eISSN: 2721-5717; pISSN: 2747-2124 https://journal.unhas.ac.id/index.php/zonalaut

ZONA LAUT

JOURNAL OF OCEAN SCIENCE AND TECHNOLOGY INNOVATION

Productivity Analisys of Rubber Tyred Gantry Crane (TRG) and Head Truck (HT) at Makassar New Container Terminal (Terminal 1)

Rifkah Fitriah[1*], Rusnaedi Rusi[1], Muslihati[1], Andi Ningrat[1], Misliah[2], Mohammad Rizal Firmansyah[2]
[1]Marine Transportation Study Program, AMI Makassar Maritime Polytechnic, Indonesia
[2]Departement of Naval Architecture, Engineering Faculty, Hasanuddin University, Indonesia
*fitriahrifkahzul@gmail.com

Abstract

The increasing trend of global trade and maritime supply chain has driven container terminals to pursue operational efficiency and equipment productivity. This study aims to evaluate the productivity of Rubber Tyred Gantry Crane (RTG) and Head Truck (HT) at Makassar New Container Terminal (Terminal 1), an important logistics hub in Eastern Indonesia. Productivity was measured through direct field observation and data collection during loading and unloading operations. Five RTGs and five HTs were analyzed for a period of one hour. The level of loading and unloading productivity at Makassar New Container Terminal (Terminal 1) is categorized as good according to the Regulation of the Director General of Sea Transportation. The productivity of RTG equipment with an average unloading process of 28 container boxes/hour and a loading process of 31 container boxes/hour. Meanwhile, for HT equipment, it reaches 5 container boxes/hour for the unloading process and 7 boxes/hour for the loading process. This analysis highlights the differences in efficiency in handling between equipment types, emphasizing the need for equipment optimization. These findings contribute to understanding terminal performance and support future operational improvements.

Keywords: *Container Terminal; Rubber Tyred Gantry; Head Truck; Port Operation; Eastern Indonesia*

1. INTRODUCTION

The increasing trend of economic globalization and the development of international trade have driven rapid growth in various transportation sectors, especially in supporting the maritime supply chain. The growth of global and regional trade has a direct impact on the increasing volume of cargoes flow through ports. Container terminals as the main node in the maritime logistics chain play a crucial role in ensuring the smooth distribution of cargoes by sea [1]. According to Grzelakowski [2], in terms of volume, more than 80% of global cargoes trade was handled through ports in 2017, with around 17.1% of it being transported in containers. The advantage of cost efficiency makes container traffic the backbone of international trade, and hence, sea transportation has a strategic role for the economies of many countries [3]. In the context of Indonesia, ports play a strategic role in supporting connectivity between regions, especially in eastern Indonesia which is highly dependent on sea transportation [4].

The performance of a container terminal is greatly influenced by the efficiency of loading and unloading equipment such as Rubber Tyred Gantry Crane (RTG) and Head Truck (HT). RTG is the main tool in arranging and picking up containers in the stacking yard, while HT functions as a horizontal connection between the dock and the stacking yard [5]. The efficiency of these two tools greatly determines the cycle time of container handling, which ultimately impacts the overall productivity of the terminal [6].

Productivity of loading and unloading equipment is the main indicator in measuring the operational efficiency of the terminal. According to UNCTAD [7], indicators such as boxes per hour and average handling time per container are important parameters in evaluating the performance of the equipment. Previous studies have shown that low HT productivity is often a bottleneck even though the crane is working optimally [8], [9].

Makassar New Container Terminal, as one of the main terminals in Eastern Indonesia, faces challenges in optimizing operations due to limited capacity and the need to accelerate the loading and unloading process [10]. This terminal is managed by PT Pelabuhan Indonesia (Persero). Since the merger of PT Pelabuhan Indonesia (Pelindo) on October 1, 2021, the container terminal has become one of the main subholdings in Pelindo's new structure. This terminal is specifically designed to handle the loading and unloading process, stacking, receiving and delivery of containers, as well as other supporting services.
As the center of economic growth in the Eastern Part of Indonesia (KTI), especially South Sulawesi Province, Makassar City has a strategic role. The Makassar New Container Terminal (Terminal 1) functions as the main consolidation point for shipping cargoes using containers [11]. This terminal, previously known as the Makassar Container Terminal, is one of the core business units of PT Pelindo (Persero). Inaugurated on July 28, 2001, by the President of the Republic of Indonesia Megawati Soekarnoputri, this terminal was officially established as an independent business branch on August 1, 2007.
Strategically located along the main maritime axis connecting the eastern and western parts of the Indonesian archipelago, the terminal serves as a critical node in the national logistics chain. It facilitates the flow of containerized goods to and from remote areas in Eastern Indonesia, playing a vital role in reducing regional disparities in trade and supporting the government's Sea Toll program. The terminal's strategic importance is further underscored by its function as a regional gateway that connects international trade routes with domestic distribution networks.
Data of container flow data at the Makassar New Container Terminal (Terminal 1) for five years from 2018 to 2022 can be seen in Table 1 below.

Table 1. Container flow at Makassar New Container Terminal (Terminal 1)

No.	Year	Foreign Trade (TEU's)		Domestic Trade (TEU's)		Total L/U (TEU's)
		Import	Export	Unloading (U)	Loading (L)	
1	2018	7.763	27.284	313.696	288.663	637.406
2	2019	7.089	24.824	322.025	327.758	681.696
3	2020	11.480	17.378	232.431	255.600	516.889
4	2021	7.398	15.203	229.876	242.823	495.300
5	2022	6.411	21.122	223.746	219.014	470.293

Source: Makassar New Container Terminal (Terminal 1)

In general, the flow of containers at the Makassar New Container Terminal (Terminal 1) has fluctuated, reflecting the dynamics of port activities over the past five years. In 2019, there was an increase in total loading and unloading (L/U) from 637,406 TEUs to 681,696 TEUs. This increase was contributed by a significant spike in the volume of domestic loaded containers, which rose from 288,663 to 327,758 TEUs. Starting in 2020, there was a sharp decline in the total flow of containers. In that year, the total volume fell to 516,889 TEUs. The downward trend continued until 2022, when the total volume reached its lowest point of 470,293 TEUs.
Import volumes increased in 2020 but declined again in the following years. Export volumes continued to decline from 2018 to 2021, although they experienced a slight recovery in 2022. Domestic loading and unloading activities are the largest contributors to total container flows. Both segments have shown a consistent decline since 2019, which is likely influenced by national and global economic conditions, including the impact of the COVID-19 pandemic.
Container terminals have a strategic role in ensuring the smooth flow of cargoes in and out of a region. Therefore, it is important to assess indicators that reflect the operational performance of a container terminal. By understanding its performance achievements, it is hoped that in the future container terminals in Eastern Indonesia will be able to provide optimal service to customers. This increase in service quality will ultimately have a positive impact on the overall performance of the terminal. It will contribute to economic growth as well, especially in reducing the price gap between Eastern and Western Part of Indonesia [12].
However, there are various factors that affect the productivity of container loading and unloading activities. This productivity is very crucial to ensure effective and efficient distribution of goods and prevent delays that can cause container accumulation at the terminal or potential fines. The success of a loading and unloading company is shown by consistent productivity increases from year to year. Factors that influence this can be measured through port service indicators, loading and unloading productivity levels, and utilization levels of loading and unloading facilities or equipment used at the terminal. This assessment refers to the provisions set by the Directorate General of Sea Transportation [13].

To ensure optimal service and support economic growth by reducing regional disparities, it is necessary to monitor productivity indicators and terminal equipment utilization according to the Ministry of Transportation standards [13], [14], [15]. Therefore, analysis of RTG and HT performance is important as a basis for managerial decision making to improve the efficiency of the loading and unloading system at the terminal.

This paper aims to analyze the productivity of RTG and HT at Makassar New Container Terminal (Terminal 1) based on actual operational data, by measuring parameters such as the number of container boxes per hour and the average handling time per container box. The results of this analysis are expected to provide a comprehensive picture of the effectiveness of the facility and equipment and provide data-based improvement recommendations.

2. METHODS

2.1 Data Collection Techniques

This study uses primary and secondary data collection methods. Primary data were collected through direct observation of five RTG units and five HT units during loading and unloading operations. Observations were made during operational hours, with each observation lasting one hour per equipment unit. In addition, the total operational time and number of containers handled were documented. The data collection was conducted over a two-month period, from February to March 2023, to ensure consistency and capture operational variability. Secondary data came from operational reports of PT Pelindo (Persero) and the Makassar New Container Terminal, as well as regulations of the Directorate General of Marine Affairs [11], [13], [15].

The data collected is focused on the parameters of equipment operational time (effective time), number of containers handled per unit per hour and time per container cycle (measured in seconds/minutes per container box).

2.2 Data Analysis

The productivity level (P) of the RTG loading and unloading equipment at the Makassar New Container Terminal (Terminal 1) can be determined by dividing the average number of loading and unloading container boxes that can be handled in effective working time units (Equation 1).

$$P = \frac{number\ of\ container\ boxes}{effective\ time\ (hour)} \quad (1)$$

Meanwhile, the productivity level for the HT loading and unloading equipment can be determined by dividing the average loading/unloading time of the HT for each container box (T). This productivity value can be calculated from each average one-around trip of unloaded and loaded time for each equipment per one container box. The one-around trip time is the transport time until the container is placed from the container yard to the head truck or vice versa (Equation 2).

$$T = \frac{total\ time\ (s)\ for\ one\ around\ trip}{container\ box} \quad (2)$$

Comparative analysis was conducted between RTG and HT for loading and unloading operations. Statistical averages were obtained to identify high and low performing units. The results were then compared with the operational standards set by the Directorate General of Sea Transportation of Indonesia [13], [15].

3. RESULTS AND DISCUSSION

3.1 Productivity of Rubber Tyred Gantry (RTG) Crane

Handling of cargo in the container yard uses RTG loading and unloading crane. RTG at the Makassar New Container Terminal 1 is available with as many as 18 units. Each RTG observed has a gantry span of 22 m, 22.25 m, and 23 m with a height of up to 4-5 tier containers.

The productivity level and carrying capacity of RTG in the loading and unloading process at the Makassar New Container Terminal (Terminal 1) in 2023 can be seen in Table 2 and Table 3. The rubber tyred gantry studied and analyzed from the data above are RTG numbers 09, 14, 17, and 18 for the unloading process and

RTG numbers 09, 16, 17 and 18 for the loading process. Observations for each RTG tool were carried out for 1 (one) hour.
Table 2 explains the productivity of the RTG crane or the average handling of one container box in the unloading process based on the total effective time used.

Table 2. Recapitulation of RTG productivity in the unloading process

No. RTG	Box / hour	Total effective time		Averages / box	
		(minute)	(second)	(second)	(minute)
09	28	58	3480	125	2.07
14	27	59	3540	131	2.19
17	30	51	3060	102	1.70
18	25	57	3540	137	2.28

Source: Data processing results, 2023

Table 2. presents productivity data of four RTG cranes (no. 09, 14, 17 and 18) in the container unloading process at the Terminal. Each RTG shows varying levels of productivity, measured in units of container boxes per hour, total effective working time, and average handling time per container box in seconds and minutes.
From the data displayed, RTG number 17 showed the best performance and recorded the highest productivity, which was 30 container boxes per hour. This RTG also recorded the fastest handling time, which was 102 seconds per container box (equivalent to 1.70 minutes), with an effective working time of 51 minutes or 3060 seconds. This performance shows that RTG 17 works efficiently, both in terms of handling speed and output achievement per hour. In contrast, RTG number 18 recorded the lowest productivity with only 25 boxes per hour and an average handling time per box of 137 seconds or 2.28 minutes. This is the longest time for handling among all units. Meanwhile, RTG 09 and 14 showed medium productivity of 28 and 27 boxes per hour, respectively. Their average time for handling per box is 125 seconds (2.07 minutes) and 131 seconds (2.19 minutes), respectively. Both units showed consistent performance, but were still below the performance of RTG 17. These data indicate variations in performance between RTG units in the unloading process, which can be used as a basis for evaluating operational efficiency.
The average effective time used for all RTG tools in the unloading process is 56.25 minutes. The average productivity of RTG tools in the unloading process in one hour reaches 28 container boxes/hour with an average handling time per container box of 2.06 minutes.
Overall, the results of Table 2 indicate that there is significant variation in efficiency and speed of work between RTG units. Factors such as operator skills, equipment conditions, and the level of coordination in the field are likely to contribute to these differences in productivity. Therefore, operational optimization and operator training can be a strategy to increase the productivity of RTG units, especially for units with below average performance.
Table 3 shows the productivity of the RTG crane or the average handling of one container box in the loading process based on the total effective time used.

Table 3. Recapitulation of RTG productivity in loading process

No. RTG	Box / hour	Total effective time		Average / box	
		(minute)	(second)	(second)	(minute)
09	33	58	3480	106	1.77
16	31	58	3540	114	1.88
17	36	53	3180	89	1.47
18	26	41	2460	95	1.58

Source: Data processing results, 2023

Table 3 shows the productivity of four RTG cranes (No. 09, 16, 17 and 18) in the container loading process at the terminal. In general, RTG with number 17 shows the most productive performance, handling 36 container boxes per hour with effective working time of 53 minutes (3180 seconds). Further, it recorder as the fastest average handling time per container box, which is 89 seconds or around 1.47 minutes. This performance indicates that RTG 17 works most efficiently compared to other units in the loading process.
RTG 09 and 16 occupy the middle productivity positions, handling 33 and 31 container boxes per hour, respectively. The average handling time per container box for RTG 09 is 106 seconds (1.77 minutes), while RTG 16 records a handling time of 114 seconds (1.88 minutes), which is the longest of the four units.

Interestingly, although RTG 18 recorded the lowest productivity with 26 container boxes per hour, its average time per container box was 95 seconds (1.58 minutes) faster than RTG 09 and 16. This shows that the much shorter effective working duration (only 41 minutes or 2460 seconds) affects the productivity results of its time. In other words, if the operational time of RTG 18 was extended like the other units, its productivity potential could be increased.
From this data, it can be concluded that in addition to the handling speed per container box, the total effective working time also greatly affects the achievement of hourly productivity. Evaluation of the duration of operation and efficiency of each RTG unit is very important to improve the overall performance of the loading process at the terminal.

3.2 Productivity of Head Truck (HT) Equipment

Handling of containers from the dock to the container yard (CY) uses HT loading and unloading equipment. The number of head trucks used at the Makassar New Container Terminal (Terminal 1) is 28 units. Determination of the level of loading and unloading productivity and the capacity of the HT transport tool at the Makassar New Container Terminal (Terminal 1) is carried out using equation (2).
The productivity level for HT transport equipment in the loading and unloading process at the Makassar New Container Terminal (Terminal 1) in 2023 can be seen in Table 4 and Table 5. The HT studied and analyzed in those Tables above are HT numbers 02, 06, 09, 23 and 36 for the unloading process and HT numbers 09, 13, 23, 30 and 35 for the loading process. Observations for each HT were carried out for 1 (one) hour.
Table 4 explains the productivity of the HT or the average handling of one container box in the unloading process for each one around trip from the head truck to the container yard.

Table 4. Recapitulation of HT productivity in the unloading process

No. HT	Box / hour	Total effective time		Averages / box	
		(minute)	(second)	(detik)	(menit)
02	8	59	3540	442	7.38
06	6	54	3240	540	9.00
09	4	51	3060	612	10.20
23	4	52	3120	780	13.00
36	5	57	3420	684	11.40

Source: Data processing results, 2023

Table 4 presents data on HT productivity in the container unloading process at the terminal. The main indicators being the number of container boxes per hour, total effective working time, and average handling time per container box in seconds and minutes.
Of the five recorded HT units, HT number 02 showed the highest productivity of 8 container boxes per hour, with a total effective time of 59 minutes (3540 seconds). The average handling time per container box on this unit was 442 seconds or 7.38 minutes, which was the fastest among all HT units.
The next highest productivity is on HT 06 with a productivity of 6 container boxes per hour and an average handling time of 540 seconds (9 minutes). Although it is in second place in terms of productivity, its handling time is still relatively slower than HT 02, indicating potential improvements in work efficiency.
Meanwhile, HT 09, HT 23 and HT 36, showed relatively low productivity, each only handling 4 container boxes, 4 container boxes, and 5 container boxes per hour. Among the three, HT 23 recorded the longest handling time per container box, which was 780 seconds or 13 minutes, making it the unit with the lowest performance in this table. HT 09, although having the same productivity as HT 23, had a slightly better handling time, which was 612 seconds (10.20 minutes). The average analysis results for HT equipment productivity in the unloading process reached 5 container boxes/hour with an average handling per container box in one hour reaching 10.19 minutes. The average effective time used in the unloading process was 55 minutes.
Overall, the data shows significant differences in work efficiency between HT units, with handling times per container box ranging from 442 to 780 seconds. This variation suggests that some HT units are much more efficient than others, which may be due to factors such as the smoothness of the movement flow, operator readiness, or the technical condition of the vehicle. Therefore, it is necessary to evaluate operational and technical factors, especially for units with above-average handling times, in order to improve overall productivity in the container unloading process.

Table 5 explains the productivity of the HT or the average handling of one container box during the loading process for each one around trip from the container yard to the head truck.

Table 5. Recapitulation of HT productivity in loading process

No. HT	Box / hour	Total effective time		Average / box	
		(minute)	(second)	(detik)	(menit)
09	7	53	3180	454	7.57
13	5	53	3180	636	10.60
23	5	53	3180	636	10.60
30	7	51	3060	437	7.29
35	9	57	3420	380	6.33

Source: Data processing results, 2023

Table 5 presents HT productivity data in the container loading process at the terminal. The data was based on the number of container boxes transported per hour, total effective working time, and average handling time per container box in seconds and minutes.

Of the five HT units listed, HT number 35 shows the highest performance, with a productivity of 9 container boxes per hour and an effective working time of 57 minutes (3420 seconds). It also recorded as the fastest average handling time of 380 seconds or 6.33 minutes per container box. This shows that HT 35 operates most efficiently in the loading process.

Furthermore, HT 30 and HT 09 each recorded a productivity of 7 container boxes per hour. HT 30 completed the loading process with an average time of 437 seconds (7.29 minutes) per box, slightly faster than HT 09 with 454 seconds (7.57 minutes). Both units also showed good performance and were relatively efficient.

Unlike the previous three units, HT 13 and HT 23 recorded the lowest productivity, which is 5 container boxes per hour, with the same handling time per container box, which is 636 seconds (10.60 minutes). Although both have the same effective working time (53 minutes), the handling speed is much slower than other HT units. This shows that there is potential inefficiency both in terms of operations and coordination that can be further evaluated. For HT productivity in the loading process, it reaches an average of 7 container boxes/hour with an average per container box in one hour of 8.48 minutes. The average effective time used in the loading process is 53 minutes.

Overall, this Table shows that there is a variation in productivity and efficiency between HT units. The difference was in handling time per container box where it reaches more than 4 minutes between the highest and lowest performing units. This indicates the importance of standardizing work procedures, vehicle maintenance, and improving operator competency so that all HT units can achieve optimal productivity in the container loading process.

Based on the calculation data and analysis that has been carried out, a recapitulation of the productivity level of each loading and unloading equipment (RTG and HT) at the Makassar New Container Terminal (Terminal 1) is obtained, which can be seen in Table 6.

Table 6. Recapitulation of average productivity of loading and unloading equipment at the Makassar New Container Terminal (Terminal 1)

Equipment	Productivity (box/hour)		Average time /box (minute)	
	Unloading	Loading	Unloading	Loading
RTG	28	31	2.06	1.68
HT	5	7	10.19	8.48

Source: Data processing results, 2023

Table 6 presents the average productivity of two main types of equipment in loading and unloading activities at the Makassar New Container Terminal (Terminal 1), namely Rubber Tyred Gantry (RTG) and Head Truck (HT). Productivity is measured in units of container boxes per hour, while work efficiency is evaluated based on the average handling time per container box in minutes.

RTG showed high productivity in both loading and unloading processes, each of 28 container boxes/hour for unloading and 31 container boxes/hour for loading. This result is higher than minimum national standard of container loading and unloading in a container terminal which is 25 container box/crane/hour [13]. The average handling time per container box was faster when loading (1.68 minutes) compared to unloading

(2.06 minutes). This difference could be caused by the more systematic and controlled process of placing containers onto vehicles during loading, compared to taking containers from vehicles during unloading.
In contrast to RTG, HT shows much lower productivity, with 5 container boxes/hour for unloading and 7 container boxes/hour for loading. The average time per container box is also relatively long, which is 10.19 minutes for unloading and 8.48 minutes for loading. HT handling time is almost five times longer than RTG, indicating that this component is a bottleneck in the container loading and unloading process chain.
From this table, RTG works much more efficiently than HT in both processes. This shows that the increase in operational efficiency does not only depend on the speed of the crane (RTG) but is also greatly influenced by the performance of horizontal logistics (HT). Although RTG can handle more than 30 container boxes per hour, the low performance of HT has the potential to create queues or waiting times, which can hinder the entire process.
This data confirms that to increase total terminal productivity, there needs to be an increase in performance at HT by increasing the number of units, improving the dispatching system, increasing operator skills, or optimizing movement routes in the field. If the bottleneck at HT can be minimized, then the high productivity potential of RTG can be utilized optimally.

3.3 Discussion

The analysis shows a significant performance gap between RTG and HT. RTG, with its fixed path, can handle more container boxes per hour with shorter cycle times. On the other hand, HT is dependent on traffic conditions, operator skills, and path constraints, all of which contribute to its decreased productivity.
These findings are in line with previous studies showing that equipment utilization and operator efficiency significantly affect container terminal productivity [16], [17] [18]. Compared to international standards [5] and National Standard [13], RTG productivity at the Makassar New Container Terminal (Terminal 1) is relatively competitive. On the other hand, HT performance indicates the need for route optimization, improvement, and driver training [5], [19]. The development of Automation, Machine Learning, IoT, and predictive maintenance are also recommended [20] [21], [22], [23].
In the context of container ports and terminals, the integration of automation and machine learning (ML) has demonstrated considerable potential in enhancing operational efficiency, productivity, and sustainability. Automation, for instance, has been shown to improve productivity by 25–50% and reduce operational costs by up to 55% [23], [24]. It also contributes to a reduction in ship loading and unloading times by 18%, increases storage capacity by 27%, and improves crane efficiency by approximately 17% [25]. Nevertheless, the outcomes of automation are not universally positive; certain terminals have reported a 7–15% decline in productivity following its implementation [26]. These variations underscore the necessity of tailoring automation strategies to the specific internal and external conditions of each port [27]. Conversely, machine learning has proven effective in supporting data-driven decision-making and enhancing sustainable port operations. At Izmit Bay Port, for example, a Support Vector Machine (SVM) model accurately predicted ship energy requirements at berth with 82% accuracy, facilitating the integration of renewable energy sources [28]. At Tanjung Priok Port, a Linear Regression model demonstrated superior performance in predicting vessel dwell times, aiding in operational optimization [29]. Furthermore, a hybrid machine learning and discrete event simulation framework proposed by Benghalia et al. [30] attained prediction accuracy rates as high as 99.91%, and proved effective in reducing vessel dwell times, empty trips, and CO_2 emissions. Collectively, the integration of automation and ML enhances port competitiveness and addresses the growing demands for sustainability in the era of Industry 4.0. By enabling more intelligent equipment management and streamlined workflows, container terminals are better positioned to improve their overall performance and resilience within the global logistics landscape.

4. CONCLUSION

The productivity calculation of the RTG and HT loading and unloading equipment above was taken in normal situations or conditions without bad weather and during busy service times. From the processed data above, the productivity of the equipment in the unloading process is as follow. The RTG equipment is 28 container boxes/hour with an average handling time of 2.06 minutes per container box while HT is 5 container boxes/hour with an average handling time of 10.19 minutes/box. While for the productivity of the equipment in the loading process for the RTG equipment as many as 31 container boxes/hour with an average handling time of 1.68 minutes/box and HT 7 container boxes/hour with an average handling time per container box of 8.48 minutes.

RTG is more productive than HT in the Makassar New Container Terminal (Terminal 1). RTG 17 is proven to be optimal, while HT needs performance improvement. Recommendations include improving the RTG–HT coordination system, adopting dispatching and predictive maintenance technology, and operator training. This study provides an important benchmark for equipment efficiency in regional terminals. Moreover, these recommendations align with national logistics targets and are crucial to strengthening connectivity and supply chain reliability in Eastern Indonesia, where Makassar serves as a strategic maritime hub.

Future research could further explore how seasonal variations, ship arrival volume, and peak-hour traffic patterns affect the productivity of loading and unloading equipment. In addition, evaluating the long-term impact of automation and predictive maintenance adoption on operational resilience, cost efficiency, and environmental sustainability could provide deeper insight into the readiness of regional ports to compete in the global logistics landscape.

DAFTAR PUSTAKA

[1] Steenken, D., Voβ, S., Stahlbock, R, Container Terminal Operation and Operations Research – a Classification and Literature Review, *OR Spectrum*, Vol. 26, pp. 3–49. DOI: 10.1007/s00291-003-0157-z, 2004.

[2] Grzelakowski, A, S, Global Container Shipping Market Development and Its Impact on Mega Logistics System, *TransNav the International Journal on Marine Navigation and Safety of Sea Transportation*, Vol. 13, No. 3, pp. 529-535, DOI:10.12716/1001.13.03.06, 2019.

[3] Kotachi, M., Rabadi, G., Seck, M. N, Msakni, M. K, Al-Salem, M., Diabat, A, Sequence-Based Simulation Optimization: An Application to Container Terminals, *2018 IEEE Technology and Engineering Management Conference (TEMSCON)*, Evanston, IL, USA, 2018. DOI:10.1109/TEMSCON.2018.8488396.

[4] Adam, L., Dwiastuti, I., Membangun Poros Maritim Melalui Pelabuhan, *Masyarakat Indonesia*, Vol. 41, No. 2, pp. 163–176, 2015.

[5] UNCTAD, Review of Maritime Transport 2020, *United Nations Conference on Trade and Development*, United Nations Publications, New York, USA, 2020, https://unctad.org/webflyer/review-maritime-transport-2020.

[6] De Souza, R., Goh, M., Petering, M. E. H., Yong, W., Wenkai L., Optimizing Container Terminal Operation, Think Logistics 2006: Creating The Future Today, *TLI – Asia Pacific White Papers Series*, Vol. 06-Nov-SCO01, 2006.

[7] UNCTAD, Review of Maritime Transport 2018, *United Nations Conference on Trade and Development*, United Nations Publications, New York, USA, https://unctad.org/system/files/official-document/rmt2018_en.pdf, 2018.

[8] Kalangi, M H E., Kristiawati, I., Kusuma R A E., (2023). Pengaruh Keterampilan Kerja, Kinerja dan Pemeliharaan Terhadap Produktivitas: Studi pada Operator Head Truck di PT Terminal Petikemas Surabaya, *Academia Open*, Vol. 8, No. 1, pp. 6–14, DOI: 10.21070/acopen.8.2023.6664, 2023.

[9] Budiansyah, Pengaruh Waktu Tunggu Muatan dan Waktu Tunggu Head Truck Terhadap Lost Productivity di PT Terminal Petikemas Surabaya, Skripsi, STIA dan Manajemen Kepelabuhanan Barunawati, Surabaya, 2019.

[10] BPS (Badan Pusat Statistik), Statistik Transportasi Laut 2023, Vol. 9, 2024, BPS-Statistics Indonesia, Jakarta, 2024, https://www.bps.go.id/id/publication/2024/11/25/3fcd0493a7b0a2de5a18004b/statistik-transportasi-laut-2023.html

[11] Peraturan Direksi Nomor 28 PT Tahun 2021 tentang sistem dan prosedur pelayanan jasa peti kemas pada Terminal Peti kemas di Lingkungan PT Pelabuhan Indonesia IV (PERSERO),

[12] Sulistiana, Oktavera, ANALISIS KINERJA OPERASIONAL TERMINAL PETI KEMAS DI KAWASAN TIMUR INDONESIA (Studi Komparasi Terhadap TPM dan TPB), Program Pascasarjana Universitas Hasanuddin Makassar, Buku dan Haki, Vol. 1, No. 1, pp. 1-111, 2023.

[13] Peraturan Direktur Jenderal Perhubungan Laut Nomor: Hk.103/2/18/DJPL-16 tentang Standar Kinerja Pelayanan Operasional Pelabuhan pada Pelabuhan yang Diusahakan Secara Komersial.

[14] Sudarmanto, Eko, *Desain Penelitian Bisnis: Pendekatan Kuantitatif*. Penerbit Yayasan Kita Menulis, 2021.

[15] Peraturan direktur jenderal perhubungan laut no. HK 103/2/2/DJPL-17 tentang pedoman perhitungan kinerja pelayanan operasional pelabuhan.
[16] Lun, Y.H.V., Lai, K.H., Cheng, T.C.E., Yang, D, *Shipping and Logistics Management - 2nd Edition*, Springer, 2023
[17] Mazloumi M., van Hassel, E., Improvement of Container Terminal Productivity with Knowledge About Future Transport Modes: A Theoretical Agent-Based Modelling Approach, *Sustainability*, Vol. 13, 9702, https://doi.org/10.3390/su13179702, 2021.
[18] Kurniawan, F., Musa S N., Moin N H., Sahroni, T R., A Systematic Review on Factors Influencing Container Terminal's Performance, *Operations and Supply Chain Managemnt*, Vol. 15, No. 2, pp. 174-192, 2022.
[19] Ardiansyah, C D., Darujati, C., Gumelar, A B., Analisa Perhitungan Performance Head Truck Menggunakan Metode Total Productive Maintenance (TPM), *Jurnal Ilmiah NERO,* Vol. 8, No. 1, pp. 41–52, 2023.
[20] Aslam, S., Navarro, A., Aristotelous A., Crevillen E G., Romero, A M., Ceballos, A M., Cassera A., Orphanides, K., Herodorou H., Michaelides M P., Machine Learning Based Predictive Maintenance at Smart Ports Using IoT Sensor Data, *Sensors*, Vol. 25, No. 13, 3923, doi:10.20944/preprints202505.2382.v1, 2025.
[21] Benghalia, A., Ferdjallah A., Oudani M., Boukachour, J., Machine Learning and Simulation for Efficiency and Sustainability in Container Terminals, *Sustainability*, Vo. 17, No. 7, 2927. https://doi.org/10.3390/su17072927, 2025.
[22] Mekkaoui, S E., Benabbou, L., Berrado, A., Machine Learning Models for Efficient Port Terminal Operations: Case of Vessels' Arrival Times Prediction, *IFAC PapersOnLine*, 55-10, pp. 3172-3177, 2022.
[23] Rodrigue, J. P., Notteboom, T. Automation in Container Port Systems and Management, *TR News*, July-August 2021.
[24] Harbi, A., Determinants for Automation Levels in Port Containers Terminals at Antwerp and Rotterdam, Master Thesis in Maritime Economics and Logistics, Erasmus University Rotterdam, 2021.
[25] Jobran, Y., Kara, G., Examining the Efficiency of Automation in Container Terminals, *Journal of Transportation and Logistics*, Vol. 7, No. 1, DOI: 10.26650/JTL.2022.1039692, 2022.
[26] International Transport Forum (ITF), "Container Port Automation: Impacts and Implications", *International Transport Forum Policy Papers*, No. 96, OECD Publishing, Paris, 2021.
[27] Majoral, G., Reyes, A., Saurí, S., Lessons from Reality on Automated Container Terminals: What Can Be Expected from Future Technological Developments?, *Transportation Research Record*, Vol. 2678, Issue 2, pp. 401-415, https://doi.org/10.1177/03611981231174422, 2024.
[28] Seyhan, A., A Novel Study for Machine-Learning-Based Ship Energy Demand Forecasting in Container Port, *Sustainability*, Vol. 17, 5612. https://doi.org/10.3390/su17125612, 2025,
[29] Simanjuntak, R., Sibarani, M., Cahyadi, T., Sihombing, D. W., Bernadtua, M., Yuherlina, R., Prediction of Ship Time in Port Using Machine Learning Algorithm, *International Journal of Marine Engineering Innovation and Research*, Vol. 10, No. 2, pp. 320–328, 2025.
[30] Benghalia, A., Ferdjallah, A., Oudani, M., Boukachour, J., Machine Learning and Simulations for Efficiency and Sustainability in Container Terminal, *Sustainability*, Vol. 17, 2927. https://doi.org/10.3390/su17072927, 2025.