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EVALUATION OF THE PORT OPERATION CONDITIONS INFLUENCING THE SELECTION OF BERTH OCCUPANCY RATE (BOR)

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Abstract

This article presents a new approach to evaluate the factors that influence the selection of Berth Occupancy Rates (BOR) using a simulation method. The berth occupancy rate is a crucial parameter used to determine the number of berths and the operational capacity of a port. Typically, studies, guidelines, and standards suggest that the berth occupancy factor should be based on the pattern of ship arrivals at the port. However, these recommendations often overlook natural conditions and port operational regulations. This paper investigates how port operation conditions (such as waves and water levels) and safety conditions (including safety protocols) affect the determination of the berth occupancy factor and provides a comprehensive analysis of these influences. The research findings are specifically applied to Lach Huyen Port in Hai Phong, offering a representative example for selecting an appropriate berth occupancy factor under varying conditions.

Keywords: port operation; berth occupancy rate; simulation method; queuing theory.

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1. General

The global maritime transport sector has been continuously increasing both in terms of tonnage and the size of ships in recent years. This growth puts pressure on operators and investors to expand existing ports or build new ones to meet the demand. The scale and handling capacity of berths and seaports are determined by the choice of equipment productivity, the port's operational time, and related coefficients. Among these, the berth occupancy rate is a crucial coefficient, as its selection or determination significantly impacts the calculation of berth size and capacity.

Berth occupancy studies help the designers to plan a terminal for optimum throughput, traffic conditions and ship waiting time. Low value of berth occupancy ratio is not acceptable to the port authority from economical point of view, while the high values lead to traffic congestion and increase of ship waiting time [1].

Currently, there are numerous guidelines and standards that offer different methods for choosing or determining the berth occupancy rate. According to the Vietnamese seaport operation standard [2], the berth occupancy rate is determined based on the type of ships calling at the port. Thoresen [3] and Memos [4] propose berth occupancy rates that correspond to the congestion levels of the port, depending on the number of berths available. However, a limitation of these methods and guidelines is that they do not take into account the operational conditions of the port.

The PIANC guidelines [5] provide a method for determining the berth occupancy rate based on different types of probability distribution functions for the ship's arrival time (the interval between

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successive ship arrivals). Similarly, some authors applied queuing theory to ship arrivals for studying the berth occupancy rate [6, 7] and for optimizing the berth numbers [8, 9]. Guolei Tang [10] investigated how the size of the channel (number of channel lanes) affects the determination of the berth occupancy rate. However, these methods have not comprehensively explored how the operational conditions of the channel influence the selection of the berth occupancy rate.

Cahyadi & Sugiyono [11] explored increasing the berth occupancy rate by enhancing the capacity of cargo handling equipment and proposed an optimal berth occupancy rate based on ship waiting times. Zamanirad et al. [1] recommended a reasonable berth occupancy rate for ports handling liquid and bulk cargo across various throughput scenarios, noting that the rate suggested in their study was 24% lower than those indicated by existing guidelines and standards. Several studies assessed the dwell time and BOR for the optimization of cargo handling capacity and quality service [12–14]. Seçil Gülmez et al. [15] introduced a neural network model to predict berthing and handling time, which are directly related to the calculation of BOR. While Peng Wang et al. [16] considered BOR as a key indicator for improving handling efficiency and minimizing congestion risks. This study treated BOR as a performance outcome resulting from optimized berth allocation decisions, rather than as a direct optimization objective.

However, these approaches have not fully examined how the operational conditions of the channel influence the selection of the berth occupancy rate. There remains a need for a more comprehensive understanding of how factors related to channel operations, such as navigational constraints, tidal variations, and traffic management, impact the optimal determination of the berth occupancy rate.

Therefore, this study aims to contribute to the refinement of the selection and determination of the berth occupancy rate. Specifically, the research will consider the following factors when determining or selecting the berth occupancy rate:

- Distribution patterns of ship arrival times: examining how different probability distributions for ship arrival times impact berth occupancy.

- Weather conditions (wave impact): Assessing how adverse weather, such as waves, influences berth operations and occupancy rates.

- Water level conditions (navigational depth): Evaluating how variations in water depth and tidal conditions affect the operational efficiency and berth usage.

- Number of berths and handling equipment productivity: Analyzing the impact of the number of available berths and the productivity of cargo handling equipment on the optimal berth occupancy rate.

- Ship safety regulations: considering the influence of safety protocols and regulations on vessel operations and berth occupancy.

By integrating these factors, the study seeks to provide a more comprehensive approach to determining the berth occupancy rate that accounts for the complex and dynamic conditions of port operations.

2. Overview of Berth Occupancy Rate

2.1. Formula for determination

Several formulas are available for determining the berth occupancy rate, each applicable to specific scenarios and contexts. Below is a discussion of some key formulas:

a. General Formula

The general formula for berth occupancy rate (BOR) can be expressed as:

$$BOR = \frac{Total\ time\ vessels\ occupy\ berths}{Total\ time\ available\ for\ berthing} \times 100\% \tag{1}$$

where *total time vessels occupy berths* includes the cumulative time all vessels spend at the berth for loading, unloading, and any other operations; *total time available for berthing* refers to the total operational time of the berth during the specified period. It typically excludes downtime for maintenance, non-operational periods, and other factors that restrict the use of the berth.

The result is expressed as a percentage, indicating how effectively the berth space is utilized over a given period. This general formula provides a broad measure of berth usage and efficiency, applicable across various types of ports and operational conditions.

b. Additional Considerations

While the general formula is a useful starting point, it's important to note that the specific operational characteristics and conditions of each port can significantly influence the berth occupancy rate. Therefore, further refinement and adjustments are often necessary to account for the unique factors affecting each port's operations.

c. Refinements and Specific Scenarios

Different ports may adopt variations or more specialized formulas that consider additional operational details such as:

- Cargo type: different types of cargo (liquid, bulk, container) require different handling times and equipment, influencing the berth occupancy rate.

- Ship size and handling equipment productivity: larger ships or higher productivity equipment can affect the occupancy duration and frequency of ship arrivals.

- Operational and safety regulations: local regulations and safety protocols can impose restrictions on berth usage and ship operations, impacting the berth occupancy rate.

Each of these factors can be integrated into more complex formulas or adjustments to the general formula to better reflect the actual conditions at specific ports.

Continuous straight alignment berth is a facility that is used for ships that are moored in alongside position position. The ship that is moored is not in the position of the hull attached to the pier wall but only as a small part of the ship attached to the pier wall, namely the bow of the ship. The calculated pier length does not follow the length of the ship, but the actual length of the mooring used, so the BOR calculation uses the formulation:

$$BOR = \frac{\sum (length\ of\ usage\ of\ berth \times berthing\ time)}{length\ of\ berth \times \sum available\ time} \times 100\% \tag{2}$$

d. BOR by Thorensen [3]

The berth occupancy ratio (BOR) in percent taking account of the cargo handling capacity proposed by Thorensen as follows:

$$\begin{aligned} BOR &= \frac{T_{wtc} \times 100}{B_n \times \dfrac{W_d \times W_h}{S_{cs}}} \\ BOR &= \frac{G_{sts} \times 100}{B_n \times W_d \times W_h} \end{aligned} \tag{3}$$

where T_{wtc} is total working time per container ship from berthing to unberthing in hours; B_n is the number of berths; W_d is working days/week; W_h is working hours/day; G_{sts} is total ship to shore container gantry cranes working hours/week; S_{cs} is the number of container ships berthing/week.

2.2. Guidelines and standards for selecting the Berth occupancy rate

Vietnamese seaport operation standard [2] recommends BOR for different cargo types used in the determination of berth numbers, as shown in Table 1. When applying this standard, port planners and operators should:

- Assess cargo composition: identify the types and proportions of cargo that will be handled at the port to select the appropriate occupancy rate.

- Consider operational dynamics: factor in the operational conditions of the port, such as peak and off-peak periods, equipment capabilities, and workforce efficiency, to adjust the baseline rates if necessary.

- Adjust for local conditions: take into account specific local conditions, such as weather patterns, navigational constraints, and regulatory requirements, which can affect berth occupancy.

- General cargo (0.50 - 0.60): this category includes goods that are typically shipped in smaller quantities or packages, often requiring moderate handling and storage facilities. The occupancy rate is relatively balanced, reflecting the varied nature and moderate volume of the cargo.

- Containerized cargo (0.60 - 0.70): container cargo involves standardized cargo containers, which are typically moved using specialized handling equipment. The higher occupancy rate reflects the efficiency and high volume associated with container operations.

- Bulk Cargo (0.40 - 0.50): bulk cargo, such as grains, ores, or coal, is usually transported without packaging in large quantities. The occupancy rate is lower due to the significant handling time and space required for these operations.

- Liquid Cargo (0.30 - 0.40): liquid cargo includes commodities like oil, gas, and chemicals. Handling these materials often involves complex and specialized equipment and safety procedures, resulting in a lower berth occupancy rate.

Table 1. Recommended Berth occupancy rates by cargo type (TCCS 04-2010/CHHVN) [2]

Cargo type	Berth Occupancy Rate (BOR)
General cargo	0.50 – 0.60
Containerized cargo	0.60 – 0.70
Bulk cargo	0.40 – 0.50
Liquid cargo (eg., oil, chemicals)	0.30 – 0.40

Instead of relying solely on the berth occupancy rate, PIANC [5] proposes using the acceptable waiting time for ships relative to their cargo handling time at the berth. This approach offers a more practical measure for assessing port efficiency by directly linking ship wait times to the operational handling duration. The recommended acceptable waiting times for different cargo types are provided below:

- General cargo (25% - 30%): for general cargo, which often involves varied handling times, the acceptable waiting time can be up to 30% of the total time spent handling the cargo. This higher percentage accommodates the diverse nature of general cargo operations.

- Containerized cargo (5% - 10%): container operations are typically more streamlined and efficient, so the acceptable waiting time is lower, reflecting the expectation of quicker turnaround times for these vessels.

- Bulk cargo (20% - 25%): Bulk cargo handling requires significant time for loading and unloading due to the large volumes involved. Therefore, a higher waiting time percentage is acceptable.

- Liquid cargo (10% - 20%): handling liquid cargoes, such as oil and chemicals, requires specialized equipment and safety procedures. Despite these complexities, the acceptable waiting time is relatively low, reflecting the critical nature of these cargoes and the need for timely handling.

Queueing theory has been used in port management since early 60s as a support to determine the optimal number of berths based on the occupation rate of the berths and the expected waiting time for the vessels operating in them. Determines the number of berths based on the yearly average waiting times for vessels in the queue at different utilizations which are statistically approximated from Erlang queuing theory equations as suggested by UNCTAD [17] given in Table 2.

Table 2. Ratio of queuing time to service time for varying berth numbers and berth occupancy

Berth occupancy rate	Number of berths							
	1	2	3	4	5	6	7	8
30%	0.32	0.08	0.03	0.02	0.01	0.00	0.00	0.00
40%	0.48	0.14	0.06	0.03	0.02	0.01	0.01	0.00
50%	0.72	0.24	0.11	0.06	0.04	0.03	0.02	0.01
60%	1.08	0.42	0.20	0.13	0.08	0.0	0.05	0.04
70%	1.70	0.72	0.42	0.27	0.19	0.18	0.11	0.09
80%	2.95	1.40	0.82	0.57	0.43	0.34	0.27	0.22
90%	6.60	3.20	2.00	1.34	1.12	0.92	0.76	0.64

As a rough guide, the berth occupancies for container and conventional general cargo berth operations (multi-purpose berth) should be below the figures given in Table 3. The actual occupancy figures will depend on the port administration's control of the arrival of the ship at the berth. High berth occupancy factors can seem attractive because they yield the highest berth utilisation, but it is usual to assume a ratio of the average waiting time or congestion time to the average berth service time of not higher than 5–20%. The berth occupancy time will also depend on the type of berth, the type and size of ship, transfer equipment, environmental conditions, etc.

Table 3. BOR by Thorensen [3] and Memmos [4]

Number of berths	By Thorensen			By Memmos	
	Control level of ship arrival (%)			BOR	Congestion rate (%)
	Low	Average	high		
1	25	35	45	0.40 – 0.50	50 – 75
2	40	45	50	0.50 – 0.60	26 – 43
3	45	50	55	0.53 – 0.65	14 – 30
4	55	60	65	0.56 – 0.65	11 – 19
5	60	65	70	0.60 – 0.70	09 – 19
6 – 10	65	70	75	0.62 – 0.75	02 – 21
> 10	-	-	-	0.70 – 0.85	0 – 26

3. Port simulation model for port layout planning and BOR study

Numerous simulation models with different levels of accuracy and capacity are used for a wide range of applications in the maritime field. Simulation is generally implemented to explore ship maneuvering behavior in micromodels (transit of a ship under specified external conditions) or ship traffic in macromodels (within waterway and port systems). The goal of developing traffic simulation models can differ based on specific goals. For example, investigation of traffic behavior [18, 19], assessment of port layout and investment [20–24], identification of challenges in ship handling and port operation [20, 25], and assessment of the dwell time and BOR for the cargo handling capacity analysis [12, 13].

This newly developed model for port performance study [21] and was used in the current study to estimate BOR and the waiting times as well. Some key features of that model are discussed as follows:

- Based on the historical information, the ship arrival at the port is randomly generated by a given probability distribution function.

- Climate factors include the wave (period, height, and wave direction), wind (speed and direction), and current (direction and speed) are generated randomly based on historical data.

- Hourly tidal water levels of at least one year are considered during the simulation period.

- The model considered all port processes and facilities including approach channel, anchor areas, berths, turning basin, and in addition to safety criteria.

- The ships are categorized based on size and type, regulated berthing at four groups of terminals like container, bulk, general cargo, and other terminals.

- According to the port information guideline, the model calculated a ship speed as a constant variable through the passage considering the external impact.

- The simulated results are highlighted in statistical and probabilistic distributed forms considering all the port activities and processes.

- Lastly, based on the simulated results, cost-based strategy analysis is performed to optimize port investment.

4. Case study

4.1. Project background

The simulation study is examined for Berths No. 1 and No. 2 of Lach Huyen Port, as its location and layout are shown in Fig. 1.

Figure 1. Port layout and location (from Google Earth_2025 Maxar Technologies)

a. Port dimensions

The simulation model was implemented for the current status with dimensions and port regulations as shown in Table 4.

Table 4. Berth and channel dimensions

Facility	Item	Unit	Values	Notes
Berth	Number of berths	No.	2	
	Total length	m	750	
	Cargo handling rate	TEU (tons)/h	200 (1,500)	for one berth
	Total handling rate	tons/year/m length		
Approach channel	Type of channel	-	one lane	
	Soil condition	-	soft soil	
	Channel alignment	degree	300 to north	
	Length of the channel	m	14,000	
	Channel width	m	120	
	Channel depth (CDL)	m	−10	basic scenario

b. Ship data

We propose ship sizes, and their arrival rates are as shown in Table 5.

Table 5. Designed ships

Ship type	Index	DWT	Loa (m)	B (m)	Draft (m)	Arrival rate (%)
Container	Con_1	40,000	237	32.2	11.7	50.00%
	Con_2	50,000	267	32.2	12.5	30.00%
	Con_3	60,000	290	32.2	13.2	20.00%

c. Navigational rules

When a vessel arrives at the port, the model computes its schedule and calculates the delays by checking weather conditions for sailing and cargo handling, the occupancy, availability of berths, and channels. We applied the safety criteria and operational rules in Table 6 by considering the Lach Huyen port operation guidelines in this study.

Table 6. Safety conditions for ship navigation

Items	Safety criteria
Maximum allowable wave for navigation	1.5 m, 2 m, 2.5 m
Water depth for navigation	1.25 ship draft
Traffic rule	One lane, no passing is allowed

4.2. Environmental conditions

One year data of wave specification in time domain at offshore Lach Huyen area has been collected for the study. Near shore waves and currents at the proposed port locations have been estimated from the offshore waves using wave transmission model [26]. The winds and currents were reported to be inconsiderable and therefore disregarded in this study. One year of hourly measured tidal levels were used in the simulation to handle the effect of water tidal variation on the navigational depth. By checking with the safety operation policies (Table 6), we can estimate times of port downtime and ship times at port for each alternative due to the adverse weathers.

4.3. Simulation results

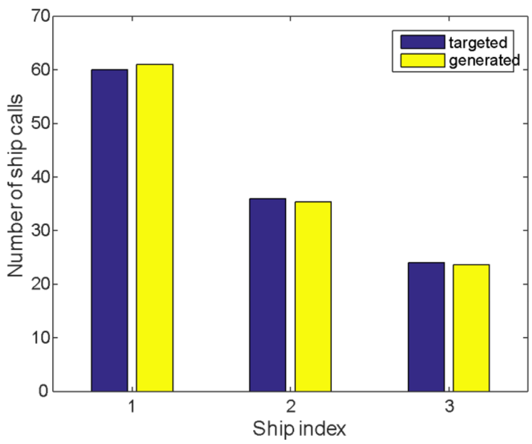
a. Basic scenario

The detailed simulation results of port performance are depicted in Fig. 2. Some observations drawn from the base scenario are as follows:

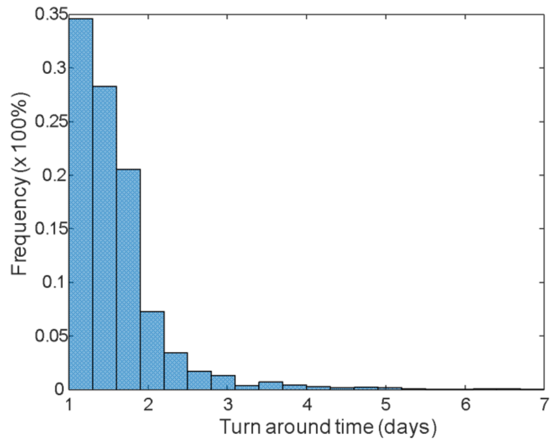
- The handling capacity has increased from 7,500 tons to 11,000 tons per meter of berth length, corresponding to an increase in the number of vessels arriving at two berths from 120-180 for one year simulation. This capacity is equivalent to modern container ports worldwide.

- The vessel turnaround time of 1.75 days is considered average compared to statistics for ports of similar capacity.

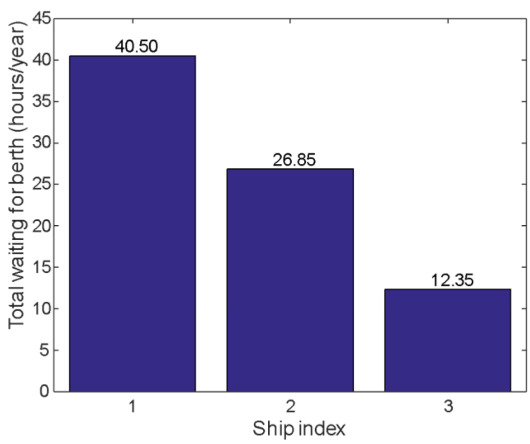
- The berth occupancy time, considering only the time spent loading and unloading cargo at the berth, varies from 0.22 to 0.34, corresponding to 120, 150, and 180 vessel arrivals, respectively. However, when including ancillary operation times and vessel maneuvers within the channel,



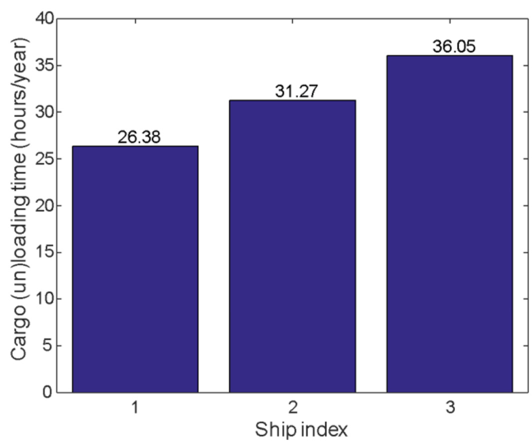
(a) Verification of the simulated ships



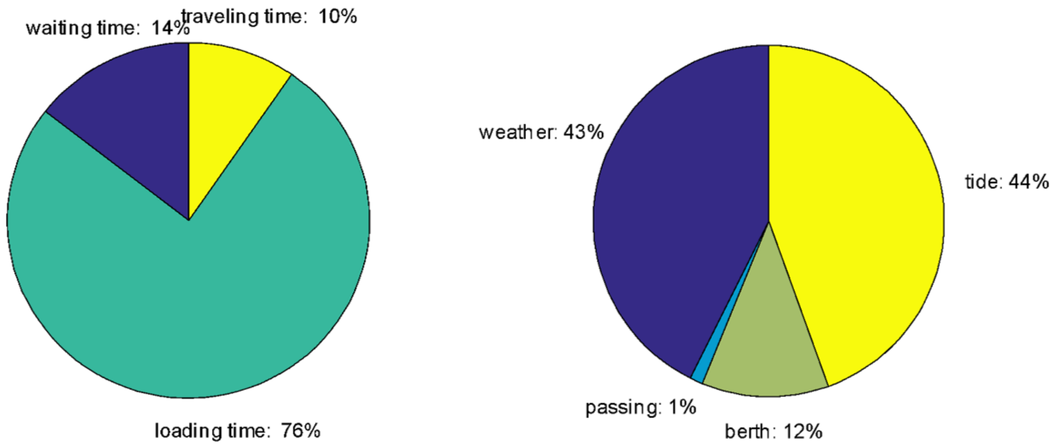
(b) Density of the ship turn around time



(c) Total waiting time for different ship types



(d) Cargo handling time for different ship types



(e) Time distribution of ship activities at port

(f) Percentage of ship waiting time at port

Figure 2. Simulated port performance for basic scenario

the berth occupancy rate doubles. This highlights the significant contribution of ancillary operation times, which nearly equals the actual cargo handling time at the berth.

- Comparing against PIANC guidelines [5] regarding the ratio between cargo handling time and ship waiting time, which is recommended at 16.5%, reveals non-compliance. This indicates that despite a relatively low berth occupancy rate, the waiting time for ships is relatively high. With this waiting time, the attractiveness and competitiveness of the port are significantly diminished according to PIANC [5] recommendations.

b. Comparative scenarios

To assess the variability of the waiting and service time (W/S) ratio, and determine an investment and operational strategy that meets PIANC [5] recommendations, we have proposed scenarios involving increased dredging depth in the channel and increased wave height allowance (by enhancing the capacity and size of tugboats). The scenarios are listed in Table 7.

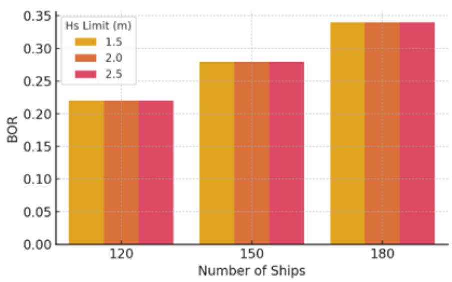
Table 7. Comparative simulation scenarios

Depth (m)	Hs limit (m)	No. ships	Scenario	Depth (m)	Hs limit (m)	No. ships	Scenario
12.5	1.5	120	KB 1.1	13.5	1.5	120	KB 2.1
		150	KB 1.2			150	KB 2.2
		180	KB 1.3			180	KB 2.3
	2.0	120	KB 1.4		2.0	120	KB 2.4
		150	KB 1.5			150	KB 2.5
		180	KB 1.6			180	KB 2.6
	2.5	120	KB 1.7		2.5	120	KB 2.7
		150	KB 1.8			150	KB 2.8
		180	KB 1.9			180	KB 2.9

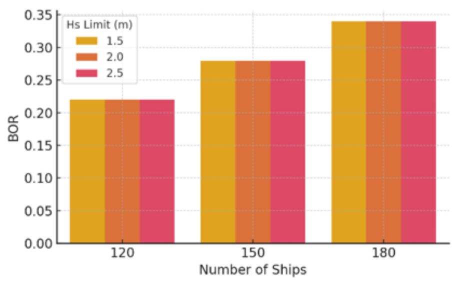
The results in Table 8 are clearly and intuitively illustrated through Fig. 3.

Table 8. Main simulation results for the comparative scenarios

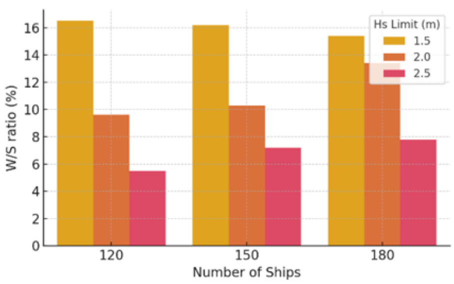
Depth (m)	Hs limit (m)	No. ship	Cargo (Million tons)	Waiting (hour)	Service (hour)	BOR	W/S ratio
12.5	1.5	120	4.506	589.70	3568.80	0.22	[16.5%]
		150	5.663	724.32	4478.40	0.28	[16.2%]
		180	6.791	826.32	5373.60	0.34	[15.4%]
	2.0	120	4.541	343.20	3592.56	0.22	{9.6%}
		150	5.637	457.92	4463.04	0.28	[10.3%]
		180	6.745	715.68	5345.04	0.34	[13.4%]
	2.5	120	4.497	195.60	3563.28	0.22	{5.5%}
		150	5.611	319.44	4449.36	0.28	{7.2%}
		180	6.770	416.88	5355.84	0.34	{7.8%}
13.5	1.5	120	4.502	360.48	3566.88	0.22	[10.1%]
		150	5.606	462.24	4443.60	0.28	[10.4%]
		180	6.722	660.24	5328.72	0.34	[12.4%]
	2.0	120	4.557	186.48	3600.00	0.22	{5.2%}
		150	5.610	274.08	4446.00	0.28	{6.2%}
		180	6.745	376.56	5346.96	0.34	{7.0%}
	2.5	120	4.516	97.68	3575.04	0.22	(2.7%)
		150	5.654	187.20	4478.16	0.28	(4.2%)
		180	6.789	228.72	5371.68	0.34	(4.3%)



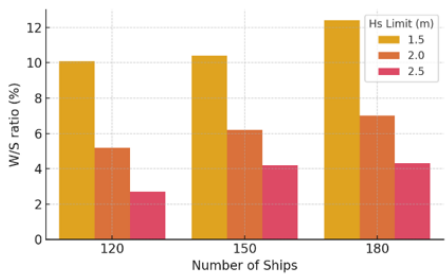
(a) BOR (depth = 12.5 m)



(b) BOR (depth = 13.5 m)



(c) W/S ratio (%) (depth = 12.5 m)



(d) W/S ratio (%) (depth = 13.5 m)

Figure 3. Simulated results in terms of BOR and W/S

Main simulation results for the comparative scenarios are compiled in Table 8. From these results, several interesting observations can be made:

- Berth occupancy rate changes only when the number of vessels arriving at the port changes, not depending on the infrastructure scale (dredging depth) and operational conditions (wave conditions). Therefore, the berth occupancy rate (excluding equipment capacity) does not fully reflect the port's operational conditions.

- In addition to berth waiting time (mainly caused by the uneven distribution of vessel arrivals), waiting time due to dredging depth and wave conditions significantly affects the total ship waiting time. These factors are often not adequately considered in many current standards and guidelines.

- Increasing the scale of channel investment (deeper dredging) and improving operational conditions (allowing higher wave heights) significantly reduces ship waiting time. Meanwhile, berth waiting time remains almost unchanged. This suggests that relying solely on berth occupancy rate does not fully reflect the port's operational conditions. Therefore, it is only one of the necessary conditions for determining scale (number of berths).

- The table indicates that scenarios in square bracket do not meet the PIANC [5] requirements for the S/W ratio. Scenarios in curly bracket meet PIANC [5] requirements below the 5% threshold. However, investing in these scenarios may be excessively costly. Therefore, scenarios in opening parenthesis are reasonable choices. These scenarios can balance initial investment and operational costs while maintaining the port's attractiveness by keeping ship waiting time at an acceptable level.

5. Conclusions

The assessment of the impact of port operational conditions on the selection of berth occupancy factor has been studied using simulation models for berths 1-2 at Lach Huyen port. Based on this research example, several important conclusions can be referenced when determining/selecting the berth occupancy factor in project scale calculations:

- The berth occupancy rate defined in current guidelines and standards primarily reflects the distribution law of vessel arrivals at the port. Other influencing factors are almost neglected. Therefore, relying solely on this factor can lead to either excessive investment or inefficient port operations (low port attractiveness).

- It is advisable to consider and select the berth occupancy rate based on the analysis of total ship waiting time influenced by investment and operational conditions. Guidelines such as those from PIANC on the S/W ratio can be useful during the facility design phase.

- It is essential to perceive the berth occupancy rate as a consequence of design rather than a design condition itself. Therefore, more accurate methods should be employed in calculating berth facility scale and port operational capacity. Simulation methods are effective tools for addressing this challenge.

This conclusion highlights the importance of comprehensive analysis and consideration of various operational factors when determining berth occupancy factors to ensure optimal port performance and competitiveness.

References

[1] Zamanirad, S., Mazaheri, S., Ghafourian, M. (2017). Introducing a Method for More Precise Prediction of Berth Occupancy Ratio in Bulk Liquid Terminals. *International Journal of coastal and offshore engineering*, 1(2):21–26.

[2] Vinamarine (2010). *Seaport operation standard (TCCS 04-2010/CHHVN)*.

[3] Thoresen, C. A. (2019). *Port Design Handbook*. 4th edition, ICE Publishing, One Great George Street, Westminster, London SW1P 3AA.

[4] Memos, C. D. (2004). Port Planning. In Tsinker, G. P., editor, *Port Engineering: Planning, Construction, Maintenance, and Security*, Hoboken, New Jersey, John Wiley & Sons, Inc.

[5] PIANC (2014). *Harbour approach channels design guidelines*. Report No 121.
[6] Loc, D. V. (2008). Study on queing theory for determination of berth occupancy rate. Master's thesis, Hanoi University of Civil Engineering.
[7] de la Peña-Zarzuelo, I., Freire-Seoane, M. J., López-Bermúdez, B. (2020). New Queuing Theory Applied to Port Terminals and Proposal for Practical Application in Container and Bulk Terminals. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, 146(1):04019031.
[8] El-Naggar, M. E. (2010). Application of queuing theory to the container terminal at Alexandria seaport. *Journal of Soil Science and Environmental Management*, 1(4):77–85.
[9] Gokkus, Ü., Yildirim, M. S. (2015). Determination of the Optimum Berth Number of the Izmir Seaport by Deterministic and Probabilistic Methods Based on Artificial Neural Networks. *International Journal of Hybrid Information Technology*, 8(9):11–24.
[10] Tang, G., Wang, W., Song, X., Guo, Z., Yu, X., Qiao, F. (2016). Effect of entrance channel dimensions on berth occupancy of container terminals. *Ocean Engineering*, 117:174–187.
[11] Cahyadi, T. H., Sugiyono, S. (2021). Analysis of Loading and Unloading Productivity on Berth Utility at the Multipurpose Terminal Teluk Bayur Port. *Dinasti International Journal of Economics, Finance & Accounting*, 2(3):306–315.
[12] Hassan, R., Gurning, R. O. S. (2020). Analysis of the container dwell time at container terminal by using simulation modelling. *International Journal of Marine Engineering Innovation and Research*, 5(1).
[13] Kuznetsov, A., Kirichenko, A. (2016). Simulation for Service Quality and Berths Occupancy Assessment. *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation*, 10(3):489–492.
[14] Gurning, R. O., Fikri, F. (2016). The Assessment of Berth Occupancy Ratio (BOR) to Achieve Required Standardised Level and Optimum Throughput: A Case of Oil and Gas Terminal in Kalimantan. In *The 2nd Conference on Innovation and Industrial Applications (CINIA 2016)*, Sukolilo, Indonesia, 9–13.
[15] Gülmez, S., Gülmez, Y., Tapaninen, U. P. (2025). Predicting cargo handling and berthing times in bulk terminals: A neural network approach. *Case Studies on Transport Policy*, 19:101351.
[16] Wang, P., Li, J., Cao, X. (2024). Discrete Dynamic Berth Allocation Optimization in Container Terminal Based on Deep Q-Network. *Mathematics*, 12(23):3742.
[17] UNCTAD (1985). *Port development - A handbook for planners in developing countries*. New York.
[18] Almaz, O. A., Altiok, T. (2012). Simulation modeling of the vessel traffic in Delaware River: Impact of deepening on port performance. *Simulation Modelling Practice and Theory*, 22:146–165.
[19] Gucma, L., Bąk, A., Sokołowska, S., Hajduk, J. (2016). Stochastic mode of ship traffic congestion in waterways applied to determine the influence of Liquefied Petroleum Gas tanker introduction on ship traffic on the Świnoujście-Szczecin waterway. *Scientific Journals of the Maritime University of Szczecin*, 45(117):69–74.
[20] Cho, S. W., Park, H. J., Kim, A., Park, J. H. (2022). GMM-based online optimization for container stacking in port container terminals. *Computers & Industrial Engineering*, 173:108671.
[21] Nguyen Minh, Q., Sadiq, R., Gucma, L. (2021). Simulation-based performance assessment framework for optimizing port investment. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, 147(4):04021010.
[22] Scott, D., Taylor, D., El-Solh, S., Elliott, T. (2016). Port simulation modelling and economic assessment. *Journal of Marine Science and Engineering*, 4(1):16.
[23] Tang, G., Wang, W., Guo, Z., Song, X., Yu, X., Zhang, Y. (2017). Decision support system for designing integrated coastal berths and entrance-channel systems. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, 143(1):04016013.
[24] Wang, H., Huo, D., Ortiz, J. (2015). Assessing energy efficiency of port operations in China-A case study on sustainable development of green ports. *Open Journal of Social Sciences*, 3(5):28–33.
[25] Cao, X., Lam, J. S. L. (2019). Simulation-based severe weather-induced container terminal economic loss estimation. *Maritime Policy & Management*, 46(1):92–116.
[26] PORTCOAST (2015). *Feasibility Study for Development of Lach Huyen Sea Port*. Ho Chi Minh: PORTCOAST Consultants.