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ENHANCING OVERBURDEN PRODUCTION ACHIEVEMENT THROUGH LEAN SIX SIGMA: A CASE ANALYSIS OF PIT WEST MHY MINING OPERATIONS AT PT ABC BY PT XYZ

MENINGKATKAN PENCAPAIAN PRODUKSI OVERBURDEN MELALUI LEAN SIX SIGMA: ANALISIS KASUS OPERASI PENAMBANGAN PIT WEST MHY DI PT ABC OLEH PT XYZ

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ABSTRACT

This research examines the persistent problem of underachievement in overburden (OB) production at Pit West MHY, part of PT ABC's mining operations, where actual production averaged only 63% of the planned target of Q1 2025. Overburden removal at this site is managed by PT XYZ as the mining contractor. Applying the Lean Six Sigma DMAIC framework, this research systematically identified and analyzed operational inefficiencies contributing to production shortfalls, including long hauling roads slippery after rain, lack of road maintainance (RM) equipment, hauling road damage, truck's long cycle time, delays during shift changes, limited number of dozing unit at disposal, and queuing at loading fronts. Data sources included internal production reports, time studies, loss time records, and structured discussions with the supervisory team of PT ABC and operational staff of PT XYZ to confirm root causes. Various Lean Six Sigma tools, such as Pareto analysis, time studies, hypothesis testing, cause-and-effect diagrams, and field observations, were used to identify, analyze, and validate these root causes. Targeted improvement actions were implemented, such as addition of RM unit, hot seat change shift procedures, partial resurfacing of critical hauling road segments, additional dozer allocation to improve disposal readiness, and truck fleet split strategies to reduce congestion at loading points. As a result, average daily production achievement increased significantly to over 102% of the target on April 2025. To maintain these gains, standardized daily inspections using Condition Index forms for Haul Road, Front Loading, and Disposal areas were adopted as part of routine operational controls. This research shows that applying the Lean Six Sigma approach can deliver practical and measurable improvements to production reliability in mining operations.

Keywords: *Overburden Production, Lean Six Sigma, DMAIC, Root Cause Analysis, Operational Improvement*

ABSTRAK

Penelitian ini mengkaji masalah rendahnya pencapaian produksi overburden (OB) di Pit West MHY, bagian dari operasi penambangan PT ABC, di mana produksi aktual rata-rata hanya mencapai 63% dari target yang direncanakan pada Q1 2025. Pengupasan lapisan tanah penutup di lokasi ini dikelola oleh PT XYZ sebagai kontraktor penambangan. Dengan menerapkan kerangka kerja Lean Six Sigma DMAIC, penelitian ini secara sistematis mengidentifikasi dan menganalisis inefisiensi operasional yang berkontribusi terhadap kekurangan produksi, termasuk jalan angkut yang panjang dan licin setelah hujan, kurangnya peralatan pemeliharaan jalan (RM), kerusakan jalan angkut, waktu siklus truk yang panjang, keterlambatan selama pergantian shift, terbatasnya jumlah unit dozer yang tersedia, dan antrean di front loading. Sumber data yang digunakan termasuk laporan produksi internal, studi waktu, catatan loss time, dan diskusi terstruktur dengan tim supervisor PT ABC dan staf operasional PT XYZ untuk mengkonfirmasi akar permasalahan. Berbagai alat Lean Six Sigma, seperti analisis Pareto, studi waktu, pengujian hipotesis, diagram sebab-akibat, dan observasi lapangan, digunakan untuk mengidentifikasi, menganalisis, dan memvalidasi akar masalah ini. Tindakan perbaikan yang ditargetkan telah diimplementasikan, seperti penambahan unit RM, prosedur pergantian shift kerja, pelapisan ulang sebagian segmen jalan angkut yang kritis, penambahan alokasi dozer untuk meningkatkan kesiapan pembuangan, dan strategi pembagian armada truk untuk mengurangi kemacetan di titik pemuatan. Hasilnya, pencapaian produksi harian rata-rata meningkat secara signifikan menjadi lebih dari 102% dari target pada bulan April 2025. Untuk mempertahankan pencapaian ini, inspeksi harian terstandardisasi dengan menggunakan formulir Indeks Kondisi untuk area Haul Road, Front Loading, dan Disposal diadopsi sebagai bagian dari kontrol operasional rutin. Penelitian ini menunjukkan bahwa penerapan pendekatan Lean Six Sigma dapat memberikan peningkatan yang praktis dan terukur terhadap keandalan produksi dalam operasi pertambangan.

Kata Kunci: Produksi Overburden, Lean Six Sigma, DMAIC, Analisis Akar Masalah, Peningkatan Operasional

INTRODUCTION

Coal is one of the fossil energy sources that plays an important role in supporting global energy needs. Since the Industrial Revolution, coal has become the backbone for various strategic sectors, such as power generation, metal refining industry, cement industry, and other manufacturing sectors. The advantages of coal are in its abundant availability, relatively low cost, and its ability to provide large and stable amounts of energy. This makes it one of the main energy sources, especially in developing countries that have high energy demand to support industrialization and economic development.

Coal production is carried out on a large scale through structured stages, as follows:

1. Exploration: This stage aims to determine the location of potential coal reserves through geological mapping, exploration drilling, and analysis of the quality and quantity of reserves.
1. Mine Planning: Based on exploration results, the most effective and economical mining method is planned, including cost estimation, mine design, and logistics and environmental planning.
2. Mining (Exploitation): The process of extracting coal from subsurface, which in Indonesia generally uses the open-pit mining method because it is more cost and operationally efficient.
3. Hauling: Coal that has been mined is transported using trucks or conveyors to stockpiles, then distributed to ports and sent to buyers via barges or large ships.
4. Reclamation: The final stage is the restoration of ex-mining land so that it can return to its initial condition, as a form of commitment to environmental sustainability.

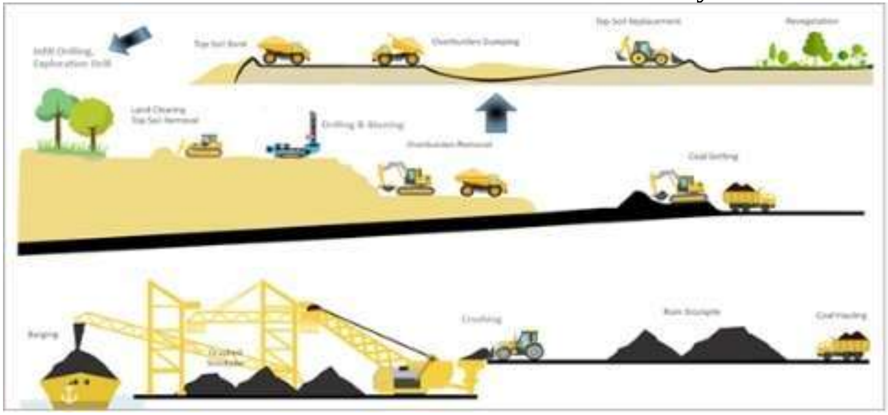

Figure 1. Coal Mining Process
(Source: Harywibowo et al, 2022)

The production of overburden (OB) is a critical component of coal mining operations, particularly in Indonesia, where open-pit mining is widely implemented. Overburden refers to the layers of soil and rock that must be removed to access the underlying coal seams. In many cases, the volume of overburden can far exceed the volume of coal extracted, making OB removal one of the most resource-intensive and costly activities in the mining process. High stripping ratios can lead to increased fuel consumption, equipment utilization, and labor needs, which in turn elevate operational costs and affect overall mining efficiency. Furthermore, geological conditions such as the depth, moisture, and composition of the overburden layer may introduce technical challenges that disrupt productivity

BUSINESS ISSUE

Overburden (OB) removal is a fundamental activity in open-pit coal mining that enables access to coal seams and ensures the continuity of production. Delays or shortfalls in OB production disrupt not only coal output realization but also the broader stability of supply plans and cost structures. During the first quarter of 2025, OB removal at Pit MHY, operated under contract by PT XYZ for PT Bukit Asam (PTBA) as mine owner, fell significantly below target, achieving only about 62.8% of the planned volume. This shortfall led to underperformance in coal production, creating a backlog that must be absorbed in subsequent quarters, thereby increasing pressure on operational schedules and elevating unit costs.

Table 1. Pit West MHY Operation Plan 2025

Month	OB (BCM) Plan	OB (BCM) Actual	Coal (Ton) Plan	Coal (Ton) Actual	SR Plan	SR Act
Jan	1,000,000	358,999	140,000	31,745	7.14	11.31
Feb	1,100,000	774,589	120,000	118,052	9.17	6.56
Mar	1,360,000	1,040,221	140,000	124,002	9.71	8.39
Apr	1,655,000		170,000		9.74	
May	2,355,000		190,000		12.39	
Jun	4,020,000		190,000		21.16	
Jul	4,350,000		330,000		13.18	
Aug	4,440,000		330,000		13.45	
Sep	4,270,000		320,000		13.34	
Oct	4,320,000		320,000		13.5	
Nov	3,530,000		270,000		13.07	
Dec	3,600,000		280,000		12.86	
Total	36,000,000		2,800,000		12.86	

(Source: Internal Company, 2025)

To compensate for the Q1 backlog, planned OB volumes in later quarters must be increased, resulting in a higher stripping ratio and raising the cost per ton of coal produced. Financial analysis indicates that this shift reduces per-ton margins and total profitability across the remaining annual production. Such cost pressures highlight the strategic importance of maintaining production alignment and effective planning to avoid cascading operational inefficiencies.

Table 2. Additional Cost Simulation of Operational Condition of Pit West MHY

Condition	Stripping Ratio	OB Cost per BCM (Rp)	Coal Cost per Ton (Rp)	Total Cost per Ton (Rp) (SR x OB Cost per BCM) + Coal Cost per Ton
Ideal (no backlog)	12.86	40,000	55,000	569,400
Actual (with backlog)	13.39	40,000	55,000	590,600

Description	Value
Increase in unit cost due to SR deviation	Rp21,200
Remaining coal volume (tons)	2,526,200
Total estimated additional cost	Rp53,555,440,000

(Source: by Author)

Table 3 Margin Analysis

Item	Planned Scenario (No Backlog)	Backlog-Adjusted Scenario
Selling Price (Rp/ton)	763,755	763,755
Stripping Ratio	12.86	13.39
OB Cost per BCM (Rp)	40,000	40,000
Coal Mining Cost per ton (Rp)	55,000	55,000
Unit Cost (Rp/ton)	569,400	590,600
Gross Margin per ton (Rp)	194,355	173,155
Remaining Coal Volume (tons)	2,526,200	2,526,200
Total Gross Margin (Rp billion)	490.8	437.2
Difference in Total Margin (Rp billion)	—	-53.6

(Source: by Author)

Addressing this challenge requires more than administrative measures or contractual enforcement. A systematic, data-driven improvement approach such as the Lean Six Sigma DMAIC framework can support the identification and resolution of root causes, enabling more sustainable and efficient mining operations.

METHODOLOGY RESEARCH

Research Design

This study applies a mixed-methods research design by integrating quantitative and qualitative approaches to analyze and improve overburden production at Pit West MHY. Quantitative data, such as daily OB production, delay hours, and equipment cycle time, were collected to assess performance before and after improvements, focusing on March 2025 and the following month. Qualitative methods, including field observations, time studies, and operational team discussions, were used to capture waste activities and operational inefficiencies not visible in numerical data. The research follows the DMAIC framework of Lean Six Sigma to systematically guide the improvement process, making it possible to identify root causes qualitatively in the Define and Analyze phases, while monitoring performance improvements quantitatively in the Measure and Control phases. Despite data limitations, this case study provides valuable early insights into operational gains, combining both data-driven analysis and real field validation to optimize overburden productivity.

Data Collection Method

The data collection method in this study was designed to support Lean Six Sigma's DMAIC methodology, combining both primary and secondary data. Primary data were obtained through direct field observations and informal discussions with operational supervisors and engineers from PT XYZ and PT ABC, enabling real-time validation and practical insights. Meanwhile, secondary data were collected from internal operational documentation, including mine layouts, OB production reports, cycle time records, hauler speed, and loss time logs, covering the first quarter of 2025 and early second quarter after improvement initiatives. This data set was complemented by relevant literature reviews from mining productivity studies, ensuring a comprehensive and contextual understanding of operational conditions and industry practices.

Data Analysis Method

Data analysis in this study was structured using the DMAIC framework. In the Define phase, descriptive analysis and a SIPOC diagram were used to clarify the problem and map the OB removal process. During the Measure phase, delay records were categorized using Pareto analysis, while time studies classified operational activities into value-added, non-value-added, and waste categories. The Analyze phase identified root causes through structured team discussions and Fishbone diagrams, validated by operational calculations for equipment productivity (Komatsu, 2019) and supported by statistical tests using Minitab software. In the Improve phase, comparative statistical analyses, including t-tests and control charts, measured performance changes before and after improvement, while updated time studies monitored operational time allocation. Finally, in the Control phase, standard operating procedures and monitoring tools were introduced to sustain improvements, ensuring operational consistency and early detection of future inefficiencies.

LITERATURE REVIEW

OB Production in Surface Mining

Overburden (OB) removal is a critical operation in surface mining, especially in the coal sector, as it directly affects equipment productivity, pit development, and mining costs. Seervi et al. (2024) report that OB activities account for over 60% of total mining costs in large-scale opencast operations, with even minor deviations in parameters like bench height or cut width significantly impacting excavation equipment performance. The OB removal process comprises interconnected stages such as excavation, loading, hauling, dumping, road maintenance, and material spreading, all influenced by material properties, haul road conditions, and equipment availability.

Lean Six Sigma

Lean Six Sigma (LSS) is a process improvement methodology combining Lean's waste reduction focus with Six Sigma's data-driven variation control. George (2002) explains that Lean eliminates non-value-added (NAV) activities and waste (Muda), while Six Sigma reduces process variation and defects, aiming for no more than 3.4 defects per million opportunities (Pande et al., 2000). The DMAIC framework (Define, Measure, Analyze, Improve, Control) structures improvement efforts (Sundram et al., 2023). Vallejo et al. (2023) demonstrated LSS's effectiveness in reducing unproductive time in OB loading and hauling at a coal mine in Peru, while Chele (2023) found LSS superior in improving productivity, downtime, and operator engagement in a diamond mining operation.

Root Cause Analysis (RCA)

Root Cause Analysis (RCA) is a structured approach for identifying the underlying factors contributing to operational problems, rather than merely addressing symptoms. Sakdiyah et al. (2022) emphasize that RCA examines issues by considering their timing, location, and frequency, often visualized using tools like cause-and-effect diagrams (Vorley, 2008). Supporting tools include the SIPOC diagram (Nandakumar et al., 2020), Pareto Chart (Juran & Godfrey, 1999), and Fishbone Diagram (Brassard & Ritter, 2010), all of which systematically map and prioritize root causes. Additionally, Gemba observation (Imai, 1986) validates findings directly at the worksite, providing real-time insights into operational inefficiencies.

Statistical Tools

Statistical tools are essential for evaluating process performance, distinguishing between normal (common cause) and abnormal (special cause) variation. Montgomery (2012) highlights control charts in Statistical Process Control (SPC) as tools for early detection of process shifts. Hypothesis testing tools such as t-tests and ANOVA (Ghozali, 2016) help assess whether mean differences between groups are statistically significant. Variance analysis methods like Levene's test and F-tests (Ott & Longnecker, 2015) ensure homogeneity of variances across groups, preserving the validity of inferential statistics used in operational performance analysis.

Time Study

Time study is a structured method to measure and analyze the time required to complete specific work elements under standard conditions, providing benchmarks for performance evaluation and process improvement. Duran et al. (2015) confirm that time studies enhance productivity by identifying inefficiencies, reducing delays, and improving workflow coordination. By consistently recording and analyzing work times, organizations can eliminate non-value-added activities, optimize operations, and support continuous improvement initiatives in industrial environments.

Conceptual Framework

This study's conceptual framework addresses underperformance in OB removal at Pit West MHY by integrating Lean Six Sigma (LSS) to identify inefficiencies and deliver sustainable performance improvements.

In Q1 2025, only 62.8% of the OB removal target was achieved, risking coal production plans and raising stripping ratios. Operational factors contributing to this gap include equipment capacity mismatches, delays, and process waste, classified using Lean's VA, NVA, and Muda categories. Time study measurements support identifying wasteful activities, while LSS's combination of Lean waste elimination and Six Sigma variation control provides a comprehensive, data-driven strategy for resolving productivity issues and stabilizing OB production

RESULTS

Define Phase

In the Define Phase, the research identified the core problem of underperformance in overburden (OB) production at Pit West MHY, particularly focusing on March 2025 when operational conditions were stable compared to earlier months. The analysis revealed that daily OB production achievement was highly inconsistent, often falling short of targets, with an overall monthly production rate of only 76%. Through the Voice of Customer analysis, key stakeholders emphasized the need to improve production, analyze operational delays, and reduce repeat issues. A SIPOC diagram was developed to map the OB production process, which consists of excavation and hauling stages, highlighting how inefficiencies in the hauling and operational cycles significantly contributed to production gaps. This structured framework formed the basis for investigating operational bottlenecks and prioritizing process improvements.

Measure Phase

In the Measure Phase, operational delay records from March 2025 were analyzed to quantify problems affecting OB production. Loss time logs showed a total of 3,402 hours of delays, averaging 16.16 hours per day, with rain and slippery conditions being the most significant contributors. A Pareto analysis revealed that seven primary issues, including rain, slippery roads, rest and meal breaks, shift changes, hauling road problems, disposal delays, and front congestion, accounted for over 90% of total delays. Additionally, a time study classified operational activities into Added Value (60.11% of time), Non-Added Value (19.91%), and Muda (19.99%) activities, uncovering inefficiencies such as prolonged maintenance stoppages and loading queues. This comprehensive measurement identified clear areas where operational time was being lost and where improvements should be focused.

Analyze Phase

The Analyze Phase sought to validate root causes behind production delays identified in the Measure Phase, prioritizing issues like slippery conditions, shift changes, hauling road damage, disposal problems, and loading point queues. Structured discussions with field personnel and Gemba observations confirmed several operational challenges, including inadequate road maintenance resources, inefficient shift handovers, and poor haul road conditions post-rain.

Statistical tests validated significant deviations, such as slippery durations exceeding the standard (p-value 0.007) and truck speeds falling below operational benchmarks (p-value < 0.0001).

After the rainy hour, once the rain stops, the RM team has to prepare the hauling road by using the RM equipment, which consists of a motor grader and compactor. The primary RM unit is the motor grader, and in Pit West MHY operations the motor grader used is a Komatsu unit with type GD825A. Once the hauling road gets ready, the operation supervisor will instruct the driver to start the hauling operation. To validate whether the number of RM equipment was not enough, the team conducted calculations to compare area coverage and the capacity of road intemperance equipment. The data required for calculating the area coverage of the motor grader were taken from its equipment specifications and field observations. Based on calculations using equation III.1, the area covered per hour for each motor grader as follows:

$$QA = V \times (Le - Lo) \times 1000 \times E$$

$$QA = 6.4\,km/hr \times (3.4\,m - 0.6\,m) \times 1000 \times 0.8$$

$$QA = 14{,}336\,m^2/hr$$

With the number of RM equipment available, which consists of 3 units serving the OB hauling road, it takes 3.2 hours to accommodate the maintenance of the OB hauling road which is 5.5 km long with average width of haul road is 25 m. This shows that the time that may be needed to restore the hauling road facilities is still below the set operational target, which is 2.12 hours.

The next stage of analysis involved assessing the sufficiency of dozing equipment allocated to this operation. At the time of observation, there were four Komatsu D155A-6R units assigned to support nine PC1250 excavator fleets. Based on operational planning, the expected productivity was 980 bcm per hour for the D155 units. However, actual field measurements, based on the calculation using Equation III.2 for bulldozer productivityas follows :

$$Q = \frac{60 \times q \times FF \times E \times e}{Ct \times Sf}$$

$$Q = \frac{60 \times 13.2\,m^3 \times 0.9 \times 0.67 \times 1}{0.49\,minutes \times 1.25}$$

$$Q = 778.86\,bcm/hour$$

The data required for calculating the productivity of dozer were taken from its equipment specifications and field observations. The reduction in productivity was attributed to the dominance of difficult overburden material, with a ratio of poor to good material estimated at 2:1, which significantly affected dozer efficiency.

Equipment capacity calculations showed that road maintenance and disposal equipment were insufficient to meet operational demands. The analysis concluded that these validated causes directly contributed to long delays and inconsistent OB production, providing clear targets for improvement actions.

DISCUSSION

Business Solution

This section focuses on the final two phases of the DMAIC framework, Improve and Control, where validated root causes of overburden productivity issues at Pit West MHY are addressed through targeted solutions and sustained through operational controls. Following the Define, Measure, and Analyze phases, which clearly identified and quantified the main operational bottlenecks, the project team collaborated with field operations to design practical, data-driven improvement actions. These actions were developed to be both effective and feasible within the site's operational constraints and conditions, ensuring seamless integration into daily mine operations while directly tackling the key problems identified.

In the Improve phase, several critical, interrelated problems, including prolonged slippery conditions, hauling road damage, extended truck cycle times, and inadequate road maintenance resources were grouped into two comprehensive improvement programs: *Hauling Road Improvement* and *Additional Road Maintenance Units*. These programs aim to enhance road surface conditions, reduce operational delays, and stabilize truck travel speed and productivity, especially during and after rainfall. Road maintenance readiness was also strengthened by optimizing the number of motor graders on-site, ensuring faster road recovery after disruptions. These improvement initiatives were finalized through management discussions and operational evaluations, with specific actions outlined to address each validated root cause as detailed in the improvement plan.

Table 4. Improvement Plan

Root Cause	Improvement Solution
Long Slippery Time	Resurface Hauling Road with claystone and sandy clay to reduce slippery time Add one more Motor Grader unit
Hauling Road Damage	Resurface Hauling Road with claystone and sandy clay to reduce slippery time
Change Shift	Hot Seat Change Shift Implementation
Lack of Supporting RM Equipment	Add one more Motor Grader unit
Truck Long Cycle Time	Resurface Hauling Road with claystone and sandy clay to reduce slippery time Add one more Motor Grader unit
Disposal Problem	Addition of 1 unit of Dozer
Queue at Loading Points	Split the hauling truck fleet movement during shift changes

A total of five improvement initiatives were designed to resolve the validated root causes identified during the Analyze phase. One of the most critical actions was the *Hauling Road Improvement* program, aimed at addressing interconnected issues such as long slippery times, hauling road damage, and extended truck cycle times. Field observations revealed that specific road segments, notably Persiraja Road and Semen Padang Road, consistently became operational bottlenecks after rainfall, causing delays as trucks had to wait for safe road conditions. These delays not only prolonged slippery periods but also disrupted hauling productivity by increasing overall cycle durations.

To mitigate this, the project team carried out partial road upgrades by replacing problematic surface materials in these critical areas with higher-quality materials claystone and sandy clay, known for their superior load-bearing strength and low permeability. This upgrade was essential as the previous materials quickly turned muddy under wet conditions. Because claystone was not available at Pit West MHY, it was sourced from a nearby mining site, Pit TSBC, located eight to nine kilometers away. The new material's durability under rain exposure ensured more stable road conditions and minimized post-rain operational delays.

Supporting this effort, five smaller dump trucks were temporarily reassigned from infrastructure support roles to transport claystone from Pit TSBC to the improvement areas. The road repair process involved layering the claystone to improve road surface strength and drainage. Due to limited time and equipment, the team prioritized the most problematic segments for immediate repair instead of resurfacing the entire route. This targeted improvement strategy enabled faster road recovery after rain events, stabilizing hauling operations without significantly affecting other operational activities.

Figure 2. Hauling road resurfacing using claystone material at (A) Persiraja Road; (B) Semen Padang Road; (C) Road Condition after Layering.

(Sources : Author's Documentation)

To evaluate the effectiveness of this improvement, slippery time data before and after road repair were compared under similar rainfall conditions. With a rainfall intensity of 12 to 15 mm and a duration of four to six hours, the average slippery time prior to the improvement was recorded at 2.93 hours. After implementing the improvement, the average duration decreased significantly to 2 hours. This result confirmed that the new road material helped reduce the recovery time post-rain, thereby improving overall productivity.

Addition of RM Unit

Based on the calculation, to cover RM of 5.5 kilometres compared with equipment capacity, the company needs 4 units of Motor Grader instead of 3 units. PT XYZ team decided to purchase 1 more motor grader to improve hauling road quality. The RM crew can scrap spoil quickly and manage road drainage properly. After using the new units, the team collects average trucks speed. The result is described in the individual value control chart in Figure 3. The average trucks speed has been increased from 16.9 km/h to 21.04 km/h. The addition of RM equipment has improved hauling road quality, which enables trucks to have stable speeds due to better road conditions. The standard deviation has also been reduced from 0.82 to 0.71.

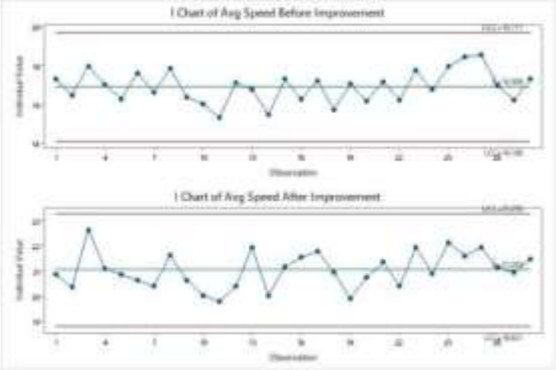

Figure 3. Truck Speed Before and After Improvement
(Sources : by Author)

Anderson-Darling test has been carried out to test the normality of truck speed data before and after the improvement. Before the improvement, the AD statistic was 0.184, and after the improvement, it was 0.208. These values are below the 5% critical value of 0.712, indicating that both data sets are normally distributed.

A significance test was conducted using a two-sample t-test to compare the average truck speeds before and after the addition of a motor grader unit. The result showed a p-value of < 0.0001, which is far below the 0.05 significance level. This indicates a statistically significant difference in truck speeds before and after the improvement, confirming that the additional motor grader had a positive impact on hauling road performance.

To measure process capability, a statistical analysis was conducted using the Cp index, as shown in Figure 4.

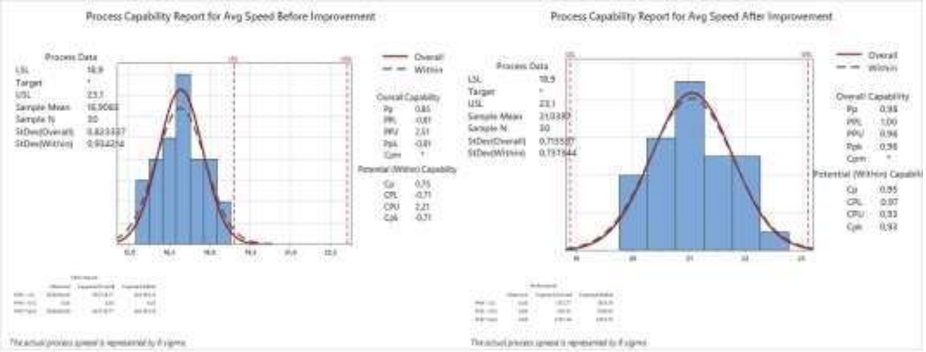

Figure 4. Process Capability Hauler Speed : (a) Before Improvement and (b) After Improvement
(Sources : by Author)

In this study, specification limits for truck speed were set between 18.9 km/h and 23.1 km/h, based on 90%–110% of the planned 21 km/h target, with results showing the process capability index (Cp) improving from 0.75 to 0.95 after road surface upgrades, indicating better operational consistency though still below the ideal Cp of 1.00. Additionally, to address significant idle time during shift changes caused by a lack of operator overlap under PT XYZ's policy, a *hot seat change shift* system was proposed and implemented. This system allows incoming operators to directly replace outgoing operators at the equipment in the field without requiring machines to return to the office, as illustrated in Figure IV.12. While requiring coordinated scheduling and field discipline, this method is widely used in the mining industry and was found feasible for Pit West MHY, effectively reducing unproductive transition time and supporting improved daily production outcomes.

Figure 5. Operator Handover during Hot Seat Change Shift on a Dump Truck.

(Sources : Author's Documentation)

After implementing the improvement initiatives, shift change durations at Pit West MHY were reduced significantly from around 2.00 hours to 0.95 hours per shift. PT XYZ agreed to adopt the hot seat change shift system despite the additional labor cost of one extra hour per operator, as the operational benefit of gaining more productive time outweighed the minor increase in expenses.

This change effectively boosted equipment availability and supported efforts to raise Effective Working Hours (EWH), resulting in more stable and consistent daily production performance. Additionally, delays at the disposal area were resolved by deploying an extra Komatsu D155A-6R dozer unit, addressing the mismatch between material inflow and dozing capacity. This unit increased daily spreading output by about 9,360 bcm/day, reducing truck queuing, improving hauling cycle times, and highlighting the importance of aligning support equipment capacity with production demands to avoid bottlenecks.

Another major improvement involved splitting the hauling truck fleet's movement pattern during shift transitions to reduce queuing at the loading front. Previously, simultaneous mobilization caused significant wait times sometimes over 20 minutes for the last trucks in line. Under the new system, trucks near the loading front completed a final load cycle, while those closer to the disposal area returned to base without a new load. This adjustment allowed staggered truck positions at the start of the next shift, with some already loaded and others empty, which minimized queuing and improved operational flow. As a result, daily delay time from front crowding dropped from 1.34 hours to 0.4 hours, and a follow-up time study confirmed a notable reduction in non-productive time (Muda) from 2.40 hours to 0.81 hours per day, marking clear improvements in operational efficiency.

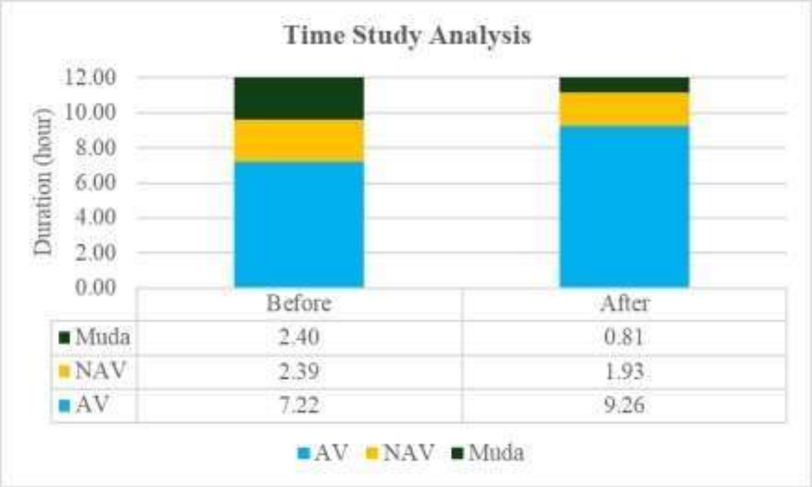

Figure 6. OB Production Operation Time Study Analysis Before and After Improvement

Additionally, the time allocated to Non-Added Value (NAV) activities also declined slightly, from 2.39 hours to 1.93 hours per day. This was largely influenced by the adoption of a more efficient change shift system, which reduced equipment idle time during operator transitions. As a result, Available Value (AV) activities saw a considerable increase, rising from 7.22 hours to 9.26 hours. This shift indicates a better utilization of working hours, reflecting improvements in both time management and overall productivity. Along with these improvements, the average productivity of the OB fleet at Pit West MHY increased to 500 BCM per hour.

To evaluate the effectiveness of the improvements implemented in the overburden removal process at Pit West MHY, daily production achievement data were analyzed both before and after the changes. Prior to improvement, the average achievement rate was approximately 76.49 % of the target, reflecting frequent delays and operational inefficiencies. After the implementation of improvement initiatives, including hot seat change shifts, road maintenance enhancement, disposal optimization, and split hauling trucks fleet, the average achievement rate significantly increased to 102.67%, as shown in Figure 7.

Figure 7. Comparation of Daily OB Production Achievement Before vs After Improvement
(Source : by Author)

As illustrated in Table 5, the updated time loss analysis, the most notable reductions were seen in the areas directly addressed by the improvement initiatives.

Table 5. Summary Result of LSS Implementation

Loss Time	Before (hours/day)	After (hours/day)	% Improvement
Slippery Road Conditions	2.93	2.04	30.38%
Change Shift	2	0.95	52.50%
Hauling Road Problem	1.65	0.33	80.00%
Disposal Problem	1.17	0.15	87.18%
Front Crowded	1.07	0.4	62.62%

(Source : by Author)

To validate the effectiveness of the improvement initiative implemented at Pit West MHY, two statistical tests were conducted using the Mann–Whitney U Test and Levene's Test. The Mann–Whitney U Test was applied to compare the distribution of overburden production achievement between the before and after periods. The test produced a p-value of 0.034, which indicates a statistically significant increase in achievement following the improvement. This result suggests that the initiative contributed to enhanced production performance.

In addition, Levene's Test was used to assess whether there was a significant difference in the variability of achievement between the two periods. The result showed a p-value of 0.004, as shown in Figure 7, indicating a significant reduction in variance after the improvement. This finding implies that the production process became not only more effective but also more consistent. Taken together, the results of both tests provide strong statistical evidence that the improvement effort led to increased operational performance and greater process stability.

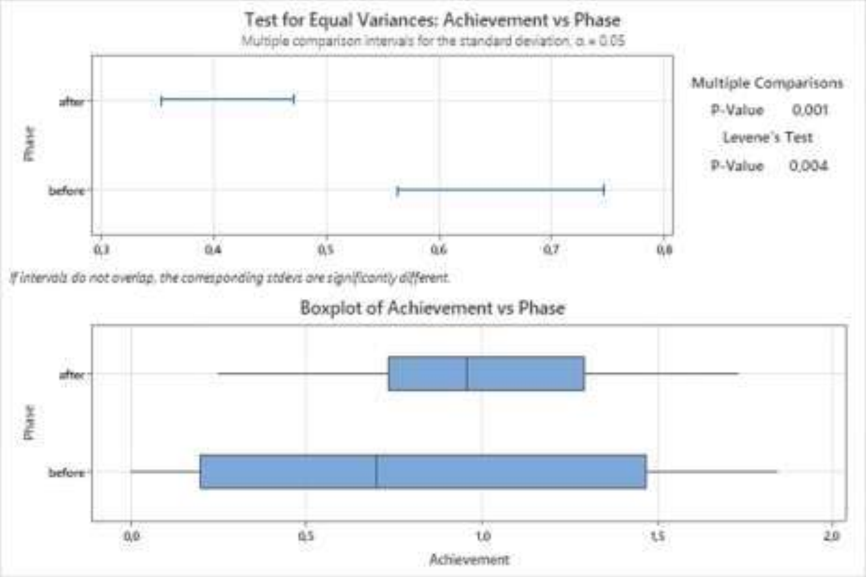

Figure 8. Statistical Analysis of Variance Before and After Improvement
(Sources : by Author)

Control Phase

The Control phase represents the final stage of the DMAIC cycle, focusing on sustaining the improvements achieved in the overburden removal process at Pit West MHY. In line with the analysis approach described earlier, this phase emphasizes standardization to ensure that the improvements implemented remain effective over time and do not regress to previous underperformance.

To achieve this objective, the operation team has developed and applied standardized monitoring procedures in the form of Condition Index inspections. These routine inspections are carried out by operational supervisors and cover three key operational areas: Front Loading, Haul Road, and Disposal. Each inspection requires the use of structured forms to document field conditions, assign standardized ratings, and note recommended corrective actions where needed.

These forms have been implemented in an online format using Google Forms to facilitate consistent daily reporting and easier data collection. The inspections are designed not only to record daily operational conditions but also to function as an early warning system for issues that could impact production targets. By applying consistent, scored evaluations, supervisors can objectively assess the operational readiness of each area, identify problems such as surface damage, drainage issues, or limited working space, and prioritize maintenance activities to prevent delays. A summary of the inspection form is shown in 3.

Table 6. Condition Index Monitoring Form

Area	Inspector Role	Frequency	Target Outcome
Haul Road	Operational Supervisor	Daily	Ensure safe, drivable conditions
Front Loading	Operational Supervisor	Daily	Ensure loading area readiness
Disposal Area	Operational Supervisor	Daily	Ensure space, safety, and readiness

(Sources : by Author)

The use of these forms also reinforces accountability, as supervisors must formally document their observations and the actions planned to address any deficiencies. This process supports a proactive approach to resolving problems in the field and helps maintain consistent operational standards. To illustrate how the inspection results feed into daily operational control, Figure 9 shows a simplified flow of the Condition Index monitoring and response process, from field assessment through to planning of corrective actions.

Figure 9. Flow of Condition Index Monitoring and Response Process
(Sources : by Author)

In addition, the records generated from these inspections provide management with a clear view of daily operational conditions, enabling better planning and resource allocation. Over time, the data collected can be analyzed to identify recurring issues or trends, supporting continuous improvement and longer-term infrastructure planning. Overall, the Condition Index inspections serve as a practical control mechanism that helps maintain safe, efficient, and reliable overburden production activities in line with planned targets and operational standards.

CONCLUSION

The study identified several critical operational factors causing shortfalls in overburden (OB) production at Pit West MHY, including prolonged slippery conditions after rainfall, poor haul road quality, idle equipment during shift changes, insufficient road maintenance support, limited dozer capacity at the disposal area, and queues at loading points. Data analysis using loss time records, Pareto charts, and time studies revealed that over 50% of operational time was consumed by Muda, or non-value-added activities. By applying the Lean Six Sigma DMAIC framework, the team successfully identified, measured, and validated seven key root causes through SIPOC mapping, time studies, one-sample t-tests, capacity calculations, and Gemba investigations. These findings confirmed that recurring delays and operational inefficiencies were measurable, actionable, and directly responsible for underperformance.

Following targeted improvements, operational results showed clear, measurable enhancements. Average daily OB production increased from 76% to over 102% of target, while time study data reflected substantial reductions in non-value-added (NAV) and Muda activities, and a rise in value-added working hours. Statistical tests confirmed these gains were significant, with reduced process variability and improved efficiency. To sustain and build on these outcomes, it is recommended that PT ABC and PT XYZ maintain standardized daily Condition Index inspections and consider integrating digital monitoring systems to track fleet performance, road conditions, and operational metrics in real-time. Future research should also explore seasonal impacts on haul road conditions and develop predictive maintenance models to optimize road readiness, particularly during wet seasons, ensuring continuous improvement in overburden removal operations.

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