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Waterway Capacity Enhancement through Traffic Flow Simulation: A Case Study of the Policki Canal Passing Lane

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ABSTRACT: This paper presents a simulation study of marine traffic optimization along the Świnoujście-Szczecin waterway, with a particular focus on the proposed implementation of an additional passing lane in the Policki Canal. Using a microscopic simulation model based on the Monte Carlo method, the study evaluates three traffic scenarios for 2022 and beyond 2025 under different infrastructure development conditions. The results highlight the operational and economic benefits of the proposed lane, including reduced vessel delays and associated congestion costs. The results offer strategic insight into future maritime infrastructure planning in the region.

1 INTRODUCTION

Efficient vessel traffic management on constrained inland waterways requires robust modeling tools to support both infrastructure planning and operational decision-making. The Świnoujście–Szczecin waterway, a vital maritime corridor in Poland, is under increasing pressure due to the expansion of port operations and the expected deployment of larger vessels following the implementation of the "12.5m Project."

To mitigate these challenges, a new passing lane has been proposed in the Policki Canal to reduce bottlenecks and enhance navigational efficiency. This paper evaluates the potential impacts of this improvement using a custom-built microscopic simulation model (Figure 1).

Conventional analytical models for capacity estimation, based on ship domain theory, are inherently static and fail to reflect the stochastic nature of ship traffic processes. To address this, stochastic simulation models are increasingly used [Groenveld, 2006; Almaz and Altiok, 2012; Olba et al., 2018]. Several approaches incorporate alternative transitions [Bačkalić and Škiljaica, 1998; Ugurlu et al., 2014], discrete optimization [Mohring et al., 2005], queueing theory [Mou et al., 2005], and cellular automata [Feng, 2013]. Typically, domain-based models [Zhou et al., 2013] are employed, where the ship's domain defines a safety area around each vessel.

Marine traffic system performance is generally evaluated using two primary indicators:
- Delay time of ships and its distribution.
- Average queue length of waiting ships and its distribution.

Gucma and Sokołowska [2012] validated a stochastic model of vessel traffic on the Świnoujście–Szczecin waterway using empirical delay data. Further validation with real-world observations (Gucma et al., 2016) confirmed the model's reliability.

In this study, we assess the effectiveness of introducing a new passing lane in the Policki Canal (Figure 1).

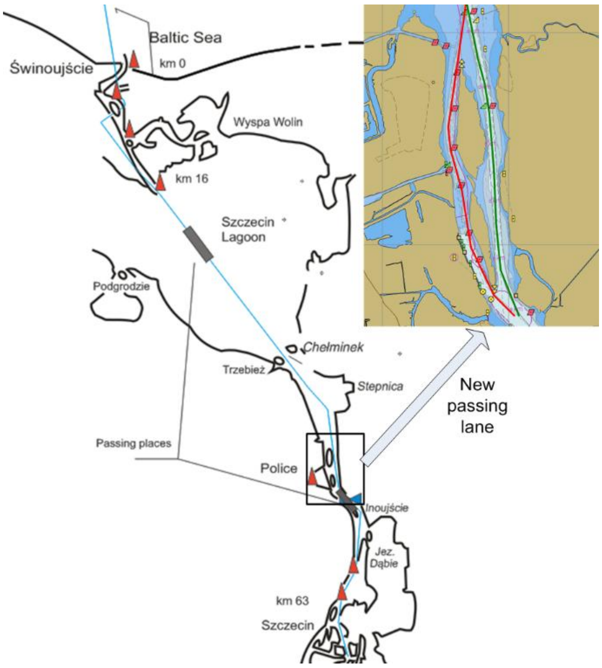

Figure 1. Location of the proposed deep-water passing lane in the Policki Canal (marked in red) and the existing 12.5 m deep-water fairway (marked in green).

2 STUDY ASSUMPTIONS

A study of the parameters of ship traffic streams for the modernized Świnoujście-Szczecin waterway is presented, taking into account the new passing lane on the Police Canal. It will allow 2-way traffic of all vessels passing through the Świnoujście-Szczecin waterway. The model excludes inland and recreational vessels operating outside the main fairway.

In the context of ship traffic streams, particularly passing and overtaking maneuvers, vessels were categorized into four main size groups (Table 1) and two ballast-related subgroups, resulting in six distinct traffic categories. Based on these classifications, the permissible passing combinations for vessels across different sections of the waterway were determined and are summarized in Table 2. This division, while conventional, provides a practical framework for analyzing ship traffic patterns. A graphical representation of the traffic regulation zones along the Świnoujście–Szczecin waterway is provided in Figure 2. In the simulation model, a detailed table specifying allowable passing widths and draught limits was used to support the analysis of ship traffic streams.

Table 1. Adopted division of ships in terms of traffic streams

Group of ships	Dimensions	Group name (designation)
1 & 2	L < 100m	Small
3 & 4	L >= 100m and L < 150m	Medium
5	L >= 150m L <200m	Large
6	L >= 200m	Maks

Vessel speeds were assumed according to the speed table (Table 3).

Table 3. Permissible ship speeds [knots] in groups on individual sections of the Świnoujście-Szczecin waterway

No.	Fairway section [km]	Container ship (c_B < 0.65)		Bulk carrier ($c_{(B)}$ ⩾ 0.75)	
		T > 10 m	T ⩽ 10 m	T > 10 m	T ⩽ 10 m
1	5.7 ÷ 17.0	8	8	6	6
2	17.0 ÷ 48.5	10	12	8	10
3	48.5 ÷ 54.4	8	10	7	9
4	54.4 ÷ 63.5	7	7	6	6

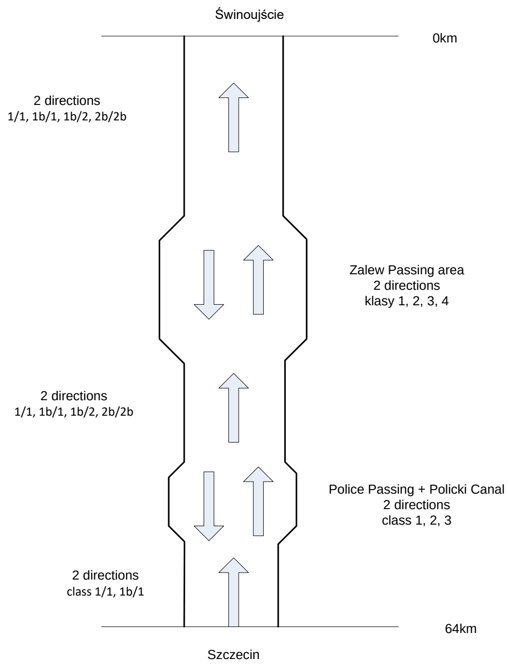

Figure 2. Basic principles of traffic regulation on the approach of the Świnoujście-Szczecin waterway.

The adoption of arbitrary groups of ships was preceded by an analysis of ship size and a table of width and length ratios of passing ships for the planned Świnoujście-Szczecin waterway dredged to 12.5 meters.

Table 2. Basic principles of traffic regulation on the Świnoujście-Szczecin waterway

No.	Episode	Kilometer of track "from" [km]	Kilometer of track "to" [km]	Type	Slope	Ability to pass in accepted size classes
1a	Port of Świnoujście	0	5.3	Bend/straight	1:3	1/1, 1/2, 1/4, 2/2, 2/4
1b	Paprotno/Mielin	5.3	11.4	Bend	1:3	1/1, 1/2, 1/4, 2/2, 2/4
1c	Piastowski Canal	11.4	17.0	Straight	1:3	1/1, 1/2, 1/4, 2/2, 2/4
2	Szczecin Lagoon N	17.0	23.8	Straight	1:4	1/1, 1/2, 1/4, 2/2, 2/3, 2/4, 2/5, 4/4
3	Pass Lagoon BT II-III	23.8	28.8	Passing area	1:4	1/2/3/4/5/6
4	Szczecin Lagoon S	28.8	41.0	Straight	1:4	1/1, 1/2, 1/4, 2/2, 2/3, 2/4, 2/5, 4/4
5	Mixed N	41.0	49.5	Bend/straight	1:3	1/1, 1/2, 1/4, 2/2, 2/4
6	Pass Police (Scenario A and B)	49.5	51.5	Passing area	1:3	1/2/3/4/5
6	Police Pass and Police Canal (Scenario C)	43.6	51.5	Passing area	1:3	1/2/3/4/5/6
7	Mixed S	51.5	64.0	Bend/straight	1:2	1/2, 2/2

Legend: example designations: 1/2 - group 1 can pass with group 2. 1/2/3/4/5/6 - can pass in all groups, 1/2/3/4/5 - can pass in all groups except 6 (Max).

2.1 *Analysis and forecast of traffic volumes*

Both the Port of Szczecin and Police show no significant growth in ship traffic, which fluctuates at the level of 3,000 and 300 ship entries per year for Szczecin and Police, respectively. Świnoujście shows some change in ship traffic between 2014 and 2021, as it increased by a value of about 3-5% per year. This increase is mainly due to ferry traffic. The ship intensity yearly data presented in Figure 3 show the entrances of vessels to the Szczecin-Świnoujście port complex in 2009-2021.

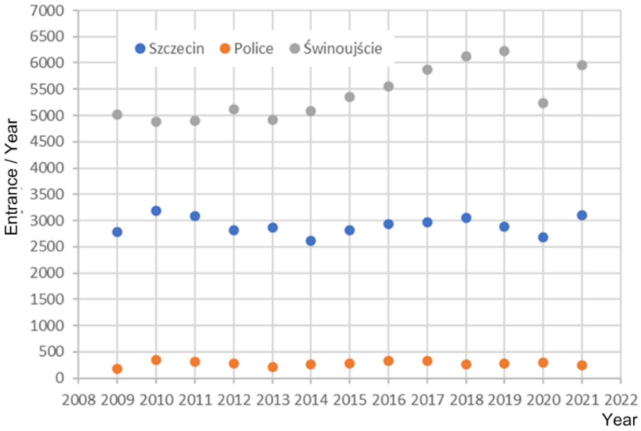

Figure 3. Dynamics of vessel traffic entering Szczecin, Police and Świnoujście in 2009-2021.

In order to determine the intensity of vessel traffic in ship classes on the approach to Świnoujście, data from the government database of vessels entering Polish ports were analyzed. Accurate data from 01.2008 to 08.2021 were analyzed, and the frequencies of vessel lengths entering Szczecin and Police were determined (Fig.4).

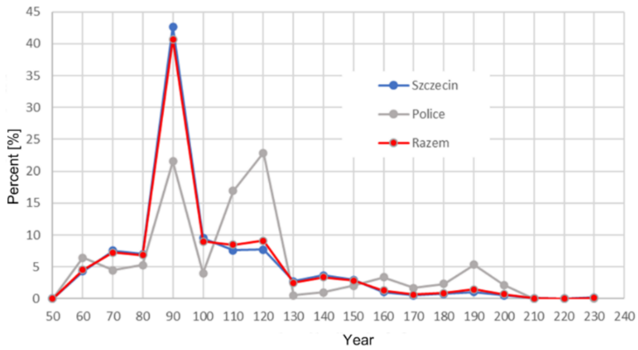

Figure 4. Frequencies of vessel lengths entering Szczecin and Police between 2009 and 2021.

The group of medium-sized vessels, i.e. from 100m to 150m in length, is made up of vessels with a draught not exceeding the draught allowed in the previous fairway of 10.5m (i.e. T<9.15m), i.e. these are vessels that were not limited by their draught (a typical vessel with L=150m has B=20m and T=9m). The dynamics of change in this group for the period 2008-2020 was analyzed and is shown in Fig. 4. From this figure it can be seen that although there has been some upward trend in such units in recent years, but in general they maintain a fairly stable level of inputs, which may indicate the dynamics of future increases in maximum vessels for the 12.5m track. However, the changes between 2018 and 2020 are not large and amount to 1% per year.

The analysis and traffic forecasts, accounting for the enlargement of the fairway parameters under the so-called "12.5m Project," were primarily based on planned developments aimed at accommodating larger vessels in the ports of Szczecin and Police. The key wharf modernization projects following the implementation of the "12.5m Project," along with the anticipated vessel traffic intensities, are summarized in Table 4. It was optimistically assumed that all infrastructure upgrades enabling the operation of maximum-size vessels on the 12.5m fairway would be completed by 2025. For several projects where no specific traffic forecasts were available, it was conservatively assumed that each terminal would handle two vessel calls per month, corresponding to an estimated cargo throughput of approximately 120,000 tons per month.

Table 4. Projected numbers of entries Group 4 (Max) vessels over 200 m in the port of Szczecin and Police after 2025

No.	Name	Expected annual number of entries of units over 200m	Vessel type, data origin notes
1	PDH Police Terminal	30	Gas carrier. Navigational analysis
2	Skolwin Terminal	70	Tanker. Navigational analysis
3	CPN Terminal Szczecin	25	Tanker. Estimated - no data available
4	Słowackie and Zbożowe quay	20	Bulk carriers.
5	Fińskie, Czeskie and Norweskie quay	70	Container ships.
6	Gryfia dock	10	Renovation. Estimated - no data.
7	Katowickie & Chorzowskie quay	25	Bulk Carriers. Estimated - no data available
8	Huk quay	25	Bulk Carriers. Estimated - no data available
9	Alfa Terminal	25	Tankers. Estimated - no data available
10	Skolwin	25	Tankers. Estimated - no data available
Total		325	

The main criterion for estimating future ship traffic is the assumption that the average intensity of entering ships to Szczecin and Police is 3000 and 300 entries/year, respectively, which corresponds roughly to a ten-year average. Attached to these intensities was the number of estimated maximum ships according to the projects' assumptions, that is, the value of 325 ships per year. The approach track to Świnoujście and Świnoujście itself were not taken into account.

Three traffic scenarios, labeled A, B, and C, were analyzed:

- Scenario A: Baseline conditions for 2022, assuming the upgrading of the main waterway to a 12.5 m depth, but without corresponding modernization of individual wharves and without the construction of a passing facility in the Policki Canal.
- Scenario B: Projected conditions after 2025, assuming a target increase in large vessel traffic to 325 calls per year on the 12.5 m fairway, but without the construction of a passing facility in the Policki Canal.

– Scenario C: Projected conditions after 2025, assuming both the increase in large vessel traffic to 325 calls per year on the 12.5 m fairway and the construction of a new passing facility in the Policki Canal.

The initial parameters for traffic estimation are shown in Table 5.

Table 5. The assumed growth dynamics of the number of entries of each size group of ships in Szczecin and Police (combined) and the traffic forecast for scenarios A, B and C

Group	Dimensions	Baseline frequency for 2022 [%].	Scenario A. 2022 without quays for 12.5m	Scenario B. 2025 completion of all quays 12.5m	Scenario C. 2025 Traffic as in Scenario B and the passing of the Police Canal
1	L < 100m	59.4	1960	1960	1960
2	L >= 100m L < 150m	32.5	1073	1073	1073
3	L >= 150m L < 200m	7.2	238	238	238
4	L >= 200m	0.9	30	355	355
	Total	100	3300	3625	3625

For the target projected number of ship entrances to Szczecin and Police for each scenario, group traffic intensities were determined for both one-way and two-way traffic (Tables x.9 and x.10). These intensities served as input data for the simulation model.

3 SIMULATION MODEL FOR PORTSYM SHIP TRAFFIC FLOW STUDY

A dedicated simulator was developed to model vessel movements along the waterway. The simulation approach is microscopic, meaning that each vessel is treated individually as a discrete object. The model operates based on stochastic principles, utilizing a Monte Carlo simulation framework (Figure 5).

The simulation logic is organized into three core modules:
- Ship generation and input: Randomized creation of vessels based on defined traffic parameters.
- Movement and queue handling: Vessel progression along the waterway, including queuing when passage is restricted.
- Decision logic for entry and exit: Rules governing when vessels are permitted to enter or leave the simulated waterway sections.

The basic features of PortSym are:
1. Ship Characteristics
   - Vessel arrival times are generated according to a Poisson distribution.
   - Ship lengths and dimensions are sampled from uniform distributions, constrained within group-specific bounds.
   - Vessel speeds are drawn from a truncated normal distribution, with regulatory limits applied as upper bounds.
   - It is assumed that 50% of vessels are outbound (seaward) and 50% are inbound (toward port).
   - Night-time traffic operations are excluded from the simulation.
2. Waterway Representation
   - The fairway is divided into discrete sections, each characterized by specific passing capabilities and speed restrictions.
   - Passing rules between vessel groups are implemented through pre-defined matrices that govern allowable encounters.
3. Movement Logic
   - The model verifies whether a vessel can enter the waterway based on the real-time positions of other ships and the applicable passing rules.
   - If passage is not possible, the vessel queues until conditions permit safe entry.
   - Vessel movement is modeled at constant, section-specific speeds without dynamic speed adjustments.
4. Output and Data Handling
   - The simulation logs detailed data for each vessel, including delays, passing events, and queuing statistics.
   - Simulation dynamics are driven by three synchronized loops operating at a 1-minute time resolution:
     - Ship generation and system status logging.
     - Vessel position updates and verification of passing conditions.
     - Decision-making for vessel entry permissions.

The simulation model operates through three primary loops, each with a time step of 1 minute, as specified in the program input parameters:
1. Ship Generation and System Logging Loop: Responsible for generating new vessels according to traffic intensity profiles and recording the key operational parameters of the system.
2. Ship Position Update and Passing Event Loop: Updates vessel positions along the fairway and logs passing or overtaking events between ships.
3. Entry Decision Loop: Verifies whether conditions permit a new vessel to enter the waterway, based on real-time traffic states and predefined passing rules.

The core algorithm of the simulation model operates according to the following sequence:
1. Generate ship groups: Ships are generated according to predefined group characteristics and traffic intensities.
2. Create ship objects: For each generated ship, an individual object is created with assigned attributes such as length, speed, and direction of movement.
3. Register ship objects: Each ship object is added to the active list of vessels present within the simulation environment.
4. Evaluate passing possibilities: For every new ship, the model checks existing vessels on the waterway to determine whether safe passing is possible according to the passing rules matrix.
5. Decision on entry or waiting: If passing conditions are satisfied, the ship enters the track; otherwise, it queues and its waiting time is calculated.
6. Update ship positions: Ships already on the track move forward by a distance corresponding to their assigned speed and the elapsed simulation time step.
7. Record passing events: When vessels pass or overtake, the events are logged along with associated positional data.

8. Record queuing data: Waiting times and queuing statistics for delayed vessels are recorded for further analysis.

The model was verified for algorithmic errors using simple, properly selected test input data at the outset.

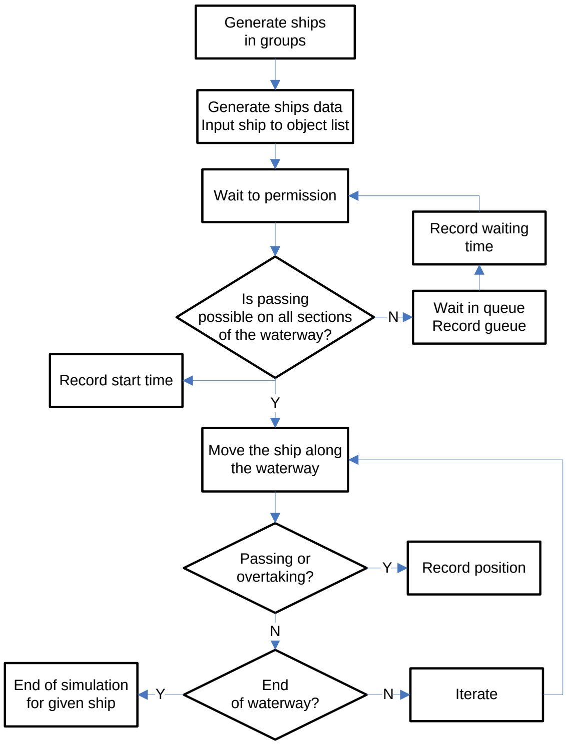

Figure 5. PortSym model operation diagram for a single vessel

The data provided by the model makes it possible to analyze the basic parameters of the waterway system's traffic stream, including:

1. Queue distribution at the entrance in classrooms.
2. The distribution of the exit queue in the classrooms.
3. Track transition time without delays (ideal).
4. Total delay time in classes and types.
5. Totals of ships generated in classes and types.
6. Average delays per ship in classes and types.

Model verification was carried out on simple examples for which analytical solutions existed. At a further stage, the model was verified with real track delays [Gucma et al. 2016]. A high convergence of the resulting values was obtained (differences of 10%). For the first time, the model was used during the design of a passing pass at the Szczecin Lagoon for the so-called "12.5m" project (deepening of the Świnoujście-Szczecin track to 12.5m).

The program was written in Python using the PyCharm interpreter and relevant modules. The model was verified for algorithm errors using simple appropriately selected test input data at the beginning. The hourly intensities for the model are shown in Table 6.

Table 6. Hourly ship intensities [st./h] in one direction (to sea / to port) for each year adopted into the model for the traffic scenarios studied

Group/year	2022	2025	2035
1	0.1119	0.1119	0.1119
2	0.1119	0.1119	0.1119
3	0.0612	0.0612	0.0612
4	0.0612	0.0612	0.0612
5	0.0136	0.0136	0.0136
6	0.0017	0.0202	0.0202
Total 1 direction of traffic	0.3615	0.3800	0.3800

3.1 *Dynamic approach - the domain of the ship*

The dimensions of a ship's domain in such very narrow waterways, when port regulations play a major role, depend on the cross-section of the waterway (x). The domain length $D_L(x)$ can be defined as (Figure 3):

$$D_L(x) = L + D_F(x) + D_A(x) + \delta_L$$

where:
L - length of the ship,
$D_F(x)$ - the length of the domain from the bow (from zero to the minimum tracking distance)
$D_A(x)$ - length of the domain from the stern (assumed as 0)
δ_L - domain variability

A similar formula can be applied to the width $D_B(x)$ of the ships' domain:

$$D_B(x) = B + D_S(x) + D_P(x) + \delta_B$$

where:
B- width of the ship
$D_s(x)$ - right side domain width
$D_p(x)$ - width of the left side domain
δ_B - domain variability

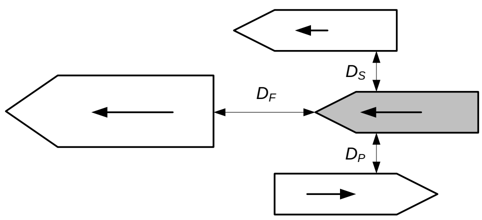

Figure 6. Definition of a ship's domain in a restricted waterway.

In the one-dimensional domain model used, $D_B(x)$ can be defined as two state variables: $D_B(x) = \{o(x) = (1,0); p(x) = (0,1)\}$ where o(x) and p(x) are logical variables that determine whether passing or overtaking of the vessels in question is allowed on a given section of the waterway (0 - passing/overtaking possible, 1 - passing/overtaking prohibited).

The navigator has very limited influence on adjusting the length of the domain aft (D_A), and subsequent ships adjust the size of this domain according to ship dimensions, port regulations and intentions, so it is set to zero. The dependence of the domain dimensions x is due to the variability of the waterway sections and regulations within the sections, and the variability of ship speeds in the sections. The variability of the domain (error) changes according to the behavior of navigators.

The most important domain dimension in this study is D_F i.e. the length in front of the ship that the navigator intends to keep free when one ship is following another due to the prohibition of overtaking. This distance is determined by regulations or by the navigator himself, taking into account the possibility of accidentally stopping his own ship. Accidental stopping on a narrow waterway is usually performed by means of a so-called stage maneuver, which depends on the maneuvering characteristics of the ship. The stage maneuver is usually performed in steps that change the set to the engine in order to prevent the ship from running aground. Usually, in the first phase of the stage maneuver, "Full Astern" is set on the engine, and then, when the ship begins to change course significantly (usually to starboard), the speed telegraph is set to "Stop" and the rudder is set to starboard (right or left depending on the maneuverability of the ship). The procedure is then repeated. In the last step, an anchor is usually thrown, if possible.

4 RESULTS OF SIMULATION STUDIES OF TRAFFIC PERFORMANCE ON THE UPGRADED TRACK FOR SELECTED

4.1 *Cost of ship downtime*

Based on the publication [Pocuca 2006], the daily total cost of ships was determined for three different groups: bulk carriers, container ships and tankers. It was assumed that in 2020 the cost increased compared to 2006 (about 3% per year - average inflation). Based on these, the daily average cost of operating units in size groups was determined (Table 7). It does not take into account the cost of LNG or LPG units, which, due to the specific cargo, is much higher than analyzed.

Table 7. Averaged daily demurrage costs of ships in groups

Group	Cost [USD/day]
1 and 2	15000
3 and 4	20000
5	25000
6	30000

4.2 *Conduct surveys and analyze their results*

The study was conducted for the assumed size groups, their intensities and the adopted traffic stream layout. A simulation time of 365 days (1 year), a simulation step time of 1min and a simulation parameter recording time of 3h were assumed. Simulations of a single scenario take about 1 minute.

The data was analyzed in terms of the basic parameters of the waterway system's traffic stream, including:

1. Distribution and probability of entry/entry queue in classrooms,
2. Classroom lag time,
3. Sums of ships generated in classes,
4. Downtime costs.

Table 8 shows the results of the annual simulation for the projected traffic data in the 3 scenarios considered.

Table 8. Annual downtime in entry and exit groups [days/year]

Group/year	A	B	C
1	29	35	32
2	14	19	14
3	75	74	61
4	31	32	23
5	17	18	16
6	2	27	25
Total	169	205	171

The simulation results (without active traffic control) indicate that annual vessel downtime under current traffic conditions is approximately 170 ship-days per year. However, following the introduction of Group 6 (maximum-sized) vessels, which exert the greatest load on the waterway, this figure is projected to increase to around 205 ship-days per year. With the implementation of a passing lane in the Policki Canal, the annual downtime is expected to return to approximately 170 ship-days.

The probability of a group queue increases significantly with the traffic load of large vessels is particularly high for the group of maximum and medium (L=150m) loaded vessels (Table 9).

Table 9. Probability of queuing in groups

Group/year	A	B	C
1	3.3%	2.5%	5.5%
2	1.9%	2.7%	3.6%
3	12.3%	14.2%	15.1%
4	3.6%	3.6%	4.4%
5	2.2%	1.6%	3.6%
6	0.3%	3.6%	1.1%

The annual cost of vessel downtime, without the introduction of maximum-sized vessels, is estimated at approximately USD 2.5 million (Table 10). Following the introduction of Group 6 vessels, this cost is projected to increase to around USD 3.1 million per year. However, the implementation of a passing lane in the Policki Canal would reduce the annual downtime cost to approximately USD 2.6 million, representing a 16% reduction.

The net annual savings resulting from the construction of the passing lane are estimated at USD 0.5 million (i.e., USD 3.1 million minus USD 2.6 million). Assuming a service life of 25 years for the facility, the cumulative financial benefit would amount to approximately USD 12.5 million, equivalent to over 50 million PLN.

Table 10. Annual cost of downtime [million USD]

Group/year	A	B	C
1 and 2	0.6	0.8	0.7
3 and 4	1.6	1.6	1.3
5	0.3	0.3	0.2
6	0.0	0.4	0.4
Total	2.5	3.1	2.6

5 RESULTS AND CONCLUSIONS

Three simulation-based study offers a clear view of how projected traffic growth and infrastructure investments will shape navigation efficiency along the Świnoujście–Szczecin waterway. Based on the model outcomes, the following conclusions can be drawn:

1. The developed microscopic traffic flow model, based on the Monte Carlo method, demonstrated

high consistency with empirical data from the Świnoujście–Szczecin waterway. Deviations did not exceed 10%, confirming the model's adequacy for practical applications.

2. Under present (2022) traffic conditions, annual vessel downtime is approximately 169 ship-days. The existing infrastructure, without additional improvements, will not sustain future traffic demands, particularly with the introduction of larger vessel classes (Group 6).
3. Without the implementation of a new passing lane, projected traffic growth after 2025 would raise vessel downtime to 205 ship-days per year, significantly deteriorating the operational efficiency of the waterway.
4. The construction of a passing lane in the Policki Canal is projected to reduce vessel downtime to approximately 171 ship-days per year, representing a 17% reduction compared to the no-intervention scenario. This confirms the functional necessity of the investment.
5. The passing lane would yield annual savings of approximately 0.5 million USD in reduced downtime costs. Over a projected 25-year operational lifetime, this translates to cumulative savings exceeding 12.5 million USD, justifying the investment economically.
6. Delays and queuing probabilities are most pronounced for medium-sized (Group 3) and maximum-sized (Group 6) vessels. Infrastructure planning should prioritize enhancements that accommodate these groups to ensure optimal system performance.
7. While the model realistically captures the stochastic nature of vessel traffic, it does not include active traffic control mechanisms such as dynamic VTS interventions or pilot scheduling optimization. Incorporating these elements could further improve system performance and should be considered in future studies.
8. The proposed passing lane in the Policki Canal should be considered a critical element of the long-term development strategy for the Świnoujście–Szczecin waterway. Its implementation is essential for maintaining competitiveness, reducing congestion, and supporting the expected growth in cargo throughput.

REFERENCES

[1] 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 vol. 22.

[2] Bačkalić T. & Škiljaica V. (1998). Modelling of Vessel Traffic Process in One-Way Straits at Alternating Passing, Proceedings of the "MARIND '98" Bulgaria.

[3] Feng H. (2013). Cellular Automata Ship Traffic Flow Model Considering Integrated Bridge System. International Journal of Service, Science and Technology Vol.6.

[4] Groenveld, R. (2006). Ship traffic flow simulation study for port extensions, with case extension Port of Rotterdam. In: 31st PIANC Congress, Estoril, 2006.

[5] Gucma L. & Sokolowska S. (2012) The ships entering to Szczecin port dimensions analysis with over-normative vessels consideration. EXPLO-SHIP 2012.

[6] Gucma L., Sokolowska S. & Bak A. (2016). Stochastic Model of Ships Traffic Capacity and Congestion - Validation by Real Ships Traffic Data on Świnoujście - Szczecin Waterway. Annual of Navigation. Vol. 24.

[7] Mohring R. et all. (2005). Conflict-free real-time AGV routing. Operations Research Proceedings 2004, Berlin, Springer-Verlag.

[8] Mou. J.M. et all (2005). Research on application of queuing theory in communication engineering, Journal of Wuhan Institute of Shipbuilding Technology.

[9] Olba X.B., Daamen W., Vellinga T., Hoogendoorn S.P. (2018). State-of-the-art of port simulation models for risk and capacity assessment based on the vessel navigational behavior through the nautical infrastructure. Journal of Traffic and Transportation Engineering. Vol.5.

[10] Pocuca M. (2006) Methodology of day-to-day ship cost assessment. Transport Economics Review vol.18 2006.

[11] Ugurlu, O.; Yuksekyildiz, E.; Kose E. (2014) Simulation model on determining of port capacity and queue size: a case study for BOTAS Ceyhan Marine Terminal. TransNav International Journal on Marine Navigation and Safety of Sea Transportation 2014, 8, 143-150.

[12] Zhou H. et all (2013). Nanjing Yangtze River Bridge Transit Capacity Based on Queuing Theory 13th COTA International Conference of Transportation Professionals.