning, organization, guidance, as well as supervision of the production and supporting machines. Naturally, there is no human-made thing that can't be broken. Periodic repair activities performed to extend the service life of a product are known as maintenance.

According to (British Standard Institution, 2010) in the BSI Standards Publication: Maintenance – Maintenance Terminology, maintenance refers to a variety of technical, administrative, and management operations carried out over the lifecycle of an object with the goal of preserving or restoring its functioning. According to another expert (Dunn, 2001) in the Plant Maintenance Resource Center – Maintenance Terminology explains that maintenance refers to any action taken on an asset to maintain its continued functionality or to repair the equipment. And what needs to be careful is that the modification is not maintenance, even though it may be done by maintenance staff.

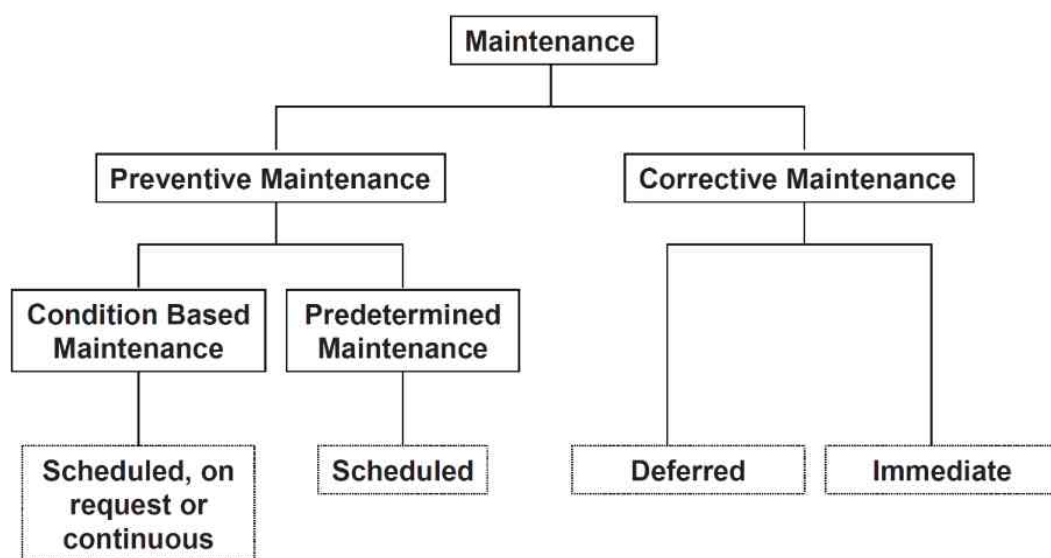


Figure 2.1 Maintenance Strategy Classification (British Standard Institution, 2010).

Based on the above theory, it can be concluded that maintenance is the process of preserving and upkeeping the buildings, machinery, and equipment in a factory. It involves carrying out repairs, changes, or replacements as needed to ensure that production operations meet the desired standards. According to the British Standard Institution, in the BSI Standards Publication: Maintenance – Maintenance Terminology, maintenance management is all management activities that determine the purpose of maintenance, strategy, and responsibility, and implement it in ways such as maintenance planning, maintenance control, and improvement of maintenance and economic activities. Figure 2.1 Maintenance Strategy Classification (British Standard Institution, 2010) shows a classification of maintenance strategies where there are activities that can be done in maintenance: corrective maintenance, preventive maintenance, and predictive maintenance.

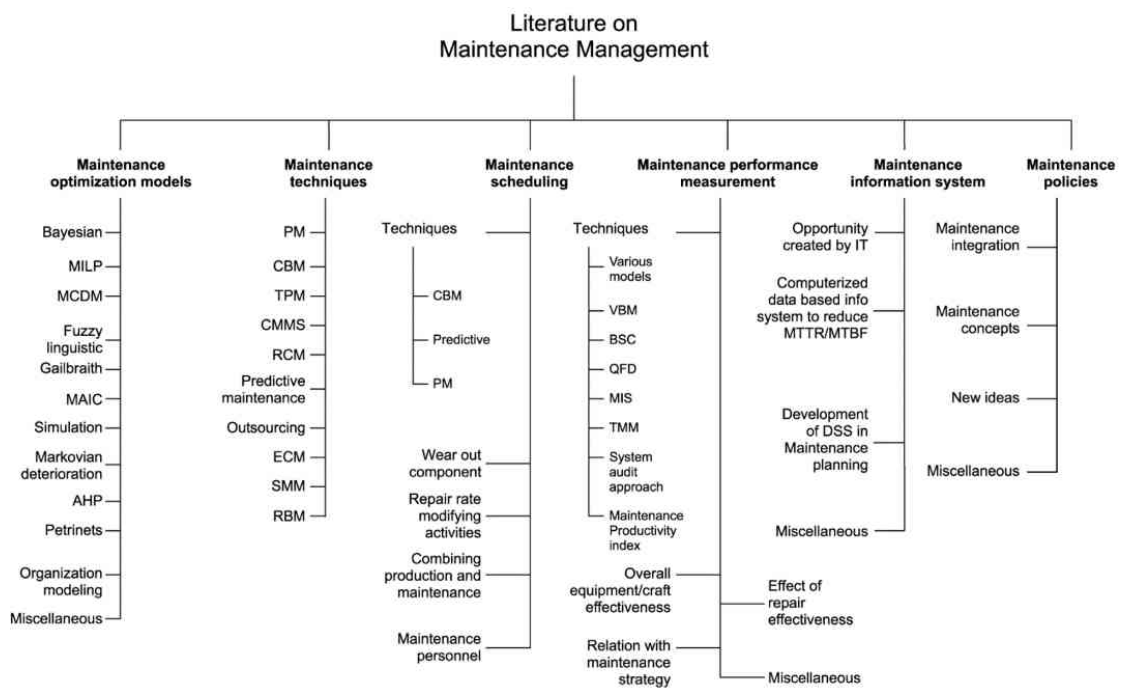


Figure 2.2 Maintenance Management Classification Tree showing Various Sub-Areas.

Figure 2.2 Maintenance Management Classification Tree showing Various Sub-Areas. provides information that to perform maintenance scheduling there are several techniques that can be used, namely PM, Predictive, and CBM. In addition, there are also some types of Maintenance Information System namely opportunity created by IT,

computerized data-based info to reduce Mean Time to Repair (MTTR)/Mean Time Between Failure (MTBF), development of DSS in maintenance planning, etc.

2.2 Condition-Based Maintenance

According to (Gillespie, 2015), in Condition-Based Maintenance: Theory, Methodology, and Application, condition-based maintenance (CBM) is a treatment technique that is actively used to manage the health condition of equipment with the primary purpose of optimizing treatment by performing treatment only when needed and at the most appropriate time, so that the availability and security of the system and equipment as a whole can be improved.

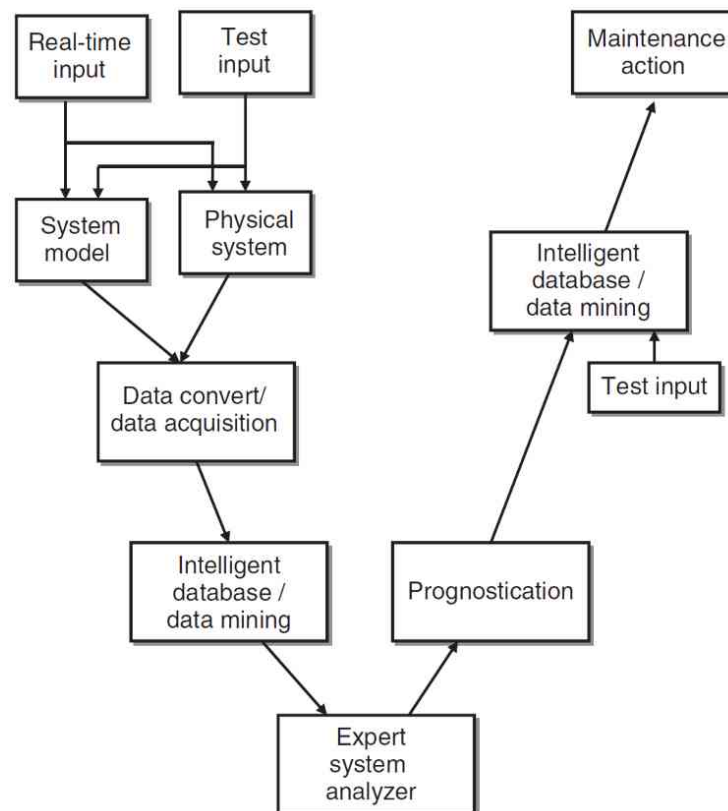


Figure 2.3 The V-Architecture of CBM.

Figure 2.3 The V-Architecture of CBM. represent the CBM process called V diagrams where the left side of the V indicates data collection and database filling procedures. The vertex of the V figure, “expert system analysis,” is the heart of CBM. The right

half of the V diagram shows prognostication and display (Prajapati A., Bechtel J., Ganesan S., 2012).

2.3 Predictive Maintenance

According to (Ebriyik, 2022), the heads indicate that this sort of maintenance predicts equipment breakdown likelihood using automated computerized monitoring and evaluation stages and provides a new maintenance plan to avert failure.

To conduct Predictive Maintenance (PdM) and ensure machinery-equipment good functioning, it is recommended to provide the following data:

- a. Equipment Operational Records.
- b. Historical data on downtimes, failures, and performance.
- c. Machinery equipment condition based on prior operating parameters.
- d. Machine learning and data analytics AI data.

The preceding statistics and benchmarking from comparable equipment and cases are used to build a new maintenance schedule. Predictive maintenance gives average performance values, potential breakdowns, maintenance schedules, and repair methods for machinery and equipment. Thus, it advises the maintenance staff on repair and maintenance methods to minimize equipment downtime before significant production equipment breakdowns. This increases manufacturing efficiency, and sustainability, and lowers production and maintenance costs.

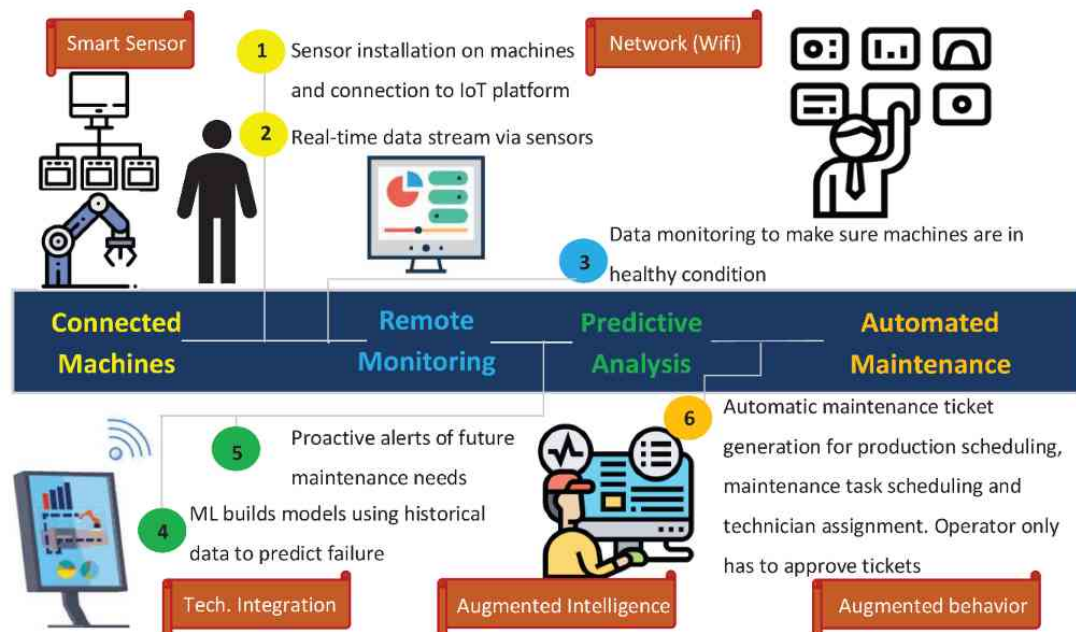


Figure 2.4 Predictive Maintenance (PdM) Process and Technologies to Drive PdM.

Figure 2.4 Predictive Maintenance (PdM) Process and Technologies to Drive PdM. shows the PdM Process and driving technologies, which include smart sensors, artificial intelligence, network, big data, and cloud systems.

(Deloitte, 2015) categories PdM technologies into five groups. Add sensors, networks, integration, enhanced intelligence, and behavior. Smart sensors gather data from machines or the environment by utilizing either internal or external sensors. The network utilizes Bluetooth and Wi-Fi to store and transmit data. The integration of technology enables the administration and gathering of data through the Internet of Things (IoT). Augmented intelligence aids in the processing and analysis of data, while augmented behavior assists operators in using virtualization, computing, and service platforms through apps and tickets.

2.4 Availability

Availability is a metric that quantifies the reliability and ease of maintenance of a repairable component or system. The term refers to a quantifiable indication of the extent to which machinery and equipment are functional and available for use when

required. This phrase comprises variables that may be operated and committed, including those related to equipment, processes, surrounding facilities, and activities. The term has varying interpretations and calculations depending on its usage. (Katukoori, V.)

The types of downtimes included in the analysis determine availability, which is rather adjustable. There are several availability classes, including:

2.4.1. Instantaneous or Point Availability

Instantaneous availability refers to the probability that a system or component will be functioning at any given instant, t . This suggests the probability of a system operating at time t , similar to the reliability function. Instantaneous availability encompasses the aspect of maintainability, unlike dependability. The system is functioning at t if the following requirements are met:

The item functioned successfully from 0 to t with probability $R(t)$ or since the last repair at time u , $0 < u < t$, with probability:

$$\int_0^t R(t-u)m(u)du \quad 2.1$$

With $m(u)$ being the renewal density function of the system.

The point availability is the summation of these two probabilities:

$$A(t) = R(t) + \int_0^t R(t-u)m(u)du \quad 2.2$$

2.4.2. Average Uptime Availability (or Mean Availability)

The mean availability is the percentage of mission or time period the system is available. The mean value of the instantaneous availability function across $(0, T]$ is:

$$\overline{A(t)} = \frac{1}{t} \int_0^t A(u)du \quad 2.3$$

2.4.3. Steady State Availability

System steady-state availability is the instantaneous availability function's limit as time approaches infinity.

$$A(\infty) = \lim_{t \rightarrow \infty} A(t) \quad 2.4$$

The instantaneous availability function will reach a stable condition after four times the typical time-to-failure. The Figure 2.5 Illustration of Point Availability Approaching Steady State below shows this.

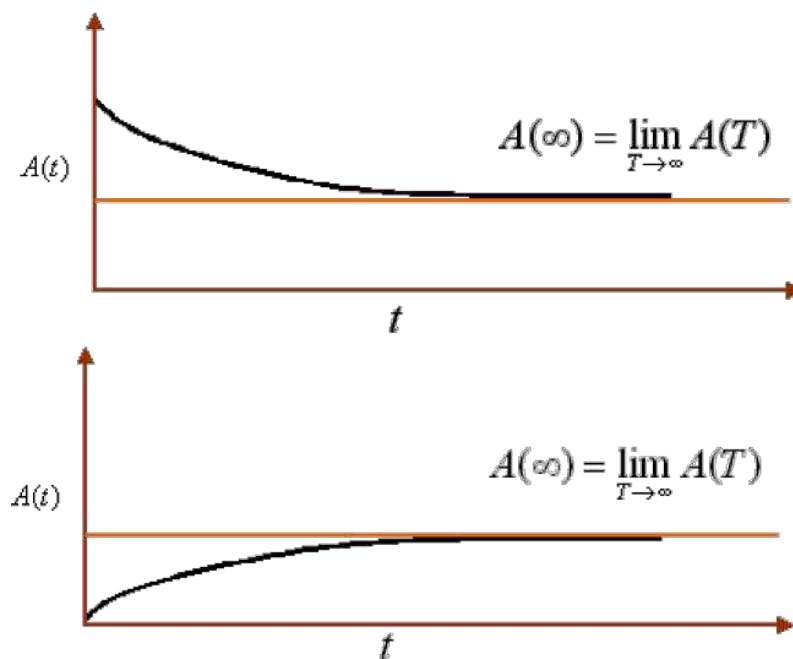


Figure 2.5 Illustration of Point Availability Approaching Steady State.

Stable state availability is a stabilizing point when system availability is continuous. Some systems cannot employ steady-state availability alone.

2.4.4. Inherent Availability

When considering solely system corrective downtime, inherent availability equals steady state availability. It is the estimated availability for corrective repair only. Equipment design alone determines inherent availability. It assumes 100% spare parts and labour availability without delays. Logistics, waiting, administrative, and

preventative maintenance downtime are excluded. Corrective maintenance downtime is included. Engineering design study usually determines inherent availability. Inherent availability distinguishes expected performance between scheduled shutdowns.

For a single component, this can be computed by:

$$A_I = \frac{MTTF}{MTTF+MTTR} \quad 2.5$$

For a system, it is written as:

$$A_I = \frac{MTBF}{MTBF+MTTR} \quad 2.6$$

2.4.5. Achieved Availability

The likelihood that an item would work well under specified conditions in an ideal support environment (i.e., with immediate staff, tools, spares, etc.). Logistics, waiting, and administrative downtime are excluded. Active preventive and corrective maintenance downtime. The level of corrective and preventive maintenance availability attained is called achieved availability. The hard design of equipment and facilities determines availability. Aa also anticipates 100% replacement parts and personnel availability without delays. Achieved availability is like inherent availability but includes PM downtimes. When considering system corrective and preventative downtime, it is steady state availability. The mean time between maintenance activities, often known as the MTBM, and the mean maintenance downtime, $\overline{M}$, or:

$$A_A = \frac{MTBM}{MTBM+\overline{M}} \quad 2.7$$

Find the curve peak and operate at that level in availability-based maintenance activities. Knowing the location and form of the obtained availability curve is critical. Otherwise, operational availability and plant production cannot be determined. Manufacturing operations management may accidentally exceed performance if the Aa curve is unknown. The effect is overpaying and overusing maintenance resources.

Achievable availability is the result of several factors:

- Plant hard design shapes and locates the Aa curve. This design ensures the likely accessibility.
- The location of the plant's Aa curve is determined by maintenance practices. Therefore, these techniques define true availability.

2.4.6. Operational Availability

Operational availability quantifies the average level of availability over a specific period of time and encompasses administrative, logistic, and other downtime. It is the chance that an item will work properly in a realistic operating and support environment at a particular moment. Logistics, readiness, waiting, administrative, and preventive and corrective maintenance downtime are included. The consumer experiences operational availability. The system availability is determined using a posteriori analysis, which relies on actual occurrences. The earlier availability definitions were based on system failure and downtime distribution models.

$$A_0 = \frac{Uptime}{Operating\ Cycle} \quad 2.8$$

Uptime refers to the total duration that the system remained operational during its operating cycle. Maintaining maintenance effectiveness and efficiency requires operational availability. It is the facility's actual daily availability. Plant maintenance resource levels and organizational effectiveness are shown. Maintaining maintenance effectiveness and efficiency requires operational availability. Performance hinges on operational availability. It's the plant's performance at a certain production level.

2.4.7. Physical Availability (PA)

Physical Availability (PA) is the percentage of time availability of a unit of heavy equipment operating without due to unplanned damage or planned repairs (Schedule) based on (Silalahi Rajandi, Zaenal and Dono Guntoro, 2018). The equation used to calculate Physical Availability (PA) is:

$$PA = \frac{W+S}{W+R+S} \times 100\% \quad 2.9$$

Description:

- PA = Physical Availability (%)
W = Number of Machine Working Hours (Hours)
S = Number of Hours Machine Unused/*Standby* (Hours)
R = Number of Hours for Repair (hours)

2.5 Reliability

According to (Odeyar, P., Apel, D., et.al. 2022), reliability refers to the probability of a system meeting its performance requirements and producing output within a certain timeframe and under specific conditions. For instance, a machine that runs consistently for 10,000 hours without defects is 100% dependable. After 10,000 h, the machine's dependability is less than 100% if it fails. Reliability tests for components are conducted at predetermined operation times. Reliable functioning is stopped by failures. A failure is the inability to perform tasks and fulfil standards. $R(t)$ represents the theoretical definition of dependability (dependability = $1 \sim$ Probability of Failure). Reliability is dependent on availability and maintenance.

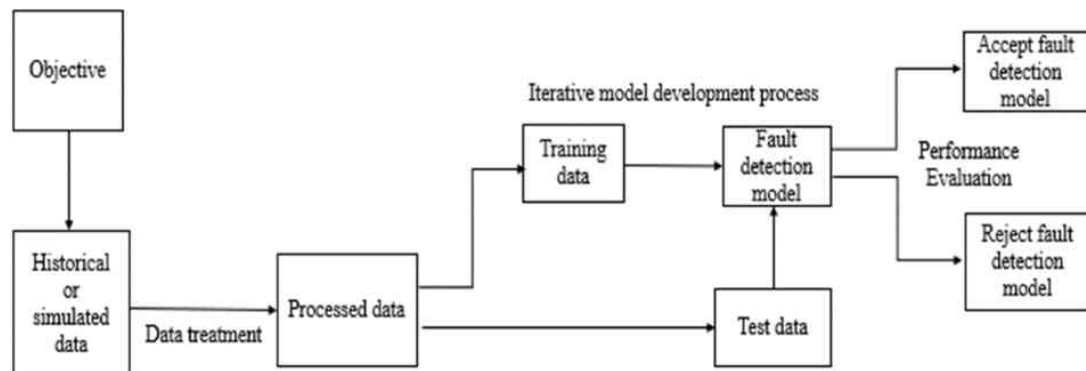


Figure 2.6 Workflow for developing data-driven ML model for fault detection.

From Figure 2.6 Workflow for developing data-driven ML model for fault detection., we can see that from the standpoint of equipment failure, machine learning can be advantageous in preemptively replacing or repairing a component prior to a defect occurring, hence restoring the equipment to its original state and ensuring dependability. To analyze failures and provide forecasts, the algorithms use previous failure data or vibration/condition monitoring data from the equipment. This would

result in reduced periods of inactivity and consistently meet anticipated levels of productivity. Machine learning aids in forecasting future malfunctions to precisely plan maintenance procedures. ML approaches are specifically developed to extract information from preexisting data.

2.6 Continuous Data

According to (Mueller, I. Berliner, L. 1999), continuous data is a sort of quantitative data that can have an endless number of values inside a particular range. This type of data is measured and can be expressed in decimal or fractional form. Continuous data contrasts with discrete data, which can only take on distinct, separate values. Common examples of continuous data include height, weight, temperature, and time.

Here are a few key characteristics of continuous data:

a. Infinite Possibilities

Continuous data has the potential to encompass an unlimited number of values within a defined range. For instance, the height of an individual can vary within a certain range and can be measured with utmost accuracy.

b. Measurable and Quantifiable

Continuous data is typically measured using instruments or tools that allow for precise quantification. This can include instruments such as rulers, thermometers, or scales.

c. Fractional or Decimal Values

Continuous data can be expressed as fractions or decimals. For instance, a person's weight might be 65.5 kg, and this value can be further refined to include additional decimal places for increased precision.

2.7 Discrete Data

According to (Gonick, L., & Smith, W. 1993), discrete data refers to a type of quantitative data that can only take on distinct, separate values. These values are typically countable and finite, often representing items that can be counted in whole numbers. Unlike continuous data, which may have an endless number of values inside a range, discrete data is specific and individual.

Here are some key characteristics of discrete data:

a. Distinct Values

Discrete data consists of individual, separate values. These values cannot be subdivided further and are often whole numbers. For instance, the quantity of pupils in a class or the quantity of automobiles in a parking lot are discrete data points.

b. Countable

Discrete data represents countable items or events. You can count the number of occurrences, and the values are often integers. For example, the number of goals scored in a soccer game is a discrete variable.

c. Non-continuous

Unlike continuous data, which may take on any value within a range, discrete data has gaps between values. There are no intermediate values between two adjacent data points.

2.8 Vehicle Health Monitoring System

Vehicle Health Monitoring System is an additional device from Komatsu that is installed on mining units especially for big machines such as Dump Truck HD785-7. This system is designed to track and analyze the condition of vehicles, providing real-time data on various parameters such as engine performance, fuel efficiency, and overall health. These systems can help with preventive maintenance, reduce downtime, and improve the overall efficiency of a vehicle or a fleet.

There are 2 data trends that VHMS can provide using various type of sensor installed on HD785-7:

a. Temperature Data Trending

Temperature data trending that can be monitored using VHMS include:

1. Engine exhaust gas temperature
2. Engine coolant temperature Max
3. Engine oil temperature
4. Transmission oil temperature Max
5. Hydraulic oil temperature

6. Brake oil temperature
 7. Retarder oil temperature
- b. Pressure Data Trending

Pressure data trending that can be monitored using VHMS include:

1. Engine blowby pressure
2. Engine boost pressure
3. Engine oil pressure Hi
4. Engine oil pressure Lo
5. Engine oil pressure Max
6. Steering oil pressure
7. Brake oil pressure
8. Hoist oil pressure

VHMS will automatically record the value of each parameter every 20 hours for each individual machine. Vehicle Health Monitoring System (VHMS) activity starts with the initial setting and downloading VHMS data on each machine manually download or automatic download. Then the data is uploaded and analyzed to check the condition of the machine using software called VHMS BAGUS.



Figure 2.7 VHMS wired data downloading and processing.

Figure 2.7 VHMS wired data downloading and processing shows the process of VHMS data downloading using the conventional method that still uses cable to connect from machine to notebook or laptop. Meanwhile, Figure 2.8 VHMS wireless data downloading and processing shows the process of VHMS data downloading from the machine with wireless. Both methods still rely on human intervention to obtain and

process data, so the accuracy of the data presented depends on the consistency of VHMS data downloads.



Figure 2.8 VHMS wireless data downloading and processing.



Figure 2.9 VHMS BAGUS Display.

Figure 2.9 VHMS BAGUS Display. shows the display of VHMS BAGUS that can read and display some machine parameters from the uploaded previous VHMS download data.

2.9 Periodic Inspection

Periodic inspection is a crucial component of a heavy equipment maintenance program. It involves regularly scheduled examinations of equipment to assess its condition, identify potential issues, and ensure that it operates efficiently and safely. The goal is to prevent breakdowns, extend the equipment's lifespan, and minimize the risk of accidents. Here's an explanation of periodic inspection in a heavy equipment maintenance program:

2.9.1. Scheduled Frequency

Periodic inspections are conducted at predetermined intervals based on factors such as equipment type, usage, manufacturer recommendations, and regulatory requirements. Common frequencies include daily, weekly, monthly, quarterly, and annual inspections.

2.9.2. Comprehensive Checklists

Inspection checklists are developed for each type of heavy equipment. These checklists outline specific components, systems, and functions that need examination. Examples include engine components, hydraulic systems, brakes, electrical systems, safety features, and structural integrity.

2.9.3. Visual and Functional Examination

During periodic inspections, maintenance personnel visually inspect equipment for signs of wear, damage, leaks, or other abnormalities. They also perform functional tests to ensure that various systems and components are operating as intended.

2.9.4. Documentation

Detailed records are maintained for each inspection, including findings, repairs or replacements made, and recommendations for future actions. This documentation serves as a historical record and helps in tracking the equipment's overall health over time.

In summary, periodic inspections play a vital role in a heavy equipment maintenance program by promoting equipment reliability, safety, and longevity. They form an integral part of a proactive maintenance strategy that aims to catch and address issues before they lead to unplanned downtime or safety hazards.

2.9.5. Periodic Inspection Komatsu Dump Truck HD785-7

So that inspection work can run effectively, efficiently, and well controlled, it is necessary to divide work zones so that inspection activities can be more focused. The HD785-7 dump truck work zone is divided into 3 zones, namely:

a. Zone 1: Front and Upper Area

In zone 1, as described in Table 2.1 Inspection Zone 1 of HD785-7 there are 38 checking items consisting of 4 sub-areas:

1. Front side of machine check: 7 items
2. Upper side of Machine check: 11 items
3. Operator cab check: 14 items
4. Accessories check: 6 items

b. Zone 2: Left Area

In zone 2, as describe in Table 2.2 Inspection Zone 2 of HD785-7 there are 48 checking items consisting of 4 sub-areas:

1. Left side of engine check: 10 items
2. Left side of machine check: 26 items
3. Left side of lubrication check: 8 items
4. Dump body check: 4 items

c. Zone 3: Right Area

In zone 3, as described in Table 2.3 Inspection Zone 3 of HD785-7 there are checking items consisting of 5 sub-areas:

1. Right side of engine check: 9 items
2. Right side of machine check: 26 items
3. Right side of lubrication check: 13 items
4. Dump body check: 2 items
5. Rear axle and rear lamp check: 5 items

Table 2.1 Inspection Zone 1 of HD785-7

NO	CHECK ITEM
A. FRONT SIDE OF MACHINE CHECK	
1	Abnormal noise and discuss with operator (get opinion)
2	Shutdown switch & lockout switch function and condition.
3	Radiator fin and grille, unit code no., after cooler, ac condenser, oil cooler, hoses, and mounting bolts check condition.
4	Work lamp function and condition
5	Rotary (Accessories) check function
6	LH & RH Front Turn Lamp/Clearance Lamp check function.
7	Emergency Shutdown check condition
B. UPPER SIDE OF MACHINE CHECK	
1	Radiator water coolant level.
2	Dust indicator + Evacuator Valve check 3 pcs
3	Air cleaner check condition 3 pcs.
4	Battery electrolytes check level.
5	Battery poles tighten, clamping and wiring condition
6	Grease tank level
7	Auto lubrication condition and function
8	Open engine cover then checks turbocharger & related upper engine
9	Window washer tank level and condition
10	Fire Extinguisher & fire suppression check condition
11	Front pad dump body condition 2 pcs
C. OPERATOR CAB CHECK	
1	All Monitor Panel/Gauge check function
2	Error code record
3	Door check condition
4	Operator seat check condition
5	Washer wiper function and blade condition
6	Dump body lever & lock condition
7	Differential lock switch check condition.
8	Air Conditioner check function
9	Horn check function
10	Emergency Shutdown check condition
11	Emergency steering check function (Engine stopped)
12	Fatigue warning alarm condition
13	Radio/Tape/Speaker function
14	Check auto lubrication/controller check condition
D. ACCESSORIES CHECK	
1	LH Mirror check condition
2	RH Mirror check condition 2 pcs
3	Front Ladder Mirror check condition
4	LH Step Ladder check condition
5	RH Step Ladder check condition
6	Handrail check condition

Table 2.2 Inspection Zone 2 of HD785-7

NO	CHECK ITEM
E. LEFT SIDE OF ENGINE CHECK	
1	Engine oil level
2	Starting motor and wiring condition
3	Engine oil pan and drain port condition
4	Water Separator 2 pcs.
5	Pre fuel filter 1 pcs
6	Fuel filter cartridge 2 pcs
7	Corrosion resistor 2 pcs
8	Horn condition
9	Fan and belt tension
10	Refrigerant level check
F. LEFT SIDE OF MACHINE CHECK	
1	LH Front Wheel Hub check for leakage and loose
2	LH Front Suspension condition and check for level
3	LH A-frame check for condition
4	LH Front Brake check for leakage and pipe connection
5	Steering valve (orbitrol) condition
6	Steering cylinder check condition
7	Hoist cylinder check condition
8	LH tyre/side lamp condition
9	Accumulator LH and related condition
10	LH dump body pad condition
11	Hydraulic tank oil level.
12	Hydraulic oil filter condition: 2 pcs
13	Hoist control valve condition
14	Transmission oil level.
15	Transmission oil filters condition: 4 pcs
16	Transmission strainers condition
17	Steering & Hoist filters condition: 2 pcs
18	Brake cooling line hose & pipe check condition
19	Transmission line hose & pipe check condition
20	Pumps condition: 3 pcs
21	Crossover valve check for leakage and hose connection
22	Brake cooling solenoid valve check for leakage and wiring condition
23	Dump control solenoid valve check for leakage and wiring condition
24	LH Rear Suspension check level and leakage. Bushing, pin check condition
25	LH Final Drive condition and oil level (add if necessary)
26	LH Rear brake leakage and pipe connection condition (loose, crack, broken, etc)
G. LEFT SIDE OF LUBRICATION CHECK	
1	LH Dump Body Hinge Pin, bushing and lock bolt
2	LH Rear Suspension pin, bushing and lock bolts: 2 points.
3	LH Rear axle upper support pin 2 points, bushing and lock bolt.
4	LH Rear axle lower support pin 2 points, bushing and lock bolt.
5	LH Hoist Cylinder Pin, bushing and lock bolts: 2 points
6	LH Front Suspension pin, bushing and lock bolts: 1 point
7	LH Steering linkage pin, bushing and lock bolts: 2 points
8	LH Steering cylinder pin, bushing and lock bolts: 2 points
H. DUMP BODY CHECK	
1	LH Dump Body and code number check condition
2	LH Rock Ejector check condition
3	Dump body safety pins available: 2 Pcs
4	Dump body positioner check condition

Table 2.3 Inspection Zone 3 of HD785-7

NO	CHECK ITEM
I. RIGHT SIDE OF ENGINE CHECK	
1	Water separator glasses RH side check condition: 2 pcs
2	Engine oil filters check condition: 4 pcs
3	Pre fuel filter check condition: 1 pc
4	Fuel filter cartridges check condition: 2 pcs
5	Brake oil filter check condition: 1 pc
6	Alternator Belt tension check, Adjust
7	Fan & Tension Pulley check condition
8	Radiator drain plug tighten check
9	AC Compressor mounting and belt tension check condition
J. RIGHT SIDE OF MACHINE CHECK	
1	RH Front Wheel Hub check for leakage and bolt loose
2	RH tire and side lamp check condition
3	RH Front Brake check for leakage and hose condition
4	RH Front Suspension condition and check for condition
5	RH A-frame check for condition
6	Brake sub-tank oil level.
7	Accumulator RH and related condition
8	Retarder control solenoid valve leakage and wiring condition
9	RH dump body pad condition
10	Front Drive shaft mounting bolt check for loose.
11	Brake cooling pump condition check condition
12	Hose & Pipe check for leaking and crack.
13	Steering cylinder check condition
14	Hoist cylinder check condition
15	Brake line hose & pipe check condition
16	Transmission line hose & pipe check condition
17	Fuel tank and transmitter condition
18	Parking Brake solenoid valve leakage and wiring condition
19	Rear Drive shaft mounting bolt check for loose.
20	Slack Adjuster and related check for leakage
21	RH Rear Brake check for leakage
22	RH Rear Suspension check level and condition
23	RH Final Drive condition and oil level (add if necessary)
24	RH Rear brake leakage and pipe connection condition
25	Differential condition and oil level (add if necessary)
26	Dump body control condition
K. RIGHT SIDE OF LUBRICATION CHECK	
1	RH Dump Body Hinge Pin, bushing and lock bolt
2	RH Rear Suspension pin, bushing and lock bolt 2 points.
3	RH Rear axle upper support pin 2 points, bushing and lock bolt.
4	RH Rear axle lower support pin 2 points, bushing and lock bolt.
5	RH Hoist Cylinder Pin, bushing and lock bolt 2 points
6	RH Front Suspension pin, bushing and lock bolt: 1 point
7	RH Steering linkage pin, bushing and lock bolts: 2 points
8	RH Steering cylinder pin, bushing and lock bolts: 2 points
9	RH Steering linkage pin and bushings: 2 points
10	Front drive shafts lubrication 2 points check condition
11	Rear drive shafts lubrication 2 points check condition
12	Transmission front support mountings lubrication 1 point check condition
13	Tension pulley & fan pulleys lubrication 3 points check condition

continue...

NO	CHECK ITEM
K. RIGHT SIDE OF LUBRICATION CHECK	
1	RH Dump Body Hinge Pin, bushing and lock bolt
2	RH Rear Suspension pin, bushing and lock bolt 2 points.
3	RH Rear axle upper support pin 2 points, bushing and lock bolt.
4	RH Rear axle lower support pin 2 points, bushing and lock bolt.
5	RH Hoist Cylinder Pin, bushing and lock bolt 2 points
6	RH Front Suspension pin, bushing and lock bolt: 1 point
7	RH Steering linkage pin, bushing and lock bolts: 2 points
8	RH Steering cylinder pin, bushing and lock bolts: 2 points
9	RH Steering linkage pin and bushings: 2 points
10	Front Drive Shafts lubrication 2 points check condition
11	Rear Drive Shafts lubrication 2 points check condition
12	Transmission front support mountings lubrication 1 point check condition
13	Tension Pulley & Fan pulleys lubrication 3 points check condition
L. DUMP BODY CHECK	
1	RH Dump Body and code number check condition
2	RH Rock Ejector check condition
M. REAR AXLE AND REAR LAMP CHECK	
1	Rear Lamp check condition
2	Stop Lamp check condition
3	LH & RH Rear Turn Lamp check condition
4	Reverse lamp and alarm check condition
5	Dump body and code no. Check condition

2.10 Lubricant Analysis Program

A lubricant analysis program for heavy equipment involves regularly monitoring and analyzing the condition of the lubricating oils used in the machinery. This proactive approach helps assess the health of the equipment, identify potential issues, and optimize the performance and lifespan of critical components as described in Figure 2.10 The basic of oil analysis for equipment maintenance.



Figure 2.10 The basic of oil analysis for equipment maintenance.

Here are key aspects of a lubricant analysis program for heavy equipment:

2.10.1. Oil Sampling

Regular oil sampling is a fundamental part of the lubricant analysis program. Small samples of the lubricating oil are taken from the equipment and sent to a laboratory for analysis. Sampling should be done at specified intervals based on factors like operating hours, manufacturer recommendations, and equipment usage. Figure 2.11 Hydraulic Oil Sampling of HD785-7 shows the example of sampling hydraulic oil from hydraulic reservoir of HD785-7 using vacuum pump.



Figure 2.11 Hydraulic Oil Sampling of HD785-7

2.10.2. Laboratory Analysis

The collected oil samples are analyzed in a laboratory to evaluate various parameters. Common tests include:

- **Viscosity:** Measures the oil's thickness and its ability to flow.
- **Wear Debris Analysis:** Identifies metal particles and other contaminants in the oil, providing insights into the wear and tear of internal components.
- **Particle Count:** Quantifies the number and size distribution of particles in the oil, indicating the cleanliness of the lubricant.
- **Chemical Composition:** Determines the presence of additives and assesses the oil's chemical stability.

2.10.3. Wear Particle Analysis

By examining wear particles in the oil, analysts can identify which components are experiencing abnormal wear. This information helps diagnose potential issues with specific parts of the equipment, allowing for targeted maintenance.

2.10.4. Contamination Detection

As described in Figure 2.12 Illustration of contaminants contained in , lubricant analysis helps detect contaminants such as dirt, water, aeration, sludge, particles, or coolant in the oil. Contaminants can accelerate wear and adversely affect the lubricant's performance. Identifying and addressing contamination issues early can prevent damage to critical components.

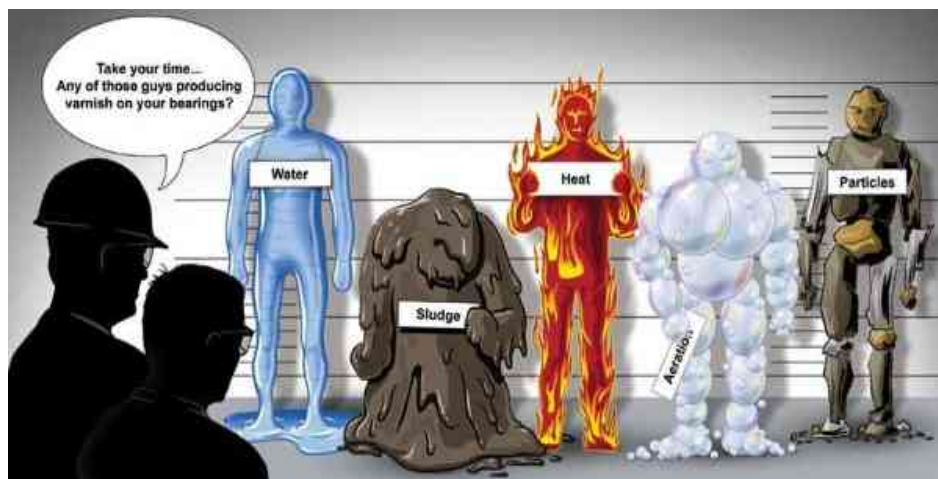


Figure 2.12 Illustration of contaminants contained in oil.

2.10.5. Oil Condition Monitoring

Monitoring changes in oil properties, such as viscosity and chemical composition, provides insights into the overall health of the lubricant. Trends in these parameters can indicate potential problems or abnormal operating conditions.

2.10.6. Predictive Maintenance Strategy

The data obtained from lubricant analysis contributes to a predictive maintenance strategy. By identifying potential issues early, maintenance teams can schedule repairs or component replacements during planned downtime, reducing the risk of unexpected breakdowns.

2.10.7. Extend Equipment Life

Regular lubricant analysis helps ensure that the equipment operates with well-maintained and appropriate lubricants. This, in turn, can contribute to extending the life of critical components and the overall lifespan of heavy equipment.

2.10.8. Cost Savings

Implementing a lubricant analysis program can result in cost savings by avoiding unnecessary oil changes, preventing premature component failures, and reducing unplanned downtime.

2.10.9. Customized Maintenance Plans

Lubricant analysis results can be used to tailor maintenance plans based on the specific needs and conditions of each piece of heavy equipment. This targeted approach maximizes the effectiveness of maintenance efforts.

In summary, a lubricant analysis program for heavy equipment is a proactive and data-driven strategy to monitor the condition of lubricating oils, identify potential issues, and optimize equipment performance and reliability. It is an integral part of a comprehensive maintenance program aimed at minimizing downtime, reducing costs, and extending the life of heavy machinery.

2.11 Previous Study

Table 2.4 Previous Study

No	Research Title	Author	Focus Area	Research Challenge	Research Findings
1	An Intelligence Condition-Based Maintenance Scheduling Model	Jun Geol Baek, 2007	Maintenance Management	As technology advances, products become more complex, requiring better quality and reliability , increasing the cost of preventive maintenance.	This paper presents an intelligent maintenance scheduling approach , proving through simulation-based experiments that it provides practical goods scheduling policies.
2	Machine Learning in Predictive Maintenance towards Sustainable Smart Manufacturing in Industry 4.0	Zeki Murat Çınar, Abubakar Abdussalam Nuhu, Qasim Zeeshan 2019	Predictive Maintenance	Selection of inappropriate predictive maintenance (PdM) technique , dataset, and data size may cause time loss and infeasible maintenance scheduling.	Predictive maintenance presents significant market opportunities, and machine learning is a promising solution for implementing this technology.
3	Availability Analysis and Preventive Maintenance Planning for Systems with General Time Distributions	Naichao Wang, Jiawen Hu, Lin Ma, Boping Xiao, Haitao Liao, 2020	Maintenance Management	Steady-state availability is crucial for repairable systems, and preventive maintenance models are studied to improve it.	The study explores a PM planning model that maximizes steady-state availability in a system with general lifetime and maintenance duration distributions.
4	IoT-based Predictive Maintenance for Fleet Management	Patrick Killeen, Bo Ding, Iluju Kiringa, Tet Yeap, 2019	Maintenance Management	IoT and big data revolutionize predictive maintenance , with COSMO being an example of a system diagnosing faulty buses in public transport fleets.	The present work proposes a novel IoT architecture for predictive maintenance and proposes a semi-supervised machine learning algorithm that attempts to improve the sensor selection performed in COSMO.
5	Intelligent Predictive Maintenance and Remote Monitoring Framework for Industrial Equipment Based on Mixed Reality	Dimitris Mourtzis, John Angelopoulos, Nikos Panopoulou, 2020	Maintenance Management	Current maintenance strategies, like reactive and preventive, are outdated due to advancements in Information and Communication Technologies and computational power.	This paper proposes a Predictive Maintenance and Remote Monitoring system using Artificial Intelligence algorithms for data acquisition, fusion, and post-processing.
6	Improving Physical Availability KOMATSU Dump Truck HD785-7 by Optimizing Machine Health Monitoring System – <i>Proposed Study</i>	Pratama Ardie Kurniawan, 2023	Maintenance Management	The study proposes a design of a real-time machine health monitoring system that will give pre-warning information to prevent unscheduled breakdown of the machine.	The optimized machine health monitoring system can reduce unscheduled downtime and increase the Physical Availability (PA) of the machine by giving pre-warning information.