

CHAPTER 2 - LITERATURE REVIEW

2.1. Mining Operation

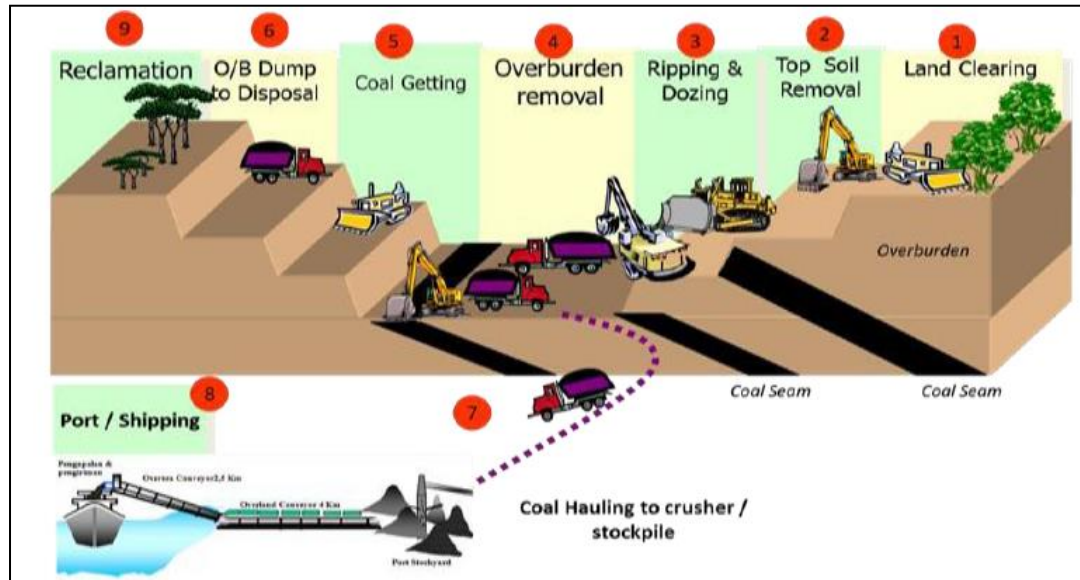


Figure 2. 1 Mining Open Pit Operation

Mining activities carried out are in an open pit system, usually this type is applied to coal deposits that have thick layers and is carried out by making benchmarks. Generally, the stages in coal mining activities are (1) land clearing, (2) top soil removal, (3) ripping and dozing, (4) stripping the overburden (overburden removal), (5) excavating and transporting coal, (6) transporting overburden to overburden to disposal, (7) transporting coal to stockpile/crusher (coal hauling to crusher/stockpile), (8) coal transportation to port and shipment, and (9) reclamation as can be seen in figure 2.1 (Ardyan et al., 2020)

Generally, most critical units in mining operations are excavators and dump trucks, which function as material movers and transporters. In customer area it will be PC2000-8 as an excavator and HD785-5 as a hauler.

2.2. Komatsu Unit Model in Mining Operation

In mining operations, Komatsu has many units model to support customer's both productivity and operational refers to the classification and specific type. There are Motor Grader, Crawler Dozer, Wheel Loader, Hydraulic Excavator, Dump Truck. The

following Komatsu unit models have been specifically engineered to meet the operational demands of the mining industry.

2.2.1. Hydraulic Excavator



Figure 2. 2 Hydraulic Excavator PC2000

Figure 2.2 shows Komatsu PC2000 unit model, market leader excavator for 200-ton class suitable for mining sector, thanks to its high productivity. This excavator has low operating and maintenance cost and can achieve optimum production when collaborated with Komatsu HD785 dump truck. The latest SAA12V140E-7 engine provides high productivity and fuel efficiency for Komatsu PC2000 especially PC2000-11R with its 780 kW/1,050 HP engine power. This giant excavator is equipped with the latest version of working mode, the P+ Mode, which results in 12% higher productivity than the previous generation.



Figure 2. 3 Hydraulic Excavator PC1250

Figure 2.3 shows PC1250-11R, Komatsu's latest generation 125-ton class excavator with a wide selection of modes that can be set according to work needs. This 7.5 m³ bucket excavator has high productivity and is highly effective in all mining applications.

2.2.2. Motor Grader



Figure 2. 4 Motor Grader GD825

Figure 2.4 shows Komatsu GD825A-2, specifically designed for use in difficult terrain, especially for road maintenance in mining. With an operating weight of 26 tons, this product has an ergonomic cabin cab design that ensure safety and comfort for operator. This product uses a high-power S6D140E engine with an output of 209 kW (280 HP) and the strongest torque. This engine is designed to reduce emissions (clean engine) and equipped with the best performance blades which can rotate at high speed and change

quickly. The cab equipped with suspension seat with armrest that can be adjusted in three different positions. In addition, several tools such as lever, rudder, and console could be tilted to provide perfect position for operator. In addition, this heavy equipment has low noise and vibration. This product uses a double-walled gooseneck, circle drive slip clutch, and a heavy-duty differential. In addition, to support durability, product is equipped with a 4-stroke diesel engine, direct injection, turbocharged, water cooled S6D140E-2 diesel with 6 cylinders in-line and has a total movement of about 15.24 L (140 mm).

2.2.3. Crawler Dozer



Figure 2. 5 Crawler Dozer

Komatsu D155A is a crawler dozer used in mining areas for the process of pushing materials and supporting work in the disposal and front areas. This dozer is powered by 354 HP with strong durability and is equipped with the latest sigmadozer blade so that it will produce high work productivity. This product used the SAA6D140E-5 engine with an output of 264 kW 354 HP 1900rpm. It is recognized as a superior engine for high productivity ripping and dozing activities because its powerful engine and also has low fuel consumption. The large blade capacities of 9.4 m³ 12.3 yd³ (Semi-U dozer) and 11.9 m³ 21.7 yd³ (U dozer) provide outstanding production results. This product is

supported by the best control system and understandable. Komatsu's ergonomic control system design used the Human-Machine interface PCCS (Palm Command Control System) to provide complete control of the operator. The cab design of this product complies with ROPS standards which is equipped with a damper on the cab mount, to reduce shock and vibration and increase operator comfort when operating the machine. There is also a large and color LCD monitor with multi-language that understandable by the operator.

2.2.4. Dump Truck



Figure 2. 6 Dump Truck

Our 91-tonne capacity mechanical drive HD785-7 offers the highest brake retardation in its class, along with Komatsu's advanced transmission system for greater safety in all types of mining applications. As with all our trucks, key components are designed and manufactured by Komatsu to work together in an integrated package. And it comes standard with our Komtrax Plus remote monitoring and location system, backed by our Australia-wide service and support network. High productivity on this product is supported by the Komatsu SAA12V140E-3 engine with a power of 879 kW (1,178HP). This engine provides acceleration and faster travel times. This product is also equipped with a High-Pressure Common Rail (HPCR) injection system and an air-to-air aftercooler turbo charger, making the engine EPA Tier2 certified. Front Support has been integrated with a reinforced, high-durability frame, resulting in stiffness but

flexibility. The standard dump body is made of 400 Brinell strength steel, the V-shape and V-bottom designs also add strength to this product. Spacious cab with excellent visibility, ensuring the operator comfort. The cab has ergonomic designed with various control features such as synchronized control between engine & transmission, the sophisticated K-ATOMICS with “Skip Shift” function, as well as a comfortable and spacious ROPS/FOPS cab.

2.3. Komatsu Major Component in Mining Operation

Table 2.1 shows all model units that are commonly found in coal mining locations throughout Indonesia specially in open pit mining. There are several popular units with the largest population such as HD785-7, HD465-7, D155A-6, D375A, GD825, PC1250 and PC2000-8. That products provide good durability, good performance and the most important is good product support with best mechanic, tools and solid team which can help customers to reach their production target in mining business.

Table 2. 1 Komatsu Unit Model in Mining Operation

No	Unit Model
1	D155A-6R
2	D375A-6R
3	GD825A-2
4	HD1500-7
5	HD465-7
6	HD465-7R
7	HD785-7
8	HM400-3R
9	PC1250SP-8
10	PC2000-8
11	PC850-8R1
12	D155A-6
13	D375A-6
14	PC850SE-8
15	PC1250SP-11R

2.4. Komatsu Major Component in Mining Operation

The following are the part numbers and names of the components in the model units in mining:

Table 2. 2 Component and Part Number D155A-6R

Unit Model	Component	Parts Number
D155A-6R	ENGINE ASSY	RM626A-G0-0040
D155A-6R	FINAL DRIVE LEFT	RM17A-27-00142
D155A-6R	FINAL DRIVE RIGHT	RM17A-27-00152
D155A-6R	POWER MODULE	RM17A-22-50001
D375A-6R	ENGINE ASSY	RM624E-E0-0010
D375A-6R	FINAL DRIVE LEFT	RM195-27-00860-NA
D375A-6R	FINAL DRIVE RIGHT	RM195-27-00870-NA
D375A-6R	POWER MODULE	RM195-22-80050

Table 2.2 shows major components from unit Dozer. One of popular unit model in mining area. That specific model has an engine assy, final drive left and right, power module as their major component.

Table 2. 3 Component and Part Number D155A-6R

Unit Model	Component	Parts Number
GD825A-2	ENGINE ASSY	RM6211-00-8500
GD825A-2	FINAL DRIVE	RM235-22-00131
GD825A-2	TRANSMISSION	RM235-15-21014

Table 2.3 shows major components from unit Motor Grader. That specific model has an engine assy, transmission, final drive left and as their major component.

Table 2. 4 Component and Part Number HD1500-7

Unit Model	Component	Parts Number
HD1500-7	AXLE ASSY	RM562-22-30005
HD1500-7	DIFFERENTIAL	RM562-22-31901
HD1500-7	TORQFLOW ASSY	RM562-13-50000

Table 2.4 shows major components from unit Dump Truck. Specifically for Dump Truck HD1500 type. That specific model has an axle assy, differential and torqflow assy as their major component.

Table 2. 5 Component and Part Number HD465-7R

Unit Model	Component	Parts Number
HD465-7R	ENGINE ASSY	RM624E-B0-0012
HD465-7R	DIFFERENTIAL	RM569-22-81000
HD465-7R	TORQFLOW ASSY	RM569-13-70001
HD465-7R	WHEEL BRAKE LH ABS	RM569-88-80301
HD465-7R	WHEEL BRAKE RH ABS	RM569-88-80201

Table 2.5 shows major components from unit Dump Truck. Specifically for Dump Truck HD465-7R type. That specific model has an engine assy, differential and torqflow assy, wheel brake LH and RH as their major component.

Table 2. 6 Component and Part Number HD465-7

Unit Model	Component	Parts Number
HD465-7	ENGINE ASSY	RM6241-F0-0110
HD465-7	DIFFERENTIAL	RM569-22-81000
HD465-7	DIFFERENTIAL W/O LOCK	RM569-22-71001
HD465-7	TORQFLOW ASSY	RM569-14-51000
HD465-7	WHEEL BRAKE LH	RM569-22-70300
HD465-7	WHEEL BRAKE RH	RM569-22-70200

Table 2.6 shows major components from unit Dump Truck. Specifically for Dump Truck HD465-7 without R type. That specific model has an engine assy, differential, torqflow assy, wheel brake LH and RH as their major component.

Table 2. 7 Component and Part Number PC850-8RI

Unit Model	Component	Parts Number
PC850-8R1	ENGINE ASSY	RM626A-F0-0013
PC850-8R1	MAIN PUMP	RM708-2K-00114

Table 2.7 shows major components from unit Hydraulic Excavator specifically for Hydraulic Excavator PC850 type. That specific model has an engine assy and main pump as their major component.

Table 2. 8 Component and Part Number HM400-3R

Unit Model	Component	Parts Number
HM400-3R	ENGINE ASSY	RM626A-J0-0020
HM400-3R	DIFFERENTIAL CENTER	RM56B-23-31000
HM400-3R	DIFFERENTIAL FRONT	RM56B-27-31000
HM400-3R	DIFFERENTIAL REAR	RM56B-22-31000
HM400-3R	FINAL DRIVE CENTER LH	RM56B-23-34001
HM400-3R	FINAL DRIVE CENTER RH	RM56B-23-34050
HM400-3R	FINAL DRIVE FRONT LH	RM56B-27-34001
HM400-3R	FINAL DRIVE FRONT RH	RM56B-27-34051
HM400-3R	FINAL DRIVE REAR LH	RM56B-22-34000
HM400-3R	FINAL DRIVE REAR RH	RM56B-22-34050
HM400-3R	TORQFLOWASSY	RM56B-13-30000

Table 2.8 shows major components from unit Articulated Dump Truck specifically for HM400-3R type. That specific model has many major components such as engine assy, differential, final drive and torqflow assy as their major component.

Table 2. 9 Component and Part Number PC1250SP-8

Unit Model	Component	Parts Number
PC1250SP-8	MAIN PUMP1	RM708-2L-00680
PC1250SP-8	MAIN PUMP2	RM708-2L-00690
PC1250SP-8	SWINGMOTOR	RM706-7K-01110
PC1250SP-8	SWING PUMP	RM708-2H-00440
PC1250SP-8	TRAVELMOTOR	RM21N-60-34100
PC1250SP-8	ALTERNATOR	RM600-861-9121
PC1250SP-8	FUEL PUMP HPCR	RM6245-71-1101
PC1250SP-8	STARTING MOTOR	RM600-813-9512
PC1250SP-8	TURBOCHARGER	RM6502-52-5020
PC1250SP-8	WATER PUMP	RM6240-61-1106
PC1250SP-11R	ENGINE ASSY	RM624F-D0-0010
PC1250SP-8	ENGINE ASSY	RM624E-C0-0020
PC1250SP-8	FINAL DRIVE	RM21N-27-00130
PC1250SP-8	POWER TAKE OFF	RM21N-38-00080
PC1250SP-8	SWING MACHINERY	RM21N-26-00110

Table 2.9 shows major components from unit Hydraulic Excavator specifically for Hydraulic Excavator PC1250 type. That specific model has many major components

such as main pump, swing motor, swing pump, travel motor, alternator, fuel pump, starting motor, turbocharger, water pump, engine assy, final drive, power take off (PTO) and swing machinery as their major component.

Table 2. 10 Component and Part Number PC2000-8

Unit Model	Component	Parts Number
PC2000-8	ENGINE ASSY	RM6219-C0-0030
PC2000-8	FINAL DRIVE LH	RM21T-27-00300
PC2000-8	FINAL DRIVE RH	RM21T-27-00310
PC2000-8	POWER TAKE OFF	RM21T-38-00160
PC2000-8	SWING MACHINERY	RM21T-26-00300
PC2000-8	SWINGMOTOR	RM706-7K-01120
PC2000-8	TRAVELMOTOR	RM706-7L-01110
PC2000-8	FAN PUMP	RM708-2L-00280
PC2000-8	ALTERNATOR	RM600-825-9331
PC2000-8	FUEL PUMP HPCR LH	RM6219-71-1111
PC2000-8	FUEL PUMP HPCR RH	RM6219-71-1201
PC2000-8	STARTING MOTOR	RM600-813-9911
PC2000-8	TURBOCHARGER LH	RM6505-67-5080
PC2000-8	TURBOCHARGER RH	RM6505-67-5070
PC2000-8	WATER PUMP	RM6219-61-1150
PC2000-8	CONTROL VALVE ASSY RH	RM709-1A-11500

Table 2.10 shows major components from unit Hydraulic Excavator specifically for Hydraulic Excavator PC2000 type. One of the popular units that mining customers usually rely on to getting high production. That specific model has many major components such as engine assy, final drive, power take off (PTO), swing machinery, swing motor, travel motor, fan pump, alternator, fuel pump, starting motor, turbocharger, water pump and control valve assy as their major component.

Table 2. 11 Component and Part Number D155A-6

Unit Model	Component	Parts Number
D155A-6	ALTERNATOR	RM600-825-6271
D155A-6	FUEL PUMP	RM6261-71-1111
D155A-6	STARTING MOTOR	RM600-813-9323
D155A-6	TURBOCHARGER	RM6505-68-5540
D155A-6	WATER PUMP	RM6261-61-1204

Table 2.11 shows major components from unit Dozer specifically for D155A-6 type. That specific model has many major components such as alternator, fuel pump, starting motor, turbocharger and water pump as their major component.

Table 2. 12 Component and Part Number HD785-7

Unit Model	Component	Parts Number
HD785-7	ENGINE ASSY	RM6219-B0-0041
HD785-7	AXLE ASSY FRONT LEFT	RM561-27-8B204
HD785-7	AXLE ASSY FRONT RIGHT	RM561-27-8B104
HD785-7	AXLE ASSY SEGMENT	RM561-88-70006
HD785-7	DIFFERENTIAL	RM561-22-71003
HD785-7	FINAL DRIVE LEFT	RM561-88-70201
HD785-7	FINAL DRIVE RIGHT	RM561-88-70301
HD785-7	FRONT BRAKE LEFT	RM561-88-70250
HD785-7	FRONT BRAKE RIGHT	RM561-88-70650
HD785-7	TORQFLOW ASSY	RM561-13-70001
HD785-7	STEERING VALVE	RM561-40-84300

Table 2.12 shows major components from unit Dump Truck specifically for HD785 type. This type is similar to the HD465-7R type but larger. That specific model has many major components such as engine assy, axle assy, differential, final drive, front brake, steering valve and torqflow assy as their major component.

2.5. Component Remanufacturing

2.5.1. Understanding Component Remanufacturing

Remanufacturing is an industrial process in which used components (damage cores) are reconditioned and restored to meet quality and performance standards equivalent to new components (Shanshan et al., 2022). In the context of the heavy equipment industry, remanufacturing is an important part of the aftermarket strategy to reduce customer operating costs, improve maintenance efficiency, extend component life, and support environmental sustainability by reducing industrial waste.

2.5.2. Goals and Benefits of Remanufacturing

The main goals of remanufacturing include:

- a. Reducing the customer's Total Cost of Ownership (TCO) by providing more economical yet reliable component replacement options, thereby reducing the overall product life cycle costs, including maintenance costs, downtime, and procurement of new components (Kanagaraj et al., 2016)
- b. Extending the service life of components by returning their functional condition to new specifications, allowing the components to be reused in the next operational cycle without significant performance degradation (Tchertchian et al., 2012).
- c. Reducing the consumption of new materials by reusing viable components from damaged cores, thereby reducing the need for new raw materials and reducing the environmental impact of material extraction and processing activities (Singhal et al., 2019).
- d. Supporting the Circular Economy program by minimizing industrial waste through extending product life cycles, reducing the need for new production, and optimizing resource use through the practice of reusing, repairing, and remanufacturing previously used components (Psarommatis et al., 2025).

The advantages compared to new components, namely:

- a. The cost of remanufacturing components is generally 30–50% lower than that of new components because most of the original structure of the component is retained and only damaged or worn parts are replaced (Corum et al., 2014).
- b. Procurement time can be faster because remanufactured components that have Ready for Use (RFU) status are usually prepared in advance based on estimated customer needs, so that the ordering and delivery process can be carried out directly without waiting for the re-production process (Hoffmann et al., 2025), (Graham et al., 2015),
- c. Continuous availability of spare parts for equipment older than 10 years. Remanufacturing allows companies to maintain component availability for discontinued equipment models, while reducing

inventory costs and extending the product life cycle (Wlazlak & Johansen, 2025)

2.6. Component Remanufacturing Business Cycle

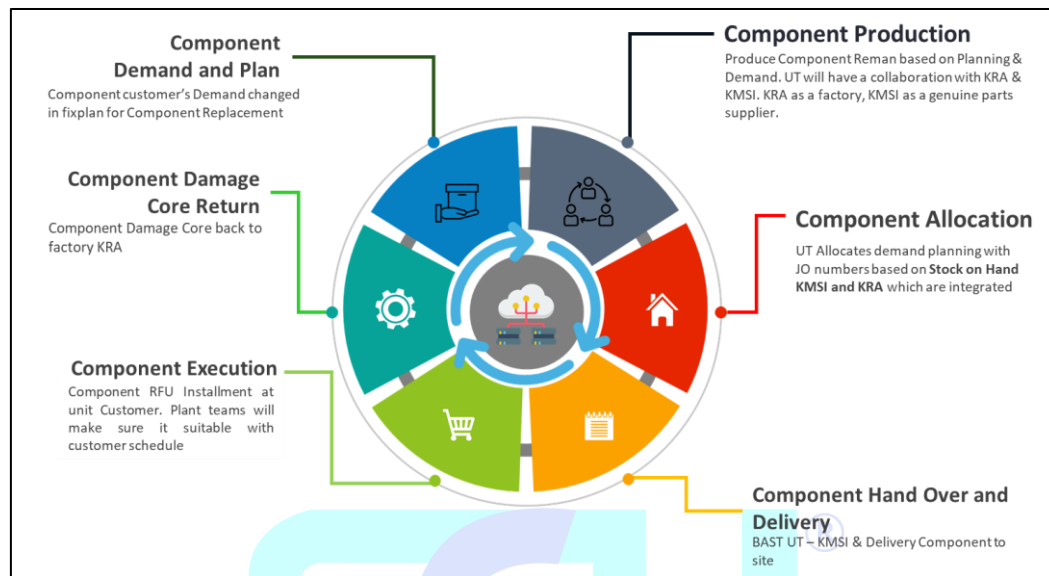


Figure 2. 7 Component Remanufacturing Business Cycle

Figure 2.7 illustrates the overall component remanufacturing business cycle, which consists of six main stages: (1) Component planning and requisition, (2) Remanufacturing production, (3) Component Allocation and distribution, (4) Component Delivery and handover of components to customers, (5) Execution or installation of components to heavy equipment, and (6) Return of damaged cores from customers to the remanufacturing facility (factory). Each stage in this cycle is interconnected and contributes to optimizing the efficiency of the remanufactured component supply chain, ensuring quality, availability, and sustainability of the business process (PT XYZ Internal Documentation, 2025).

2.6.1. Component Demand and Planning

The initial stage of the remanufacturing business process involves identifying and planning the customer's component replacement needs. This information is derived from historical maintenance data, component life cycles, preventive maintenance

schedules, and the actual condition of the unit in the field (Ijomah & Childe, 2007). This demand data is then converted into a fixed plan, which forms the basis of the remanufacturing production process. Digital technology plays a key role in this stage as it enables accurate projection of needs based on usage trends and past failure data (Okorie et al., 2024).

2.6.2. Component Production

This stage is the process of realizing remanufacturing production based on previously prepared needs plans. Component production is carried out by remanufacturing facilities such as Komatsu Remanufacturing Asia (KRA) in collaboration with Komatsu Marketing and Support Indonesia (KMSI) as a provider of original components. This process begins with the receipt of damage cores, followed by the process of disassembly, cleaning, inspection, replacement of damaged or worn components, reassembly, and final performance testing to ensure that the components meet OEM (Original Equipment Manufacturer) specifications (Tchertchian et al., 2012). Modern manufacturing technology and quality control systems play an important role in ensuring that the final result of the remanufacturing process has quality, reliability, and service life comparable to new components (Ijomah, 2008)

2.6.3. Component Allocation

After the production process is completed, Ready for Use (RFU) components are allocated to customer needs based on the demand plan that has been made. Allocation is carried out by considering the latest inventory data integrated between KRA and KMSI meet with stock availability, and generate Job Orders (JO) as the basic document for shipping execution. Important factors such as urgency level, customer location, and maintenance schedule are also considered in the allocation process, to ensure supply chain efficiency and customer satisfaction (Jiang et al., 2013).

2.6.4. Component Hand Over and Delivery

This stage involves the physical process of delivering RFU components to the customer. The handover of components is carried out through an official document, the Handover Report (BAST) between PT XYZ and KMSI. The components are then packaged and

distributed to the customer's operational location according to the specified shipping procedure. The accuracy of the documents, delivery time, and the physical condition of the components when received are important indicators of the success of this process. Errors or delays at this stage can have a direct impact on the maintenance schedule of the unit in the field (Hoffmann et al., 2025)

2.6.5. Component Execution

At this stage, the PT XYZ's technical team installs the RFU components on the customer's heavy equipment unit. The installation process is carried out in accordance with OEM standards and adjusted to the customer's operational schedule. Installation accuracy is very important because it will affect the performance of the unit and the success of the overall remanufacturing cycle. After installation, performance validation is carried out to ensure that the components function optimally. Coordination between the technical team and the customer is crucial to minimizing downtime and ensuring smooth operation of the unit in the field (Tchertchian et al., 2012).

2.7. Big Machine Remanufacturing Transaction

2.8. Define, Measure, Analyze, Improve, Control (DMAIC)

Continuous improvement is a core principle of organizational management, aimed at enhancing operational efficiency, product quality, and overall performance. One of the most structured and widely adopted methodologies for achieving this progress is the DMAIC framework. DMAIC which is stands for Define, Measure, Analyze, Improve, and Control—offers a systematic, data-centric approach to problem solving and process improvement. While it is the backbone of the Six Sigma methodology, DMAIC has proven highly adaptable and effective beyond Six Sigma applications. Its structured nature enables organizations to identify root causes, measure current performance, implement targeted improvements, and sustain it performance, driving long-term excellence across a wide range of industries and sectors (Mittal et al., 2023)



Figure 2. 9 DMAIC Methodology

1. Define

The Define phase is the initial stage in the DMAIC process. In this phase, the problem at hand, the objectives of the improvement project, and the scope of activities are clear and structured. This stage plays a crucial role because it serves as the primary foundation that determines the direction and focus of the entire improvement project.

2. Measure

In the Measure phase, the current performance of the process is quantified. This phase involves collecting data to establish a baseline and to identify areas for improvement.

3. Analyze

The Analyze phase is where the root causes of the problem are identified. This phase involves analysing the data collected in the previous phase to pinpoint where and why defects or inefficiencies are occurring.

4. Improve

In the Improve phase, solutions to eliminate the root causes are developed and implemented. This phase focuses on designing and testing solutions to ensure they effectively address the identified problems.

5. Control

The Control phase is the final step in the DMAIC process. It involves monitoring the improved process to ensure that the solutions are sustained over time and that the process remains within acceptable limits.

The DMAIC methodology provides a structured and systematic approach to continuous improvement that is applicable across various industries and processes. By following the DMAIC phases: Define, Measure, Analyze, Improve, and Control, organizations can effectively identify and address process inefficiencies, enhance quality, and achieve sustainable improvements. The success of DMAIC lies in its data-driven approach, emphasis on root cause analysis, and commitment to ongoing monitoring and control. As a result, DMAIC has become a cornerstone of quality management and continuous improvement efforts worldwide.

2.9. Fishbone Diagram

Across industries, teams often encounter persistent problems that persist despite attempted solutions. These problems often hide beneath surface symptoms, with root causes difficult to identify within the complex web of contributing factors. Fishbone diagrams, also known as Ishikawa diagrams or cause-and-effect diagrams, are invaluable tools for addressing this challenge. Developed by Dr. Kaoru Ishikawa in the 1960s, these diagrams provide a structured method for uncovering the root causes of problems by visually organizing potential causes into categories (Majka, n.d.).

A fishbone diagram is a powerful visual tool used in problem-solving and quality management to help systematically organize potential causes. Its visual representation is so named because it resembles the structure of a fish's bones.

- a. The "head" of the fish represents the problem or effect being investigated. It is the starting point and focal element of the diagram. The problem statement must be clearly defined, precise, and unambiguous, as this directs the investigation to the relevant causes.
- b. The "bones" extending from the spine represent various categories of potential causes. These categories often cover broad areas such as people, methods, machines, materials, measurements, and environmental conditions.

By visually mapping causal factors, a Fishbone Diagram allows teams to see the relationship between effects and their possible causes, making it easier to explore and identify the root causes of complex problems. This structured approach not

only improves the clarity and comprehensiveness of the analysis but also encourages collaboration among team members by providing a common framework for discussion. The primary purpose of a Fishbone Diagram is to facilitate the systematic exploration of all potential causes of a particular problem, especially in situations where the problem is complex and multifaceted. Key benefits include:

- a. **Root Cause Identification**
Enable teams to move beyond symptoms and superficial fixes to address the fundamental problem.
- b. **Comprehensive Analysis**
By categorizing causes and sub-causes, the diagram ensures that all possible areas are considered, reducing the possibility of missing important factors.
- c. **Facilitate Team Collaboration**
Provide a common framework for discussions that encourages input from all relevant stakeholders, improves the quality of analysis and fosters a sense of shared ownership of the problem and its solution.
- d. **Continuous Improvement**
Serves as a fundamental tool in the continuous improvement process, guiding organizations towards more efficient, effective, and sustainable solutions.
- e. **Preventing Future Problems**
Empowering organizations to not only solve current problems but also implement preventative actions, fostering a culture of continuous improvement and operational excellence.

6M Model Fishbone Diagram Structure

The Fishbone Diagram structure is carefully designed to facilitate a comprehensive exploration of the factors contributing to a particular problem.

- a. **Head (Problem/Effect)**
The problem or effect being investigated is placed in the “head” of the fish. This problem statement should be clearly and precisely defined.

- b. Major Bones (Categories): From the spine of the diagram, extend “major bones” that represent the main categories of causes. Commonly used standard categories, known as the 6Ms, include:
1. People
Includes human factors such as the skills, training, experience, attitudes, and behavior of the individuals involved.
 2. Methods
Focuses on the procedures, processes, and policies that govern how tasks are performed. This may reveal problems with procedural inefficiencies or inconsistent process execution.
 3. Machines
Relates to the equipment, technology, and tools used in the process. This investigates any malfunctions, outdated technology, or improper use of equipment.
 4. Materials
Discusses raw materials, consumables, and supplies integral to the process. This includes assessing the quality, consistency, and availability of materials.
 5. Measurements
It's important to examine how data is collected, metrics are tracked, and processes are monitored. Inaccurate or inadequate measurements can lead to poor decisions.
 6. Environment
Consider the physical environment (workspace conditions, area) and the organizational environment (company culture, management policy).

The true power of a Fishbone Diagram lies in its ability to facilitate a comprehensive and collaborative problem-solving process. The visual nature of this diagram allows teams to see the relationships between different causes and prioritize their efforts. It encourages a balanced and methodical exploration of all potential factors, fostering a culture of rigorous analysis and continuous improvement.

2.10. SQCD (Safety, Quality, Cost, Delivery)

The SQCD approach is a widely used framework for operational management and continuous improvement in the industrial and manufacturing sectors. SQCD consists of four main dimensions: Safety, Quality, Cost, and Delivery which are collectively used to measure and evaluate process performance, identify root causes, and systematically develop improvement strategies (Cha & Kim, 2011)

1. Safety

The safety aspect emphasizes the importance of safety in the implementation of work processes. In an industrial context, safety not only concerns worker protection but also encompasses product and environmental safety. Evaluation of this dimension helps organizations identify potential risks of workplace accidents, system failures, and hazards arising from operational errors.

2. Quality

Quality refers to the conformity of a product or process to specifications and customer expectations. Evaluation of this dimension encompasses the quality of inputs, the production process, and the final product. The quality dimension is often a key indicator in identifying potential defects, process variations, and non-conformance to standards

3. Cost

The cost dimension is directly related to resource efficiency and cost control. Within the Fishbone framework, causal factors related to costs can include waste, non-value-added processes, and failures in supply chain management. Cost optimization through root cause analysis has a direct impact on the profitability and sustainability of the production process (Zhang et al., 2019).

4. Delivery

The delivery dimension relates to the timeliness of meeting customer needs or subsequent processes. Common problems identified in this dimension include production delays, inaccurate logistics planning, and inconsistent deliveries.

Using SQCD as a supporting framework in a Fishbone Diagram provides a more structured and operational analysis approach. Each dimension allows researchers or practitioners to categorize the root causes of problems according to the measured performance focus. This also clarifies areas that require follow-up for continuous improvement, whether in production systems, logistics, service, or risk management.

2.11. Machine Learning



Figure 2. 10 Propose Research Model based on data collection

Machine Learning (ML) is a branch of artificial intelligence (AI) that focuses on the development of algorithms and statistical models that enable computer systems to learn from historical data, recognize patterns, and produce predictions or decisions without the need for explicit instructions (Mitchell, 1997).

In the last two decades, ML has developed rapidly and is now a major approach in various fields, including business forecasting, industrial process automation, pattern recognition, and data-driven decision making

In the heavy equipment industry, the application of this approach is very relevant considering the large volume of operational data and the complexity of asset management and component maintenance cycles.

In general, Machine Learning (ML) is classified into three main categories:

1. Supervised Learning: This approach uses data that has been labeled, such as machine sensor data that is categorized as “normal” or “failed.” Techniques that fall into this category include Random Forest, Linear Regression, and Support Vector Machines.
2. Unsupervised Learning: Used when the data is unlabeled. Models in this category attempt to find hidden patterns in the data, such as clustering based on operational conditions.
3. Reinforcement Learning: This approach involves learning based on direct interaction with the environment, with the goal of maximizing long-term outcomes. While more complex, this method is often applied to adaptive control systems and real-time predictive maintenance.

The use of Machine Learning in engine condition health score systems enable efficient processing of large and complex sensor data, accelerates early detection of potential damage, and supports decision-making in condition-based maintenance. The main advantage of Machine Learning lies in its ability to recognize non-linear relationships and complex correlations that are difficult to reach by conventional methods (Alshorman et al., 2020).

A. Machine Learning and Analytical Approaches

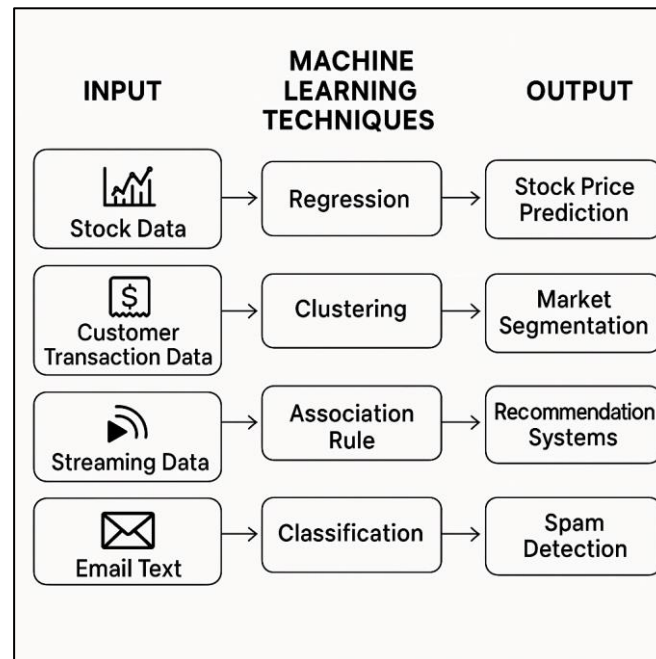


Figure 2. 11 Relationship between Machine Learning and Analytical Approaches

Machine Learning is closely related to analytical methods in terms of processing and utilizing data to support decision making. ML can be seen as a form of further development of conventional analytical approaches, where models not only analyze data based on fixed assumptions, but are also able to learn data patterns to improve prediction accuracy. Analytical methods such as Linear Regression, Classification Analysis, CART, to Random Forest, are basically part of the range of techniques used in ML, especially in the realm of Supervised Learning. The relationship between Machine Learning and Analytical Methods are:

1. Analytical Methods as Part of Machine Learning

Techniques such as linear regression and decision trees (CART) are statistical models that have long been used in data analysis. In the context of Machine Learning, these methods are enhanced through approaches such as retraining, cross-validation, and parameter optimization to produce better model performance when applied to new data.

2. Random Forest as a Development of CART

Random Forest is an advanced form of the CART method by implementing an ensemble learning approach, namely by building a number of decision trees

and combining the results. This approach aims to improve accuracy and reduce the risk of overfitting. This shows how ML is able to strengthen the effectiveness of classical analytical methods through algorithmic innovation.

3. Evolution from Descriptive to Predictive Analytics

If traditional analytical methods focus more on explaining past and present phenomena (descriptive and diagnostic analytics), then Machine Learning takes this approach to a more sophisticated direction, namely predictive and prescriptive analytics. Thus, it not only produces predictions, but is also able to provide recommendations based on predictive results (Zhang et al., 2019).

B. Automation of Analytical Processes through Machine Learning

Machine Learning enables analytical processes to be performed automatically and at scale. This is especially important in machine health monitoring systems, where thousands of sensor data must be analyzed in real-time to accurately evaluate machine conditions (Zhang et al., 2019).

C. Classification Methods and Various Algorithms

Classification method is one of the main approaches in supervised learning that aims to associate input data with predetermined categories or classes.

In the field of engineering management, especially in machine condition monitoring systems, this method is used to identify the operational status of the machine, such as in good condition, in need of maintenance, or damaged.

The essence of the classification method lies in the process of training the model using historical data that already has a class label. Once the model has been successfully trained, it can be used to classify new data whose status is unknown. Some classification algorithms that are commonly applied in engineering applications include:

2.11.1. Random Forest

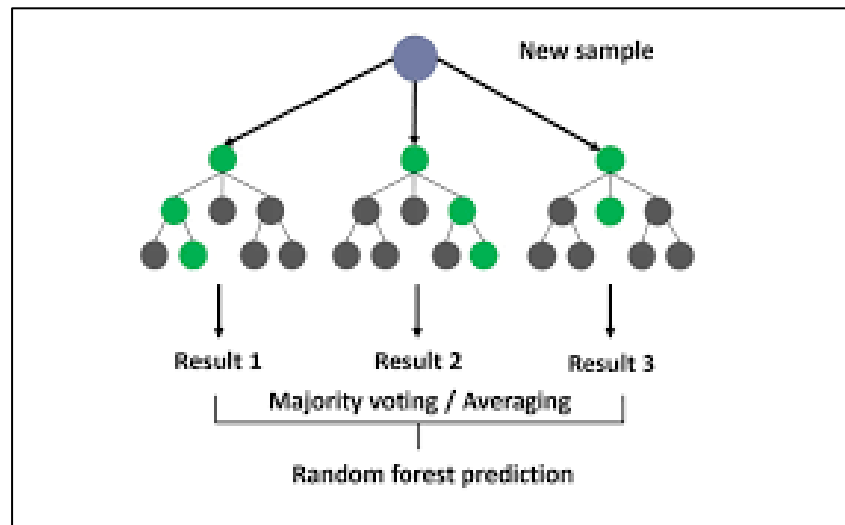


Figure 2. 12 Random Forest Modelling

Random Forest is an ensemble algorithm that builds a number of decision trees (CART) and combines their classification results. Each tree is created based on a randomly selected subset of data and features. The final prediction is determined based on the majority of the results from all the trees formed.

Main advantages:

1. Resistant to the risk of overfitting.
2. Capable of handling data with a large number of features.
3. Provides information about the importance of each feature (feature importance).

Random Forest is often used to classify machine conditions based on parameters such as temperature, vibration and pressure (Liaw & Wiener, 2002).

2.11.2. CART (Classification and Regression Tree)

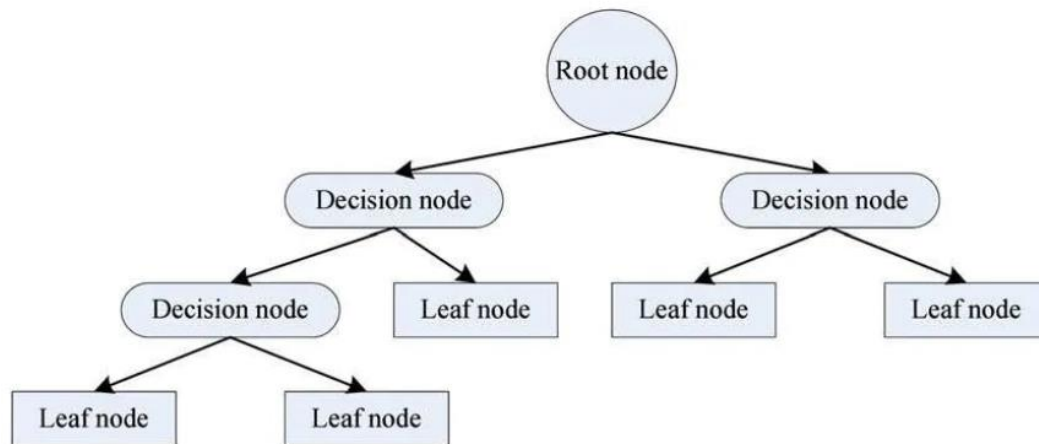


Figure 2. 13 CART Modelling

CART (Classification and Regression Tree) is a decision tree algorithm that divides data into branches (nodes) based on feature values, with the aim of producing the most homogeneous data groups in each branch. This algorithm is the foundation of several more complex ensemble approaches, such as Random Forest. (Steinberg, 2009)

Advantages of CART:

1. It has a simple structure so that it is easy to understand and explain, both visually and conceptually.
2. The inference process is fast and efficient, suitable for implementing real-time systems or applications with low computational requirements.

Disadvantages of CART:

1. Prone to overfitting when used alone.

Limitations of CART:

1. Susceptible to overfitting, especially when used as a single model without complexity control mechanisms such as pruning or ensemble techniques.
2. Performance can decrease when faced with highly variable or noisy data.

2.11.3. Logistic Regression

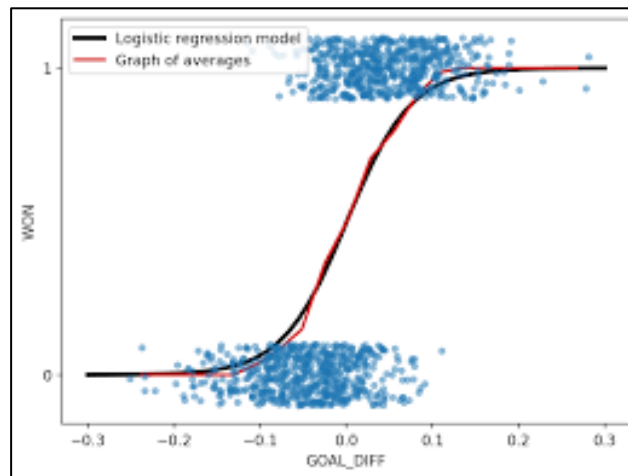


Figure 2. 14 Logistic Regression Modelling

Logistic Regression which is shown at figure 2.14 is a statistical method used to predict the probability of a binary event, such as in the case of "functioning/failing" or "health/sick". This model calculates the probability of a class based on the logistic function of the linear combination of available input variables (Dumitrescu et al., 2022).

Advantages of Logistic Regression:

1. The implementation is simple and does not require high computation.
2. The model results are easy to understand because the coefficients can be interpreted statistically (e.g. through odds ratio or significance).
3. Suitable for binary prediction cases and data with a clear linear structure.

Disadvantages of Logistic Regression:

1. Less than optimal in handling non-linear relationships or when there are complex interactions between features in the data.
2. Unable to effectively handle non-linear relationships between variables, unless a feature transformation is performed beforehand.
3. Performance can degrade on very complex datasets, with interactions between features that cannot be captured linearly.
4. Less flexible than tree-based or ensemble algorithms, especially in large and imbalanced data conditions.

Classification methods provide an important foundation in data-driven decision-making systems. In the context of engine health scoring, algorithms such as Random Forest and Logistic Regression can be used to automatically map the health status of machines based on operational parameters.

Concept Design

Logistic Regression is used to predict the probability of a binary outcome (e.g.: healthy = 1, unhealthy = 0) by utilizing a linear combination of a number of independent variables. In this study, the features used come from the VHMS monitoring system, namely:

1. Temperature (Engine Temperature)
2. Pressure (System Pressure)
3. Fuel Rate (Fuel Consumption)
4. Engine Speed (Engine Rotation)

Each variable is assigned a specific weight that reflects its impact on the engine's condition. The resulting calculation is a probability with a range of 0–1, which is then converted to a Health Score on a scale of 0–100.

Formula Model:

$$P(\text{Health} = 1) = 1/(1 + e - (\beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4)) \quad (1)$$

Where:

X_1 to X_4 are temperature, pressure, fuel rate, and engine speed.

β_1 to β_4 are the weights learned from historical data.

The selection of the appropriate algorithm depends on the characteristics of the data, interpretability needs, and desired prediction accuracy.

2.12. Previous Study

Table 2. 13 Previous Study

No	Title	Objective	Methodology	Implementation
1	Improving the Prediction and Accuracy of Parts Marketing Promotion Program for Heavy Equipment Spare Parts Business <i>Anang Wahyu Wibowo, Gembong Baskoro, Sumarsono Sudarto (2023)</i>	Developing a more accurate and relevant method for predicting spare part promotion opportunities to customer needs, by utilizing digitalization approaches such as big data and machine learning.	- Using the DMAIC (Define-Measure-Analyze-Improve-Control) approach - A combination of two techniques: Machine Learning (XGBoost, Random Forest, SVM) for sales opportunity prediction, and End of Life (EOL) Forecasting based on inspection data and unit working hours (Komtrax). - Internal discussions are conducted through Focus Group Discussions (FGD).	- Use of internal company data such as purchase order history, part interchange, operating hours (Komtrax), and customer classification. - A prediction system was developed in the form of an Undercarriage Analytics Engine to predict spare part needs at a certain time based on wear rates and active unit data. - Monitoring implementation results show an average increase in spare part sales of $\pm$ IDR 5 billion per quarter after the implementation of the predictive system.

The study aims to improve the accuracy of predictions and marketing promotion programs for heavy equipment spare parts through a digitalization approach using two main analytical approaches:

1. Machine Learning Approach: Utilizing historical sales data and spare parts demand, including operational hours data from Komtrax, as well as customer clustering.
2. End of Life (EOL) Spare Parts Approach: Special focus on Undercarriage (UC) spare parts from the Undercarriage Management System (UMS) and active unit data from Komtrax.