Available online at:
https://jurnal.integrasisainsmedia.co.id/index.php/JIMS
Journal Integration of Management Studies
Volume 3 Number 2, 2025: 261-273
DOI: 10.58229/jims.v3i2.360

Performance Optimization of Coal Hauling Operations Through DMAIC Framework: A Case Study at PT Berau Coal

Alvito Tirano Paseru*[1], Gatot Yudoko[2], Dudu Anwar Sanusi[3], Pandu Zea Ardiansyah[4], Agung Limowa[5]

[1-4]School of Business and Management, Institut Teknologi Bandung, Indonesia
[5]Faculty of Mining and Petroleum Engineering, Institut Teknologi Bandung, Indonesia

*Email: paserualvito@gmail.com

Abstract

The coal mining industry faces increasing demands to enhance operational efficiency and reduce costs in order to remain competitive amid dynamic market conditions. This research aims to optimize the coal hauling process at PT Berau Coal, one of Indonesia's major coal producers, by applying the Lean Six Sigma methodology using the DMAIC (Define, Measure, Analyze, Improve, Control) framework. A combination of quantitative and qualitative data collection methods, including process mapping, root cause analysis, and productivity measurement, is employed to systematically identify inefficiencies and bottlenecks within the coal hauling operation in Binungan Mine Operation Block 8. Research shows that significant productivity losses are attributed to prolonged waiting times, process delays, and insufficient standard operating procedures (SOPs). To address these issues, a set of improvement strategies has been formulated, emphasizing the renewal and enforcement of Standard Operating Procedures (SOPs), the implementation of a Fleet Management System (FMS) for real-time monitoring and decision-making, and the application of simulation modeling using AnyLogic software to assess the effectiveness of the suggested changes. Importantly, simulation results demonstrate that the average number of cycles per productive hour can increase from 5–6 to 9 cycles per hour through optimized operations. The findings demonstrate that implementing Lean Six Sigma within the DMAIC framework can substantially enhance coal hauling productivity, reduce operational cycle times, and improve overall cost efficiency. This research provides a framework for ongoing improvement in mining logistics and offers actionable insights for practitioners seeking sustainable operational excellence in a competitive industry.

Keywords: Coal Hauling; Cycle Time; DMAIC; Fleet Management System; Lean Six Sigma; Mining Operations; Performance Optimization

A. INTRODUCTION

Indonesia is recognized as one of the world's largest coal producers and exporters, with 30.2 billion tons of reserves as of 2023, ranking it among the top ten coal-rich nations (ESDM, 2024). The coal industry remains Indonesia's highest-valued mining export and a major contributor to GDP, supporting over 50% of the national power generation mix and playing a central role in export revenues and industrial growth (Admi et al., 2022). Despite global calls to reduce fossil fuel reliance, Indonesia continues to prioritize coal, ranking fifth globally in prospective coal-fired capacity, underscoring its ongoing dependence on coal as an energy strategy (Shearer, 2020).

Amid the national coal supply chain, PT Berau Coal stands out as one of Indonesia's leading mining companies. Since 1983, the company has managed several mining sites in East Kalimantan, including Binungan, Lati, and Sambarata, under a first-generation Coal Contract of Work (PKP2B). These sites are incorporated into a unified operational system known as the Single Mine Concept. As of 2024, PT Berau Coal produced 35.9 million tons of coal, with the Binungan mine being the largest contributor, accounting for 43% of the company's total coal output (PT Berau Coal Energy Tbk, 2025). These figures underscore the Binungan site's strategic importance as a key production hub and a crucial factor in the company's overall performance.

Despite its extensive infrastructure and production scale, PT Berau Coal is currently facing challenges in optimizing its coal hauling operations, particularly at the Binungan Mine Operation 2 (BMO2) in Block 8. Hauling coal from the ROM (Run-of-Mine) area to the CPP (Coal Processing Plant) is a critical phase in the production process. As one of the most energy-intensive activities in open-pit

* Corresponding author

mining, coal hauling can consume up to 56% of total diesel fuel usage (Sahoo & Topno, 2023), making it a significant contributor to both operational costs and environmental impact. The average round-trip hauling distance is about 50 kilometers (25 kilometers each way), making the operation highly susceptible to time delays, resource misallocation, and productivity loss. Various interrelated activities, such as refueling, pre-operational inspections, shift transitions, and equipment allocation, contribute to fluctuations in hauling performance. These inefficiencies often result in unmet production targets, reduced hourly throughput, and delays in coal delivery to downstream operations, such as blending and barge loading. Inefficiencies in hauling operations are especially critical due to their direct impact on operational targets, energy use, and overall cost structure (Pamungkas & Mulyono, 2023)

The core business issue observed at BMO2 Block 8 is the decline in coal hauling productivity, as indicated by the hourly transported tonnage falling below the general operational benchmark of 68 tons per hour (see Figure 1). This deviation not only contributes to opportunity losses but also endangers the company's capacity to fulfill its delivery commitments to customers. For example, in Q1 2025, performance across multiple shifts was inconsistent and frequently fell short of the anticipated productivity levels. Issues such as limited truck availability, ineffective shift changeovers, prolonged wait times, and external factors at the crusher or port contribute to systemic bottlenecks within the hauling process.

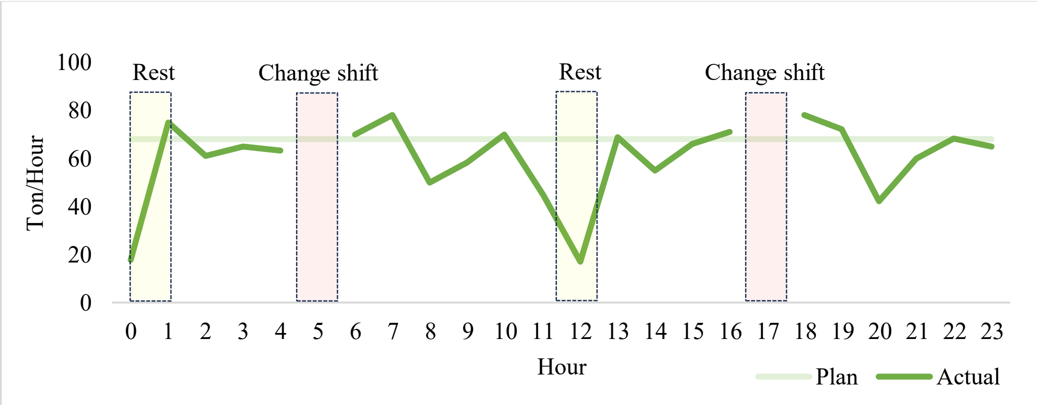


Figure 1. Coal Hauling Productivity in BMO2 Block 8 per Hour in Q1 2025
Source: Research data, 2025

These performance challenges are particularly significant in light of tightening profit margins and increased oversight of operational efficiency within the coal mining sector. Companies must not only maintain high output but also refine their cost structures and reduce variability in their supply chains. To address these challenges, this research employs a structured problem-solving approach rooted in Lean Six Sigma, specifically utilizing the DMAIC framework. The aim is to identify the root causes of inefficiency in the hauling process and implement targeted improvements that enhance productivity, minimize waste, and align with the company's broader goals of operational excellence and sustainable resource management.

B. METHODS

This study employs a structured and systematic approach to address underperformance in coal hauling operations at BMO2 Block 8, PT Berau Coal. The research adopts the Lean Six Sigma methodology, utilizing the DMAIC (Define, Measure, Analyze, Improve, Control) framework as the primary analytical tool. The DMAIC approach is well-regarded and frequently applied in mining operations to foster continuous improvement and operational excellence (Hia et al., 2025; Olanrewaju et al., 2019). This approach was selected to provide a thorough and systematic method for identifying root causes and formulating effective solutions. Effectiveness refers to doing the right things in the correct order at any given point in time (Markopoulos et al., 2022).

The data collection process integrated both primary and secondary sources of information. The primary data consisted of unstructured interviews with stakeholders, including mine superintendents and supervisors, as well as direct observations at the hauling operation site (Paradis et al., 2016). Secondary data were collected from internal company records, operational reports, and performance logs related to the coal hauling process (Taherdoost, 2021). The DMAIC framework employed distinct data collection techniques at each stage: process mapping and identifying stakeholders during the Define phase, productivity performance analysis in the Measure phase, root cause analysis in the Analyze phase, and simulation-based scenario testing in the Improve phase. In the Control phase, the focus was on methods to maintain improvements, such as documentation and ongoing monitoring. All data collection activities and interviews were carried out with the informed consent of the company's stakeholders. This research did not include sensitive personal data and did not require formal ethical approval for any interventions.

During the Define phase, process mapping and SIPOC diagrams were utilized for data analysis to enhance clarity regarding the operational flow and key actors (Oliveira et al., 2024; Seth et al., 2017). The Measure phase utilized waterfall and Pareto charts to evaluate productivity gaps and identify key contributing factors (Ituriaga et al., 2024). In the Analyze phase, the Why Tree method and the value-added ratio (VAR) through time studies were used to identify root causes and process inefficiencies (Hia et al., 2025; Obwegeser et al., 2019). The Improve phase involved developing and simulating improvement scenarios using the AnyLogic platform, a discrete event simulation software that enables the modeling of complex operational systems and the analysis of various scenarios to support data-driven decision-making. This process included parameterization based on real operational data to ensure the model's accuracy and representativeness. The Control phase established follow-up mechanisms, such as monitoring with the Fleet Management System (FMS), to guarantee the sustainability of the implemented solutions.

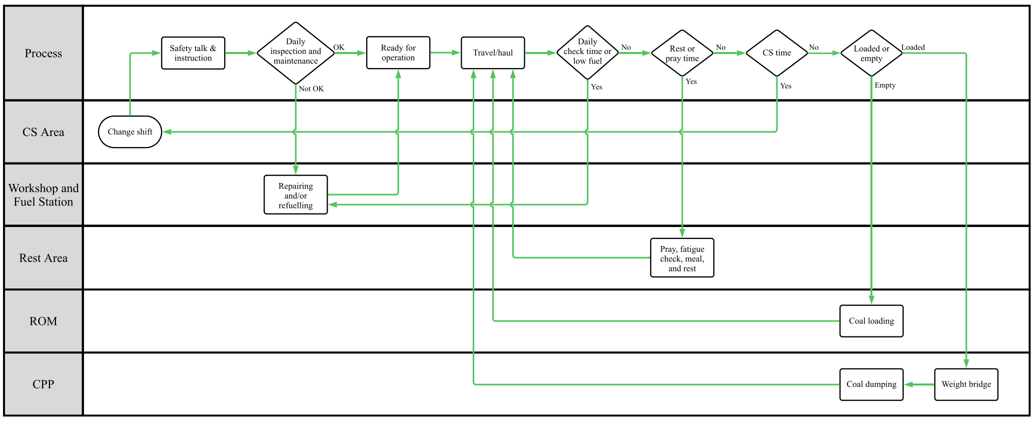
C. RESULTS AND DISCUSSION

Define Phase

The Define phase serves as the initial and foundational stage of the improvement initiative in this study. Its primary goal is to establish clear boundaries for the coal hauling process, ensuring that the scope of analysis is well-defined and aligned with operational realities. This clarity is crucial for maintaining focus and direction throughout the improvement project. At this stage, the study also aims to identify key operational problems and relevant stakeholders systematically. Engaging operators, supervisors, and management gathers diverse perspectives and ensures critical issues are not overlooked. This collaboration fosters a comprehensive understanding of performance challenges and lays the groundwork for stakeholder alignment in later phases.

A key activity in the Define phase involves creating a comprehensive process mapping diagram. This diagram visually illustrates each step and interaction in the coal hauling process, offering useful insights into the activity flow from loading at the ROM to final delivery at the CPP. This visualization identifies potential inefficiencies, bottlenecks, and critical control points in the workflow, laying a solid foundation for more in-depth analysis and targeted improvement planning.

Process Mapping of Coal Hauling Operation in BMO2 Block 8 PT Berau Coal: Establishing Baseline for Performance Measurement and Improvement Planning



Source: Research data, 2025

The process mapping diagram in Table 1 visually represents the coal hauling operation, from loading coal at the ROM area to delivery at the CPP. By analyzing individual activities and decision points, it identifies delays, bottlenecks, and inefficiencies. This map clarifies the impact of each step on overall performance and highlights areas with the most potential for improvement.

In addition to the process mapping, a SIPOC (Supplier-Input-Process-Output-Customer) diagram is created. This SIPOC diagram provides a high-level overview of the coal hauling process, outlining the key suppliers, inputs, main processes, outputs, and customers. It serves as a valuable tool for aligning stakeholder perspectives and ensuring that further analysis and improvement initiatives concentrate on the most essential components of the operation.

Table 2. SIPOC Diagram of Coal Hauling Operation in BMO2 Block 8 PT Berau Coal: Clarifying System Boundaries and Stakeholder Roles for DMAIC Implementation

Supplier	Input	Process	Output	Customer
• Procurement • Coal mining	• SDT • Driver/ operator • Coal (in ROM)	Main hauling process Travel to ROM ↓ Coal loading (ROM) ↓ Travel to CPP ↓ Weight bridge ↓ Coal dumping (CPP) ↓ Travel back to ROM	• Hauling report • Cycle timesheet • Dumped coal in CPP	• Mine owner • ROM operator • CPP Operator • Fleet dispatcher
• Procurement • Fuel vendor	• DC schedule • Mechanic • Fuel • Spare part	Refueling, daily check (DC)	• Checked/ refueled SDT • Maintenance record	SDT operator
• Outgoing operator • Fleet dispatcher	• Dispatch instruction • Safety talk • Fleet status	Change shift	• Handover log • Updated fleet status • Dispatch orders	• Incoming operator • Fleet dispatcher
HR policy	• Pray and rest schedule • Time allocation	Rest, fatigue check, meal, and pray	• Operator readiness • Rest time log	SDT operator

Source: Research data, 2025

The SIPOC diagram in Table 2 provides a concise summary of the key components and interactions within the coal hauling process, ensuring that all stakeholders share a common understanding of the process boundaries and critical elements. By establishing clear definitions for each supplier, input, process step, output, and customer, this tool lays a solid foundation for further analysis and evaluation. With this shared perspective, the study can more effectively focus on quantifying current performance levels, identifying process gaps, and gathering the necessary data in the subsequent Measure phase.

Measure Phase

In the Measure phase, the focus shifts to quantifying the current performance of the coal hauling process and identifying the most significant factors contributing to operational inefficiencies. At this stage, detailed data collection is conducted to capture key performance indicators, including cycle time, unit productivity, and downtime events. The collected data is then analyzed to provide an objective assessment of the existing performance gaps relative to established targets.

To support this assessment, visualizations such as waterfall and Pareto charts are utilized. The waterfall chart (Figure 2) helps illustrate the cumulative effects of different contributing factors on overall productivity, making it easier to trace the progression of losses and gains throughout the process. Importantly, the Pareto chart (Figure 3) is constructed by prioritizing factors within the contractor's control, ensuring that subsequent analysis and improvement efforts focus on issues that can be directly addressed through operational changes. By emphasizing these controllable factors, the analysis provides more actionable insights for targeted intervention in the following phases.

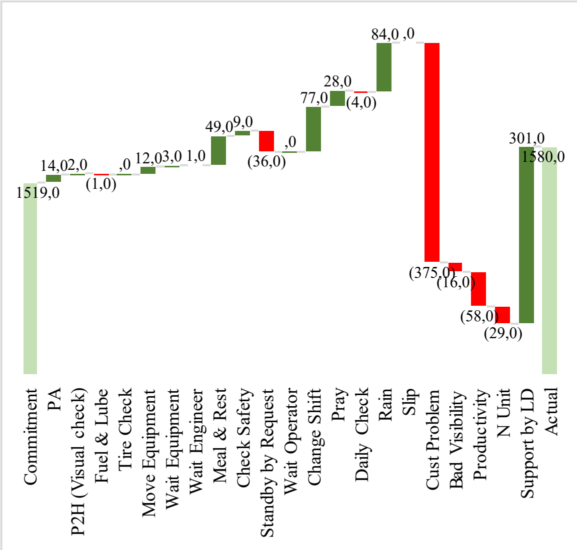


Figure 2. Waterfall Graph of Coal Hauling in Q1 2025
Source: Research data, 2025

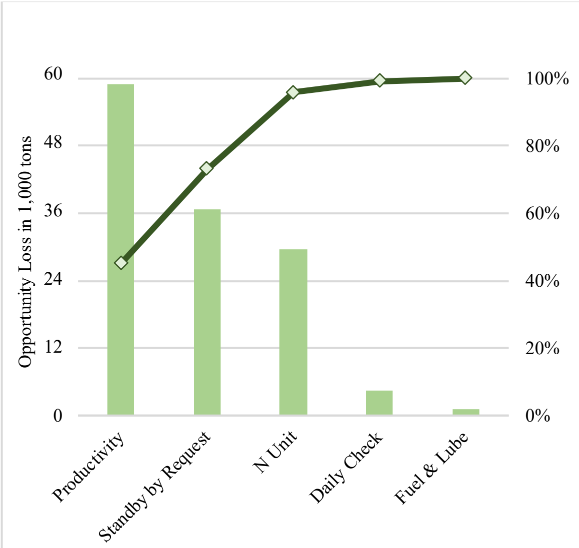


Figure 3. Pareto Chart Hauling Opportunity Loss by Contractor
Source: Research data, 2025

Analyze Phase

During the Analyze phase, the study aims to explore further the underlying causes of performance gaps identified in the previous stage. A primary focus is on understanding how actual operational practices align with established plans and targets, particularly in terms of cycle time. To achieve this, a comparative analysis is performed between the planned cycle time and the average actual cycle time realized in daily operations. This comparison indicates whether deviations are occurring and emphasizes the extent to which actual performance aligns with operational expectations.

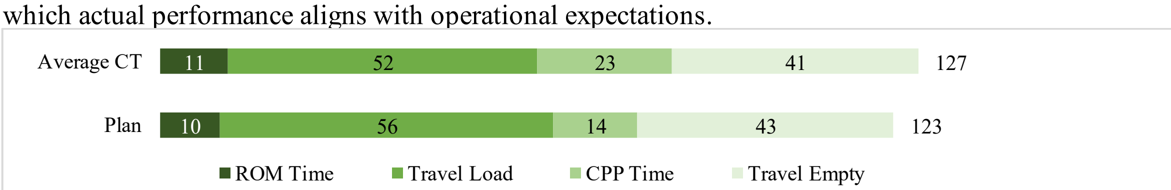


Figure 4. Plan Cycle Time Compared to Average Actual Cycle Time
Source: Research data, 2025

The comparative analysis reveals that the average actual cycle time exceeds the planned cycle time. This inconsistency reveals process inefficiencies that accumulate across different stages of the hauling operations. Several factors may contribute to these extended cycle times, including delays during loading and unloading, waiting times at the ROM or CPP, and uncoordinated shift changes. The ongoing gap between planned and actual performance suggests that the root causes are likely embedded in routine operational practices rather than being incidental. Recognizing this trend is crucial, as it directs the investigation toward specific stages or activities within the cycle that require deeper analysis and targeted improvement actions.

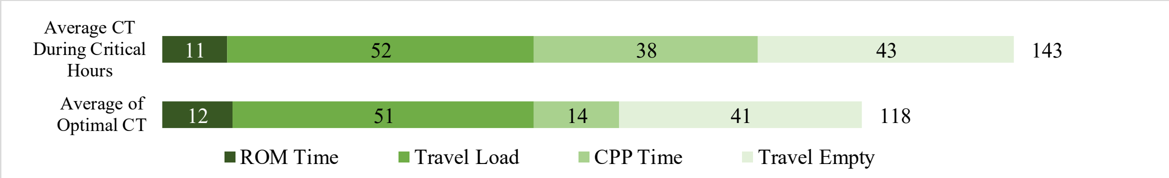


Figure 5. Average Optimal CT Compared to Average CT During Critical Hours
Source: Research data, 2025

The comparison between the average optimal cycle time and the actual cycle time during critical hours reveals a significant gap, with actual times reaching 143 minutes compared to the optimal 118 minutes. The largest increase occurs in CPP Time, indicating that queuing and delays at the Coal Processing Plant are the main sources of inefficiency. This result highlights the need to improve queue management and coordination during peak periods to bring actual performance closer to the optimal benchmark.

To further analyze the distribution of time throughout the coal hauling operation, a detailed time study was conducted throughout an entire shift. This time study breaks down each activity, including loading, traveling, unloading, resting, and other supporting tasks, offering a comprehensive view of how operational hours are utilized during daily operations.

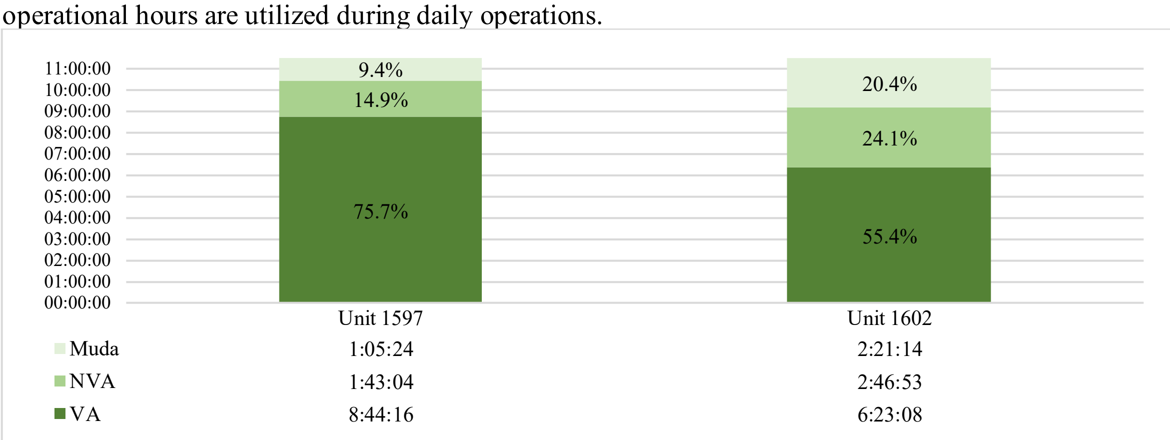


Figure 6. Time Study of One Shift Coal Hauling
Source: Research data, 2025

The time study of one shift, as shown in Figure 6, compares two SDT units, PM1597 and PM1602, to illustrate how differences in operational efficiency and time management can occur even within the same shift. PM1597 completed five trips, while PM1602 completed only 4, highlighting a clear productivity gap. This difference is primarily due to longer queuing times and a more extensive daily check for PM1602, as well as supporting activities such as rest, refueling, and non-value-added tasks, which often exceeded planned durations for both units but were more pronounced in PM1602. The two-unit comparison highlights how variations in the execution of mandatory and supporting activities can directly affect overall shift productivity. These findings underscore the importance of stricter control, standardization, and discipline in managing all supporting activities to achieve more consistent and optimal performance in coal hauling operations.

To systematically explore the underlying causes of the inefficiencies and excessive non-productive time identified in the previous analysis, a root cause analysis was conducted using the Why Tree method. This method visually breaks down each problem into its contributing factors, allowing for a clearer understanding of which issues require priority action.

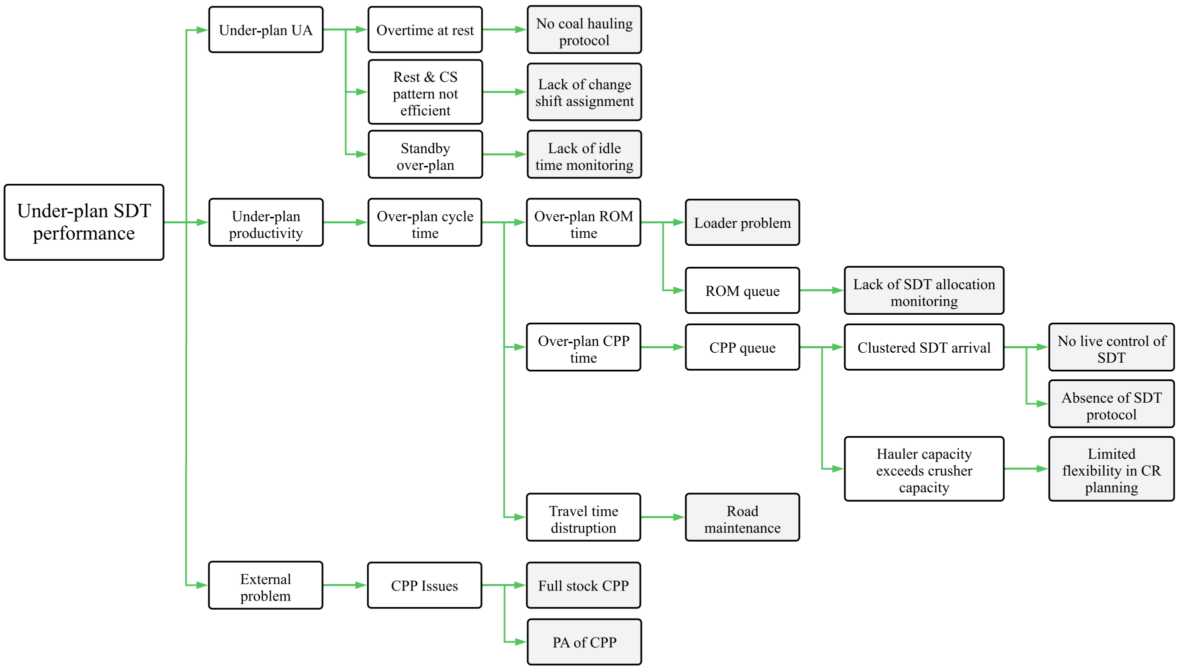


Figure 7. Why Tree of Under-plan Hauling Performance

Source: Research data, 2025

The Why Tree analysis (Figure 7) reveals that the root causes of coal hauling inefficiencies can be classified into two main categories. The first issue is the lack of standardized operational protocols, which include undefined time limits for supporting activities (such as rest, prayer, and refueling), unstructured shift change procedures, and the absence of specific Standard Operating Procedures (SOPs) for SDT operations. These factors lead to inconsistent practices, increased idle time, and ineffective use of working hours. The second category is insufficient real-time monitoring and control, including a lack of centralized unit allocation, inadequate tracking of idle and queue times, and rigid planning for CPP utilization. These shortcomings lead to poor coordination, uneven unit distribution, and frequent queuing at operational points. Root causes within the contractor's control inform improvement initiatives. The analysis also identifies external factors, such as loader availability and temporary CPP capacity constraints, that contribute to inefficiency but are beyond the contractor's authority and not prioritized for action. Table 3 provides a summary that explains the categorization of each root cause, distinguishing between internal contractor factors and external factors originating from the contractor.

Table 3. Root Causes Categorization Summary

Root Cause Category	Root Cause	Reason for Categorization
Lack of Protocols	Absence of standardized SDT hauling procedures	The absence of operating procedures and specific operational guidance for SDT leads to inconsistencies, inefficiencies, and a lack of control in hauling operations.
	Lack of change shift assignment	Disorganized shift scheduling results in uncoordinated shift starts and wasted productive time.
Lack of Hauling Monitoring & Control	Lack of idle time monitoring	No real-time monitoring system exists to effectively detect and manage idle time.
	No live control or monitoring of SDT	The absence of real-time control over unit distribution results in queuing and unbalanced SDT allocation, leading to bottlenecks and delays during loading operations.
	Limited flexibility in CR planning	Fleet flow planning to CPP (CR11 or CR12) does not adapt to real-time field conditions.
Out-of-Scope Root Causes (External Factors)	Loader problem	This issue is related to the loading equipment, which is outside the realm of SDT control and contractor responsibility.
	Full stock CPP	The issue arises from a backlog in CPP, stopping the hauling process.
	PA of CPP	CPP downtime is beyond the control of hauling and directly impacts the operational rhythm.

Root Cause Category	Root Cause	Reason for Categorization
	Road maintenance	Road maintenance remains a necessary support activity and is not classified as inefficiency in hauling.

Source: Research data, 2025

Improve Phase

Root cause analysis and identification of priority areas for improvement led to the development of targeted action plans addressing operational inefficiencies in coal hauling. These initiatives aim to standardize processes, enhance monitoring and control, and optimize resource allocation in the hauling operation. The table summarizes proposed actions, responsible parties, implementation timelines, and expected outcomes of the initiative.

Table 2. Improvement Plan of Coal Hauling Operation

Root Cause	Improvement Action Plan	Expected Impact
	Related to Protocol	
Absence of standardized SDT hauling procedures	• Develop and implement a comprehensive Standard Operating Procedure (SOP) specifically for SDT hauling operations to ensure alignment with industry best practices and company objectives. • The SOP should clearly define each step in the SDT hauling process, covering activities from the start of the shift, loading at ROM, hauling, waiting/queuing, dumping at CPP, the return trip, and the end of the shift. • Include comprehensive guidelines for critical and high-risk points, such as safe maneuvering during loading and dumping, minimum deceleration for each road segment, handling technical disruptions, and emergency response protocols. • Conduct thorough socialization and operator training on the SOP to ensure a consistent understanding and implementation among all SDT operators and relevant supporting personnel. • Regularly review and update the SOP based on feedback, monitoring outcomes, and operational insights to ensure accuracy and effectiveness.	• Ensures uniformity and standardization in processes across all SDT operators. • Decreases mistakes and risky actions during hauling. • Reduces variability and sets a clear baseline for monitoring and performance evaluation. • Enhances operational safety and efficiency.
Lack of structured change shift assignment	• Establish a structured, documented, and communicated shift assignment schedule for all operators, ensuring that each shift start is pre-coordinated and communicated effectively. • Implement a pre-assignment system in which incoming operators are designated to specific SDT units before shift handover, along with briefings and clear timing allocations. • Create a checklist for the shift handover process to ensure all critical information (e.g., unit condition, outstanding issues, previous performance) is communicated effectively. • Stagger shift change timings if necessary to avoid congestion and simultaneous shutdowns. • Monitor compliance with shift changes and address issues through additional training or disciplinary action if recurring inefficiencies are noted.	• Ensure that shift starts are well-coordinated and that productive work begins on time. • Minimizes wasted productive time due to disorganization. • Supports a stable operational cycle and reduces the ripple effect of delays.
	Related to Monitoring and Control	
Lack of real-time idle time monitoring	• Implement real-time monitoring of idle time as a required feature in the Fleet Management System (FMS) for all SDT units. • Set up automated alerts to notify the dispatcher or Operation Control Center (OCC) instantly whenever an SDT is idling beyond the predefined limit outside designated waiting areas (e.g., ROM, CPP). • Designate dispatchers (or OCC) to routinely monitor the FMS dashboard and follow up with field interventions when excessive idle time is detected. • Periodically review idle time data to identify recurring causes and update procedures or operator training as necessary. • Integrate idle time monitoring with performance evaluations and reward or penalty systems to enhance productivity and efficiency.	• It provides visibility into unproductive time that would otherwise remain hidden. • Facilitates rapid intervention, minimizing cycle time loss. • Promotes operator discipline and ongoing improvement in minimizing waste.

Root Cause	Improvement Action Plan	Expected Impact
Lack of centralized monitoring and dynamic control for SDT allocation and movement	• Integrate dynamic dispatching and centralized control of all SDT units into the FMS, with the OCC acting as the control hub. • Empower dispatchers/OCC to make real-time decisions on SDT allocation, such as assigning empty units to the best-suited loader or rerouting units to avoid congestion or clustered arrivals at CPP. • Provide dispatchers and OCC access to real-time unit statuses, loader, and crusher queue lengths, and live road conditions. • Establish a clear authority for the OCC/dispatcher to intervene directly in the field when inefficiencies or disruptions are identified. • Regularly assess the effectiveness of dynamic dispatching and modify algorithms or rules based on performance results. • Familiarize all operational personnel with the new control system and authority structure to ensure compliance and reduce resistance.	• Minimizes excessive queuing at ROM and clustered arrivals at CPP. • Improves the use of both loaders and crusher facilities. • Enhances overall responsiveness to operational disruptions. • Facilitates a smoother and more predictable hauling cycle.
Limited flexibility in crusher (CPP) planning	• Integrate real-time monitoring of CPP (CR11 or CR12) availability, status, and queue length into the FMS dashboard that is accessible by OCC and dispatchers. • Train dispatchers/OCC to dynamically assign SDT units between CR11 and CR12 using live data to balance queue lengths and maximize throughput. • Establish feedback mechanisms for operators to report any on-site bottlenecks or changes in crusher conditions that the system may not capture. • Establish key performance indicators (KPIs) for a balanced and optimal use of crusher facilities. • Regularly review and refine dispatching rules based on throughput data and operational feedback to ensure optimal performance.	• Maximizes the installed capacity and throughput at crusher facilities. • Decreases waiting and congestion during dumping. • Enhances the system's flexibility and adaptability to changing field conditions.

Source: Research data, 2025

In the Improve phase, the effectiveness of proposed operational improvements through simulation on the AnyLogic platform. The simulation modeled real hauling operations by incorporating key parameters based on actual field data, such as average speeds, loading and dumping times, and supporting activities like rest, refueling, and daily checks. The primary objective of the simulation was to analyze the impact of various operational configurations on overall performance, particularly the utilization of ROM and CPP facilities and the distribution of SDT units across CS areas. Three main facility utilization alternatives are considered: one ROM and one CPP, one ROM and two CPPs, and two ROMs and two CPPs.

For each alternative, several SDT allocation scenarios were simulated between the KM17 and KM1.5 CS areas, enabling an in-depth evaluation of different combinations. Utilizing triangular distributions for each process step allowed the simulation to reflect real operational variability. The results indicated that optimal throughput and minimized cycle times occur when both ROM and CPP are used simultaneously at a balanced capacity, along with a more equitable distribution of SDT units across CS areas. In contrast, bottlenecks or uneven allocations resulted in longer queues and decreased productivity. These insights offer data-driven recommendations for operational modifications to enhance hauling efficiency and tackle the flexibility challenges identified earlier in facility and unit planning.

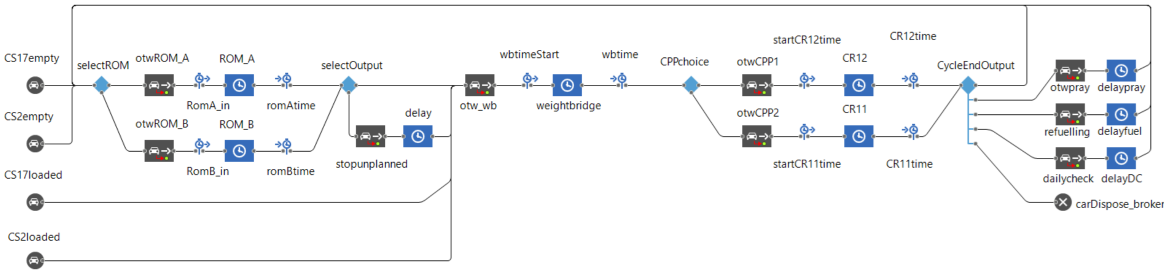


Figure 8. Simulation Results for Coal Hauling Over Five Hours Using AnyLogic
Source: Research data, 2025

Operational data from Q1 2025 (see Figure 9) indicates that coal hauling productivity generally peaks at 5 to 7 cycles per hour, reflecting the maximum performance achievable under current constraints such as scheduled rest periods, shift changes, and process delays. Despite these limitations, simulation results using the AnyLogic platform demonstrate that, with the implementation of targeted operational improvements, the average number of cycles during productive hours has the potential to increase to 9 per hour (see input number of CycleEndOutput in Figure 8). This highlights considerable room for efficiency gains and underscores the impact of optimizing key operational processes within the hauling system.

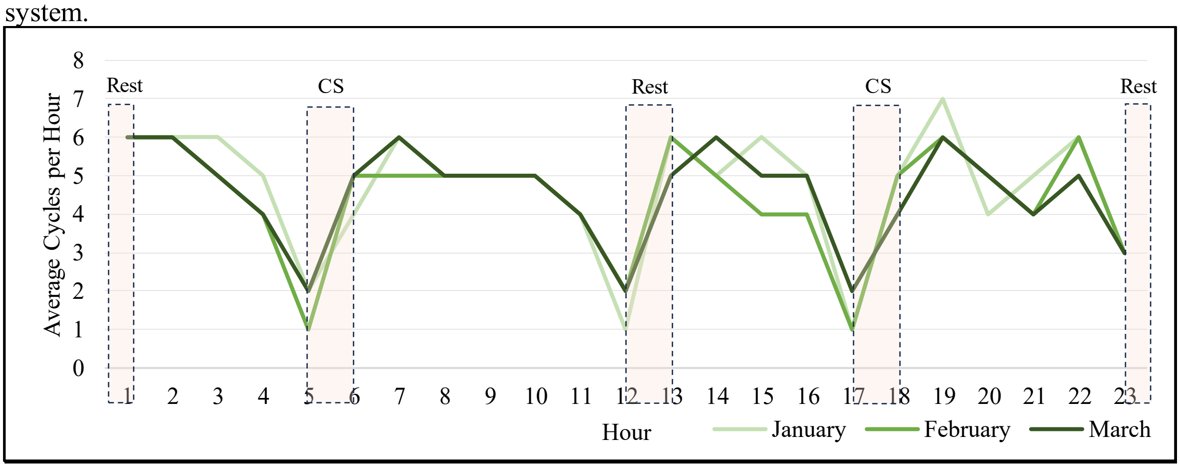


Figure 9. Average of Coal Hauling Cycles per Hour in Q1 2025
Source: Research data, 2025

Control Phase

The Control phase aims to guarantee the lasting benefits of the improvements made in earlier stages. This phase emphasizes the establishment of strong mechanisms for monitoring, controlling, and sustaining the enhanced performance of coal-hauling operations over time. Two key elements form the foundation of the control strategy: the deployment of FMS for real-time operational monitoring and the enforcement of SOPs to promote discipline and consistency in daily activities. Together, these components provide the necessary structure and oversight to prevent regression and support continuous improvement within the coal hauling process.

A detailed monitoring plan is established to track key performance indicators using the FMS. This plan specifies the metrics, measurement methods, and review frequency to ensure operational performance stays on target. Table 5 presents the structured approach for continuous performance monitoring and improvement with FMS.

Table 5. Hauling Performance Monitoring Plan Using FMS

Key Performance Indicators	Performance Target	FMS Features Used for Monitoring	Monitoring Frequency	PIC for Monitoring & Analysis	Warning Threshold	Action Procedures If Deviation Occurs
Average cycle time per shift	120 - 130 minutes	GPS tracking, Timestamp activity (loading and dumping), Production monitoring	Real-time Daily Weekly	OCC dispatcher, Field supervisor	> 130 minutes	The dispatcher conducts a cause analysis, provides instructions to the operator, and escalates the issue to a supervisor if it recurs.
Percentage of idle time	< 10% during productive hours	Idle time monitoring, GPS tracking	Daily	OCC dispatcher, Field supervisor	> 15% during productive hours	Contact the operator to investigate the cause and provide additional instructions.
Speed limit compliance (Max 60 km/h)	100% compliance	GPS tracking, Driver behavior monitoring	Real-time	OCC dispatcher, Safety officer	Speed > 65 km/h (Alert)	Provide caution to the operator and offer coaching if issues persist.
Fuel consumption per ton per km	x liter/ton/km	Fuel sensor, Production monitoring, GPS tracking	Daily Weekly	Maintenance planner, Field supervisor	> 5% of the target	Analysis of unit operating patterns, technical inspection of units
Number of cycles per shift per unit	Minimal y cycle	Production monitoring, Timestamp of activity	Per shift Daily	Field supervisor, OCC dispatcher	< (y-1) cycle	Operator performance evaluation and operational constraint analysis

Key Performance Indicators	Performance Target	FMS Features Used for Monitoring	Monitoring Frequency	PIC for Monitoring & Analysis	Warning Threshold	Action Procedures If Deviation Occurs
Compliance with the prescribed route	100% compliance	GPS tracking, Geofencing	Real-time	OCC dispatcher	Unauthorized deviation from the route	Contact the operator for clarification and instructions to resume the route.

Source: Research data, 2025

In addition to technological monitoring, maintaining consistent operational discipline is essential for maintaining long-term performance improvements. The implementation of new technologies, such as a Fleet Management System (FMS), must be supported by robust procedural controls to ensure that daily operations meet the desired standards. A detailed control plan has been developed to facilitate the effective implementation and enforcement of the updated Coal Hauling Standard Operating Procedures (SOP). This plan outlines the necessary actions to ensure compliance and delineates the responsibilities of all personnel involved in the monitoring process. Additionally, it establishes structured mechanisms for regular assessment, feedback, and corrective actions whenever discrepancies from the SOP are identified. By incorporating routine performance evaluations and continuous communication, the control plan seeks to foster a culture of discipline and accountability throughout all levels of the coal hauling operation. Table 6 summarizes the key control measures, responsible parties, and mechanisms in place for ongoing evaluation and compliance monitoring related to the SOP.

Table 6. Coal Hauling SOP Control Plan

Main Process in SOP	Critical Points Controlled by SOP	Compliance Monitoring Method	PIC for Monitoring/Audit
Start-up shift procedure & unit inspection	• Inspection completeness • Unit condition reporting • Operator readiness	Field audit (inspection checklist), Direct observation	Field supervisor
Loading procedure at ROM	• Queuing position • Communication with the loader operator • Loading time and safe maneuvering	Direct observation, FMS data (ROM time)	Field supervisor OCC dispatcher
Safe travel procedure (loaded & empty)	• Speed limit compliance • Safe distance • Brake usage • Techniques for ascending/descending slopes	FMS data (speed, driver behavior), safety patrol observation	OCC dispatcher Safety officer
Dumping procedure at CPP	• Queuing position • Communication with the CPP operator • Dumping time, and • Safe maneuvering	Direct observation, FMS data (CPP time)	Field supervisor OCC dispatcher
Rest and change shift procedure	• Rest duration • Rest location • Shift handover information transfer and • Unit position at handover	Direct observation, FMS data (Idle time in rest area)	Field supervisor
Emergency response procedure (unit damage or accidents)	• Incident reporting • Area securing • Evacuation steps, and • Emergency communication	Incident report analysis, Emergency simulation	Safety officer Field supervisor

Source: Research data, 2025

D. CONCLUSIONS

This study systematically analyzed the coal hauling operations at BMO2 Block 8, PT Berau Coal, using the Lean Six Sigma DMAIC framework. The analysis identified two primary internal root causes of underperformance: the absence of standardized operational protocols and the lack of real-time monitoring and control. These factors contributed to significant inefficiencies, particularly in supporting activities and queuing times at critical process points.

Targeted improvement actions addressed root causes by establishing SOPs, implementing a Fleet Management System (FMS), and restructuring operations for better unit allocation and shift coordination.

The control phase ensured sustainability through structured FMS performance monitoring and strict adherence to SOPs. This integrated approach to process standardization and real-time monitoring establishes a solid foundation for continuous operational excellence and increased productivity in coal hauling at PT Berau Coal.

This study has several limitations. First, it relies exclusively on operational data from PT Berau Coal's coal hauling activities, which reduces the generalizability of the findings to other mining companies with different conditions. Variations in fleet composition, regulations, and technology can affect operational challenges and the effectiveness of Lean Six Sigma interventions. Second, the DMAIC framework focuses on optimizing existing processes rather than creating new ones. Future research could address these limitations by comparing Six Sigma methodologies, such as DMADV, to support the design of new operational processes in mining logistics. Additionally, multi-site or cross-industry studies could enhance the scalability of Lean Six Sigma strategies, thereby improving the evidence for continuous improvement in industrial environments.

REFERENCES

Admi, R., Saleh, S., & Fitrianto, G. (2022). The Analysis of Coal Competitiveness and the Factors Affecting Indonesia's Coal Exports to Main Destination Countries (A Case of 8 Destination Countries). Journal of Developing Economies, 7(1), 15–28. https://doi.org/10.20473/jde.v7i1.33183

ESDM. (2024). Handbook of Energy & Economic Statistics of Indonesia 2023.

Hia, S. W., Singgih, M. L., & Gurning, R. O. S. (2025). The Application of Lean Six Sigma to Improve Mining Transportation Overall Vehicle Effectiveness (MTOVE): A Case Study in Mining Company. International Journal of Lean Six Sigma, 16(1), 54–88. https://doi.org/10.1108/IJLSS-07-2023-0121

Ituriaga, J. C., Mariñas, K. A., Saflor, C. R., Enano, W. C., Javier, D. A., Dequilla, M. G., & Cabutaje, N. S. (2024). An Implementation of Lean Six Sigma in the sortation process in Flash Express, San Jose, Occidental Mindoro: A Case Study of Optimizing Manual Sorting Delivery. 2024 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM), 308–312. https://doi.org/10.1109/IEEM62345.2024.10857124

Markopoulos, E., Refflinghaus, J., Roell, M., & Vanharanta, H. (2022). Understanding Situationality using the Kepner-Tregoe Method in the Company Democracy Model to increase Employee Engagement and Knowledge Contribution. AHFE (2022) International Conference. https://doi.org/10.54941/ahfe1001522

Obwegeser, N., T. Nielsen, D., & M. Spandet, N. (2019). Continual Process Improvement for ITIL Service Operations: A Lean Perspective. Information Systems Management, 36(2), 141–167. https://doi.org/10.1080/10580530.2019.1587576

Olanrewaju, F., Chima Uzorh, A., & Nnanna, I. (2019). Lean Six Sigma Methodology and Its Application in the Manufacturing Industry – A Review. American Journal of Mechanical and Industrial Engineering, 4(3), 40. https://doi.org/10.11648/j.ajmie.20190403.11

Pamungkas, G. J., & Mulyono, N. B. (2023). Optimizing Coal Hauling Operations: A Strategic Plan for Increased Productivity at PT Borneo. Logistic and Operation Management Research (LOMR), 2(1), 63–82. https://doi.org/10.31098/lomr.v2i1.1529

Paradis, E., O'Brien, B., Nimmon, L., Bandiera, G., & Martimianakis, M. A. (Tina). (2016). Design: Selection of Data Collection Methods. Journal of Graduate Medical Education, 8(2), 263–264. https://doi.org/10.4300/JGME-D-16-00098.1

PT Berau Coal Energy Tbk. (2025). 2024 Annual Report PT Berau Coal Energy Tbk. www.beraucoalenergy.co.id

Ramasubramanian, K., & Singh, A. (2017). Data Visualization in R. In Machine Learning Using R (pp. 129–179). Apress. https://doi.org/10.1007/978-1-4842-2334-5_4

Sahoo, L., & Topno, S. A. (2023). Energy Performance of Loading and Hauling Operations in Opencast Mines. 36th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems (ECOS 2023), 2673–2681. https://doi.org/10.52202/069564-0240

Shearer, C. et al. (2020). Boom and Bust 2020: Tracking the Global Coal Plant Pipeline.

Taherdoost, H. (2021). Data Collection Methods and Tools for Research; A Step-by-Step Guide to Choose Data Collection Technique for Academic and Business Research Projects. International Journal of Academic Research in Management (IJARM), 10(1), 10–38.