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The Effect of Tidal Current on the Length of Turning Basin Using Maneuvering Simulation

I Putu Sindhu Asmara[1) *)], Kharis Abdullah[1)], Alif Nur Rochmad[1)], Syafril Mayu Dinata[1)], Sunardi[1)]

[1)] Department of Shipbuilding Engineering, Politeknik Perkapalan Negeri Surabaya, Surabaya 60111, Indonesia
[2)] Department of Marine and Fisheries Resources Utilization, Fisheries and Marine Science Faculty, Brawijaya University, Malang 60145, Indonesia
[*)] Corresponding Author : putusindhu@ppns.ac.id

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Abstract

The development of a new port must consider several factors for efficient investment and effective operation. One of those is the turning basin dimensions, which affect the dredging area. The area of the required turning basin is still an interesting research topic. The topic involves several variables, including tugboat capacity, thruster, wind, wave, current, and under-keel clearance. This study aims to identify the effect of the tide current on the length of the turning basin. The container ships shall turn before berthing to make them easier to tow out of the jetty in an emergency. A berthing maneuver simulation was performed under extreme conditions of 20-knot wind speed and 5 current speed variations, from 0.75 to 1.75 knots, using the Mathematical Maneuvering Group model. The model simulates the forces and moments of tugboats, wind and current acting on the vessel. The acceleration and velocity of surge, sway, and yawing of the vessel are calculated, and the longitude and latitude position of the ship are obtained, as well as the speed over ground, heading, and course over ground. Environmental disturbances cause the approaching vessel to drift when tugboats push it to the jetty. The criteria used for the success of the berthing maneuver are the safe interaction distance (less than 30 m) and the acceptable berthing speed (less than 0.15 m/s). According to a standard, the diameter of turning basin is 2L. Based on maneuvering simulation results, the length of the turning basin varies linearly with the current velocity.

1. Introduction

In addition to economic considerations, the port operator must comply with the safety requirements. Safety aspects in the development of a new port include the standard dimensions of the canal, turning basin, and jetty. The required length of the jetty depends on the ship's length, the number of berthed ships, and the fore-and-aft distance between ships at the jetty. Inappropriate port design has a high risk due to the high probability of several accidents, such as collision, stranding, and grounding. A study classifies the risk into 3, including collision risk, stranding and reef risk, and traffic jam. The factors are also classified into 3, namely, environmental factors, channel characteristics and hydrographic conditions, and human factors [1]. Based on a study [2], the distance for interaction clearance for encounter ships in port area is 1.5B which is consistence with the standard from the Technical Standards and Commentaries for Port and Harbor Facilities in Japan [3]. Proper port design supported by an appropriate terminal operation manual, will minimize risk in the port area. The manual includes the environmental limits of port operations, the tug boats' bollard pull and the assistance plan for berthing maneuver [4].

Researchers have proposed several safety measures, such as the Automatic Identification System (AIS) [5], the Berthing Aids System (BAS) [6], and three-dimensional (3D) light detection and ranging (LiDAR) [7]. Based on the IWRAP method using AIS data, the collision probability in Sunda Street, one of the three main Indonesian Archipelagic Sea Lanes, is 0.153 collisions per year [8]. Indonesia has three main International Shipping Lanes and 54 streets. Accordingly, the average annual frequency of maritime accidents in Indonesia is 0.459 to 8.262 collisions, based on the 3 main shipping lanes and the 54 sea routes, respectively. Technical issues and human factors account for 52% and 46.7%, respectively, of maritime accidents in Indonesia [9]. The AIS technology has already been mandated for all port operators. Recently, the server received several duplicate data points. An operator in an overlapping covered area is transmitting the same data. An algorithm to sort and analyze AIS data should be developed for maritime safety assessment. Recently, an oil and gas port terminal in Indonesia used BAS technology to monitor berthing speed and angle.

One of the technical issues for port and ship safety operations is the berthing technical plan. The plan, including the berthing procedure, should be prepared for port structure development. A ship maneuvering simulator can help with proper port design by providing scenarios ensuring the safety of berthing and un-berthing. The method can predict the probability of ship collisions at the Great Belt Bridge, the probability is 0.007, and proposes reducing speed and altering the traffic separation scheme [10]. Determination of the canal width, the turning basin diameter and position, and port structure orientation shall comply with regulations. In addition, the regulator still needs to be provided with a study to confirm the safety of berthing and un-berthing.

The SSPA maritime operations of Sweden utilize a Full Bridge Simulator to answer whether port efficiency and port safety lie on different sides of a coin [11]. Implementation of Fast Time Simulation (FTS) to determine canal width showed that the width (95% confident) exceeded both the Permanent International Association of Navigational Congresses (PIANC) and Overseas Coastal Area Development Institute of Japan (OCDI) requirements [12]. PIANC 2018 recommended maneuvering simulation to establish the approach channel and maneuvering area. PIANC guidelines provide two phases: Concept Design and Detailed Design. In detailed Design, maneuvering simulation do validation and refine of Concept Design including the variables of weather conditions, ship size and maneuvering capacity, tug assistance, and piloting [13].

Research based on AIS data confirmed that the trajectory of different ship types in the port area is typical. A ship type has a different center of approach to a port terminal [14], indicating that the design of the approaching canal should consider the maneuverability of different ship types. The approach canal leading to the berthing position in the port terminal will determine the distance of a ship from the fore and aft of other berthing ships. In addition to the ship types, environmental disturbances will alter the ship's trajectory from its normal path. Trajectory deviations affect the approach angle to the berthing position. The prediction of ship trajectory using maneuvering simulation involves the forces and moments of the hull, propeller, rudder, and thruster, as well as tugboat assistance. The main ship dimensions and the block coefficient represent the hull derivatives, which lead to the forces and moments. Sanguino et al. [15] investigated a set of hydrodynamic derivatives due to the impact of environmental disturbances, including wind, wave, and current.

Other research on environmental disturbances has also been carried out. Esvera et al. [16] developed a physical hydraulic model of mooring vessels. It consists of a Very large Ore Carrier (VLOC) model as part of the design of a port area equipped with cameras to investigate unintentional un-berthing leading to ship-to-structure or other ship collision and grounding. The risks were identified at the flood and ebb tidal current conditions. The trajectories of ship drift were identified in both current conditions. Zhan et al. [17] performed berthing simulations in a container terminal under extreme sea conditions across several wind and current scenarios. The research found that berthing maneuver risk under extreme wind, 6 and 7 levels, is less significant than maneuvering under extreme tidal current, 2 and 3 knots of flood and ebb conditions. The study resulted in the formulation of a berthing plan in 8 conditions of the scenarios.

Yasukawa et al. [18] have verified formulas for the drifting indices through comparison with the simulation results on the effects of wave direction on ship turning in regular waves. Menges et al. [19] developed an observer framework of wave, wind, and current disturbances for autonomous surfaces vessel. This study considered wind and current disturbances in container ship berthing maneuver. Gil et al. [20] used the 6DOF of ship motion to analysis ship turning trajectory.

In this study, a specific maneuvering condition has been examined using 3DOF ship motion. The heading of a mooring ship at the jetty should be directed to the open sea for a quick release in an emergency. The pilot easily assisted a vessel in berthing when the current was contrary to the ship's course. A turning maneuver should be taken to accommodate the first condition. The second condition will not be available and will cause the ship to drift. This study aims to identify the impact of the current speed on the trajectory of the berthing maneuver and the length of the turning basin required.

2. Method

This study used a maneuvering simulator developed in MATLAB based on the MMG model described in another publication [6]. The model consists of 3DOF motions including surging, swaying, and yawing represented by Eq. 1, 2, and 3, respectively.

$$(m + m_x)\dot{v}_G - (m + m_y)v_G r_G = X_H + X_P + X_R + X_W + X_C + X_T \tag{1}$$

$$(m + m_y)\dot{v}_G + (m + m_x)u_G r_G = Y_H + X_P + Y_R + Y_W + Y_C + Y_T \tag{2}$$

$$(I_{zz} + J_{zz})\dot{r}_G = N_H + N_P + N_R + N_W + N_C + N_T \tag{3}$$

The ship mass, added mass, mass inertia, and the hydrodynamics coefficients for hull, propeller, and rudder are calculated based on empiric equations according to the main dimension of the vessel. The forces and moments are represented by the subscript of H, P, and R. This study utilizes the 3 DOF MMG model developed by Yoshimura and Masumoto [21], [22], to account for wind, sea currents, and tugboat forces. Following the framework established by Asmara et al. [23], Eq. 1 through 3 incorporate new variables for tug surging force (X_T), swaying force (Y_T), and yaw moment (N_T). Additionally, the tugboat operations are simulated in compliance with PIANC guidelines [24]. The main dimension presented in Table 1 is the dimension of the largest container ship berthed in Surabaya Container Terminal, as shown in Figure 1. The capacity of the vessel is 46,000 TEUs with a draught of 12.6 m, and the canal depth is 15 m.

Table 1. Main Dimensions [21]

Dimension	Notation	Value
Length Overall	LOA	259 m
Capacity	TEUs	46,000
Breadth	B	32 m
Height	H	19.3 m
Draft	d	12.6 m
Block Coefficient	C_B	0.65

Figure 1. MV Holsatia berthed on starboard in Surabaya Container Terminal [25, 26]

2.1. Maneuvering Scenarios

Figure 1 shows the vessel berthed on the starboard, contrary to the standard mooring heading, which should be heading out of the canal (reverse parking). In an emergency, the vessel should turn first before being pulled out of the port area. In this maneuvering simulation, in addition to berthing on the starboard side, the vessel was turned and berthed on the port side, considering that the vessel could be pulled out of the terminal in an emergency. Table 2 presents the scenarios of berthing maneuver in this study.

Table 2. Berthing Maneuver Scenarios

Scenario	Berthing Side	Wind	Current	Tugboats Capacity
1	Port Side	20 knots from Northwest	0.75 knots to West	4×45 tons Bollard Pull
2	Port Side	20 knots from Northwest	1.00 knots to West	4×45 tons Bollard Pull
3	Port Side	20 knots from Northwest	1.25 knots to West	4×45 tons Bollard Pull
4	Port Side	20 knots from Northwest	1.50 knots to West	4×45 tons Bollard Pull
5	Port Side	20 knots from Northwest	1.75 knots to West	4×45 tons Bollard Pull

2.2. Acceptance Criteria

All the maneuvering scenarios shall comply with the berthing maneuvering acceptance criteria described in Table 3. According to OCDI, the berthing speed should be less than 0.15 m/s, berthing angle is less than 10^0, and the free distance to other vessel is at least 30 m [3].

Table 3. Berthing Maneuver Acceptance Criteria

No	Criteria
1	Berthing speed is less than 0.15 m/s
2	Berthing angle is less than 10^0
3	Free space to other vessels is at least 30 m
4	The turning area does not cross the canal

3. Results and Discussion

3.1. Berthing Maneuver Simulation for Scenario 1

The berthing maneuver outcomes for Scenario 1 are illustrated in Figures 2 through 4. As shown in Figure 2, the vessel's trajectory begins near the canal bend and concludes at the jetty, positioned precisely between two previously berthed ships.

The simulation results in Figure 3 are utilized to calculate both the clear distance to these neighboring vessels and the total width of the turning area prior to berthing. Figure 4 indicates a total maneuvering duration of 5200 seconds. The process initiated at a heading of 135° and a speed of 2.27 knots and concluded at a heading of -69.36° and a speed of 0.1867 knots. Given the jetty's orientation of -78°, this yields a final berthing angle of 8.63°.

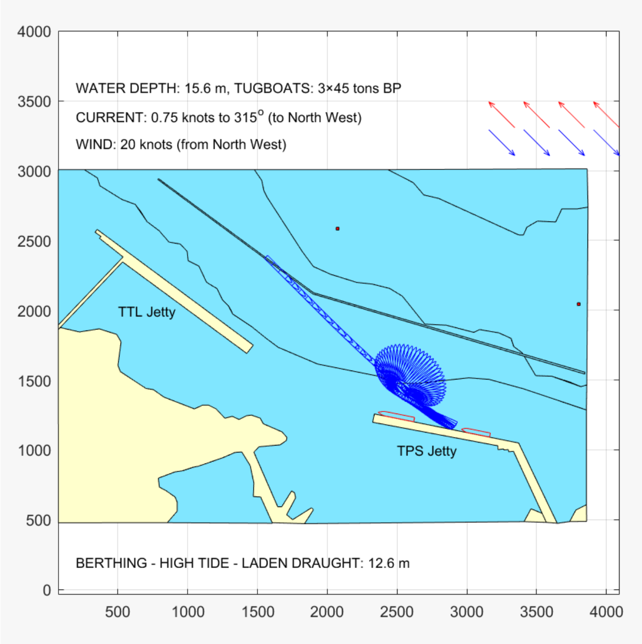

Figure 2. Berthing trajectory of the container ship for scenario 1

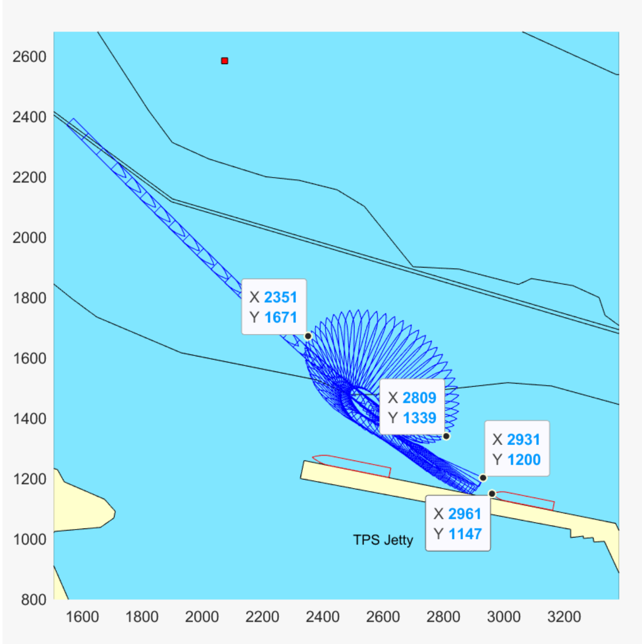

Figure 3. Berthing distance to obstacles of other vessels and turning distance for scenario 1

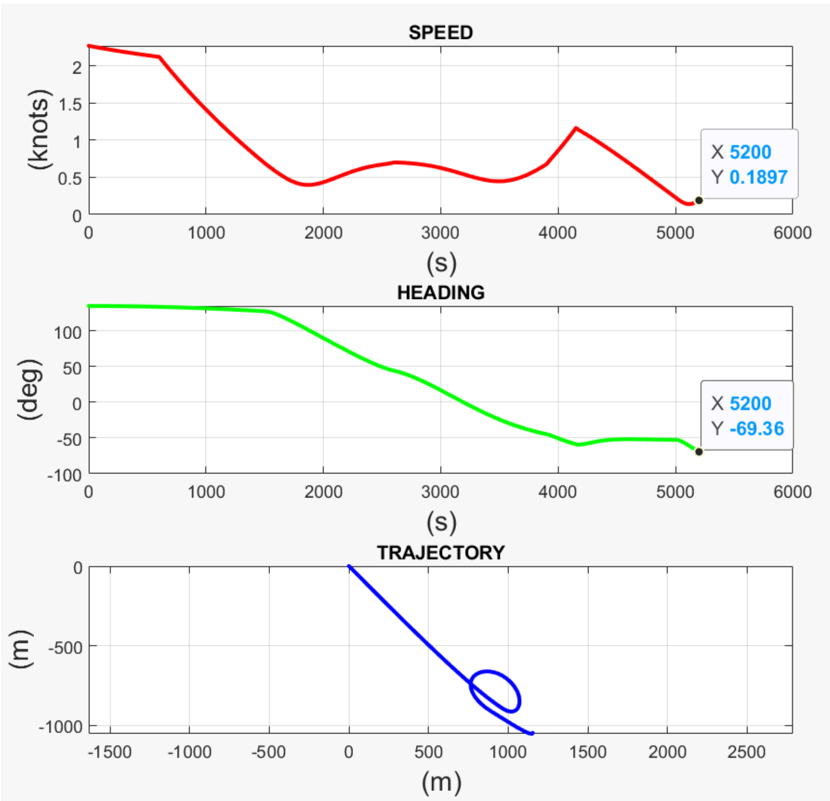

Figure 4. Duration of the berthing maneuver, velocity, and heading of the ship for scenario 1

3.2. Berthing Maneuver Simulation for Scenario 2

Figure 5 demonstrates that while the vessel successfully docked at the jetty between two berthed ships, its turning trajectory crossed heavily into the main canal. This encroachment presents a serious operational hazard; although the clearance distance to the adjacent, stationary vessels satisfies the minimum safety threshold of 30 m (as validated by the clearance telemetry illustrated in Figure 6), the spatial footprint required for the turn extends beyond the designated basin boundaries. This indicates that under Scenario 2's environmental conditions, the ship's hydrodynamic drift cannot be fully contained by the tugboats.

The severity of these conditions is further reflected in the kinematic data captured in Figure 7. The total maneuvering duration spanned 5600 seconds (nearly 1.5 hours), highlighting a prolonged and difficult approach phase where pilots had to combat external forces. The operation initiated from an approach heading of 135° at an initial speed of 2.27 knots, and concluded at a final heading of −70.38°. This resulted in a final berthing speed of 0.2399 knots and an approach angle of 7.62°. While the berthing angle remains within acceptable safe-impact limits, the prolonged duration and the severe canal crossing suggest that Scenario 2 introduces significant traffic bottlenecks and risks that make it unfeasible for standard port operations.

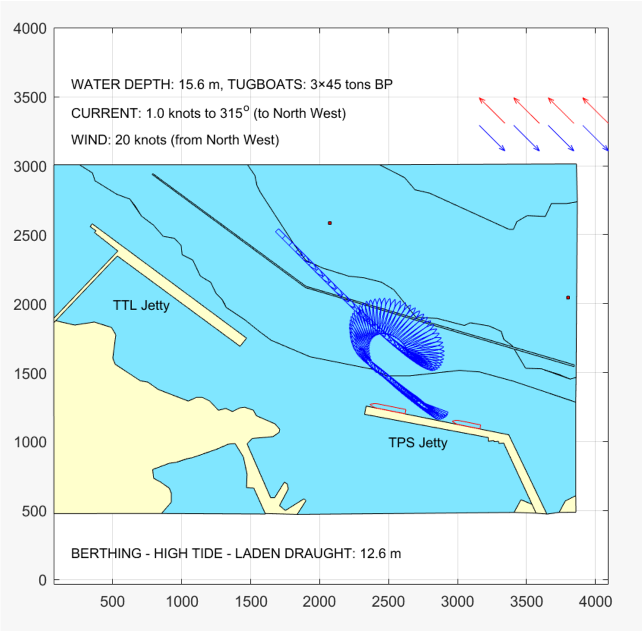

Figure 5. Berthing trajectory of the container ship for scenario 2

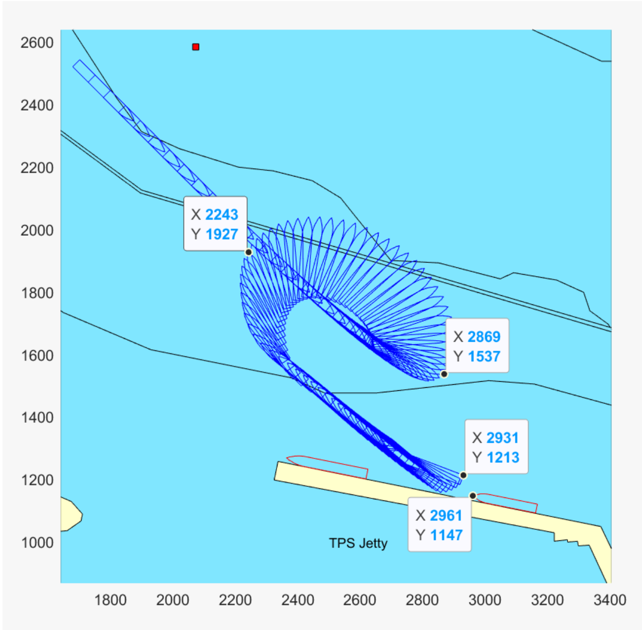

Figure 6. Berthing distance to obstacles of other vessels and turning distance for scenario 2

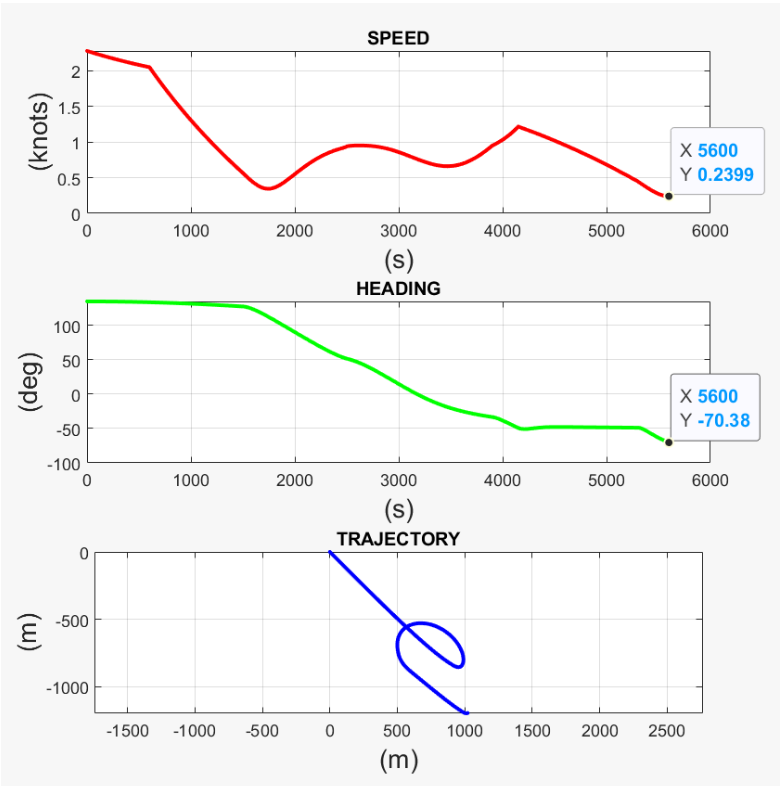

Figure 7. Duration of the berthing maneuver, velocity, and heading of the ship for scenario 2

3.3. Summary of Berthing Maneuver Simulation for Scenario 1 to 5

Apart from Scenario 1, the turning trajectories for Scenarios 2 through 5 consistently fail to meet the safety requirements of Criterion 4 (see Figures 8 to 10). Because these trajectories encroach upon and cross the canal, port authorities would be forced to halt all ongoing transit traffic to ensure safety during the berthing maneuver. While it is technically possible to prevent this canal encroachment by shifting the turning position further down-canal, doing so introduces a severe spatial constraint: the ship would draw too close to neighbor obstacles, thereby violating the safety clearances mandated by Criterion 3. This creates a critical operational bottleneck where satisfying traffic separation (Criterion 4) directly compromises safe obstacle clearance (Criterion 3).

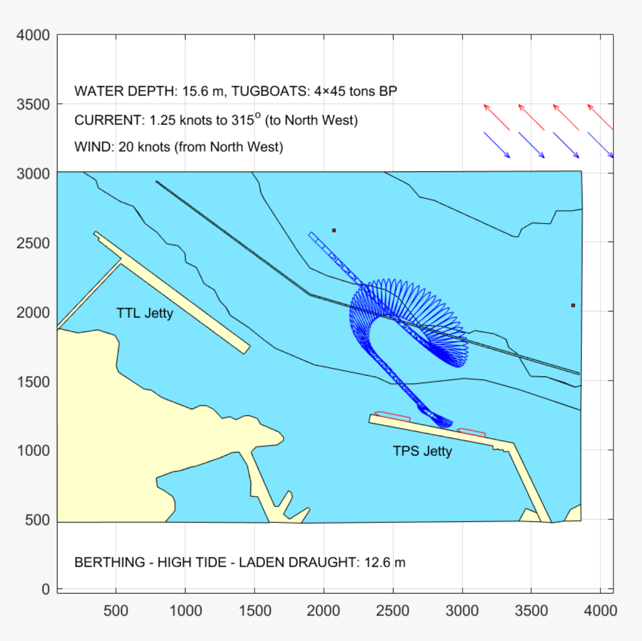

Figure 8. Berthing trajectory of the container ship for scenario 3

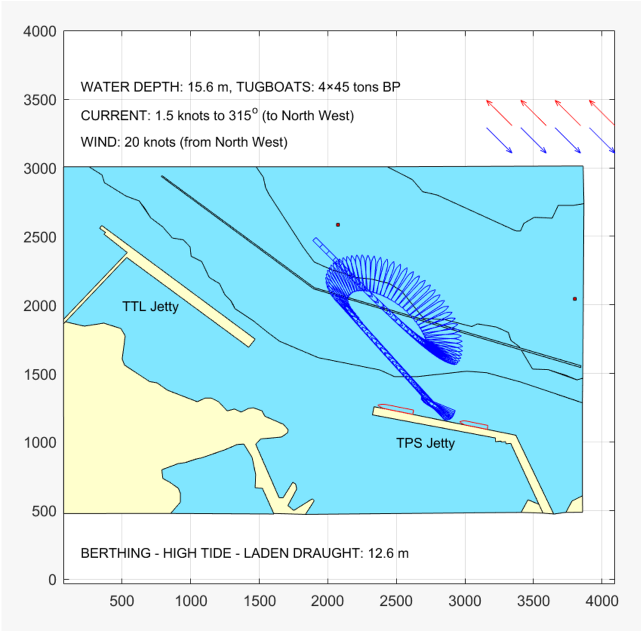

Figure 9. Berthing trajectory of the container ship for scenario 4

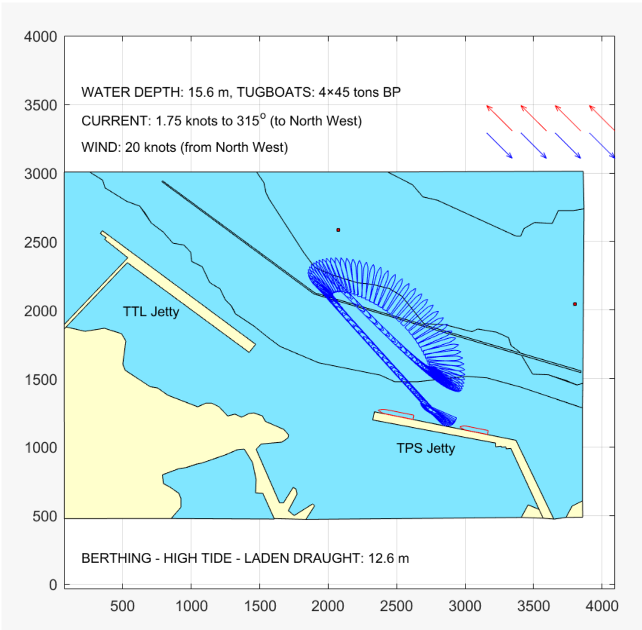

Figure 10. Berthing trajectory of the container ship for scenario 5

Table 4. Summary of Compliance with the Acceptance Criteria

Scenario	Berthing Duration (seconds)	Berthing Speed (m/s)	Berthing Angle (degrees)	Minimum Distance to Obstacles (m)	Crossing the Canal
1	5200	0.10	8.64	30	No
2	5600	0.12	7.62	30	Yes
3	5700	0.11	9.76	30	Yes
4	6150	0.15	10.09	30	Yes
5	6280	0.16	10.12	30	Yes

The berthing duration, berthing speed, berthing angle, minimum distance to the obstacle, and crossing status to the canal are presented in Table 4. All scenarios comply with the requirements of berthing speed, angle speed, and minimum distance to other vessels. Figure 11 shows that the correlation between the current speed and the length of the turning basin is linear. The correlation is similar to the equation found by Gucma and McCartney [27].

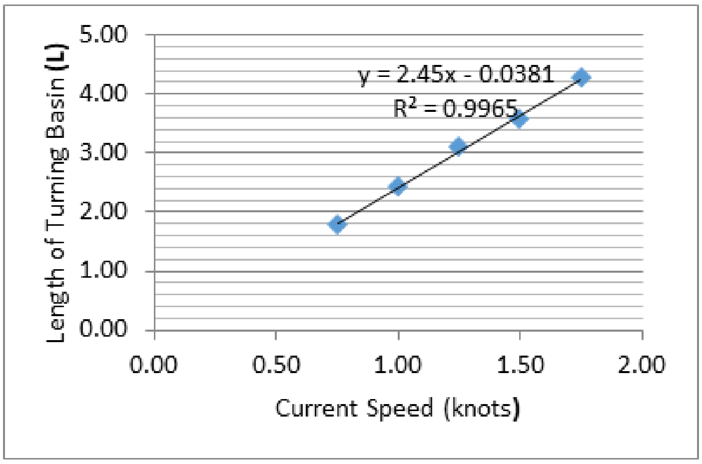

Figure 11. Correlation between turning diameter and current speed

4. Conclusion

A maneuvering simulation was performed to evaluate how current velocity affects a container ship's turning diameter. The results indicate that the standard turning diameter of 2L is maintained only when the current velocity remains below 0.83 knots. At velocities of 1 knot or higher, attempting a port-side berthing maneuver causes the vessel to cross the channel, thereby disrupting traffic. Under these conditions, port-side turning must be avoided in favor of a starboard berthing. However, starboard berthing is generally discouraged due to the increased difficulty of executing emergency evacuations from the port. While the initial speed for this study was set below 3 knots based on port pilot recommendations, future research will evaluate optimal initial speeds to establish formal safety guidelines for the port operation manual.

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References

[1] Y. Mei, B. Cai, B. Zhou, and J. Wang, "Research on Risks and Countermeasures of Berthing and Unberthing in Luojing Container Terminal," *American Journal of Traffic and Transportation Engineering*, vol. 9, no. 3, pp. 54–62, 2024, doi: https://doi.org/10.11648/j.ajtte.20240903.12

[2] J. Zhang and Y. Zhang, "A Novel Ship-Ship Distance Model in Restricted Channel via Gaussian-TRR Identification," *Mathematical Problems in Engineering*, vol. 2021, pp. 1–19, 2021, doi: https://doi.org/10.1155/2021/6626850

[3] Overseas Coastal Area Development Institute of Japan (OCDI) and Ministry of Land, Infrastructure, Transport and Tourism (MILT), *Technical Standards and Commentaries for Port and Harbour Facilities in Japan*. Tokyo, Japan: OCDI, 2002.

[4] E. D. Fuady, I. P. S. Asmara, and I. Sutrisno, "Ship Maneuvering Simulation to Determine Elements of Tugboat Handling: A Case Study of Paciran Port," *Kapal: Jurnal Ilmu Pengetahuan dan Teknologi Kelautan*, vol. 22, no. 3, pp. 162–173, 2025, doi: https://doi.org/10.14710/kapal.v22i3.74393

[5] R. Zhang, "AIS data-driven analysis for identifying cargo handling events in international trade tankers," *Ocean Engineering*, vol. 317, 2025, Art. no. 120016, doi: https://doi.org/10.1016/j.oceaneng.2024.120016.

[6] I. P. S. Asmara, "Analysis of Berthing Safety using Maneuvering Simulation and Berthing Aid System," *International Journal of Marine Engineering Innovation and Research*, vol. 10, no. 3, pp. 632–638, 2025, doi: https://doi.org/10.12962/j25481479.v10i3

[7] C. Chen and Y. Li, "Ship Berthing Information Extraction System Using Three-Dimensional Light Detection and Ranging Data," *Journal of Marine Science and Engineering*, vol. 9, no. 7, p. 747, 2021, doi: https://doi.org/10.3390/jmse9070747.

[8] N. D. Wuryaningrum, D. W. Handani, F. I. Prastyasari, and A. A. B. Dinariyana, "Frequency Analysis of Ship Collision and Its Impact on The Fulfillment of Supporting Facilities and Route Changes Due to Implementation of Sunda Strait TSS," in *IOP Conference Series: Earth and Environmental Science*, 2020, vol. 557, p. 012042, doi: https://doi.org/10.1088/1755-1315/557/1/012042.

[9] J. R. K. Bokau, R. Samad, Y. Park, and D. Kim, "From managing risk to reality: A case of maritime safety in Makassar Port, Indonesia using FRAM and AIS data analysis," *Ocean Engineering*, vol. 339, 2025, Art. no. 122012, doi: https://doi.org/10.1016/j.oceaneng.2025.122012.

[10] A. Horteborn and J. W. Ringsberg, "A method for risk analysis of ship collisions with stationary infrastructure using AIS data and a ship manoeuvring simulator," *Ocean Engineering*, vol. 235, 2021, Art. no. 109396, doi: https://doi.org/10.1016/j.oceaneng.2021.109396.

[11] J. Sandkvist, "Optimised port and fairway design by simulations," in *Year Book of Maritime Technology*, 2008.

[12] K. Lazuga, N. M. Quy, and L. Gucma, "Cost-Effective Design of Port Approaches Using Simulation Methods Based on the Example of a Modernized Port in the Ustka," *Journal of Marine Science and Engineering*, vol. 9, no. 2, p. 211, 2021, doi: https://doi.org/10.3390/jmse9020211.

[13] I. Verdugo, R. Atienza, C. Cal, J. R. Iribarren, L. Pecharroman, and C. Ayuso, "Towards a Complete Design of the Manoeuvring Areas Additional Factors Involved in the Detailed Design," in *Proceedings of PIANC World Congress*, 2018.

[14] H. Rong, A. P. Teixeira, and C. G. Soares, "Identification of ship trajectories when approaching and berthing in Sines port based on AIS data," in *Trends in Maritime Technology and Engineering*, 2022, pp. 135–142, doi: https://doi.org/10.1201/9781003320289-15.

[15] B. Sanguino, T. Wang, G. Li, Ø. K. Kjerstad, and H. Zhang, "Modeling and Analyzing the Impact of Environmental Disturbances in Vessel Model Estimation," *Modeling, Identification and Control*, vol. 46, no. 1, pp. 35–49, 2025, doi: https://doi.org/10.4173/mic.2025.1.3

[16] R. Esferra, C. C. Fernandes de Jesus, R. de Oliveira Bezerra, and J. C. de Melo Bernardino, "Simulation of the Unintentional Unberthing of Vessels (Ship Drift) in a Physical Hydraulic Model," *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation*, vol. 19, no. 2, pp. 425–430, 2025, doi: https://doi.org/10.12716/1001.19.02.11.

[17] H. Zhan, F. Zhu, J. Wu, and J. Wang, "Simulation of Ship Berthing Operation at Luojing Container Terminal Under Extreme Sea Conditions," *American Journal of Traffic and Transportation Engineering*, vol. 9, no. 3, pp. 41–53, 2024, doi: https://doi.org/10.11648/j.ajtte.20240903.11

[18] H. Yakuzawa and N. Hirata, "Effects of wave direction on ship turning in regular waves," *Ocean Engineering*, vol. 286, 2023, Art. no. 109724, doi: https://doi.org/10.1016/j.oceaneng.2023.115581

[19] D. Menges and A. Rasheed, "An environmental disturbance observer framework for autonomous surface vessels," *Ocean Engineering*, vol. 285, 2023, Art. no. 109631, doi: https://doi.org/10.1016/j.oceaneng.2023.115412

[20] M. Gil, P. Krata, P. Koziol, and T. Hinz, "A multiparameter simulation-driven analysis of ship turning trajectory concerning a required number of irregular wave realizations," *Ocean Engineering*, vol. 299, 2024, Art. no. 117281, doi: https://doi.org/10.1016/j.oceaneng.2024.117293

[21] Y. Yoshimura and Y. Masumoto, "Hydrodynamic Force Database with Medium High Speed Merchant Ships Including Fishing Vessels and Investigation into a Manoeuvring Prediction Method," *Journal of the Japan Society of Naval Architects and Ocean Engineers*, vol. 14, pp. 63–73, Dec. 2011, doi: 10.2534/jjasnaoe.14.63.

[22] Y. Yoshimura and Y. Masumoto, "Hydrodynamic database and manoeuvring prediction method with medium high-speed merchant ships and fishing vessels," in *Proceedings of the International Conference on Marine Simulation and Ship Manoeuvrability (MARSIM)*, Feb. 2012. [Online]. Available: https://www.researchgate.net/publication/347907046

[23] I. P. S. Asmara and A. W. Husodo, "Ship to Ship Manoeuvring Simulation to Determine Elements of Tugboat Handling," *IOP Conference Series: Earth and Environmental Science*, vol. 1081, no. 1, p. 012014, 2022, doi: https://doi.org/10.1088/1755-1315/1081/1/012014.

[24] PIANC, "Guidelines for the Design of Fenders Systems," Report of Working Group 33 of the Maritime Navigation Commission, 2002.

[25] "M/V Holsatia Vessel Information." SHIPNEXT. Accessed on: Jul. 8, 2026. [Online]. Available: https://shipnext.com/vessel/9233856-holsatia

[26] "TPS layani kapal bermuatan 4.600 TEUs," ANTARA News Jawa Timur, May 17, 2016. Accessed on: Jul. 8, 2026. [Online]. Available: https://jatim.antaranews.com/berita/287957/tps-layani-kapal-bermuatan-4600-teus

[27] J. Kornacki, "Analysis of the Influence of Current on the Manoeuvres of the Turning of the Ship on the Ports Turning-Basins," *TransNav: International Journal on Marine Navigation and Safety of Sea Transportation*, vol. 4, no. 4, pp. 397–402, 2010.