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Analysis of Fishing Vessel Queueing Models for Optimizing Palabuhanratu Fishing Port Operations

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***Abstract*—** This study is motivated by the importance of operational efficiency in fishing ports in addressing the dynamics of vessel arrivals and limited service facilities. The objective of this study is to analyze a fishing vessel queue model to optimize port operations at the Palabuhanratu Port based on existing facility conditions. The methods used include field observation, interviews, and quantitative analysis using a queue model with a Poisson distribution approach for vessel arrivals and an exponential distribution for service. The results of the analysis show that the queue system follows the (M/M/5):(FCFS/~/~) model with five service points operating in parallel. The vessel arrival rate is relatively low compared to the service capacity, so that the port is in an under capacity condition with a high probability of an empty system and almost no waiting time in the queue. To improve optimization, scenarios were carried out to increase the number or frequency of vessels in several vessel size categories, namely 21 vessels (21–30 GT), 63 vessels (5–10 GT), 12 vessels (11–20 GT), 123 vessels (5–10 GT), 7 vessels (51–100 GT), 5 vessels (101–200 GT), 31 vessels (5–10 GT), and 4 vessels (11–20 GT). Simulation results show that the addition is able to increase the utilization of port facilities without causing significant queues, so that operational efficiency can be improved sustainably.

Keywords— Queue model, Fishing vessels, Port optimization, Operational efficiency, Fishing ports.

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I. INTRODUCTION

Fishing ports play a strategic role in the national fisheries management system [1][2]. They serve not only as landing points for catches but also as centers for distribution and economic activity in the fisheries sector. Ports serve as meeting points for fishermen, business operators, and various parties involved in the fisheries supply chain [3].

Furthermore, fishing ports serve as administrative and service hubs to support fisheries operations. Various activities, such as production recording, supervision, and vessel services, take place within the port area. Therefore, good port management is key to ensuring the smooth operation of these activities. Operationally, ports serve as the primary interface between fishing vessels and onshore facilities. The processes of landing, loading, and unloading, and distribution of catches are highly dependent on the availability and performance of port facilities. This makes ports a crucial component of the capture fisheries system [4].

Palabuhanratu fishing port is one of the most important ports in southern West Java. It serves fishing vessels of various sizes and fleet characteristics. This diversity reflects the complexity of operational activities at the port [5].

The high intensity of vessel landing activity at the Palabuhanratu fishing port requires adequate facilities. Facilities such as docks, port basins, and loading and unloading facilities must be able to support the smooth flow of fishing vessel services [6]. Without optimal support, port activities can potentially be hampered.

In addition to primary facilities, the existence of supporting facilities also plays a crucial role in supporting port operations. Road access, information systems, and administrative facilities contribute to improving service efficiency. Integration between primary and supporting facilities is a crucial factor in maintaining port performance. The port's capacity to accommodate and service fishing vessels is an aspect that requires serious attention. Limited dock length, basin depth, and number of service facilities can lead to fishing vessel queues. This condition has the potential to slow down the loading and unloading process and reduce operational efficiency [7][8].

Furthermore, an imbalance between fishing vessel arrival rates and service capacity can also affect port utilization. If capacity is too low, congestion and queues will occur. Conversely, if capacity is too high, port facilities will be underutilized. Therefore, the ability of the port system to effectively manage fishing vessel flow is crucial. A good queuing system can help optimize facility utilization and minimize fishing vessel waiting times [9]. This study introduces a new perspective by linking facility readiness analysis with a quantitative queuing model for evaluating port performance. Unlike previous studies that focus only on infrastructure or operational aspects separately, this study combines both perspectives to assess system efficiency and identify optimal utilization strategies. Thus, a study on the readiness of facilities and infrastructure and service

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performance at Palabuhanratu fishing port is needed to formulate a strategy to increase the port's operational efficiency in a sustainable manner.

II. Method

A. Place and Time

This study was conducted over six months, from August to December 2025. The study location was the Palabuhanratu Fishing Port Sukabumi Regency, West Java Province.

B. Data and Data Sources

The data collection process was conducted through direct observation and interviews with harbormasters to identify the availability of supporting facilities and infrastructure at the Palabuhanratu Fishing Port. The data collected included a list of supporting facilities and infrastructure, dock length, port basin depth, vessel size, unloading time, number of enumerators, and the frequency of vessels holding central entry permits. Observations were used to obtain the actual condition of the fishing port's physical and operational facilities, while interviews were conducted to gather technical and procedural information and obstacles encountered in the unloading process. The results of these observations and interviews were then compiled and analyzed, supplemented by a review of the Palabuhanratu fishing port master plan and relevant literature review to ensure the field data aligns with applicable planning and policies.

C. Data Analysis

The analysis of the availability of facilities and infrastructure at the Palabuhanratu Fishing Port was conducted descriptively, describing the performance and information of these facilities and infrastructure. Furthermore, to determine the fishing port's potential capacity, one method was to calculate the standard equation for the vessel queuing system at the Palabuhanratu Fishing Port. This analysis was used to assess the fishing port's basin capacity and the utility of the queuing system at the Palabuhanratu Fishing Port.

To solve queuing problems mathematically using a dual-track system or through a standard queuing model, several basic assumptions are required [10], as follows: 1) Customer arrival patterns follow a Poisson distribution, meaning that arrivals are statistically random or irregular; 2) The service process has an exponential distribution; 3) The queuing system uses the principle of first-come, first-served (FCFS); 4) There is no limit to the number of customers or the length of the queue; and 5) The service speed (μ) must be higher than the arrival rate (λ) to ensure the system remains stable and avoids congestion.

If all of the aforementioned assumptions are met [11], queuing problems can be analyzed and solved using the following equations:

$$p = \frac{\lambda}{\mu} \tag{1}$$

$$p0 = \frac{1}{N} / \sum_{N=0}^{c-1} \frac{(\frac{\lambda}{\mu})}{N!} + \frac{(\frac{\lambda}{\mu})}{c!\,(1\,\frac{\lambda}{c\mu})} \tag{2}$$

$$Lq = \frac{(\frac{\lambda}{\mu})^c \lambda\mu}{(c-1)!\,(c\mu-\lambda)^2}\, p0 \tag{3}$$

$$Ls = Lq + \lambda/\mu \tag{4}$$

$$Wq = Lq/\lambda \tag{5}$$

$$Ws = Wq + 1/\mu \tag{6}$$

Where :
λ = average number of ship arrivals per unit time
μ = average number of ships served per unit time
P = system utility factor
$p0$ = probability of having 0 units in the system (no customers)
Lq = average number of ships in the queue
Ls = average number of ships in the system
Wq = average waiting time of ships in the queue
Ws = average waiting time of ships in the system
C = number of service facilities

III. Results and Discussion

A. Condition and performance of supporting facilities at Palabuhanratu Fishing Port

Based on Figure 1, it can be seen that the fishing port area has a fairly complete and integrated facility layout to support the loading and unloading activities of fishery catches. The port area covers a land area of approximately 35,916 m² and a port basin of approximately 50,000 m², with various main facilities such as docks, port basins, cold storage, and administrative and supervisory support facilities. The distribution of facilities shown on the map shows the proximity between fishing vessel mooring areas, loading and unloading, and production recording support facilities, thus spatially supporting the smooth flow of loading and unloading operations.

Table 1 presents the performance and condition of supporting facilities at the Palabuhanratu Port. Pier 2, with a length of 240 meters, is in good condition and serves as a primary facility for the berthing and loading and unloading of fishing vessels. However, some fenders and bolters, which secure vessels during berthing, are still damaged. This condition has the potential to impact vessel safety and comfort, especially during times of high berthing density [6]. Therefore, maintenance efforts are required to ensure optimal pier functionality for operational activities.

Port Basin 2 covers an area of approximately 20,000 m² and is generally considered in good condition. However, it has experienced shallowing in several areas, with depths decreasing by approximately 3–5 meters. This shallowing can impact the maneuverability and capacity of vessels entering the basin, particularly vessels with deeper drafts. This condition impacts the smooth loading and unloading of catches and indirectly impacts the accuracy and effectiveness of fisheries production recording [12], which serves as the basis for post-production PNBP collection.

Supporting facilities for recording and processing post-production data are also in relatively good condition. Five digital scales, four in good condition and one damaged, have been calibrated by a third party, ensuring accurate catch weight data. Furthermore, a 3,530-ton cold storage facility in good condition supports the storage of fishery products prior to distribution. This facility plays a crucial role in maintaining fish quality and ensuring accurate production volume data is recorded.

In terms of access and supervision, approximately 1,000 meters of road facilities are in good condition, although some damage to the bridge in front of the statistics post could hamper officer mobility and fishery product distribution. Information technology support is also adequate, with a 300 Mbps internet connection available, although coverage is still limited to the corridor area. Furthermore, nine CCTV cameras in Port Basin 2 are functioning properly and are connected to the Ministry of Marine Affairs And Fisheries of Indonesia (MMAF), particularly in the corridor area, supporting oversight, transparency, and accountability in fish unloading activities and post-production PNBP collection at the Palabuhanratu Fishing Port.

Figure 1. Palabuhanratu Fishing Port Map

TABLE 1.
PALABUHANRATU FISHING PORT FACILITIES SPECIFICATION

No	Facilities	Specification	Condition	Description
1	Pier 2	240 m	Good	Damaged fenders and bollards
2	Port Basin 2	20,000 m^2	Good	Sedimentation occurs in several areas (3-5 m)
3	Digital scales	5 units	4 in good; 1 damaged	Calibrated
4	Cold storage	3,530 tons	Good	Owned by fish processing unit
5	Road	± 1,000 m	Good	-
6	Internet	300 mbps	Good	Wifi available
7	CCTV	9 buah	Good	Connected to central monitoring system

B. Characteristics of unloading points and service capacity

Geospatial data (Table 2) shows that the fishing port area has five strategic unloading points distributed in latitude and longitude coordinates. The dock configuration is divided into two main sides separated by the mooring basin: the north side encompassing Point 1 (Corridor 1), Point 2 (Front of UPI 1), and Point 3 (Front of UPI 2), and the south side encompassing Point 4 and Point 5 (Pier 2). This separation of locations, as visualized in the floor plan (Figure 2), indicates a zoning strategy to break up the concentration of loading and unloading activities, where the Lobby and Front of UPI sides serve as the main facilities adjacent to the land facilities, while the opposite side of Pier 2 serves as a breakwater or support pier to maximize berthing capacity.

A hydrographic review shows that the depths in the unloading point areas are relatively uniform but shallow, ranging from 3 meters to 3.5 meters. Points 1, 2, 4, and 5 have an operational depth of 3.5 meters, which technically limits the type of vessel based on the draft of the hull. Meanwhile, Point 3 has the lowest depth of 3 meters. This depth limitation is a critical variable determining port accessibility, necessitating strict management of shipping lanes to prevent the risk of grounding, especially for large-tonnage vessels operating near this depth threshold [1].

TABLE 2.
CHARACTERISTICS OF THE UNLOADING POINT

Point	Name unloading point	Coordinate	Depth	Vessel size maximum	Condition
1	Corridor 1	6°59'25.77"S 106°32'30.87"E	3.5 m	150 GT	Vessels above 100 GT can enter during high tide
2	Front of UPI 1	6°59'26.67"S 106°32'30.38"E	3.5 m	120 GT	Vessels above 100 GT can enter during high tide
3	Front of UPI 2	6°59'23.98"S 106°32'31.07"E	3 m	80 GT	Good; frequently used for vessels larger than 10 GT
4	Pier 2 (Left)	6°59'24.88"S 106°32'28.61"E	3.5 m	150 GT	Vessels above 100 GT can enter during high tide
5	Pier 2 (Right)	6°59'23.32"S 106°32'29.18"E	3.5 m	150 GT	Vessels above 100 GT can enter during high tide

Figure 2. Unloading Point

The maximum vessel size capacity, measured in Gross Tonnage (GT), indicates a stratification of the berth infrastructure's capabilities. Points 1, 4, and 5 are designed to accommodate the port's largest vessels, up to 150 GT. Conversely, Point 2 has a maximum capacity of 120 GT, and Point 3 has the lowest capacity of 80 GT. This capacity differentiation implies the allocation of specific berthing zones; larger vessels are directed to the end of the berth (Corridor 1) and the opposite side (Pier 2) to maintain traffic stability in the narrower basin area near Point 3.

Analysis of the "Condition" column reveals a significant dependence on tidal cycles. At Points 1, 2, 4, and 5, there are explicit operational restrictions stating that vessels over 100 GT can only enter during high tide. This phenomenon confirms that at low tide, the Under Keel Clearance (UKC), or the safe distance under the keel, becomes inadequate for vessels over 100 GT. This creates a limited operational window, requiring precise scheduling of vessel arrivals and departures to synchronize with the daily tide table [13].

Overall, the data indicates that despite physical limitations, the pier's utility is managed by allocating workloads based on vessel size. Point 3, despite having the shallowest depth (3 m) and the smallest tonnage capacity (80 GT), is described as being in "Good" condition and frequently used by vessels over 10 GT.

This indicates a high turnover rate or frequency of use for small- to medium-scale fishing fleets. In contrast, infrastructure for industrial-scale vessels (>100 GT) at other points operates with intermittent limitations due to tides, potentially causing queues or congestion at port entrances while waiting for high tide.

C. Fish unloading activity performance

The data presented (Tables 2 & 3) compare the operational performance of loading and unloading at five loading points between 2024 and 2025. The table categorizes vessels by Gross Tonnage (GT), ranging from small vessels (5-10 GT) to large vessels (101-200 GT). Key indicators monitored include the frequency of vessel visits, average unloading time, average production (kg) per vessel, and average empty time at the loading point. Overall, this data provides insight into the time efficiency and productivity of catch or cargo at each landing point.

There is a noticeable downward trend in the frequency of vessel visits in 2025 compared to 2024. At Unloading Point 1, the total frequency of vessel visits of various sizes in 2024 reached more than 150 times, but in 2025, this frequency decreased to around 105 times. This downward trend is also evident at other unloading points, such as at Point 3 (5-10 GT), which saw a drastic drop from 95 in 2024 to 36 in 2025. This indicates a decline in vessel traffic entering the loading and unloading facility in 2025.

TABLE 3.
FISH UNLOADING ACTIVITY PERFORMANCE IN 2024

Point	Vessel Size	Frequency	Average unloading time (minutes)	Average fish production per vessel (kg)	Average idle time (minutes)
1	21-30 GT	17	402	17,040	2,213
	31-50 GT	52	261	14,813	
	51-100 GT	56	1,277	37,737	
	101-200 GT	28	2,607	52,909	
2	5-10 GT	33	114	5,707	5,690
	11-20 GT	1	150	8,246	
	21-30 GT	9	529	16,833	
	31-50 GT	24	352	14,864	
	51-100 GT	11	1,109	28,122	
	101-200 GT	3	1,898	46,476	
3	5-10 GT	95	128	4,903	4,259
	21-30 GT	9	582	19,077	
	31-50 GT	5	196	14,077	
	51-100 GT	5	2,585	50,542	
4	5-10 GT	7	229	4,383	4,847
	11-20 GT	6	95	2,448	
	21-30 GT	60	500	20,104	
	31-50 GT	12	391	17,950	
	51-100 GT	6	921	26,542	
	101-200 GT	4	3,326	77,640	
5	5-10 GT	4	188	6,012	5,926
	11-20 GT	2	144	4,716	
	21-30 GT	42	463	19,413	
	31-50 GT	6	572	12,274	
	51-100 GT	11	1,037	27,719	
	101-200 GT	8	3,351	74,925	

TABLE 4.
FISH UNLOADING ACTIVITY PERFORMANCE IN 2025

Point	Vessel Size	Frequency	Average unloading time (minutes)	Average fish production per vessel (kg)	Average idle time (minutes)
1	21-30 GT	14	402	13,121	2,907
	31-50 GT	28	261	9,023	
	51-100 GT	46	1,277	29,843	
	101-200 GT	17	2,607	59,709	
2	5-10 GT	12	114	7,209	8,289
	11-20 GT	1	150	8,264	
	21-30 GT	7	529	12,961	
	31-50 GT	13	352	9,054	
	51-100 GT	9	1,109	22,239	
	101-200 GT	2	1,898	52,449	
3	5-10 GT	36	128	6,194	6,650
	21-30 GT	7	582	14,689	
	31-50 GT	3	196	8,574	
	51-100 GT	4	2,585	39,969	
4	5-10 GT	3	229	5,537	6,225
	11-20 GT	3	95	2,453	
	21-30 GT	49	500	15,480	
	31-50 GT	7	391	10,934	
	51-100 GT	5	921	20,990	
	101-200 GT	2	3,326	87,619	
5	5-10 GT	1	188	7,595	7,468
	11-20 GT	1	144	4,726	
	21-30 GT	34	463	14,948	
	31-50 GT	3	572	7,476	
	51-100 GT	9	1,037	21,920	
	101-200 GT	5	3,351	84,555	

While the average unloading time per vessel remained relatively stable and consistent based on vessel size (the larger the GT, the longer the unloading time), there was a significant change in the "Average Idle Time" metric. In 2025, idle time increased at almost all unloading points. For example, at Point 2, idle time increased from 5,690 minutes in 2024 to 8,289 minutes in 2025, and at Point 5, it increased from 5,926 minutes to 7,468 minutes. This increase in idle time is likely a direct result of the reduced frequency of incoming vessels, resulting in more frequent idle time at the facility.

In terms of productivity, average production per vessel shows varying fluctuations between years. Large vessels (101-200 GT) remain the largest volume contributors with average production above 50,000 kg to 80,000 kg per vessel. However, in several size categories in 2025, there is a decrease in average production compared to 2024. For example, at Unloading Point 1 for vessels 31-50 GT, average production decreased from 14,813 kg in 2024 to 9,023 kg in 2025. The combination of the decrease in the number of vessels and the decrease in average fish production in several segments indicates a potential decrease in the total volume of port production [14] as a whole in 2025.

D. Fishing vessel queue model analysis

Table 4 presents the results of the distribution suitability test for the five unloading points. Based on the "D hit" value referring to the Kolmogorov-Smirnov test compared to its critical value, it is concluded that the fishing vessel arrival pattern at the five points follows a Poisson distribution, while the fishing vessel service pattern follows an Exponential distribution [10][11]. This statistical consistency is the basis for determining the queue model used, namely (M/M/5):(FCFS/~/~). This notation means that the system has a Markovian (Poisson) arrival pattern, Markovian (Exponential) service time, has 5 servers (unloading points) operating in parallel, uses a First Come First Served queue discipline which means first come first served with an unlimited system capacity and source population.

TABLE 5.
RESULTS OF FISHING VESSEL'S QUEUE MODEL ANALYSIS

Unloading Point	D hit fihing vessels arrival rate	Conclusion	D hit the fishing vessel's service level	Conclusion	Fishing vessel queue model
1	0,815 > (0,11)	Poisson	0,814 > (0,11)	Exponential	(M/M/5):(FCFS/~/~)
2	0,671 > (0,151)	Poisson	0,884 > (0,151)	Exponential	
3	0,913 > (0,127)	Poisson	0,810 > (0,127)	Exponential	
4	0,669 > (0,140)	Poisson	0,773 > (0,140)	Exponential	
5	0,815 > (0,159)	Poisson	0,740 > (0,159)	Exponential	

TABLE 6.
FISHING VESSELS QUEUE UTILITY

Variable	Symbol	Total
Arrival rate	λ	8.652 vessels/month
Service rate	μ	43 times/ month
Number of severs	s	5 unloading points
Probability of zero customers in the system	P0	0.818 (81,8%)
Average number of vessels waiting in queue	Lq	0.00000001 vessels
Average number of vessels in the system	Ls	0.2012 vessels
Average waiting time in queue	Wq	0.0000000115 vessels
Average waiting time in the system	Ws	0.115 vessels

Table 5 shows a significant imbalance between arrival rates and service capacity. The average arrival rate (λ) was very low, at only 8,652 vessels per month. Conversely, the average service rate (μ) per unloading point was very high, reaching 43 vessels per month. With five servers or unloading points (s=5), the port's total capacity far exceeds the demand for incoming vessels. This condition indicates that the port facility is undercapacity, or very loose, where the service rate is much faster than the rate of new vessel arrivals [5-7][11].

The impact of excess capacity is clearly visible in the system's performance metrics. A P0 value of 0.818 indicates an 81.8% probability that there are no vessels in the system at all (the system is empty/idle). This is confirmed by the Lq (average queue) value, which is nearly zero (0.00000001), indicating that there is almost never a queue of vessels waiting to be serviced. Incoming vessels can directly enter the unloading point without waiting (Wq ≈ 0). The average time a fishing vessel spends in the system (Ws) is 0.115 months, which is purely the loading and unloading service time without any queue waiting time.

The results of this study reveal a rather paradoxical situation in the operational system of the Palabuhanratu Fishing Port: structural underutilization despite the availability of adequate facilities. Unlike most research on fishing ports, which focuses on congestion and capacity limitations, this study found that service capacity far exceeds vessel arrival rates [15][16]. This is indicated by a very high probability of system idling and waiting times approaching zero. These conditions indicate that the queuing system is operating far below its optimal capacity [17]. Therefore, the primary problem lies not in limited facilities, but rather in low utilization rates, which have implications for operational and economic inefficiencies.

An integrative approach between facility condition analysis and stochastic queue modeling comprehensively evaluates port performance. This study not only assesses the physical aspects of infrastructure but also links them to the dynamics of vessel service. Interesting findings indicate that physical limitations such as sedimentation, shallow pond depths, and tidal dependence do not directly cause queues. Instead, these limitations occur in conjunction with excess service capacity. This indicates that the current system bottleneck originates not from the supply side of facilities, but from the demand side (number and frequency of vessels).

TABLE 7.
OPTIMIZATION FISH UNLOADING ACTIVITY PERFORMANCE

Point	Vessel Size	Frequency	Average unloading time (minutes)	Average production per vessel (kg)	Average idle time (minutes)
1	21-30 GT	21	402	17,040	605
	31-50 GT	52	261	14,813	
	51-100 GT	57	1,277	37,737	
	101-200 GT	28	2,607	52,909	
2	5-10 GT	63	114	5,707	620
	11-20 GT	12	150	8,246	
	21-30 GT	9	529	16,833	
	31-50 GT	24	352	14,864	
	51-100 GT	11	1,109	28,122	
	101-200 GT	5	1,898	46,476	
3	5-10 GT	123	128	4,903	675
	21-30 GT	9	582	19,077	
	31-50 GT	5	196	14,077	
	51-100 GT	5	2,585	50,542	
4	5-10 GT	7	229	4,383	600
	11-20 GT	6	95	2,448	
	21-30 GT	60	500	20,104	
	31-50 GT	12	391	17,950	
	51-100 GT	7	921	26,542	
	101-200 GT	5	3,326	77,640	
5	5-10 GT	31	188	6,012	562
	11-20 GT	4	144	4,716	
	21-30 GT	42	463	19,413	
	31-50 GT	6	572	12,274	
	51-100 GT	11	1,037	27,719	
	101-200 GT	8	3,351	74,925	

E. Optimization of the number of fishing vessels

The scenario of increasing the number or frequency of fishing vessels (Table 6) at the marked unloading points (in grey) demonstrates an effort to optimize the utilization of port facilities previously under capacity. At unloading point 1, the increase in the number of vessels in the 21–30 GT category to 21 units reflects a push to increase activity in the medium-sized vessel segment. With a relatively moderate average unloading time (402 minutes), this increase has the potential to increase production throughput without significantly increasing waiting times, thus maintaining operational efficiency.

At unloading point 2, a significant increase occurred in small-sized vessels (5–10 GT to 63 units and 11–20 GT to 12 units). This strategy demonstrates the utilization of the small vessel segment, which has a relatively fast unloading time. The impact is an increase in service frequency and vessel turnover, which can reduce facility idle time [10][11]. Furthermore, because small vessels tend to be more flexible to water conditions, there is relatively less pressure on the limited depth of the basin [13].

At unloading point 3, the increase in the number of vessels in the 5–10 GT category to 123 units demonstrates a focus on intensifying small-scale vessel activity. Given that this point has the lowest depth, this strategy is appropriate because it aligns with the infrastructure characteristics. The expected result is increased utilization of the unloading point, which previously had high idle times, while maintaining smooth operations without creating bottlenecks due to the limited draft of large vessels.

At unloading point 4, vessel additions occur in two distinct segments: small vessels (5–10 GT) and large vessels (101–200 GT). This combination demonstrates a more equitable workload distribution approach. Smallvessels maintain the continuity of daily activities, while large vessels contribute significantly to production volume. However, the success of this scenario depends heavily on the scheduling of arrivals, particularly since large vessels are affected by tides.

Meanwhile, at unloading point 5, increasing the number of vessels in the small categories (5–10 GT and 11–20 GT) aims to fill the previously high idle time at the facility. With the lowest average idle time compared to other points (562 minutes), this addition has the potential to bring the system closer to optimal conditions (closer to ideal capacity without excessive queues). Overall, this additional vessel scenario is expected to improve port utility, reduce facility idle time, and increase total landing production, without causing significant queue congestion.

Another important contribution is the identification of functional specialization at unloading points based on depth, vessel capacity, and operational conditions. Small vessels proved more suitable for optimization at points with limited depth but high frequency, while large vessels must adapt to tidal conditions [18]. This pattern suggests that optimization depends not only on the number of vessels, but also on the appropriate distribution and allocation of vessels according to facility characteristics [19][20]. This approach provides a practical framework for port management based on spatial and operational suitability.

Furthermore, this study also uncovered biases in the interpretation of port performance indicators. Conventionally, the absence of queues is often considered a good performance indicator. However, in this case, this condition actually reflects low activity levels. Increased idle time and decreased vessel frequency indicate that false efficiency can occur if queue indicators are not analyzed in conjunction with utilization and productivity indicators. Therefore, this study emphasizes the importance of using more comprehensive performance indicators in port system evaluations.

IV. Conclusion

Based on the overall analysis of facility conditions, characteristics of unloading points, fish unloading performance, and ship queue patterns, it can be concluded that PPN Palabuhanratu basically has adequate facilities and infrastructure to support fishing port operations, but still faces a number of technical constraints such as limited pool depth, dependence of large vessels on tides, and shallowing and minor damage to physical facilities. The results of the queue model analysis show that the system follows the (M/M/5):(FCFS/~/~) model with five service points, where the ship arrival rate (λ) is lower than the service rate (μ), resulting in a high probability of an empty system ($P_0 \approx 0.818$), an average queue that is almost zero ($Lq \approx 0$), and a very small waiting time ($Wq \approx 0$). This condition indicates that the port service capacity is under capacity, which is also reflected in the high idle time of facilities and minimal ship queues. Therefore, increasing the number of vessels at specific unloading points, particularly for small and medium-sized vessels, is an effective strategy for improving port facility utilization. This addition can reduce idle time, increase the frequency of loading and unloading activities, and optimize service load distribution without causing significant queue congestion. Thus, optimizing port operations is more focused on improving the utilization of existing facilities and managing ship flows more efficiently, resulting in optimal and sustainable service performance.

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