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Evaluation of the Production and Quality of Comex Engine Overhaul with 4M1E Method at PT. CA3-Indonesia

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ABSTRACT: This study aims to evaluate the production process and overhaul quality of Comex engines at PT. CA3 throughout 2024. The evaluation applies the 4M1E method and fishbone diagram analysis to identify the root causes behind the low production achievement and high rate of rework (redo). The results show that only 79 engines were overhauled out of the annual target of 179 units (46%), with 14 recorded redo cases, representing 17.7% of the total output. The main contributing factors include insufficient technician competence, inconsistent implementation of SOP and QA procedures, the use of non-genuine components due to spare part shortages, uncalibrated measuring tools, and suboptimal working conditions. Based on these findings, strategic recommendations are proposed, including technician training improvements, the addition of senior-level personnel, implementation of internal audits, and enhancements to the QA system and work environment. This study is expected to serve as a reference for improving the efficiency and quality of engine overhaul processes at PT. CA3.

KEYWORDS: Engine Overhaul, Redo, 4M1E, Quality Assurance, Fishbone Diagram

INTRODUCTION

In the heavy equipment industry, the engine is a critical component that significantly determines a unit's performance and productivity. Over time, intensive use and extreme operational conditions contribute to the degradation of machine performance, with the potential risk of severe damage if regular maintenance is neglected. One essential form of in-depth maintenance to preserve machine performance is engine overhaul. This process aims to restore the machine's condition to near-manufacturer standards by disassembling the engine, inspecting and replacing worn components, and reassembling it in accordance with technical specifications.

PT. CA3 is a national company that provides overhaul services for various heavy equipment components, including engines, main hydraulic pumps, transmissions, differentials, hydraulic cylinders, and other parts. The company operates production branches in Jakarta for Western Indonesia, and in Balikpapan and Banjarmasin for Central and Eastern Indonesia. PT. CA3 has implemented several programs and methods to improve the quality of its overhaul services, including basic overhaul training and specific training tailored to each engine type. Quality Assurance (QA) methods are also applied during the overhaul process to ensure compliance with procedures, component measurement standards, and bolt tightening specifications.

The engine overhaul process at PT. CA3 includes the following stages: engine receiving, disassembly, cleaning and washing, measurement, assembly, and test bench. PT. CA3 provides an overhaul warranty of up to 2,000 operating hours. During the warranty period, preventive maintenance such as oil and filter replacement is performed by the customer, while the branch office monitors performance through regular communication with the customer. However, the high incidence of "redo" cases before the warranty period ends indicate fundamental issues within the production system and quality control mechanisms.

LITERATURE REVIEW

A. Engine Maintenance

According to Wireman (2005), engine maintenance is a series of activities aimed at preserving, repairing, and extending the engine's service life to ensure it operates optimally. In the context of the heavy equipment industry, maintenance plays a critical role, as engines operate under extreme conditions that can accelerate wear and damage. Maintenance activities are generally categorized into three main types: preventive maintenance, corrective maintenance, and engine overhaul.

B. Engine Overhaul

An engine overhaul is a comprehensive repair process that involves complete disassembly, inspection of each component, replacement of worn or damaged p
arts, and reassembly. According to Setiawan (2018), engine overhaul is carried out to restore the engine's condition to near-original factory standards, ensuring sustained performance and efficiency. Overhauls are typically performed after the engine reaches a certain number of

operating hours or when there is a significant decline in performance. The success of an overhaul depends on the accuracy of technical procedures, measurement standards, and the quality of reassembly.

C. Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) is a comprehensive approach to maintenance management aimed at increasing engine productivity by involving all levels of the organization. As stated by Nakajima (1988), TPM emphasizes damage prevention, operator involvement in basic maintenance tasks, and continuous improvement. This concept is highly relevant in the context of engine overhauls, as it highlights the importance of work standards, documentation, and team collaboration.

D. Quality Assurance (QA)

Quality Assurance (QA) refers to a systematic effort to ensure product quality through the implementation of standardized procedures and work protocols. In the context of engine overhaul, QA ensures that all stages of the process comply with technical standards, including torque tightening, component measurement, and performance validation on the test bench.

E. 4M1E Method

The 4M1E method is used to identify the root causes of a problem comprehensively, based on the following factors:

1. Man: Technician competence and discipline
2. Method: Standard operating procedures (SOPs) and consistency of implementation
3. Material: Quality of components and parts
4. Machine: Availability and precision of tools and equipment
5. Environment: Work atmosphere, contamination control, and occupational safety

F. Fishbone Diagram

The fishbone diagram is an analytical tool used to identify the root causes of a particular problem. Developed by Ishikawa (1968), this method helps teams systematically map out potential causes of undesirable outcomes and is commonly used in quality improvement initiatives.

RESEARCH METHODS

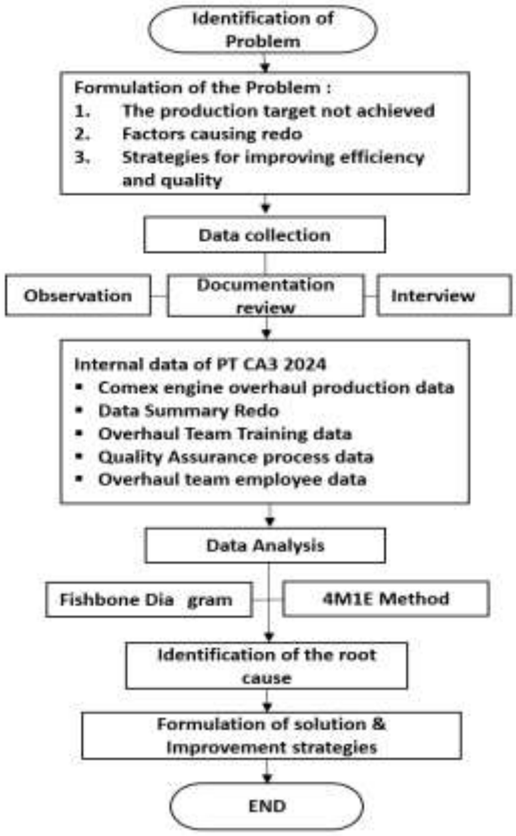


Figure 1. Flow Chart Research Methodology

This study employs a descriptive research design using both quantitative and qualitative approaches. The data sources consist of internal records from PT. CA3 for the year 2024, which include:

- Workshop production data for engine overhaul in 2024
- Engine redo summary data (including frequency and causes)
- Quality Assurance process data
- Overhaul team personnel data
- Training records for the engine overhaul workshop team

Data analysis is conducted using the fishbone diagram method and the 4M1E approach to comprehensively map problems and identify appropriate solutions. Data collection techniques include direct observation, document review, and interviews with technicians and the QA team.

Research Questions

1. Why has the overhaul production target not been achieved for the Comex engine?
2. What are the dominant factors contributing to redo occurrences in engine overhauls?
3. What improvement strategies can be implemented to enhance the efficiency and quality of engine overhauls?

RESULTS AND DISCUSSION

A. Production Summary Data and Redo Summary Data

Table 1. Summary of Engine Overhaul Production Data – PT. CA3 Workshop, 2024

Month	Jakarta	Samarinda	Banjarmasin	Engine RFU	Target Engine RFU	Target Engine RFU %
January	5	7	5	17	16	106%
February	5	1	4	10	16	63%
March	3	4	1	8	11	73%
April	2	3	1	6	11	55%
May	2	4	3	9	13	69%
June	2	4	1	7	16	44%
July	1	1	1	3	16	19%
August	2	4	0	6	16	38%
September	2	1	0	3	16	19%
October	3	2	0	5	16	31%
November	2	1	1	4	16	25%
December	1	0	0	1	16	6%
TOTAL	**30**	**32**	**17**	**79**	**179**	**46%**

Based on the 2024 engine overhaul production data, PT. CA3, which operates three production branches—Jakarta, Samarinda, and Banjarmasin—recorded a total of 79 completed engine overhauls out of an annual target of 179 units, achieving only 46% of the planned target. The Jakarta branch contributed 30 units, Samarinda 32 units, and Banjarmasin 17 units to the total output. The highest monthly production occurred in January, with 17 engines overhauled, representing 106% of the monthly target. In contrast, the lowest production was recorded in December, with only one engine completed, equating to 6% of the monthly target.

Overall, the production trend showed a significant decline throughout the year, particularly after the first quarter. Most monthly achievements remained below 70% of the target, with only January exceeding expectations. The remaining months consistently demonstrated a considerable gap between actual performance and set targets, with months such as September, October, November, and December reporting achievement levels below 35%. These low figures indicate the presence of operational bottlenecks or challenges in the engine overhaul process across all branches. Further evaluation is necessary to identify the underlying causes and to formulate improvement strategies for the subsequent year.

Table 2. Data Summary Engine Redo.

No	Month	Branch	Component	Unit	Customer	Type of Redo	Engine No	Date RFU	Hourmeter	Warranty Status
1	January	Jakarta	Engine	EXCA30	PT. BCA	Hight Blow by	076324 AC	13/01/2023	930	Waranty
2	January	Jakarta	Engine	EXCA30	PT. BCA	Hight Blow by	077106 AC	14/01/2024	812	Waranty
3	Febuary	Samarinda	Engine	EXCA52	PT. MLR	Engine Jammed	002658 AB	11/02/2024	902	Waranty
4	March	Samarinda	Engine	EXCA52	Comex	Engine Jammed	104279 AB	19/03/2024	1367	Waranty
5	April	Samarinda	Engine	EXCA52	Comex	Engine Blowby	800610 AB	19/04/2024	839	Waranty
6	May	Banjarmasin	Engine	COMPACTOR30D	PT.MKG	Engine Leaking	849594 GB	20/05/2024	1802	Waranty
7	May	Jakarta	Engine	EXCA50	PT. BCA	Engine Noise	656474 CD	23/05/2024	1221	Waranty
8	July	Jakarta	Engine	EXCA50	PT NPM	Engine Noise	212624 CD	10/07/2024	441	Waranty
9	July	Samarinda	Engine	TRUCK60	PT SKP	Oil Mix Fuel	372796 MT	31/07/2024	1653	Waranty
10	September	Samarinda	Engine	EXCA22	PT BSB	Engine Overheat	104004 AC	20/08/2024	1463	Waranty
11	October	Jakarta	Engine	EXCA52	PT. TGM	Oil Mix Coolant	800083 AB	30/09/2024	1612	Waranty
12	October	Jakarta	Engine	TRUCK50	PT. PAP	Cyl Block Damage	803691 MA	29/09/2024	1335	Waranty
13	November	Banjarmasin	Engine	EXCA50	PT MMM	Fragments of material in filter	107983 CD	21/11/2024	229	Waranty
14	November	Samarinda	Engine	EXCA52	Comex	Fragments of material in oil pan	206925 AB	05/11/2024	658	Waranty

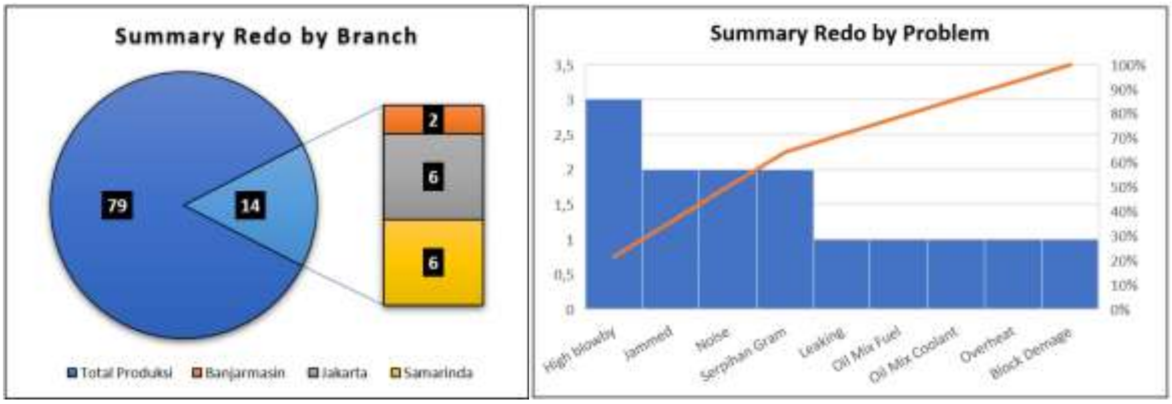


Figure 2 & 3. Diagram redo by branch & Pareto redo by problem.

Throughout 2024, a total of 14 engine overhaul redo cases were recorded across PT. CA3's three production branches—Jakarta, Samarinda, and Banjarmasin. When compared to the total of 79 overhauled engines, this represents a redo rate of approximately 17.7%, indicating significant challenges in maintaining the quality of overhaul outcomes. The distribution of redo cases shows that both the Samarinda and Jakarta branches accounted for 6 cases each, while the Banjarmasin branch reported 2 cases.

B. Redo Problem Type

Figure 4. Engine high blowby.

This issue was caused by combustion gas compression leaking into the crankcase, typically due to worn piston rings, imprecise cylinder liners, or improper assembly. The occurrence of three cases early in the year suggests a possible failure in final inspection or errors during the assembly process.

Figure 5. Piston jammed.

This indicates severe mechanical damage such as seized pistons, bent connecting rods, or damaged bearings. Such failures may result from inadequate cleaning processes, insufficient pre-lubrication, or components that do not meet standard tolerance specifications.

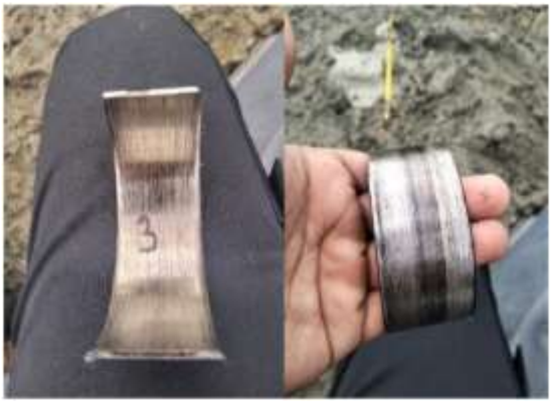


Figure 6. Main bearing crankshaft wear (Engine Noise).

Abnormal noise issues are typically caused by incorrect bearing clearances, uneven torque application during assembly, or excessive backlash between gear components. These problems reflect inaccuracies in the final checking process or negligence in torque setting during assembly.

Figure 7. Fragments of material.

Metal particles (metal shavings) were found in the filter or oil pan, indicating contamination during the assembly process or inadequate cleaning of components. This issue may also be related to insufficient cleanliness control in the work area.

Figure 8. Oil seal leak (Engine Leaking).

Leaks can occur due to improperly installed seals, damaged gaskets, or cracks in the housing. One such case occurred in a compactor unit, indicating the need for a thorough reinspection of the sealing system and fluid leakage.

Figure 9. Oil mix fuel.

This is a serious issue where lubricant mixes with fuel, which can be caused by leaking injector seals or failure of the fuel pump. This problem typically arises due to initial misdiagnosis or incorrect seal installation.

Figure 10. Oil mix coolant.

He mixture of oil and coolant can be caused by leaks in the oil cooler, cracks in the cylinder head, or a faulty head gasket. This indicates a problem in the separation system between the lubricant and the coolant.

Figure 11. Cylinder block demage.

Damage to the cylinder block can be caused by incorrect torque during installation, undetected wear during inspection, or material defects that passed inspection.

Figure 12. Engine overheats.

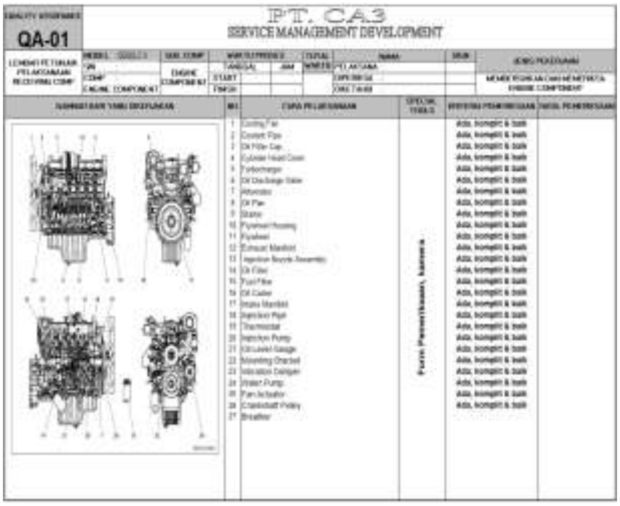
The engine experienced overheating, which may be caused by imperfect coolant circulation, suboptimal radiator performance, or malfunctioning temperature sensors. This failure often indicates insufficient thorough testing after the overhaul.

C. Quality Assurance

Figure 13. Quality Assurance Book.

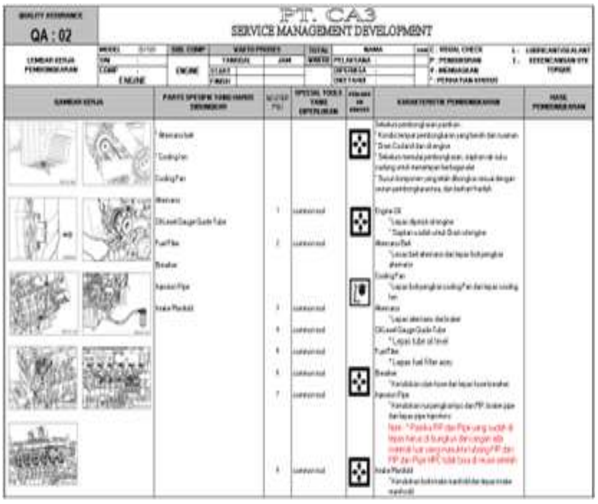
Quality Assurance (QA) in the engine overhaul process is a quality control system aimed at ensuring that every stage of engine repair is carried out in accordance with established quality standards. QA covers several critical aspects; at PT. CA3, it is implemented through five stages: Receiving (QA1), Disassembly (QA2), Measurement (QA3), Assembly (QA4), and Test Performance (QA5).

Table 3. QA1 – Receiving Engine.



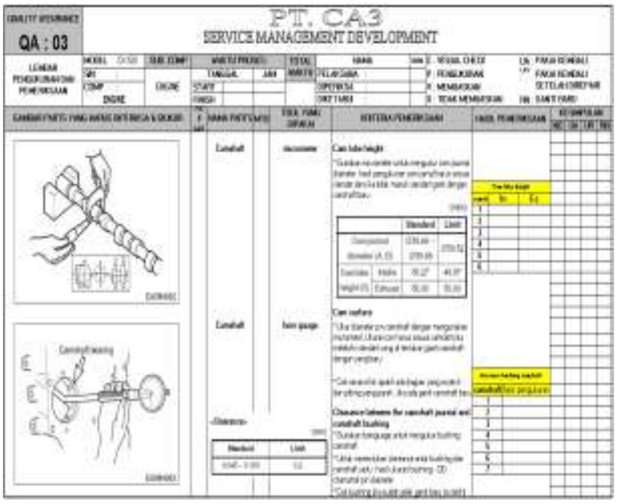
The first stage in QA is to ensure that the engine received for overhaul meets the expected specifications and does not have any damage that could hinder the repair process. Technicians perform a visual inspection to identify potential external issues such as oil leaks, excessive wear, or missing components. Component completeness is checked to ensure that all parts to be repaired or replaced are available before the process begins.

Table 4. QA2 – Disassembly.



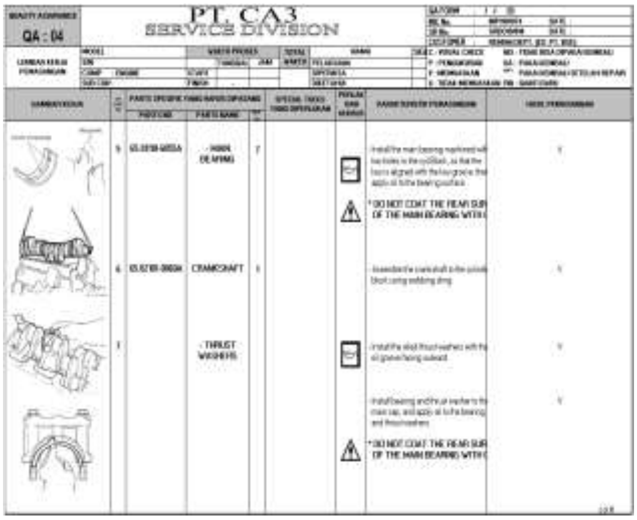
At this stage, the engine is disassembled systematically following procedures that ensure all components are removed safely and properly documented. Each removed component is identified and recorded to prevent loss or incorrect installation during the final assembly stage. Initial cleaning is carried out to remove dirt, carbon deposits, and oil residues prior to further inspection. Visual and structural examinations are conducted on key components such as the piston, crankshaft, and cylinder head to assess their initial condition before more in-depth testing.

Table 5. QA3 – Measurement.



After disassembly, detailed measurements are conducted to ensure that each component meets the technical specifications set by the manufacturer or industry standards. Precision measuring tools such as micrometers, bore gauges, and dial indicators are used to check the dimensions and tolerances of the components. Material testing is also carried out, including wear and crack analysis using non-destructive methods such as ultrasonic testing or dye penetrant testing. An inspection report is then prepared, documenting the measurement results and determining whether each component can be reused, reconditioned, or replaced.

Table 6. QA4 – Assembly.



Once the components have been inspected and confirmed to meet the required standards, the engine is reassembled. High-quality spare parts are selected to replace any damaged or worn components. Proper assembly procedures are applied, including the use of correct torque specifications for bolts and joints to prevent mechanical failure. Compatibility checks are carried out to ensure that all components are correctly installed according to the manufacturer's specifications.

Table 7. QA5 – Test Performance.

After the engine has been fully assembled, comprehensive testing is conducted to ensure that its performance meets the required standards before being put back into operation. A dyno test (dynamometer test) is performed to measure power output, torque, and fuel efficiency after the overhaul. A leakage test is conducted to verify that there are no oil, fuel, or coolant leaks that could disrupt engine operation. Work condition simulations are also carried out by running the engine under various load levels and RPMs to observe performance stability.

When the Quality Assurance (QA) process in engine overhaul is properly implemented, the results align with established quality standards, ensuring more stable engine performance and reducing the risk of mechanical failure or the need for rework (redo). However, findings indicate that in several branches, QA implementation is not optimal. Some overhauls were conducted without adequate QA procedures, and in other cases, QA documentation was incomplete or lacking.

This situation can have serious implications for engine reliability, increasing the risk of operational failure and potentially leading to losses due to substandard engine performance. Without stringent QA, the likelihood of assembly errors, the use of non-compliant components, and inadequate validation of overhaul results becomes significantly higher. Therefore, it is essential to improve the QA system by ensuring that each stage is implemented consistently and thoroughly documented in order to maintain the quality, reliability, and safety of the engine after overhaul.

D. Employee Data Engine Team

Table 8. Employee data 2024.

No	Name	Mechanic Level	Branch	Status
1	Ahmad	Senior Mechanic	Jakarta	Resign of January
2	Nanda	Midle Mechanic	Jakarta	Resign of May
3	Indra	Junior Mechanic	Jakarta	Permanent Employee
4	Amin	Junior Mechanic	Jakarta	Permanent Employee
5	Dwi	Junior Mechanic	Jakarta	Permanent Employee
6	Deden	Junior Mechanic	Jakarta	Contract Employee
7	Alim	Junior Mechanic	Jakarta	Contract Employee
8	Ali	Senior Mechanic	Banjarmasin	Permanent Employee
9	Rian	Midle Mechanic	Banjarmasin	Permanent Employee
10	Wawan	Junior Mechanic	Banjarmasin	Permanent Employee
11	Sarko	Junior Mechanic	Banjarmasin	Permanent Employee
12	Putra	Junior Mechanic	Banjarmasin	Contract Employee
13	Toni	Senior Mechanic	Samarinda	Resign per Februari
14	Mahmud	Midle Mechanic	Samarinda	Resign Mei
15	Budi	Junior Mechanic	Samarinda	Permanent Employee
16	Tama	Junior Mechanic	Samarinda	Permanent Employee
17	Edi	Junior Mechanic	Samarinda	Permanent Employee
18	Arul	Junior Mechanic	Samarinda	Permanent Employee

Based on the available data, the highest post-overhaul engine failure rates were recorded at the Jakarta and Samarinda branches. This aligns with the manpower composition at both branches, where all personnel involved in engine work are junior-level mechanics, which is the entry-level tier for mechanical technicians.

In contrast, the Banjarmasin branch demonstrated better results in terms of overhaul quality. A contributing factor is the presence of one senior-level mechanic and one mid-level mechanic, both of whom possess higher competencies and can serve as role models as well as leaders during task execution.

These findings indicate that the presence of higher-grade personnel positively impacts the quality of work. If just one mid-level mechanic can deliver significant improvement, increasing the number of mid-level or senior-level personnel at each branch has the potential to enhance overall engine overhaul quality and reduce the rate of failures or rework (redo).

E. Data Annual dan Actual training

Table 9. Annual Training 2024.

Annual Training Calender 2024		
No	Program Title	Duration (Hours)
1	Training Preventive Maintenanve ET	24
2	Training Preventive Maintenanve DTA	24
3	Training BMC Part 22	40
4	Training BMS	128
5	Training Intermediate Engine	40
6	Training Intermediate Powertrain	40
7	Training OVH XSQ 15	40
8	Training OVH PK5	40
9	Training Preventive Maintenance LW	24
10	Training Preventive Maintenance Dz	24
11	Training Preventive Maintenance Mg	24
12	Training BMC Part 23	40
13	Training Preventive Maintenance TDR	24
14	Training Intermediate Hydraulic	40
15	Training Intermediate Electric	40
16	Trainng Refreshment ET	40
	Total	632

Table 10. Actual Training 2024.

Actual Training 2024		
No	Program Title	Duration (Hours)
1	Training Basic Electric	132
2	Training Basic Engine System DS12	16
3	Training Basic Hydraulic	76
4	Training BMS	80
5	Training Basic Powertrain	100
6	Training Intermediate Hydraulic	200
7	Training Intermediate Engine	32
8	Training OVH XSQ 15	40
9	Training Preventive Maintenance Dz	64
10	Training Preventive Maintenanve DTA	48
11	Training Preventive Maintenance TDR	24
12	Training Preventive Maintenanve ET	88
13	Training Preventive Maintenance LW	32
14	Training PK	23
15	Training SVD DYC Cumns	3
16	Training ADV TD90 / TD95	40
17	Training Intermediate Hydraulic SHT E&Dz	16
18	Training Intermediate Hydraulic PT & ELT Mg	16
19	Training Intermediate Hydraulic PT & ELT Dz	24
20	Training Opt & Pm TD90 / TD 95	24
21	Training Tyre Knowledge	2
	Total	1080

In 2024, the total number of technical training hours conducted reached 1,080 hours, covering training programs from preventive to intermediate levels. Of this total, 91 hours were allocated to engine-related training, accounting for approximately 8% of all technical training. Meanwhile, according to the initial plan outlined in the 2024 Annual Training Calendar, the total planned technical training hours were 632, with 120 hours designated for engine training (around 19%).

When compared to the original plan, the overall technical training experienced a 71% increase. However, this increase was not reflected in engine training, which actually saw a decrease in realization to 91 hours, or only 76% of the original target. This discrepancy between planned and actual training hours is likely due to the dynamic nature of field demands, which can influence training priorities.

F. Discussion of the 4M1E Method

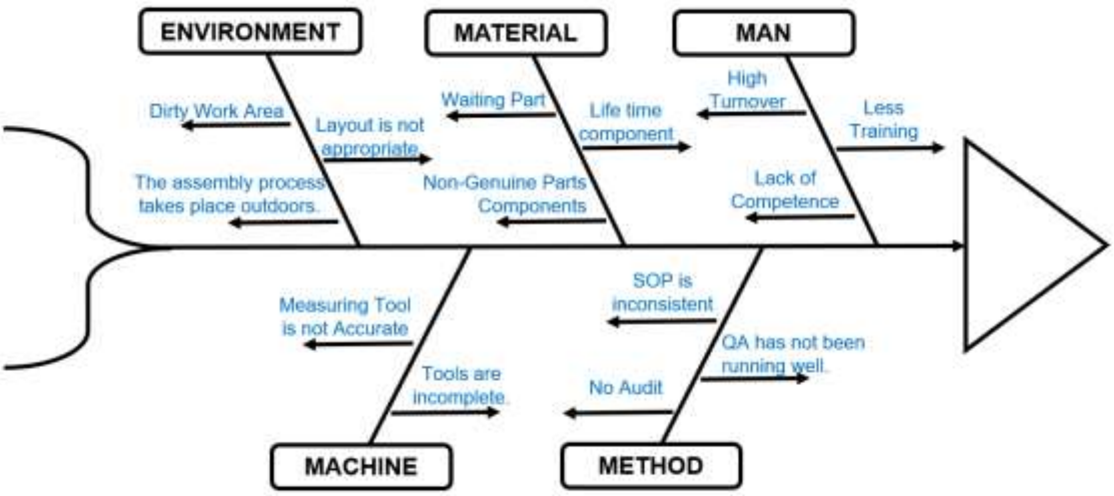


Figure 14. Diagram Fishbond 4M1E.

Based on the data presented above and the 4M1E approach, we can analyze the main causes for the high number of engine redos and the failure to achieve the overhaul production targets in 2024 across various production branches as follows:

Man (Human): The uneven composition of manpower and the varying competency levels of mechanics are the most significant factors causing rework (redo) after the overhaul process and the failure to meet production targets in 2024. The resignation of senior mechanics without replacements during the same year has contributed to a high turnover issue that has persisted from previous years. Additionally, the lack of adequate competency training related to overhaul and engine maintenance in 2024 has further contributed to the occurrence of redos and missed targets.

Method: The implementation of Quality Assurance (QA) in the overhaul process has been suboptimal, mainly due to the mechanics' lack of discipline or awareness regarding the importance of QA in ensuring overhaul quality. Weak supervision in the QA documentation and data entry processes has also increased the potential for errors during the overhaul. Furthermore, the absence of an internal audit system to ensure consistent implementation of Standard Operating Procedures (SOP) should be considered as a contributing factor to the high redo rate.

Material: The use of non-genuine components has become a serious problem in the overhaul process. Several branches rely heavily on local components, which adversely affect the final quality. This issue is exacerbated by parts waiting times in the Parts Inventory department. The variation in material quality increases the risk of component failure after the overhaul, thus shortening the overhaul lifecycle.

Machine: The supporting tools and equipment for the overhaul process are often incomplete, which constitutes a major issue. Some tools have been found to be inaccurate due to a lack of regular calibration. Additionally, the limited availability of specialized tools for inspection and engine assembly hinders both efficiency and precision in the work process.

Environment: The working conditions at several branches do not meet cleanliness and safety standards. Unclear layout, unclean areas, and assembly processes conducted in open spaces increase the risk of contamination during engine assembly. Additionally, high work pressure due to production targets causes mechanical stress, which may reduce concentration and accuracy during work.

Based on the results of the study and analysis of the Comex engine overhaul process at PT. CA3 in 2024, the following conclusions are drawn:

1. The actual production achievement of engine overhauls in 2024 reached only 46% of the established target, with 79 units completed out of the planned 179 units. This indicates the presence of significant operational challenges affecting production performance across all branches.
2. The rework rate (redo) was recorded at 17.7%, highlighting inconsistencies in meeting the expected quality standards. A majority of rework cases were concentrated in the Jakarta and Samarinda branches.
3. Using the 4M1E (Man, Method, Material, Machine, Environment) analytical framework, the root causes of the identified issues can be categorized as follows:
   - Man (Human): Disparities in technician competency levels, insufficient training programs, and a high turnover rate.
   - Method: Inconsistent application of Standard Operating Procedures (SOP) and Quality Assurance (QA) processes, as well as inadequate documentation and supervision.
   - Material: Use of non-genuine parts due to limited availability of original components.
   - Machine: Inaccurate measuring instruments and a lack of specialized tools required for precision work.
   - Environment: Poor workplace conditions, including unclean areas, non-ergonomic layouts, and high-stress environments.
4. The implementation of Quality Assurance (QA) procedures was found to be suboptimal in several branches. This directly compromised the reliability of overhaul outcomes, increased the likelihood of rework, and contributed to operational inefficiencies and potential financial losses.

CONCLUSION AND SUGGESTION

A. Conclusion

This study provides a comprehensive overview of the Comex engine overhaul process at PT. CA3 throughout 2024, focusing on three key aspects. **First**, the production achievement, which reached only 46% of the annual target, reflects significant operational challenges in achieving performance goals. **Second**, the high rework rate of 17.7% indicates that the quality of overhaul outputs remains inconsistent with established standards. In-depth analysis identified several root causes, including limited technician competencies, suboptimal implementation of Quality Assurance (QA) procedures, the use of non-original components, insufficient precision tools, and inadequate working environment conditions. **Third**, this study proposes strategic recommendations to address these issues, including enhanced technician training, strengthening of the QA system, ensuring the availability of genuine spare parts, and redesigning the workplace layout. The findings of this evaluation are expected to serve as a reference for PT. CA3 in implementing continuous improvement efforts aimed at enhancing the quality and efficiency of future engine overhaul processes.

B. Suggestion

To improve the efficiency and quality of the engine overhaul process, the following recommendations are proposed:

1. Enhance technician competencies through regular and specialized training programs focused on engine overhaul procedures. Periodic refresher training should also be implemented to reinforce technical skills.
2. Increase the presence of senior or mid-level technicians at each branch to ensure effective mentoring and on-site supervision throughout the overhaul process.
3. Strengthen the enforcement of Standard Operating Procedures (SOP) and Quality Assurance (QA) protocols, and establish a continuous internal audit system to verify the consistency of quality standard implementation.
4. Ensure the availability of original (OEM) components by improving coordination between the workshop and the inventory/parts department.
5. Conduct regular calibration of measuring instruments and invest in specialized tools to support accurate engine assembly and inspection procedures.
6. Improve cleanliness and organization of the work area, redesign the layout based on ergonomic principles, and maintain a conducive working environment that promotes technician focus and safety.
7. As a follow-up to this study, the authors recommend conducting periodic evaluations of the engine overhaul process—ideally every six months or annually—to

enable continuous monitoring of production performance and overhaul quality. In addition, future research is encouraged to adopt alternative analytical approaches or methodologies, such as Failure Mode and Effects Analysis (FMEA), Six Sigma, or other statistical methods, to validate the consistency of findings and provide broader perspectives on the root causes of performance issues.

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