[1] Selamat Walmanto Hia

[2] Moses Laksono Singgih

[3] Raja Oloan Saut Gurning

Productivity Improvement of Coal Hauling using Lean Techniques: A Case Study in Coal Mining Company in Indonesia

JES
Journal of Electrical Systems

Abstract: - The adoption of the lean concept as a company strategy to creates competitive advantages and provides important savings opportunities has been increasing recently. Its application has been extended from manufacturing to almost all types of industry including coal mining under the realization of the need for productivity improvement and the need for efficient operation. However, published information and articles showing the real application of lean in the mining sectors are still scarce. The objective of this paper is to show the application of lean production method in coal hauling operations in one of coal mining company in Indonesia. The lean method with Plan, Do, Check, Act (PDCA) cycle has been utilized to identify, analyze and improve productivity. The main result of this study reveals that implementing lean increase the productivity of coal hauling operations from 115 to 129 tons per hour. Statistical test using two sample t-test confirmed the significance of the result. This paper demonstrates lean application in coal hauling operations and bring significant result.

Keywords: Productivity, Improvement, Lean, Hauling, Mining.

I. INTRODUCTION

Business around the world are facing new challenges to improve and sustain their performance in today's competitive environment. The business environment requires companies to make the most of effort to remain competitive in the marketplace. Business markets are demanding and diverse, customer choices are changing rapidly, and global competition among industries to maintain profitability is intensifying every day. In this competitive environment, companies are looking for productive and innovative ways to compete and survive in the global market. Only company who are agile, cost-effective, flexible and of high-quality will survive.

As a successful strategy, implementation of lean principles and techniques can improve business performance in many aspects such as quality, quality, and cost reduction. Significant productivity improvements have been observed in various industries where lean is used [1]-[3]. Lean has brought significant impact on company performance [4]. To follow this concept, many companies have become lean by eliminating waste across their value chain. Lean is the integration of principles, practices, tools, and techniques to eliminate activities that do not add value [5]. Eliminating these activities improve both the cycle time and production lead time which leads to productivity improvement. Lean is a systematic method of eliminating waste within a manufacturing system.

Lean practices have received special attention in various industries outside manufacturing sectors to exceed customer expectations by improving product quality, reducing production lead times, and minimizing costs. The lean concept is also being adopted in the mining industry [6]. Mining industry today, faced with increasing operating costs, more and more coal mining companies are looking of ways to eliminate waste and improve their processes and productivity to remain competitive. Therefore, implementing lean in the coal mining is very appropriate because of the tangible benefits. However, its application in the mining environment faces big challenges. Lean application in mining context facing difficulties due to dynamic nature of mining operations, which leads to high levels of uncertainty in various unit operations [7]. Mining operation are characterized by a dynamic, unstable, uncertain, and risky working environments.

Despite a large amount of relevant research on lean concepts in the manufacturing environment, more empirical research in the mining sector is needed to apply this method. Application of this method in the mining environment is limited, with very little research on the topic of lean mining [8]. Therefore, this article aims to discuss the case study in this field. The purpose of the research is to improve coal hauling productivity using the lean method.

[1,2,3] Department Management and Technology, School of Interdisciplinary Management and Technology, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia

[1]selamat.walmanto@gmail.com

II. LITERATURE REVIEW

Lean Philosophy

Lean manufacturing is a workplace improvement method chosen by many manufacturing and processing industries around the world. Lean grew out of Henry Ford's early mass production efforts in the auto industry. Its modern roots lie in the production system developed by Toyota starting in the 1950s, initially for vehicle assembly lines and later expanding to other aspects of the business [6]. The Toyota Production System has helped make Toyota one of the most successful auto companies in the world. Since then, lean manufacturing has been one of the most powerful manufacturing systems in the world today.

The lean philosophy, also known as lean, includes proven tools and techniques focused on eliminating waste in operations and adding more value to the final product or service by meeting customer needs. In the Lean philosophy, two types of activities are clearly distinguished: Value-added activities and non-value-added activities. Value-added (VA) activities are those processes that contribute directly to the value creation of the final product or service, and customers are willing to pay for these "value-creating" activities. The higher this ratio the greater efficiency [9]. Non-value-added (NVA) activities are regarded as waste and must be eliminated. Lean philosophy can be applied to help companies or organizations examine their business processes, minimize unnecessary costs, reduce waste, and make processes more efficient and effective.

Lean is increasingly recognized as an important improvement concept for organizations of all types to improve their operations [10]. Previews study show the positive impact of lean on the overall organization performance [11] [12]. The adoption of lean brings a positive effect on efficiency and delivery [13]. Lean implementation brings lead time reduction and productivity improvement [14]. The study also indicated that there is a significant difference in firm performance between lean and non-lean companies, lean adoption improved firm performance significantly due to its ability to reduce inventory and cost of goods sold [15]. Previews studies on lean implementation has a significant impact on productivity improvement [16][17][18][19][3]. When companies implement these lean methods, several outcomes consistently result in increased production velocity by eliminating movement, waiting time, and unnecessary process steps [18]. Due to its benefits, many industries around the world are implementing or trying to adopt this concept to increase efficiency [20][21].

The application of lean concepts beyond the manufacturing sector has increased recently. In line with this, its scope has been expanded to the mining industry, considering the need to improve productivity and leverage efficient operations. There is little research regarding lean implementation in the mining sector. There is a lack of conceptual and coherent models to guide lean implementation in this field [22].

Lean Philosophy in Mining

The mining industry is one of the basic, major industries that underpin economic and social development because it provides raw materials and resources, including crude oil, natural gas, coal, copper, iron, etc. for other industries. Coal is one of the most important resources for energy production and space heating, especially in developing countries. Coal mining considered a labour-intensive industry faces many challenges including environmental, safety issues, low operational efficiency and productivity [23]. The main obstacles to improving productivity in the coal mining industry are lack of personnel training and equipment maintenance, improper operation management, and lack of awareness of operation efficiency.

In the coal industry, low productivity and operational efficiency are one of the biggest challenges due to the existence of a lot of waste such as waiting, inventory, etc. Before applying the lean philosophy in the coal mining industry, we must first understand that lean principles originated in the automotive industry and were therefore designed to regulate some specific characteristics of the automotive manufacturing system, which may not be suitable for certain operations in the coal mining sector. Compared to the automobile manufacturing process, coal mining is characterized by a higher risk of uncontrollable conditions. In addition, Table 1 presents some differences between the coal mining industry and the automobile industry [7]. These differences must first be considered when the Lean philosophy is applied in the coal mining industry to avoid potential pitfalls.

Table 1. Comparison of Coal Mining and Automotive Industry

Coal mining industry	Automotive industry
Physically challenging environment	Ambient environment
Inherently variable environment	Stable work environment Compact
Geographical dispersion	Compact plants
Remote locations	Industrial clusters
Impact of weather	Indoor environment

High environmental impact	Small environmental impact
Inherently variable raw materials	Controlled raw materials

Lean production systems require a highly stable operation to ensure production flow without any delay. A stable process that produces products of 100% quality and consistently completes this task within a defined operating time. To make production flow required stability, standardized work, quality at the source, minimizing equipment breakdown, and flexibility of manpower and production equipment [24]. These are some challenges in applying lean production in mining, however, this difficulty is not an excuse for the absence of waste elimination in the coal mining industry. There are potential lean practice applications in mining, such principle of single-minute exchange dies (SMED) to reduce delay time when repairing assembling parts, truck mechanics can perform external setup to reduce breakdown time. Flexibility of manpower allocation also can be adopted by multiple skill training between truck drivers and heavy equipment operators to reduce silo organization structure.

To date, most of the production and logistics systems used in the coal industry are "push" systems. The logic of push production systems is determined by the requirement to maximize the use of expensive fixed assets. The equipment should not idle [25]. The negative impact of the push system is slow response to changes in customer demand. Reduction in reaction time for fulfilling customer demand required production system transition to become a "pull" production system which is just in time production mode. The consequences of this approach are a reduction in work in progress, and coal stockpile reduction which lead to the reduction of production cost.

Previous studies on lean mining implementation have utilized man rider system to reduce waste and improve Overall Human Effectiveness (OHE) to achieve better productivity [26]. The article identifies some typical wastes in coal mining such as coal spillage and re-handling process of spilled coal, bottleneck of the coal transportation system, variation in coal seams height, thin and thin coal is very difficult to excavate and it is not allowed to be left un-mined.

Unlike manufacturing, there is little information or research on the lean implementation in the mining industries. Although, the adoption of lean tools in the mining industry has been discussed in the previous paper. Increased productivity in underground coal mining has revealed that the key factors influencing productivity are the operating cycle, equipment utilization, manpower utilization, and material transportation. Preventing equipment failure in underground coal mining is essential [27]. Lean practice: time study, cycle time reduction, standardized truck manoeuvre, balancing between truck and conveyor capacity have been used to improve coal barge loading conveyor productivity [28]. Lean tools such as 5S and TPM can positively impact daily mining speed, and Kaizen can increase miner safety by reducing the risk of object collisions in the workplace [29]. Waste identification in gold mining was studied, using Waste Assessment Model (WAM) tool. The results showed that the biggest waste in gold mining are defects, unnecessary motion, and waiting [30]. To eliminate waste and improve the overall efficiency of coal hauling operations in conjunction with operation improvement in the coal mining transportation process, the mining transportation overall vehicle effectiveness indicator has been developed [31] [32].

Limited lean tools have been used for productivity improvement such as sort, set in order, shine, standardize, sustain (5S), Total Productive Maintenance (TPM), Value Stream Mapping (VSM), kaizen [29]. Kaizen is the Japanese term for continuous improvement. A study on added value and waste activity has been conducted in underground fluorspar mining in Brazil using the action survey method [33]. The study map the production process based on lean concepts and techniques.

III. RESEARCH METHODOLOGY

This paper employs a case study as the research methodology. A case study is an empirical investigation aimed at identifying a contemporary phenomenon in a real-world situation. To perform this case study, Plan, Do, Check, Action (PDCA) step steps have been carried out. PDCA cycle is the lean working cycle structure [34]. The PDCA step is described below [35]:

Plan: Planning consist of two-step, where the first step is to identify and define the problems that exist within the process. The second step is to analyze and identify the activity plan for improvement solutions.

Do: Once the solution plan is created and the schedule is created, it's time to execute the plan.

Check: Once a solution using a PDCA has been implemented, the performance of the solution due to the applied technique should be observed over time.

Act: If the proposed solution works, each process improvement solution must be standardized and implemented across all business practices.

Case Study Overview

This case study was conducted in one of the coal hauling company in Indonesia. The hauling contractor worked to transport coal from the pit to the port stockpile. The mining is open-pit coal mining. The annual hauling capacity

is about 1 million tons per year, with a hauling distance of 32 kilometres. The company utilized trucks HINO JD series with a capacity of 24 tons. The company owns 12 fleet trucks to perform this duty. The main hauling process consists of loading, traveling to port, dumping, and traveling back as described in Figure 1. To perform coal loading into the truck the company utilized excavator Komatsu PC300 with bucket capacity 1.8 meter cubic. The company work 24 hours per day which is divided into 2 working shift.
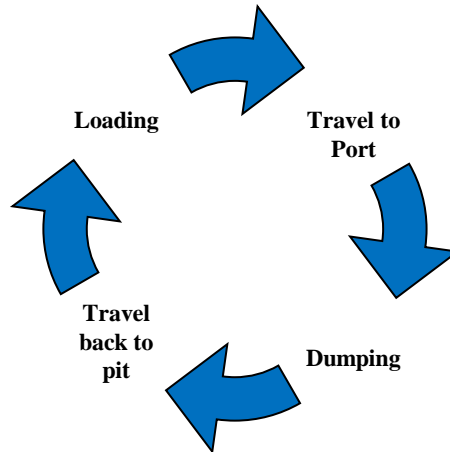

Figure 1. Coal Hauling Process Cycle

IV. RESULT AND ANALYSIS

Result divided into four sections following PDCA cycle:

1. Step Plan

This phase incorporates the definition of the problem. The company realized that productivity should be improved and sought way to increase productivity. The initial step is to collect the existing data. To get a picture of the whole activities during one shift operation, the team used time study to collect operation data. The data has been collected for five days operation consecutively. The summary of time allocation during one working shift described in Figure 2.
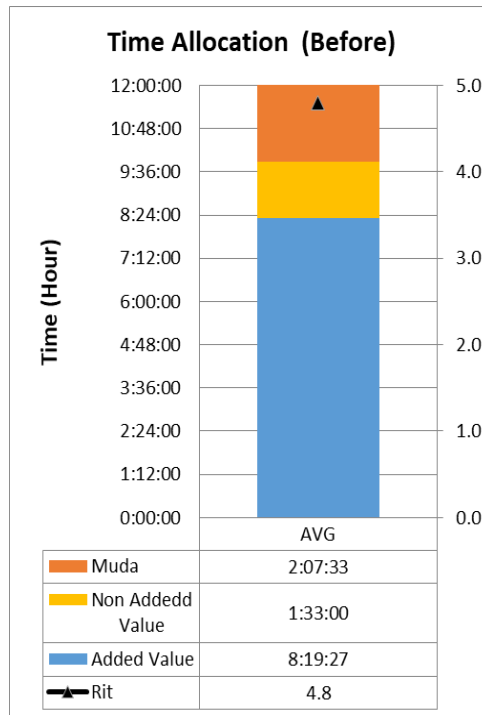

Figure 2. Hauling Time Allocation before Improvement

Hauling time allocation is divided into three categories: added value, non-added value, and Muda as described in Table 2. Added value is the process that give value to customer, including loading, traveling to port, dumping, and travel back to mining pit. Non-added value is the activities that did not give added value but must exist to support operation, including refuelling, truck manoeuvres in the loading point, weighing process, etc. Muda is the Japanese term for waste activity including queuing in front loading, truck breakdown, queuing in weight-bridge, and waiting at the end of the working shift. Based on data in Table 2, the added value activity 69%, non-added value 13%, and Muda 18%.

Table 2. Hauling Time Allocation before Improvement

Activity	Hour	Percentage
Added Value (AV)	8:19:27	69%
Non-Added Value (NAV)	1:33:00	13%
Muda	2:07:33	18%

Non-added value activities have been breakdown into detail as described in Table 3. The non-added value activities include housekeeping at the beginning of the shifts, safety talk, daily inspection, refuelling, etc. Most of the activities are required to perform the hauling process. However, some of them could be minimized.

Table 3. Non-added value (NAV) activities

Activities	Time (minutes)	Percentage (%)
Housekeeping	0:21:52	30%
Safety talk	0:11:24	16%
Daily inspection	0:08:54	12%
Refueling	0:06:59	10%
Traveling to Office	0:05:32	8%
Absent / Finger print	0:05:12	7%
Traveling to unit	0:04:54	7%
Standby (parking)	0:02:22	3%
Picking Ticket	0:02:00	3%
Maneuver at stockpile	0:01:46	2%
Maneuver at front loading	0:00:53	1%
Send ticket	0:00:45	1%
Filling time sheet	0:00:36	1%

The team also identified Muda activities, including dust at the hauling road about 29%. When hauling road dusty the operation must be stopped for safety reasons, where the driver's sight was not clear. To prevent this, usually, the hauling road needs water spraying to reduce the dust. Waiting at the end of shifts 18%, this happened since the driver stopped operation at 16:30 PM. They are afraid of being late for bus picking up. The bus will pick them up at 18:00. Since the hauling cycle time is about 122 minutes, there was not enough time to deliver the coal to the port and back again to the mining pit before 18:00 PM.

Most of Muda activities are waiting. Combining waiting time at the end of working shift 18% and waiting at front loading 17% resulted total waiting time of 35%. Waiting at front-loading due to queuing time, since cycle time for loading one truck required 7 to 8 minutes. The next truck will line up in front loading. The rest of Muda's activities are described in Table 4.

Table 4. Muda Activities

Muda Activity	Time (minutes)	Percentage %
Dusty road	0:38:44	29%
Waiting (End of shift)	0:23:51	18%
Waiting at front loading	0:22:20	17%
Others	0:16:54	13%

Rest (Early shift)	0:11:52	9%
Break Down	0:10:00	7%
Meal	0:05:12	4%
Waiting at weight bridge (WB)	0:04:00	3%
Queuing at fuel station	0:01:50	1%

At the same time, the improvement team collects the existing productivity data. Existing truck fleet productivity was 115 tons per hour (TPH) on average. There are opportunities for improvement since the time study data show 18% of Muda and 13% NAV. Minimizing Muda and NAV will lead to productivity improvement. The team discussed a solution plan, the idea was to implement kaizen activities. Kaizen activities are described in Table 5.

Table 5. Kaizen Plan

No	Kaizen Plan	Remark
1.	Relocate water fill	Reduce water truck filling time
2.	Split truck starting point	Reduce queuing time
3.	Fix access to weight bridge	Reduce waiting time in WB
4.	Refuelling schedule	Reduced queuing at fuel station

2. Step Do

To reduce loss time due to dusty roads, the team relocated the water fill station. To reduce dust the water truck must spray the dust immediately and continuously. The water truck has a capacity of 20.000M cubic. After the spraying activity, the water truck will be empty and need to be refilled immediately to perform continuous spraying. The existing refiling time required about 30 minutes. After the relocation water truck, the re-filling time was reduced to 15 minutes. This happened because the section head is shorter than the previous location increasing the water pump capacity. This relocation improved the capacity of water fill by nearly 50%.

The next kaizen execution is performed by splitting the truck starting point. 6 trucks were assigned to front-loading and the rest of the trucks were assigned traveling to port. It will reduce half of the queuing time. To perform this, 6 trucks should be loaded at the end of the shifts. Based on the time study data, there are waiting time of 18% at the end of the working shifts. At this time the drivers waiting for the bus to pick up. The team used this time to add time by asking the driver to load 6 trucks at the end of the shifts. At the end of the shift, there are 6 trucks with full load positions, ready to travel to port at the beginning of the next shift.

Before dumping the coal into the stockpile, the truck must enter the WB. There were waiting times at WB due to the access road being damaged and narrow. The space for truck manoeuvre was very narrow causing the next truck must line up in front of WB. To reduce waiting time at WB the team fixed the access to WB by compacting and making the access for manoeuvre more comfortable for driver and truck could enter WB continuously without waiting.

One of the loss times during the hauling operation was queuing at fuel station for refuelling. After several trips, the truck must enter the fuel station for refuelling. It was found the truck lined up in the fuel station. The trucks enter the fuel station randomly. The fuel station serves all equipment in mining including truck, road maintenance equipment, light vehicle, bus, etc. The team arranges a schedule for truck refuelling time to prevent queuing time.

3. Step Check

After kaizen activity was carried out, the team collecting data after kaizen. The improvements have been made and the result is shown in Figure 3. Kaizen activities resulted in a reduction of Muda and NAV thus making AV increase.
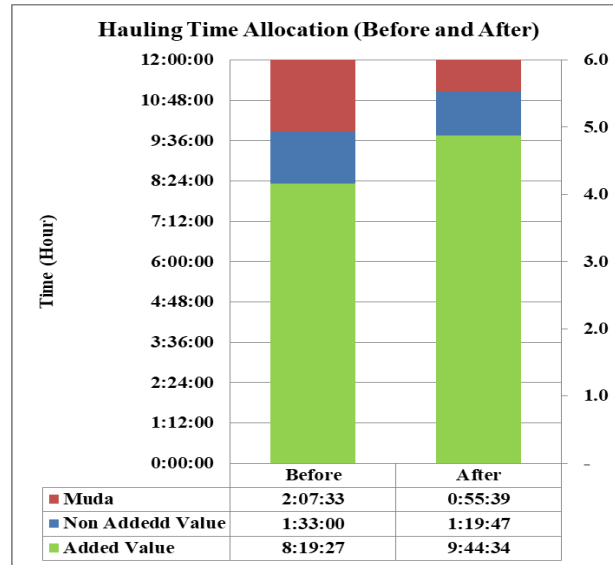
Figure 3. Hauling Time Allocation after Improvement

NAV activities reduced by 14% and Muda reduced by 56%. This is because some of the waiting times at the end of the working shift have been reduced and converted to AV. The driver performed loading for 6 trucks at the end of the working shift. At the same time reduce queuing time at the loading point at the beginning of the working shift. Waiting time at WB and refuelling time has been reduce which resulted in Muda and NAV. Kaizen activities made AV increase by 17% and hauling productivity improved by 12% from 115 TPH to 129 TPH as described in Table 6.

Table 6. Improvement Result

Remark	Added Value	Non-Added Value	Muda	Productivity (TPH)
Before	8:19	1:33	2:07	115
After	9:44	1:19	0:55	129
Result	17%	(14%)	(56%)	12%

4. Step Act

After obtaining the good result from the kaizen activity, to sustain the result the team developed a standard operational procedure that cover all improvement item.

The result of kaizen solution shows the average productivity increased from 115 TPH to 129 TPH. To evaluate the significance, statistical two sample t-test has been performed using Minitab software. The p-value 0.000 which indicate there is significant difference of productivity before and after improvement. To provide visual summary of the result, a boxplot has been made as described in Figure 4.
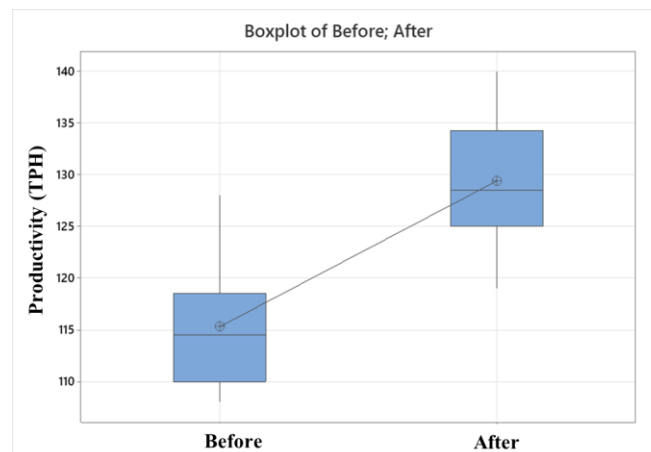

Figure 4. Boxplot Hauling Productivity

V. CONCLUSION

This research used time study to identify added value, non-added value and Muda activities in coal hauling operations. Non-added value and Muda activities that contribute to productivity have been identified. PDCA and kaizen resulted in a reduction of non-added value and Muda which lead to productivity improvement. This study shows added value increased 17% and hauling productivity improved from 115 to 129 TPH. This paper contributed to how to implement lean in the coal mining business, especially in coal hauling operations.

The limitation of this study is that it was conducted in one of the coal mining operations processes called the hauling process. In addition to hauling processes, there are also other processes in mining. In the future, lean implementation in the mining industry will need to be carried out on a larger scale. In addition to the fact that this study collected operational data manually, significant effort was also expended in collecting data from trucking vehicles. Future research should consider implementing the Internet of Things (IoT), which allows managers to collect real-time data using modern devices.

References:

[1]   A. Kumar, R. Giri, S. Mishra, and N. Gupta, "Productivity Improvement of HLLS Using Lean Technique in Assembly Line of an Automotive Industry," Evergreen, vol. 9, no. 2, pp. 356–366, 2022, doi: 10.5109/4794160.

[2]   M. Bukhsh et al., "Productivity improvement in textile industry using lean manufacturing practices of 5s & single minute die exchange (Smed)," Proc. Int. Conf. Ind. Eng. Oper. Manag., pp. 7374–7385, 2021.

[3]   D. Shah, P. Ratilal Patel, and P. Patel, "Productivity Improvement by Implementing Lean Manufacturing Tools In Manufacturing Industry Continuous improvement in SME View project Water Jet Machining View project Productivity Improvement by Implementing Lean Manufacturing Tools In Manufacturing Indu," Int. Res. J. Eng. Technol., pp. 3–7, 2018, [Online]

[4]   S. Rahman, T. Laosirihongthong, and A. S. Sohal, "Impact of lean strategy on operational performance: A study of Thai manufacturing companies," J. Manuf. Technol. Manag., vol. 21, no. 7, pp. 839–852, 2010.

[5]   S. G. Gebeyehu, M. Abebe, and A. Gochel, "Production lead time improvement through lean manufacturing," Cogent Eng., vol. 9, no. 1, 2022.

[6]   K. Dunstan, B. Lavin, and R. Sanford, "The application of lean manufacturing in a mining environment," Australas. Inst. Min. Metall. Publ. Ser., no. October, pp. 145–157, 2006.

[7]   A. Wijaya, R. Kumar, and U. Kumar, "Implementing lean principle into mining industry issues and challenges," Int. Symp. Mine Plan. Equip. Sel., pp. 1–9, 2009.

[8]   J. Lööw, Lean Production in Mining. 2015.

[9]   T. Ohno, "Taiichi Ohno (Author) - Toyota Production System-Beyond Large-Scale Production-Productivity Press (1988).

[10]   Q. Hu, R. Mason, S. J. Williams, and P. Found, "Lean implementation within SMEs: A literature review," J. Manuf. Technol. Manag., vol. 26, no. 7, pp. 980–1012, 2015.

[11]   I. Belekoukias, J. A. Garza-Reyes, and V. Kumar, "The impact of lean methods and tools on the operational performance of manufacturing organisations," Int. J. Prod. Res., vol. 52, no. 18, pp. 5346–5366, 2014.

[12]   P. Manfredsson, "Textile management enabled by lean thinking: a case study of textile SMEs," Prod. Plan. Control, vol. 27, no. 7–8, pp. 541–549, 2016.

[13]   P. Danese, P. Romano, and T. Bortolotti, "JIT production, JIT supply and performance: Investigating the moderating effects," Ind. Manag. Data Syst., vol. 112, no. 3, pp. 441–465, 2012.

[14]   M. Ghosh, "Lean manufacturing performance in Indian manufacturing plants," J. Manuf. Technol. Manag., vol. 24, no. 1, pp. 113–122, 2013.

[15]   H. C. Wang, N. Chen, and H.-J. Chang, "The Impact Of Just In Time On Firm Performance," J. Bus. Econ. Res., vol. 2, no. 7, pp. 1–8, 2011.

[16]   A. L. Gazoli de Oliveira and W. R. da Rocha Junior, "Productivity improvement through the implementation of lean manufacturing in a medium-sized furniture industry: A case study," South African J. Ind. Eng., vol. 30, no. 4, pp. 172–188, 2019.

[17]   S. Parthasarathi, P. M. P. Vellingiri G., and R. C. S., "Productivity Improvement and Reduction of Lead Time in Manufacturing Industry Using Lean Tools," Ind. Eng., vol. 5, no. 1, p. 1, 2021.

[18]   J. Mandloi and A. Yadav, "Productivity Improvement by Lean Manufacturing an Automobile Industry with the Help of Method Study," Glob. J. Res. Eng. Ind. Eng., vol. 14, no. 4, 2014.

[19]   L. Silvério, L. G. Trabasso, and M. V. P. Pessôa, "Application Phases for Productivity Improvement through Lean Methods Assessments in an Aeronautical Company - Case Study," IOP Conf. Ser. Mater. Sci. Eng., vol. 859, no. 1, 2020.

[20]   G. B. Ram, "Improving the Performance by Lean Methodology," vol. 5, no. 07, pp. 1–9, 2017.

[21]   S. Taj and C. Morosan, "The impact of lean operations on the Chinese manufacturing performance," J. Manuf. Technol. Manag., vol. 22, no. 2, pp. 223–240, 2011.

[22]   A. Seifullina, A. Er, S. P. Nadeem, J. A. Garza-Reyes, and V. Kumar, "A Lean Implementation Framework for the Mining Industry," IFAC-PapersOnLine, vol. 51, no. 11, pp. 1149–1154, 2018.

[23]   H. Yu and X. Sun, Implementation of Lean Philosophy and Lean Tools in Coal Mining Industry Complimentary Contributor Copy, no. September. 2019.

[24]   J. C. Yingling, D. R.B., and S. J., "Lean Manufacturing Principles and Their Applicability To the Mining Industry," Miner. Resour. Eng., vol. 09, no. 02, pp. 215–238, 2000.

[25]   V. Mikhalchenko, Y. Rubanik, N. Osokina, and A. Mikhalchenko, "qLean productionq in the coal mining industry," pp. 33–38, 2016.

[26]   E. M. Ade and V. S. Deshpande, "Lean Manufacturing and Productivity Improvement in Coal Mining Industry," Int. J. Eng. Res., vol. 2, no. 10, pp. 35–43, 2012.

[27]   D. P. Mishra, M. Sugla, and P. Singha, "Productivity Improvement in Underground Coal Mines - A Case Study," J. Sustain. Min., vol. 12, no. 3, pp. 48–53, 2013.

[28]   S. W. Hia, "Productivity Improvement of Coal Barge Loading Conveyor using Lean Techniques: A Case Study in Coal Mining Company," pp. 562–573, 2023.

[29]   A. N. Rouzbahani, "Lean Tools Selection For Mining : An Occupational Health And Safety Approach By Master ' S Degree With Thesis In Occupational Health And," 2019.

[30]   L. Indriyani and M. L. Singgih, "Lean Mining Analysis in Gold Mining Use Waste Assessment Model," IPTEK J. Proc. Ser., vol. 0, no. 1, p. 70, 2021.

[31]   S. W. Hia, M. L. Singgih, and R. O. S. Gurning, "Transportation Performance Measurement for Coal Mining: A Review and Framework," Proc. Int. Conf. Ind. Eng. Oper. Manag. Istanbul, Turkey, March 7-10, 2022, pp. 3391–3398, 2022.

[32]   S. W. Hia, M. L. Singgih, and R. O. S. Gurning, "Performance Metric Development to Measure Overall Vehicle Effectiveness in Mining Transportation," Appl. Sci., vol. 12, no. 23, 2022.

[33]   A. F. Klippel, C. O. Petter, and J. A. V. Antunes, "Lean management implementation in mining industries," DYNA, vol. 75, no. 154, pp. 81–89, 2008.

[34]   A. Bhardwaj, J. Nagar, and R. S. Mor, "Productivity gains through PDCA approach in an Auto Service Station," Proc. Int. Conf. Ind. Eng. Oper. Manag., vol. 2018, no. JUL, pp. 2595–2602, 2018.

[35]   P. Pratik and D. Vivek, "Application Of Plan-Do-Check-Act Cycle For Quality And Productivity Improvement," Int. J. Res. Appl. Sci. Eng. Technol., vol. 5, no. I, pp. 197–201, 2017.

AUTHORS PROFILE

Selamat Walmanto Hia obtained BSc in Mechanical Engineering from the University of Indonesia. M.Eng in Mechanical Engineering from the National Taiwan University of Science and Technology, and presently a doctoral student of Management and Technology in the Institut Teknologi Sepuluh November, Surabaya, Indonesia. He is a senior manager of operation and supply chain in a coal mining company, a certified Six Sigma Master Black Belt, Certified Production and Inventory Management from Association for Supply Chain Management (APICS), Certified Productivity Specialist, an Executive Professional Engineer, and member of The Institution of Engineers, Indonesia.

Moses Laksono Singgih is a professor in the Department of Management and Technology, Interdisciplinary School of Management and Technology, Institut Teknologi Sepuluh Nopember (ITS), Surabaya, Indonesia. Doctor of Philosophy (Ph.D.) in Industrial Economics, University of Queensland, Australia. Master of Regional Science (MRegSc) Regional Science, University of Queensland, Australia. Master of Science (MSc) in Industrial Engineering, Institut Teknologi Bandung (ITB). BSc in Industrial Engineering, Institut Teknologi Bandung (ITB). He was in charge as Head of Postgraduate Program, Industrial Engineering Department ITS, Head of Quality Assurance and Performance Measurement, ITS. He is also a member of the Institute of Electrical and Electronics Engineers (IEEE) and The Institution of Engineers Indonesia.

Raja Oloan Saut Gurning is an associate professor in the Department of Management and Technology, Interdisciplinary School of Management and Technology, Institut Teknologi

Sepuluh Nopember (ITS), Surabaya, Indonesia. He is an experienced Director of Business Innovation and Venture of ITS, Head of Postgraduate Program of Marine Technology faculty, and also currently the Head of Marine Engineering Post-Graduate Program. Moreover, he has also strongly been involved in the management of ports, shipping, and maritime-related industry in Indonesia and Australia apart from the years of experience at the tertiary education level and also skilled in marine engineering, maritime business, port management and development, and cargo handling equipment. He has a strong professional background as indicated by a Master's Degree in Port Management from World Maritime University, Malmo-Sweden, a Ph.D. degree in Maritime Logistics and Management from The University of Tasmania Australia, and also a chartered Maritime Technologist (CMarTech) from IMarEST and UK Engineering Council.