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Turnaround Time Efficiency In MRO Industry : A DMAIC Based Evaluation Of Gate System Quality Performance

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ABSTRACT

Purpose – This research aims to evaluate the effectiveness of implementing a gate based quality control system to improve turnaround time efficiency in an engine maintenance process at PT. GMF AeroAsia. The root cause of the problem began with the consistent failure to achieve the TAT target during the 2022-2024 period, with gates 4-5 contributing the largest delays, particularly in the supply chain. The objective of this study was to identify the root cause of the problem at these gates.. **Methodology/approach –** The research employed quantitative and qualitative descriptive methods. Data collection involved quantitative analysis, observation of operational documentation, and semi-structured interviews. The analysis followed the DMAIC process, including cross-variable testing and mapping of the main root causes. **Findings –** The main root causes were identified as the lack of a Service Level Agreement per gate, limited front-loading working capital, and weak coordination between units. Systemic non-compliance in the approval and purchasing processes was also a contributing factor. DMAIC implementation resulted in significant improvement strategies, including planning system integration, reserve fund policies, and procurement process digitization.**Novelty/value –** This study offers a comprehensive solution that utilizes Six Sigma DMAIC integrated with Critical Chain Project Management and Reliability Centered Maintenance in the MRO industry. The approach taken not only increases efficiency but also builds a continuous improvement strategy.

INTRODUCTION

The main challenges in the aircraft engine maintenance process are the demand for high Turnaround Time (TAT), which will have an impact on the operational efficiency of MRO companies. Therefore, an effective strategy is needed to optimize the Quality Control process in business processes in the company. In the process of maintenance at Engine Maintenance, there is a business flow that occurs so that the process runs sequentially. This process is called the Gate System. Where this process will go through a project management approach, which will divide the work process into a series of stages or gates that must be passed sequentially. Each gate functions as a checkpoint where project progress can be evaluated before moving on to the next stage. The gate system is used to ensure that every step in the aircraft engine maintenance process runs according to standards, is efficient, and is well documented.

The aviation and aircraft maintenance industry needs operational efficiency as one of the main indicators in assessing business performance and sustainability. Not only related to the speed of service, but also related to quality control, work safety, and strict time management. In this case, managerial transformation and adaptive leadership have also been proven to have an impact on increasing work efficiency and operational safety (Usman et al., 2022) The Maintenance, Repair, and Overhaul (MRO) industry is fully responsible for ensuring that every aircraft engine that is maintained meets the established standards. In its operations, engine maintenance is divided into several work scope maintenance. This maintenance process follows a gate system that starts from Gate 0 (disassembly) to Gate 10 (exit meeting and invoicing) which functions to ensure that each stage of maintenance is carried out systematically. However, in practice, there are various obstacles that cause the Turnaround Time (TAT) for aircraft engine maintenance to often not reach the target. Based on operational data during the period 2022 - 2024, the average TAT produced rarely reaches the target of 100%. The report shows that maintenance faced various challenges. Based on evaluations conducted in the last 3 years, there are several main factors that cause TAT inefficiency. Starting with delays in various stages of the gate system, especially at Gate 2 (Inspection), Gate 4-5 (Supply Chain) Gate 6 (Sub-assembly), and Gate 8 (Final & Assembly Test).

Furthermore, by analyzing the causes of delays, it shows that the main categories that contribute to TAT inefficiency are working capital with a total of 1091 days, followed by external vendor causes with a delay of 164 days, material sourcing/purchasing 93 days, additional finding 90 days, and planning & scheduling 60 days. Delays in payment and material procurement cause the repair process to stagnate, while the lack of coordination in planning and inspection has an impact on the overall TAT extension. This problem shows that Quality Control in the engine maintenance gate system is not optimal in supporting the achievement of Turnaround Time. In previous studies, the Lean Six Sigma method has been proven to increase efficiency in various manufacturing and service sectors, including the aviation industry. However, there have not been many studies that specifically examine the integration of Quality Control with the Gate System in the Engine Maintenance process. Such as research conducted by (Prashar, 2014) shows that the application of Six Sigma DMAIC can reduce the Cost of Poor Quality (COPQ) and defect rate in aircraft maintenance but has not been widely applied in the context of commercial aircraft engine maintenance.

LITERATURE REVIEW

Operations management in the MRO industry plays a crucial role in ensuring the efficiency and effectiveness of the maintenance process. Cost leader ship operations strategies and supply chain integration are the foundation for managing resources and planning efficient production processes (Gupta & Boyd, 2008). Operational efficiency is not only measured by the speed of service but also in terms of the organization's ability in terms of time, cost, labor, and materials in a balanced manner (Zidane & Olsson, 2017). This efficiency is important in the engine maintenance process because it has a direct impact on operational delays that occur.Quality control plays a role as a maintenance stage in accordance with established standards. In the aviation industry, Six Sigma DMAIC has proven effective in identifying the root cause of process problems, reducing variation and increasing efficiency (Maleyef, 2022; Prashar, 2014). This method helps organizations map problems from the start until improvements are made. In addition, DMAIC is able to eliminate waste that causes TAT to be inefficient (Jones & Dowdall, 2022).

When the process approach is often insufficient in complex projects such as engine maintenance, there are challenges in time and resource management that are major factors in delays. To overcome this, CCPM is used as an alternative support to reduce buffer management and avoid multitasking. CCPM has proven effective in accelerating project completion while maintaining quality, especially on projects with limited technicians and materials (Junqueira et al., 2020; Leach, 2000).

On the other hand, engine reliability is highly dependent on risk-based maintenance strategies. RCM is a method with a systematic framework for identifying potential failures, evaluating their impact, and designing preventive and predictive maintenance strategies. The application of RCM in the aviation sector is able to reduce downtime and increase operational reliability (Ali Ahmed Qaid et al., 2024;

Moubrey, 2000). Overall, integration using the Six Sigma DMAIC approach supported by CCPM and RCM provides a more holistic strategy to overcome maintenance delay problems. This third combination is very relevant in the context of the gate system, especially at gates 4-5 as the point of greatest delay in TAT (MacDonnell & Clegg, 2007;Salama et al., 2021; Sarjono et al., 2021). The integration carried out is expected to overcome bottlenecks as a whole and increase efficiency and effectiveness in the MRO industry.

METHOD

The research methodology in this study uses a mix method approach with quantitative as the main method and is supported by a descriptive qualitative approach. The design carried out in this study was designed to evaluate the application of six sigma DMAIC to the gate system, especially those that occur at gates 4-5. This study aims to analyze the influence of delay factors such as working capital, external vendor causes, and material purchasing on the engine maintenance process. The quantitative approach was chosen because it is able to provide an objective measurement picture and strong statistical analysis in answering the relationship between variables (Sugiyono, 2013). While the qualitative approach is used to explore a deeper context related to unrecorded process obstacles such as coordination between units or external vendor constraints (Cresswell, 2016).

The object of research is carried out on the gate 4-5 in the engine maintenance process. This process is reviewed because based on data that has been collected in the period 2022-2024, gate 4-5 are the contributor to the highest percentage of delays. Activities that occur at gate 4-5 include the supply chain management process, repair activities, and material procurement. The main materials and tools in this study include historical data on engine maintenance delays, TAT reports, Repair Documents, and the ERP system used in the company. In the quantitative approach, IBM SPSS Statistics software is used to conduct linear regression and chi-square tests. Value stream mapping tools are also used to identify process bottlenecks (Jones & Dowdall, 2022). The research location was at PT. GMF AeroAsia, Tangerang, Banten, Indonesia in the engine maintenance division. Data collection techniques were carried out by triangulation, namely documentation, observation, and semi-structured interviews

This study used descriptive statistical data analysis techniques to describe the pattern of delays and data characteristics. The study was also conducted with a linear regression test to determine the effect of the delays that occurred, while the chi-square test was used to determine the relationship between two variables. A thematic analysis process was also carried out to process interview data qualitatively to strengthen the results of the statistical analysis.

RESULT AND DISCUSSION

This study analyzes the delays that occur at gate 4-5 in the engine maintenance process. The results of the study were obtained based on quantitative and qualitative data analysis. This study uses the Six Sigma DMAIC approach to evaluate process effectiveness, identify delays that occur, and develop recommended alternative solutions to improve TAT efficiency. The results obtained will be followed by the DMAIC stages as follows

A. DEFINE

Delays in the gate system are caused by several internal and external factors. Based on data obtained from 2022-2024, the causes of delays can be classified as external and internal delays. Based on data focused on gates 4-5, the causes of delays stem from both internal and external factors. There are four categories of delays caused by internal factors and three categories of delays caused by external factors. To understand the scope that occurs in the working capital gate 4-5 process, a SIPOC (Supplier, Input, Process, Output, Customer) approach is used, which functions to map the scope that occurs according to the following table.

Table 1. SIPOC Gate 4-5 Working Capital

SIPOC Working Capital GATE 4-5 SCM	
Supplier	Procurement Team Budget/Finance Team External Vendor
Input	Material Request Purchase Requisition Project Budget Proposal
Process	Verification of Requirements Budget Approval Purchasing Order Publish Down Payment
Output	Availability of funds for the assembly process Availability of materials for the assembly process
Customer	Technician Gate 6 Quality Control Team Customer Engine

The SIPOC approach used helps to understand how working capital delays can significantly impact TAT. This SIPOC overview explains that working capital problems are not only related to internal issues but have a systemic impact on the entire engine maintenance process.

B. Measure

This stage aims to measure the actual performance of the process occurring at gates 4-5. Existing issues will be quantified based on historical engine maintenance data. This discussion will focus on metrics that influence delays.

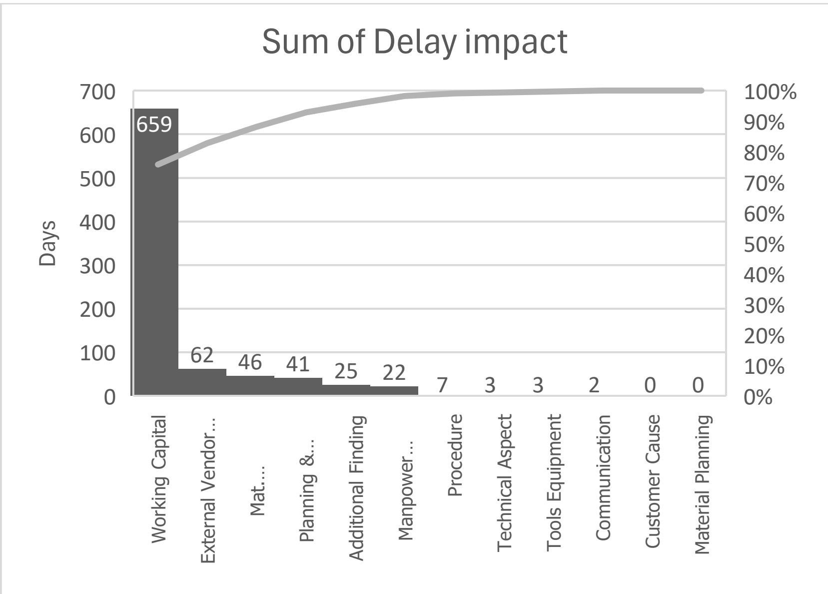

Figure 1. Delay cause Impact

Based on the Pareto diagram in Figure 1, working capital is identified as a category with a high incidence of delays. From 2022 to 2024, it resulted in 659 days of delays at gates 4-5. This suggests several causes within the working capital category that require further investigation. However, based

on measurements made on the frequency of the number of incidents with the delay category in the following image.
The research shows that customer causes were the most frequent, with 33 occurrences, while working capital came in second with 22 occurrences. This suggests that the number of delays does not necessarily influence the impact of the delay. The initial analysis used to determine the relationship between the delay in working capital at gates 4-5 and actual TAT used a simple linear regression test so that the following results were obtained. The resulting coefficient of determination of 0.270 indicates that 27% of the variation in actual TAT can be explained by the delay in working capital at gates 4-5. Meanwhile, the R value of 0.520 indicates a moderate but significant correlation.

Table 2. Summary of Statistical Analysis Results

Analysis	Description	Statistical Results
ANOVA (Effect of Working Capital Delay on Actual TAT)	Model significance	F = 31.810; p = 0.000
	Model strength	Indicates strong model fit (R^2 implied)
Simple Regression Coefficients	Constant	B = 77.302; p = 0.000
	Working Capital Delay	B = 0.720; Beta = 0.520; t = 5.640; p = 0.000
Multiple Regression (Three Predictors)	Constant	B = 83.236; p = 0.000
	Working Capital Delay	B = 0.661; Beta = 0.477; t = 5.599; p = 0.000
	Vendor Delay	B = –1.547; Beta = –0.364; t = –4.272; p = 0.000
	Material Delay	B = –0.310; Beta = –0.036; t = –0.423; p = 0.673
Pearson Correlation	Working Capital Delay ↔ Delay Impact Gate 4–5	r = 0.675; p = 0.000 (significant)**

Furthermore, in table 2 the results of the ANOVA test strengthen the results of the measurements carried out where the F value is 31.81 and the significance of p is 0.000 below 0.
The regression coefficient test for working capital delay yielded a β of 0.720, a t-value of 5.640, and a p-value of 0. To strengthen the measurement results, a multiple regression analysis was conducted involving the categories Working Capital, External Vendor Cause, and Material on TAT. These results can be used to identify the combined influence of several factors causing TAT delays. The results showed that working capital had the most significant influence compared to other categories, with a β value of 0.447, while the other categories showed a negative relationship and no significance.
The Pearson test aimed to demonstrate a strong relationship between working capital and delays at gates 4-5 and actual TAT. The test results are presented in the following table.
The Pearson test results show an r value of 0.675 and a p value of 0. This means that most of the delays occurring at gates 4-5 are significantly influenced by constraints in the approval and funding processes. Improvements should be focused on financial processes and budget planning.
Based on the Sigma Level calculation, namely the proportion of engines that successfully complete the TAT process on time at gates 4-5 with a yield value of 47.46% where based on the sigma level table,

the yield value is equivalent to 1.45 sigma. These results indicate that there is a high level of variation, the results are far from the industry minimum level of 3 sigma.

C. Analyze

The problems found in gates 4-5 were predominantly caused by working capital. Measurement results also showed that the working capital category in gates 4-5 exhibited a strong correlation as the main cause of the problems. To strengthen the quantitative evidence of the relationship between variables, a scatter plot visualization was performed as follows.

Visually, the distribution of points indicates a positive trend, where working capital delays are followed by increasing days of delay at gates 4-5.

There is a concentration of points in the low working capital delay area of around 0-20 days, with relatively smaller variations in delays on the y-axis. Several points at the top of the graph also illustrate the case of engine units with significant working capital delays of 80-90 days, followed by gate delays of 80-100 days. This indicates that working capital allocation constraints are a major driver of prolonging the material procurement and completion time at gates 4-5.

The complex factors that are interconnected are compiled using a fishbone diagram using the 6M approach (Man, Method, Material, Measurement, Money) to identify the main causes of working capital.

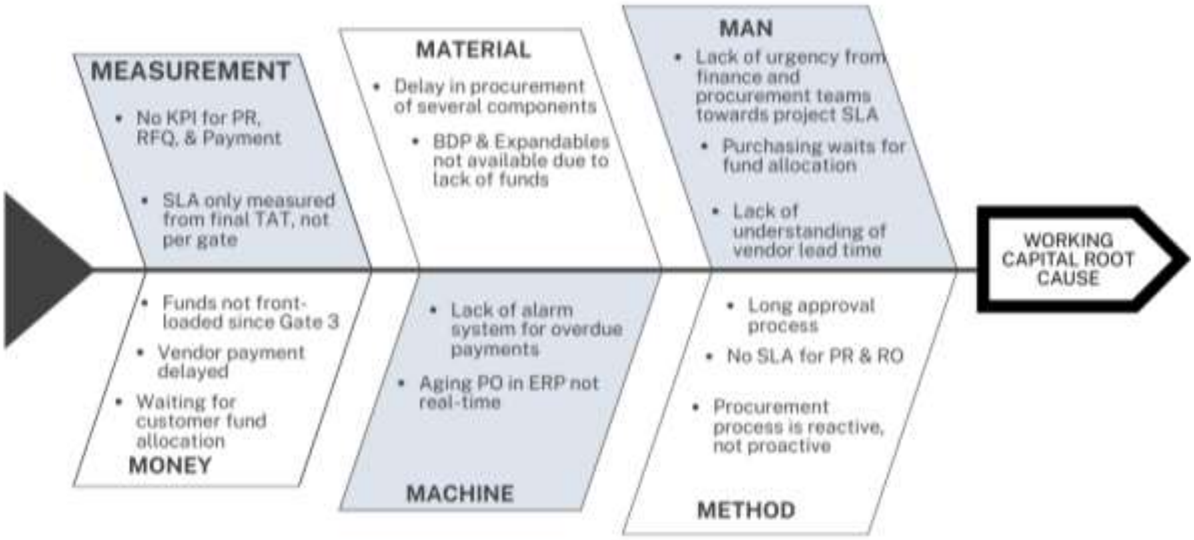

Figure 2. Fishbone Diagrams

Late payments cause a comprehensive impact like a domino effect on vendors, shipping, readiness parts, and assembly at gate 6. The reactive process that occurs in the system is not yet based on proactive planning or no front loading and relies on purchase orders where the maintenance process will resume once funds are available.

To develop into the root causes studied, the analysis will continue using the 5 whys to uncover the root causes of problems that significantly impact TAT. The 5 whys are based on the root cause themes in the fishbone diagram.

Table 3. 5 whys analysis

ROOT CAUSE	MATERIAL NOT AVAILABLE	INTERNAL REPAIR PENDING	AREA OVERLOAD & NO PRIORITY	APPROVAL PURCHASE REQUISITION & LONG ORDER REQUEST	CUSTOMER CASHFLOW DEPENDENT PROJECT

WHY 1	Why is the material not available during induction?	Why is the internal repair process delayed in the workshop?	Why is the repair process delayed?	Why is the procurement of spare parts delayed?	Why is the repair process delayed?
	because the vendor has not sent the components ordered	because spare parts for repair are not yet available	due to overload area capacity and the lack of critical materials available	because PR & RO were not approved on time	because the vendor refused to continue the work without certainty of payment
WHY 2	Why hasn't the vendor shipped the ordered components?	Why are repair spare parts not available yet?	Why are critical materials not yet available?	Why is PR & RO approval late?	Why is the payment process delayed?
	Because the vendor is still waiting for the installment payment or down payment.	because the procurement process is delayed waiting for the budget allocation to be approved	because the new purchase order was issued at gate 4 and the repair was already scheduled previously	Because the process is manual and consists of several stages	Because the project's operational funds still depend on cash in from customers
WHY 3	Why hasn't the down payment been made?	Why hasn't the budget allocation process been approved?	Why is the PO made close to the repair time?	Why is there no automated approval system?	Why does cash in depend on customer payment?
	because payment approval is late	because cash allocation is given after customer payment is received	because there is no priority system for procuring critical parts	due to the absence of a digital workflow and internal SLA for gate procurement	due to the absence of cash reserves or working capital for the project
WHY 4	Why is the payment approval late?	Why is cash allocation only done after customer payment?	Why is there no procurement priority system?	why internal SLA is not implemented?	Why is there no working capital reserve for the project?

	because the approval process is manual and the SLA is not binding	because the company does not apply the front loading working capital mechanism	because the scheduling process does not consider material readiness and only focuses on induction slots	Because the SLA policy only focuses on total TAT not per gate.	because the allocation of funds is based on the principle of incoming cash flow, not based on critical parts
WHY 5	why is it not automatic and SLA is not available?	Why is front loading capital not implemented?	Why doesn't scheduling take material readiness into account?	Why isn't the SLA detailed per gate?	Why is there no critical part-based cash flow planning?
	because the SLA policy per Gate has not been implemented and cash flow management is still reactive based on customer cash in	because there is no cash flow control policy based on project milestones that is integrated into the planning per gate	because there is no system integration between planners, procurement, and logistics based on project milestones	because there is no gate system-based procurement process control structure design	because there is no integration policy between project planning, procurement and finance at the start of the project

From the results of these five patterns, it can be concluded that the main root causes of gate 4-5 delays are:

- The absence of a binding SLA at gate 4-5
- The absence of front-loading working capital
- Weak integration between units, resulting in procurement and repair processes not synchronizing with scheduling

Process improvements are needed, focusing on implementing SLA policies per gate, milestone-based funding, and integration between planning, logistics, and finance functions.

The kitting and detail grouping processes contribute to delays due to a lack of manpower, the lack of a real-time part tracking system, and the mixing of different hardware between engines due to unorganized documentation procedures. In the completion and closure processes, delays occur in the input of PKL and closure data, manual verification, and the queuing of parts to the kitting area. These results in output not being delivered on time even though the previous process has been completed.

D. Improve

Based on the research conducted in the previous stage, namely "define, measure, and analyze," at gates 4-5, the dominant cause of delays was constraints in the working capital category. These constraints occurred due to slow PR and RO approval processes, as well as unprepared engine materials during induction. Therefore, in the "improve" stage, several measurable and implementable process improvement proposals were designed.

1. Implementation of Service Level Agreements for Each Gate

This implementation aims to ensure that administrative processes run efficiently and on time. This SLA can include a maximum of 3 business days for Purchase Request (PR) approval, 2 business days for Purchase Order (PO) issuance, and 7 days for vendor payments from invoice issuance. The proposed SLAs for each stage of the procurement process have measurable time limits and can be monitored in real time.

2. Implementation of Front-Loading Working Capital

The implementation of Front-Loading Working Capital aims to provide a project budget before the project begins. This approach is realized through a milestone-based budgeting system that allocates funds based on specific project gate stages.

3. Integration of Planning, Procurement, and Finance Systems

This system is built on a structured workflow based on milestones and gate stages, rather than relying on manual PR submissions. In the early stages of the project, this system must identify a priority list of critical parts that must be available before assembly or test cell work can begin.

4. Digitalization of the Approval Process and Procurement Workflow

This process increases transparency and speed in the procurement process while minimizing potential administrative bottlenecks. E. Vendor Early Payment Program

As an innovation in vendor management, companies can implement the Vendor Early Payment Program (VEPP), which provides incentives in the form of discounts to vendors who accept early payments. This program is not only financially beneficial but also reduces the risk of part delays due to vendor cash flow constraints.

5. Reserve Fund Policy

This fund serves as a safeguard in the event of delayed customer payments, while urgently requiring materials. This buffer allows projects to proceed without interruption due to short-term flow disruptions and ensures that engine maintenance TATs remain within the SLA.

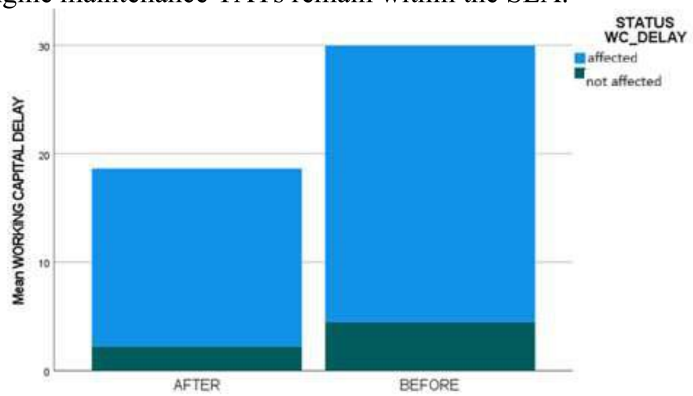

Figure 3. Working Capital Delay before and after improve

Following the implementation of improvements including front-loading working capital, the implementation of service level agreement gates 4-5, integration of planning, procurement, and finance systems, and an emergency buffer policy, the average delay decreased significantly to approximately 19 days. This indicates that the implemented solutions are beginning to reduce the burden of delays caused by working capital. Although the impacting components still dominate the total delay, their proportion of the overall average has decreased substantially. This indicates that some processes have been equipped with earlier funding allocations and integrated systems that have become more efficient.

E. Control

The final phase of the DMAIC approach aims to ensure that the improvements implemented in the Improve stage are consistent and sustainable. The primary focus of this phase is to prevent recurrence of problems in the working capital process at gates 4-5.

1. Implementing SLAs per Gate

The SLAs established in the improvement phase serve as the primary foundation for a KPI-based control system. Delays in SLAs will be detected by automated alerts and escalation mechanisms to ensure consistent process efficiency.

2. Implementation of Front-Loading Working Capital
The control phase involves establishing a milestone-based disbursement schedule and auditing the use of working capital used in the gate phase. This ensures that project funding allocation is not only sufficient but also accountable.

3. Planning-Procurement-Finance System Integration
The implemented integrated system must be controlled through an ERP project module that can synchronize schedules, material requirements, payment status, and part delivery processes. This is achieved by locking the schedule baseline and activating an early warning system for any deviations between plans and actual results.

4. Digitalization of Approval and Procurement Workflow
This digitalization process is realized through automated, controllable SLA tracking, approval audit trails, and timestamp monitoring at each procurement stage. Any delays in approval can be tracked in detail to enable immediate corrective action and promote transparency between each function.

5. Vendor Early Payment Program
The program creates a symbiotic relationship with vendors. At the control stage, the effectiveness of the VEPP can be monitored by comparing delivery times before and after early payment. Vendor discounts and incentive programs are controlled through a vendor scoring and review system that can be integrated into the procurement system.

6. Emergency Working Capital Buffer
This fund serves as a risk buffer that can be controlled through an emergency approval procedure and monthly reports using reserve funds. The indicators used in the control stage can be the frequency of buffer use and the effectiveness of its use in suppressing

DISUCSSION

Gate 4–5 proved to be the main bottleneck with a total delay of 1289 days due to obstacles in the repair process, sourcing, and material readiness, which were exacerbated by weak coordination between units and material procurement issues. Limited working capital was a significant cause of the delay due to the pattern of customer payments in stages and often late, thus hampering payments to vendors and extending lead times to 3–4 months. Using the DMAIC method, root causes were successfully identified such as the absence of SLAs, long PR/RO approvals, unavailable materials, and lack of integration between units, and resulted in solutions such as the implementation of SLAs, front-loading working capital, integration of planning-scheduling-finance systems, digitalization of approvals, early vendor payments, and reserve funds. To ensure the sustainability of repairs, CCPM was used to ensure scheduling based on resource availability and realistic buffers, while RCM improved component reliability in addressing potential unexpected damage that often causes delays in the assembly and test cell stages.

CONCLUSION

This study shows that gates 4–5 are the main bottleneck in engine maintenance at PT GMF AeroAsia due to obstacles in repair, material procurement, and inter-unit coordination, which are exacerbated by limited working capital so that material lead times can reach 3–4 months. The DMAIC approach identifies root causes such as the absence of SLAs, slow approvals, and weak system integration, while the Improve phase presents solutions such as SLAs per gate, system integration, front loading working capital, VEPP, and emergency buffer policies that reduce the average delay from 30 to 19 days. The integration of CCPM and RCM further strengthens the improvement through buffer management and increased component reliability. It is recommended that academic studies comparing the effectiveness of conventional project management methods and CCPM in the maintenance context be conducted to enrich the literature on risk-based and resource-constrained project management.

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