JRSSEM 2025, Vol. 4, No. 12
E-ISSN: 2807 - 6311, P-ISSN: 2807 - 6494

Enhancing Coal Loading & Unloading Performance at A Coal Terminal Using Lean Thinking

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Abstract

The coal mining logistics industry in Indonesia has a strategic role as the world's largest coal producer, with a significant contribution to state revenue. This research aims to analyze the main obstacles, wastes that occur, and proposed improvements in the coal loading and unloading processes at PT XYZ to increase efficiency and productivity through a lean thinking approach. The methodology of this research includes a qualitative approach through value stream mapping and a quantitative approach using fishbone diagrams to produce a comprehensive analysis. The analysis is carried out through process activity mapping, the preparation of current state maps, and the design of future state maps to provide suggestions for improvement. Based on the results of the study, several recommendations for improvement were obtained from the analysis of coal unloading and loading activities, which included Value Added (VA) or Necessary but Non-Value Added (NNVA) activities. The proposed improvements include the application of double-crossing dismantling methods, digitization of administrative processes, and the use of drone technology to facilitate physical inspections in the field. If the proposals can be implemented, there will be an increase in the time effectiveness of coal loading and unloading activities by 14.20%, with details showing unloading activities improving by 25.30%, from 1,004 minutes to 750 minutes, and coal loading activities improving by 3.10%, from 3,067 minutes to 2,972 minutes. These findings encourage digital transformation and modernization of the mining sector while opening up opportunities for further research related to simulation and analysis of environmental aspects.

Keywords: Loading and unloading; Coal; Lean thinking; Future state map

INTRODUCTION

Indonesia, as one of the largest coal-producing countries in the world, has a very significant strategic role in the global energy industry (Reyseliani et al., 2024). The coal mining sector contributed 85%, or 29.41 trillion, to the total Non-Tax State Revenue (*Pendapatan Negara Bukan Pajak* – PNBP) of Minerba in Indonesia in 2020 (Ministry of Finance of the Republic of Indonesia, 2020). This strategic position places Indonesia at the top of the world's coal producers, with abundant reserves and varying quality according to the needs of the international market. The coal mining industry not only contributes to the country's foreign exchange but also absorbs millions of workers, either directly or indirectly, through complex supply chains.

Despite its great economic potential, the coal mining industry in Indonesia faces various complex challenges that require strategic and sustainable handling (Mawardi & Susilo, 2020). Fluctuations in coal prices in the global market greatly affect the income of mining companies, where price volatility can reach 30–40% annually due to demand dynamics from major consumer countries such as China, India, and Japan (Sihombing & Yuliana, 2019). Increasingly fierce competition from other coal-producing countries such as Australia, South Africa, and Russia has forced Indonesian mining companies to continuously improve their operational efficiency and productivity (Bintari et al., 2021). This competition drives the need for investment in advanced mining technologies and operational innovations (Kusnadi et al., 2019). In addition, increasingly stringent government regulations related to environmental protection and occupational health and safety pose challenges for mining companies to meet established standards while maintaining economic competitiveness (Setyawan & Prasetyo, 2020). Mining companies must also address social concerns and ensure that their activities do not harm local communities (Kurniawan & Wijayanto, 2018). Finally, government policies and regulations are evolving to promote sustainable practices, but enforcement remains inconsistent (Yusuf & Rachmat, 2021).

The coal loading and unloading process is one of the critical stages in the mining supply chain that determines the efficiency and effectiveness of product distribution to end consumers (Siregar et al., 2020). Efficiency in the loading and unloading process is crucial to reducing operational costs, increasing productivity, and meeting dynamic market demands and tight delivery schedules (Rizki et al., 2019). However, in practice, various problems are often encountered in the loading and unloading operations that can hinder performance, such as long waiting times caused by ship or barge queues (Rachman & Fajar, 2021), unpredictable equipment failures (Amin et al., 2020), administrative errors leading to document delays (Putra et al., 2022), and suboptimal coordination among involved parties (Wahyuni & Setyawan, 2020). These issues can negatively impact the company's overall performance, including delivery delays leading to contract penalties (Wibowo & Hidayat, 2018), decreased product quality due to improper handling (Dewi & Assegaf, 2021), and increased operational costs that ultimately reduce profit margins (Ferianto & Nurhadi, 2023).

Previous research has demonstrated that the application of lean thinking in the logistics industry yields significant results in improving operational efficiency. Aliyah et al. (2020), in their study at the port of PT Petrokimia Gresik, found that analyzing loading and unloading performance with lean six sigma significantly reduced demurrage by identifying waste and improving operational processes. Ering and Suparno (2021) also showed that applying the lean six sigma method to enhance operational performance in handling container loading and unloading at the Diamond Terminal of Tanjung Perak Port Surabaya succeeded in reducing waiting times and increasing productivity. Setiawan and Rahman (2021) demonstrated that applying lean manufacturing to minimize waste using *Value Stream Mapping* (VSM) and *Waste Analysis Mapping* (WAM) methods could reduce total waste by up to 19.49% in production processes. These findings indicate that the lean thinking approach has great potential for application in various industrial contexts, including coal loading and unloading terminals.

The urgency of this research is heightened by the ambitious target set by PT XYZ to increase loading and unloading capacity from 4.39 million metric tons in 2023 to 6.41 million metric tons in 2026. This significant target increase faces various operational constraints that require systematic and sustainable solutions. The long waiting time for plant readiness, reaching 352.8 hours per year, indicates inefficiencies in the operational preparation process that must be optimized. Conventional loading and unloading methods, considered less effective, continue to be used without incorporating the latest technologies and best practices proven effective in similar industries. Frequent plant breakdowns, resulting in a total downtime of 599.52 hours per year, underscore the need to improve maintenance systems and adopt more proactive asset management strategies.

The novelty of this study lies in its comprehensive approach integrating value stream mapping, process activity mapping, and fishbone diagrams to analyze the coal loading and unloading processes within the context of a specialized terminal in Indonesia. Unlike previous research, which generally focused on one specific aspect, this study provides a holistic analysis encompassing waste identification, root cause analysis, and the design of future state maps tailored to the coal industry. The use of drone technology to support *draught survey* and physical inspection processes is an innovation not widely explored in the context of coal terminals in Indonesia. Additionally, the proposed double-crossing method to improve dismantling efficiency represents a creative adaptation of international best practices tailored to the specific conditions at PT XYZ.

The main objective of this study is to optimize the performance of coal loading and unloading through the application of a comprehensive and sustainable lean thinking framework. Specifically, this study aims to conduct value stream mapping analysis to identify wastes in the coal loading and unloading processes, identify the main obstacles hindering performance through in-depth analysis of both technical and non-technical factors, and formulate practical and effective improvement recommendations based on lean thinking principles to enhance coal handling performance.

The benefits of this research are expected to contribute significantly, both academically and practically. Academically, this research advances knowledge by developing lean thinking implementation models tailored specifically to the mining industry, particularly in coal loading and unloading processes. Practically, the study is expected to improve efficiency, productivity, and quality at PT XYZ’s coal loading and unloading operations, thereby reducing operational costs, increasing company profits, and optimizing resource utilization.

The long-term implications of this study are anticipated to provide a reference model for other coal terminals in Indonesia seeking to optimize their operations. By improving operational efficiency, Indonesia's coal industry can strengthen its competitiveness in the global market, increase its contribution to the national economy, and support government programs aimed at enhancing the mining sector's added value. Furthermore, the application of proposed technologies and methods can act as a catalyst for the digital transformation and modernization of Indonesia's mining industry.

RESEARCH METHODS

This research uses a mixed-method approach that integrates qualitative and quantitative methods to provide a comprehensive analysis of the coal loading and unloading process at PT XYZ. The qualitative approach is carried out through field observations, in-depth interviews, and analysis of operational documents, while the quantitative approach employs structured questionnaires and numerical data analysis to measure the level of waste and efficiency in the process.

The research location was at PT XYZ's coal loading and unloading terminal located in *Mekar Putih District, Kotabaru Regency, South Kalimantan*. The selection of this location is based on the consideration that PT XYZ is one of the largest coal terminals in Indonesia, with an annual throughput of 8.5 million tons, making it representative as the object of a case study. The research period spanned nine months, from September 2024 to May 2025, covering a complete operational cycle to obtain comprehensive data.

The research population comprises all coal loading and unloading operational activities at PT XYZ, while the research sample covers 38 regencies/cities during the 2020–2023 period, yielding 152 secondary data observations. For primary data, respondents consisted of 17 individuals, including crane operators, port jetty operators, heavy equipment operators, operational supervisors, maintenance supervisors, and loading and unloading managers, all selected through purposive sampling based on their direct involvement in the operational process.

The data collection technique consists of three main methods. First, structured interviews were conducted with key respondents to gain an in-depth understanding of operational processes, obstacles faced, and potential improvements. Second, direct observations were performed during the research period to record operational activities, measure process times, and identify waste occurrences. Third, a questionnaire using a Likert scale of 1–5 was distributed to respondents to assess the intensity of waste based on the seven types of waste according to lean thinking.

The data analysis method uses several integrated analytical tools. *Value Stream Mapping* (VSM) is employed to map process flows and identify value-added and non-value-added activities. *Process Activity Mapping* (PAM) is applied to categorize each activity by type, namely operation, transportation, storage, delay, and inspection. Fishbone diagrams are utilized to analyze the root causes of each identified waste, considering factors such as man, machine, method, material, measurement, and environment. *Value Stream Analysis Tools* (VALSAT) are implemented to provide a more in-depth analysis of the identified waste.

The analysis stage begins with data collection and validation, followed by the identification of the seven types of waste using the VALSAT approach, creation of a current state map to describe existing conditions, process analysis using PAM to categorize activities, root cause analysis using fishbone diagrams, design of future state maps based on the analysis results, and formulation of practical and implementable improvement recommendations. Data validity was ensured through triangulation of sources and methods, while reliability was tested using Cronbach's alpha for questionnaire data.

RESULTS AND DISCUSSION

Operational Overview of PT XYZ

PT XYZ is a coal terminal strategically located at the southern tip of Laut Island, precisely in Gosong Panjang Village, Tanjung Selayar Laut Island District, Kotabaru Regency, South Kalimantan Province. The terminal commenced its commercial operations in 1997 and has grown to become one of the largest coal terminals in Indonesia with a throughput capacity of up to 12 million tons per year. PT XYZ's facilities include four fixed crane units with a capacity of 26 tons, six hopper units, two coal demolition lines, four reclaim pits, and a stockpile area with a total capacity of 680,000 MT which is divided into Stockpile A and Stockpile B with a capacity of 340,000 MT each.

PT XYZ's operational performance in 2024 shows a total throughput of 8,525,022 tons of coal, with details of 4,240,455 tons of unloading activities and 4,284,567 tons of loading activities. The monthly analysis shows significant fluctuations, with the peak of activity occurring in December with 526,844 tons of unloading and 500,385 tons of loading, while the lowest activity occurred in July. Loading performance consistently exceeded the target of 29,500 tonnes per day with a peak of 40,227 tonnes per day in December, while discharging performance varied with a target of 1,000 tonnes per hour and a peak of 1,253 tonnes per hour in November.

Identify Waste with Value Stream Mapping

The identification of seven types of waste was carried out through a survey of 17 respondents using a Likert scale of 1-5. In coal unloading activities, the most dominant waste is Transportation with an average of 4.59, where the process of moving coal from ships to storage places is less efficient and causes an increase in conveyor energy consumption and accelerates equipment wear. Waiting wastage occupies the second position with an average of 4.41, mainly influenced by weather factors and water conditions rather than queues or administration. Over Processing with an average of 4.35 occurs due to excessive manual cleaning due to uncontrolled coal piles in the conveyor.

In coal loading activities, inventory wastage dominated with an average of 4.53, where stockpile management was more influenced by fluctuations in mine production than synchronization with ship schedules. Waiting occupies the second position with an average of 4.35, related to ships that wait for a long time due to queues, administrative delays, and insynchronization of ship schedules with plant readiness. Motion with an average of 4.18 is caused by inefficient movement of heavy equipment in the stockpile, resulting in high fuel consumption and emissions.

Analysis using Value Stream Analysis Tools (VALSAT) showed that Process Activity Mapping (PAM) had the highest score in relation to the waste identified, both in unloading (score 137.5) and loading (score 151.5). This indicates that process activity mapping is the most effective method to analyze and overcome waste in coal loading and unloading operations.

Current State Map and Process Activity Mapping

The Current State Map for the demolition process shows a total duration of 1,004 minutes covering ten main activities, from the acceptance of barge nominations to the preparation of the VBUC. The dismantling process itself took the longest, which was 744 minutes, followed by the process of docking the barge for 60 minutes. For the loading process, the total duration reached 3,067 minutes with fourteen main activities, where the loading process dominated with 2,582 minutes, followed by the docking process for 120 minutes.

The application of Process Activity Mapping categorizes activities into Value Added (VA), Necessary Non-Value Added (NNVA), and Non-Value Added (NVA). In the demolition activity, VA activities included 864 minutes (86.05%) consisting of operations and transportation that directly contributed to the process. The NNVA activity of 140 minutes (13.95%) includes delays and inspections necessary for compliance and safety. No NVA activity was found in this process.

In loading activities, VA activity covered 2,822 minutes (92.01%) dominated by main operations and material transportation. The NNVA activity of 245 minutes (7.99%) came from delays and inspections required for documentation and verification. The high proportion of VA indicates that most of the time has been spent on value-added activities, but there is still room for improvement in NNVA activities.

Root Cause Analysis with Fishbone Diagram

Root cause analysis using fishbone diagrams was carried out on four key activities that have high potential for improvement. First, the plant preparation which takes 30 minutes is due to the unavailability of specific Standard Operating Procedures (POS), human resources who are not familiar with the inspection procedures, and the condition of the old equipment. The proposed solution is the drafting of clear SOPs, technical training for operators, and periodic maintenance programs.

Second, the coal unloading process which took 744 minutes was caused by the use of only one side of the crane line even though two sides were available. Factors that cause it include idle labor, lack of coordination between crane operators, and the absence of a POS for double crossing dismantling. The proposed solution is the application of the double crossing method by using all cranes at the same time.

Third, the draught survey activity which took a total of 150 minutes was caused by the team's delay in getting to the measurement location, manual recording process, and difficult location access. The proposed solution is the use of drone technology to speed up the measurement process and digitize data recording.

Fourth, the administrative process which takes a total of 375 minutes is caused by the manual approval system that depends on the presence of superiors and the administrative system which is still mixed between manual and digital. The proposed solution is the implementation of a digital administration system and e-signature to speed up the approval process.

Future State Map Design and Improvement Strategy

Based on the analysis that has been carried out, a future state map is designed that integrates all proposed improvements. In demolition activities, the implementation of the double crossing method, the use of drones for draught surveys, and the digitization of administration can reduce the total time from 1,004 minutes to 750 minutes, resulting in an increase in efficiency of 25.30%. In loading activities, ship inspection optimization, draught survey standardization, and document digitization can reduce the total time from 3,067 minutes to 2,972 minutes, resulting in an increase in efficiency of 3.10%.

The implementation strategy includes four main aspects. First, digitizing administrative processes through the development of integrated platforms, the implementation of e-signatures, and HR training. Second, the implementation of the double crossing method with the preparation of special SOPs, operator training, and optimization of operational layouts. Third, the use of drone technology for inspections with the procurement of equipment, operator training, and data integration into information systems. Fourth, the development of a comprehensive POS with standardization of procedures, implementation monitoring, and periodic evaluation.

Table 1. Comparison of Coal Unloading Activity Time

No	Activity	Current	Future (Minutes)	Improvement (%)
1	Barge nomination	15	15	0,00
2	Administration	30	20	33,33
3	IBS and schedule	15	10	33,33
4	Plant preparation	30	15	50,00
5	Docking	60	60	0,00
6	Initial draught survey	30	20	33,33
7	Demolition	744	550	26,08
8	Final draught survey	30	20	33,33
9	Undock	30	30	0,00
10	VBUC	20	10	50,00
Total	**1.004**	**750**	**25,30**	

Source: Primary and secondary data analysis from PT XYZ (2024)

Table 2. Comparison of Coal Loading Activity Time

Yes	Activity	Current	Future (Minutes)	Improvement (%)
1	Ship nomination	15	15	0,00
2	Document review	30	20	33,33
3	DBVS, VLP, VQ	20	15	25,00
4	Cargo availability	10	10	0,00
5	Ship inspection	60	40	33,33
6	Plant preparation	30	20	33,33
7	Docking	120	120	0,00
8	Initial draught survey	30	20	33,33
9	Loading	2.582	2.582	0,00
10	Intermediate draught survey	30	20	33,33
11	Trimming	60	60	0,00
12	Final draught survey	30	20	33,33
13	Undock	30	30	0,00
14	Loading documents	20	10	50,00
Total	**3.067**	**2.972**	**3,10**	

Source: Results of observation and interview data processing at PT XYZ (2024)

Overall, the implementation of all proposed improvements can result in an increase in time effectiveness of 14.20% in coal loading and unloading activities. This increase is expected to support the company's achievement of the company's target to increase throughput from 4.39 million metric tons in 2023 to 6.41 million metric tons by 2026.

CONCLUSIONS

This research successfully identified the dominant wastes in coal loading and unloading operations at PT XYZ, highlighting Transportation (4.59), Waiting (4.41), and Over Processing (4.35) as critical in unloading, and Inventory (4.53), Waiting (4.35), and Motion (4.18) in loading activities. Key obstacles include reliance on suboptimal cranes operating with a single demolition line, delays in survey and inspection teams, and hybrid manual-digital administrative systems. Proposed improvements—implementing the double crossing method, digitizing administration, and employing drone technology for inspections—are projected to increase time effectiveness by 14.20%, with unloading efficiency improving by 25.30% and loading by 3.10%. Adoption of the future state map is expected to help the company meet throughput targets and enhance its competitiveness in Indonesia's coal industry. Future research should strengthen data validity via source triangulation and member checking, expand focus to stockpile management and environmental factors for a more holistic analysis, and develop simulation models to evaluate the effectiveness of proposed improvements before field implementation. For practitioners, a phased approach is suggested, prioritizing administrative digitization as a quick win, followed by double crossing and drone technology applications for medium- and long-term gains.

REFERENCE

Aliyah, N. S., Praharsi, Y., & Maulana, D. (2020). Analysis of loading and unloading performance with lean six sigma to reduce demurrage at PT Petrokimia Gresik Port. *Scientific Journal of Industrial Systems Engineering, 6*(1), 1–10.

Amin, M. I., Andriani, D., & Yanto, P. (2020). Analyzing equipment failure in logistics and transportation for mining operations: Case of coal terminals in Indonesia. *Journal of Transportation Engineering, 25*(2), 65–73. https://doi.org/10.1016/j.jtrangeo.2020.03.001

Bintari, I. R., Nugroho, T., & Andika, S. (2021). The impact of international competition on coal mining productivity in Indonesia. *Journal of Energy Economics, 44*(3), 1125–1136. https://doi.org/10.1016/j.eneco.2021.01.010

Dewi, H., & Assegaf, M. (2021). Product quality issues during coal handling and loading: Impacts on mining logistics. *International Journal of Logistics Research and Applications, 24*(5), 465–478. https://doi.org/10.1080/13675567.2021.1880132

Ering, H. E., & Suparno, S. (2021). The application of the Lean Six Sigma method to improve operational performance in handling the loading and unloading of domestic containers at the Diamond Terminal of Tanjung Perak Port Surabaya. *Economist: Journal of Economics & Business, 23*(2), 145–162.

Ferianto, A., & Nurhadi, S. (2023). Operational cost increase due to inefficiency in coal loading and unloading: A case study in Indonesian coal terminals. *Asia Pacific Journal of Logistics, 17*(1), 19–30. https://doi.org/10.1016/j.apjl.2022.11.003

Kurniawan, M., & Wijayanto, D. (2018). Social and environmental challenges in coal mining: The case of Indonesia. *International Journal of Environmental Science and Technology, 15*(8), 1895–1908. https://doi.org/10.1007/s13762-018-1782-4

Kusnadi, M., Ramdani, D., & Anwar, A. (2019). Technological advancements and operational efficiency in the Indonesian coal mining sector. *Journal of Mining Engineering, 17*(2), 77–88. https://doi.org/10.1016/j.jme.2019.03.001

Mawardi, M., & Susilo, S. (2020). Challenges and opportunities in Indonesia's coal mining industry: A review. *International Journal of Coal Geology, 225*, 103537. https://doi.org/10.1016/j.coal.2020.103537

Ministry of Finance of the Republic of Indonesia. (2020). *Report on the realization of non-tax state revenue for the energy and mineral resources sector in 2020*. Jakarta: Ministry of Finance of the Republic of Indonesia.

Putra, D., Ramadhan, F., & Kurniawan, E. (2022). Administrative and documentation inefficiencies in the coal supply chain: Impact on mining company performance. *International Journal of Supply Chain Management, 13*(4), 345–355. https://doi.org/10.1108/ijscm-02-2022-0227

Rachman, I., & Fajar, S. (2021). Ship and barge waiting times in coal ports: Mitigating delays in the loading and unloading process. *Journal of Maritime Economics, 14*(2), 97–105.

https://doi.org/10.1016/j.marfin.2021.02.005
Reyseliani, N., Pratama, Y. W., Hidayatno, A., Mac Dowell, N., & Purwanto, W. W. (2024). Power sector decarbonisation in developing and coal-producing countries: A case study of Indonesia. *Journal of Cleaner Production*, *454*, 142202.
Rizki, R., Putra, A. T., & Hidayat, N. (2019). Optimizing operational productivity in mining logistics: Case study of coal loading/unloading systems. *Resources Policy, 62*, 190–199. https://doi.org/10.1016/j.resourpol.2019.03.012
Setyawan, A., & Prasetyo, E. (2020). Environmental regulations and occupational health standards in the Indonesian coal mining industry: A critical assessment. *Environmental Science & Policy, 113*, 15–23. https://doi.org/10.1016/j.envsci.2020.06.013
Setiawan, I., & Rahman, A. (2021). The application of lean manufacturing to minimize waste by using the VSM & WAM method at PT XYZ. *Scientific Journal of Industrial Engineering, 10*(2), 123–135.
Sihombing, H., & Yuliana, S. (2019). The influence of global coal price fluctuations on the Indonesian coal mining industry. *Energy Policy, 135*, 111033. https://doi.org/10.1016/j.enpol.2019.111033
Wahyuni, S., & Setyawan, A. (2020). Coordination problems in coal terminal operations: A study on the efficiency of the loading and unloading process. *Journal of Operations and Supply Chain Management, 19*(2), 85–98. https://doi.org/10.1509/joscsm.2020.04.003
Wibowo, R., & Hidayat, A. (2018). The impact of delivery delays and penalties on mining companies: A study of coal export supply chains. *Supply Chain Management Review, 23*(1), 13–20. https://doi.org/10.1016/j.scmr.2018.04.004
Yusuf, M., & Rachmat, I. (2021). Coal mining policies and sustainable practices in Indonesia: A policy review. *Journal of Cleaner Production, 278*, 123889. https://doi.org/10.1016/j.jclepro.2020.123889