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Simulation analysis of safe passing between ships on the seaway Szczecin–Świnoujście with the applicable port regulations

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Abstract
This paper presents simulation analysis of vessels approaching and vessels departuring from the port of Szczecin and Police focusing on the encounters between two vessels. The analysis parameters such as length and draft were examined. Particular attention was paid to the restricted sections of the seaway between Zalew Szczeciński and Basen Górniczy. The results of these simulation trials and the resulting analysis can be helpful while updating port regulations and for the assessment of the traffic density and the capacity of the waterway.

Introduction

An appropriate choice of certain conditions and the areas for safety manoeuvre of ships passing is the primary factor that determines a safe navigation, safety of hydrotechnical structures and the capacity of waterways. Vessels encounter when two ships are moving in opposite directions in navigationally restricted areas is one of the most difficult and demanding manoeuvres for navigators. Safe passing manoeuvre in narrow channels such as Przekop Mieleński requires a good knowledge of sailing directions, manoeuvring characteristics of the vessel, and the experience of the pilot.

The analysis was performed on the simulation trials where vessels were entering and leaving the port of Szczecin and Police only for a ships passing manoeuvre. Vessels of equal size and larger than allowed by the current port regulations were chosen for the purpose of the simulation. This article should be considered as the beginning of further extended research in this subject, expanded to include other exercises and other parts of the Świnoujście–Szczecin seaway.

Possibilities to increase the number of the seaways sections designated for ships passing or to increase the passing vessels dimensions, will undoubtedly help to optimize the use of the examined seaway. Knowledge of such data may provide a basis for dredging, widening or changing the navigational marking of certain sections in order to improve the safety of navigation.

Regulations on the two-way traffic of the seaway Świnoujście–Szczecin

The Ordinance No. 3 of the Director of the Maritime Office in Szczecin on 26 July 2013 of the Port Regulations provides information about maritime safety and traffic order on the Świnoujście–Szczecin fairway. The following are some excerpts of the port regulations related to the two-way traffic on the test sections of the waterway [1]:

§ 52.

2 a) At the stretch of the seaway: from buoys No. 15 and 16 to Orli Przesmyk (63 km) in Szczecin, two way traffic is allowed for ships drawing not more than 7.40 m on condition that the sum of the overall lengths of the passing vessels is not more than 320 m.

2 b) At the seaway stretch mentioned in subsection 2a) vessels of draught more than 7.40 m may

pass vessels of draught up to 6.10 m, on condition that the sum of the overall lengths of the passing vessels is not more than 320 m.

3 d) In relation to the provisions of subsection 2 two way traffic is extended in the following stretches of the seaway:

– from Karsibór bend (10.5 km) to the northern head of Chełminek Island (35.0 km);
– from Mańków bend (abeam Mańków Dolna beacon) to Iński Nurt (abeam Ina-S beacon).

On these stretches vessels drawing up to 9.15 m may be passed by vessels drawing up to 7.40 m, on condition that the sum of the overall lengths of the passing vessels is not more than 320 m.

§ 52.

4 a) On the stretch from Orli Przesmyk to Basen Górniczy in Szczecin, vessels of draught more than 7.40 m or overall length of more than 160 m may be passed by vessels of overall length up to 60 m and a draught of up to 3 m.

4 b) On the stretch of seaway mentioned in subsection 4 a) vessels of draught up to 7.40 m and overall length up to 160 m may be passed by vessels of draught up to 5.50 m and the sum of the overall lengths of the passing vessels is not more than 240 m.

§ 56.

1. The overall length of vessels entering and leaving the ports of Szczecin and Police may not exceed 215 m and the overall breadth may not exceed 31 m.

2. The draught of vessels entering and leaving the port of Szczecin may not exceed 9.15 m and the overall length may not exceed 160 m.

3. The maximum lengths, breadths and draughts of ships longer than 160 m entering the port of Szczecin are shown in the table, Appendix 6 of this Standing Order.

4. The draught of vessels entering and leaving the port of Police may not exceed 9.15 m and the overall length may not exceed 170 m.

5. The maximum lengths, breadths and draughts of ships longer than 170 m entering the port of Police are shown in the table, Appendix 7 of this Standing Order.

9. Vessels between 180 m and 200 m in length may proceed at night-time on conditions to be determined by the Harbour Master after consultation with the Chief Pilot, provided that visibility is not less than 2 Nm.

10. Vessels more than 200 m in length with draught more than 9 m may proceed in daytime only when visibility is not less than 2 Nm.

Simulation tests

Simulation tests were performed using multipurpose manoeuvring simulator, located in the Marine Traffic Engineering Centre in Maritime University of Szczecin (MTEC).

Characteristics of the simulator

The shiphadling simulator of MTEC consists of:

– one full mission simulator with 270° visualisation and live marine ship equipment including DP class 2 (accredited by NI for DP training – details in Menu / News);
– two multi task simulators with 120° visualisation and mix of real and screen-simulated ship-like equipment including Voith-Schneider tug console;
– two desktop PC simulators with one monitor visualisation and one monitor screen-simulated ship-like equipment;
– debriefing, instructor and server rooms.

All hardware and software of MTEC shiphandling simulator is forming the Polaris System from Kongsberg Maritime AS which was granted DNV certificate for compliance or exceeding the regulations set forward in STCW'95 (section A-I/12, section B-I/12, table A-II/1, table A-II/2 and table A-II/3).

The certificates confirm full compliance (the accepted level of reliability) of simulated tasks, interaction and behavior of models in relation to reality.

The simulator allows to perform a wide range of scientific and engineering research in the field of maritime traffic, including the relevant consideration of the article topics:

1. Development of methods for the qualitative and quantitative description of vessel traffic in the restricted areas, in particular:
   a) to determine the optimum parameters of waterways and hydrotechnical structures for a given type of ship operated under certain conditions of navigation;
2. Assessment of the safety of navigation and the determination of safety measures on the waterways.

The performed tasks are determining the relationship between the navigator, the ship, water area, navigation marks, hydro-meteorological and operating factors in conditions as close as possible to the real ones.

Assumptions of the test experiment

The aim of this study was to analyze the possibilities of safe passage between vessels of the maximum permissible dimensions and larger ones than (included in port regulations for ships passing in the seaway Szczecin–Świnoujście).

As appears from the regulations, the parameters that determine the possibility of safe passing between ships in two-way traffic for the designated sections of the fairway are mainly: the overall length and the draft of the vessel. This suggests that the limits placed in the port regulations depending on restricting depends only on the available manoeuvring area and the water depth.

Given the above, the test experiment defines the following assumptions:

1. The analysis included the section of fairway specified in the regulations port, as listed in table 1. To achieve the aim, it was necessary to build a suitable geometric models and databases for the proper operation of the manoeuvring simulator (subsection *Construction of the water area model*).
2. For each of the selected sections of the fairway areas for ships passing were designated (Fig. 1). Selected locations are characterized by the smallest width of the available manoeuvring area and /or the minimum permissible depth. Such a criterion is intended to evaluated vessels passing encounter, wherein the ratio of the length and the width of the vessel to her draft and the water depth was the highest.
3. Simulation studies have been carried out under the following scenarios of vessels encounters (Table 2).
   A particular variant of passing encounter was repeated ten times for each section of the fairway subjected to simulation analysis. The variant with adverse hydrometeorological conditions, carried out for the largest possible vessels whose passing did not end up with a grounding. Parameters of selected units are described in subsection *Construction of ship* in this article.
4. The statistical analysis of: the lateral distance of passing vessels, underkeel clearance and squat.
5. It was assumed that the maximum speed vessels was 8 knots. Navigators were obliged to keep vessels as far away from the center of the fairway as possible and within a safe depth isobath.

Table 2. Variants research scenarios

Variant	Vessel 1	Vessel 2	Current [m/s]	Western Wind [m/s]	Visibility
1	Magdalena	Magdalena	0.1	2.5	good
2	Ferry30L	Magdalena	0.1	2.5	good
3	Ferry30L	Ferry30L	0.1	2.5	good
4	CNTNR16L	Ferry30L	0.1	2.5	good
5	CNTNR16L	CNTNR16L	0.1	2.5	good
6	PRODCT03L	CNTNR16L	0.1	2.5	good
7	Variant for the maximum, possible ship dimensions		0.5	12	good

Construction of ship

Selected geometrical models of ships were built in a three-dimensional environment using a dedicated graphical modeling tools. The developed models were assigned numerical by hydrodynamic models, creating a complete database of the vessels used during the trial experiment [2].

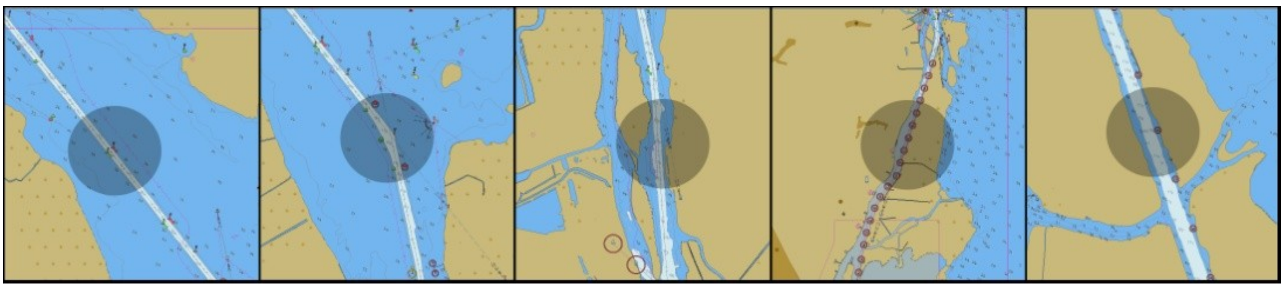


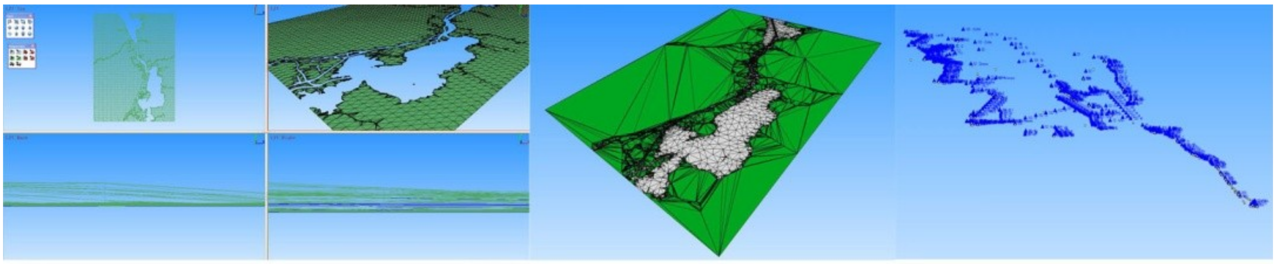
Fig. 1. Selected locations for the passing vessels [own study]

Table 1. Two-way traffic allowed on the test sections

Seaway stretch	Section within [km]	Two-way traffic allowed for vessels of drafts T		The sum of the overall lengths of vessels
Northern head of Chełminek island → to abeam of beacon Mańków Dolna	35–43	≤ 7.4	≤ 7.4	320
Northern head of Chełminek island → to abeam of beacon Mańków Dolna	35–43	≥ 7.4	≤ 6.1	320
Abeam of beacon Mańków Dolna → to abeam of beacon Ina-S	43–54	≤ 9.15	≤ 7.4	320
Abeam of beacon Ina-S → Orli Przesmyk	54–63	≥ 7.4	≤ 7.4	320
Abeam of beacon Ina-S → Orli Przesmyk	54–63	≤ 7.4	≤ 6.1	320

Vessel's name	MagdalenaB	Ferry30L	CNTNR16L	PRODCT03L
Type	General Cargo	Ferry	Conteiner	Product
Loading condition	Balast	Loaded	Loaded	Loaded
LOA [m]	149	191	202,4	141,5
Breadth [m]	22,05	26	31	23
Draught [m]	3,37 / 6,93	7,18	8,6/9,2	9
Max speed [knots]	16,93	19	24,7	13,4
Displacement [t]	20 767	22 650	33 750	23 420
Type of rudder	Normal	Normal	Normal	Normal
Maximum angle [°]	35	35	35	60
Hard-over to hard-over [s]	27	28	28	51,5
Type of engine	Diesel	Diesel	Diesel	Diesel
Maximum power [kW]	7080	7583	46820	5235

Fig. 2. Vessels parameters used in simulation studies [own study]



a) b) c)

Fig. 3. Water area database [own study]

Construction of the water area model

For the proper operation of the simulation software, it was necessary to create a database (most of the geometric models) in:

– the topography of the coast (Fig. 3a);
– bathymetry of the fairway (Fig. 3b);
– radar echoes for infrastructure and the environment;
– buoyage allocation and navigational marking (Fig. 3c);
– a simplified, two-dimensional map of the instructor, containing the most important navigation and manoeuvring information (including map of currents, wind) [3].

It should be noted that the geometric model of the bathymetry of the water area was built using the mesh of triangles. Each node is connected by a straight line with its neighbors. Thus, the required coordinates of the grid points for numerical computations in the ship-water area interaction are determined by linear interpolation.

In areas where the density of the surveys is small, in the simulation environment a cross-channel distortion of the fairway is triggered (Fig. 4). The result can lead to a situation in which the vessel in simulation conditions while experiencing contact with the bottom of the hull, in fact, will have a positive underkeel clearance value.

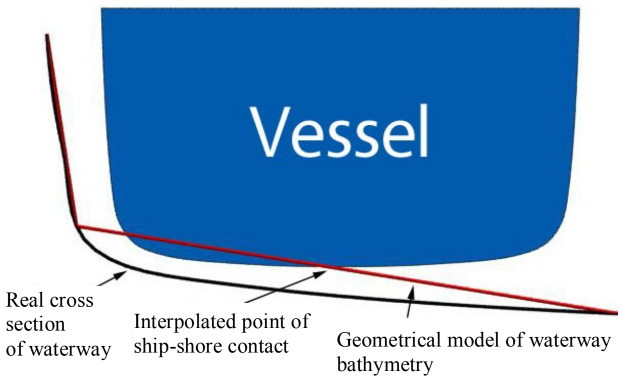


Fig. 4. Linear interpolation of the geometric model of the basin bottom bathymetry [own study]

In the process of constructing geometric models of this phenomenon is inevitable, conditional from the technique of the task and computational capabilities of the simulator. From the point of view of

Table 3. Mean values of parameters of ships passing encounter in the seaway section between IV Brama torowa – Zakręt Mańków

No.	1	2	3	4	5	6	7
Vessel 1	Magdalena	Ferry30L	Ferry30L	CNTNR16L	CNTNR16L	PRODCT03L	PRODCT03L
Max bow squat	0.19	0.5	0.41	0.38	0.4	0.38	0.38
Max stern sqaut	0.32	0.41	0.33	0.33	0.35	0.24	0.25
Minimum bow under keel clearance	6.63	2.32	2.41	1.03	1.02	1.01	0.99
Minimum stern under keel clearance	3.07	2.41	2.49	0.54	0.5	0.47	0.45
Vessel 2	Magdalena	Magdalena	Ferry30L	Ferry30L	CNTNR16L	CNTNR16L	CNTNR16L
Max bow squat	0.18	0.21	0.4	0.37	0.41	0.33	0.34
Max stern sqaut	0.33	0.34	0.32	0.3	0.33	0.29	0.29
Minimum bow under keel clearance	6.67	6.13	2.39	2.45	0.98	0.62	0.6
Minimum stern under keel clearance	3.15	2.66	2.45	2.56	0.47	0.7	0.65
Average minimum lateral distance between vessels	35.5 m	30.3 m	26 m	21.5 m	18.1 m	17.4 m	15.9 m

Table 4. Mean values of parameters of ships passing encounter in the seaway section of Zakręt Mańków

No.	1	2	3	4	5	6	7
Vessel 1	Magdalena	Ferry30L	Ferry30L	CNTNR16L	CNTNR16L	PRODCT03L	PRODCT03L
Max bow squat	0.15	0.42	0.41	0.39	0.36	0.37	0.38
Max stern sqaut	0.24	0.34	0.33	0.35	0.31	0.32	0.32
Minimum bow under keel clearance	5.40	1.32	1.39	1	1.05	0.91	0.95
Minimum stern under keel clearance	1.75	1.38	1.47	0.40	0.45	0.37	0.40
Vessel 2	Magdalena	Magdalena	Ferry30L	Ferry30L	CNTNR16L	CNTNR16L	CNTNR16L
Max bow squat	0.15	0.17	0.4	0.41	0.37	0.39	0.38
Max stern sqaut	0.23	0.26	0.35	0.37	0.32	0.35	0.35
Minimum bow under keel clearance	5.55	5.15	1.16	1.2	0.85	0.82	1
Minimum stern under keel clearance	1.85	1.46	1.12	1.18	0.30	0.29	1.01
Average minimum lateral distance between vessels	72.6 m	54.9 m	53.4 m	45.2 m	42.6 m	38.8 m	28.5 m

the conducted research, however, it is preferred. The results of the study are analyzed for the conditions compatible or randomly degraded compared to the real ones. In practice, it is compatible guidelines for simulation studies (situation of improving navigation conditions would adversely affect the simulation experiment).

Results

Based on number of trials the mean value of minimum lateral distance between vessels, the average value of the minimum under keel clearance and the average value of the maximum squat designated on the bow and stern for each vessel, while passing encounter was calculated. For the purpose of squat calculation the Barras method for shallow water channel was used.

As can be seen from the analyzes, not the length nor the width of the ship is the main determinant of the distance at which ships passing each other. It is the vessel draft. Due to the available depth and the squat phenomenon shortest distance passing vessels was obtained for vessels of the largest draft and during the adverse weather conditions (winds of 25 knots, western, output current).

Assumed the minimum acceptable value of under keel clearance of a vessels fairway was 0.5 m.

The seaway section between IV Brama Torowa – Zakręt Mańków

The ships passing manoeuvre at the narrowest part of the section between island Chałminek and Zakręt Mańków had positive results for each of the trial had been made. The level of impact of ship-to-shore and ship-to-ship was not big enough for any of the ships to lose their course stability. In each trial it was possible to maintain the units on the designated track. Ship passing parameter values for a given section are shown in table 3.

The seaway section of Zakręt Mańków

As in the previous scenario the ships passing manoeuvre at the narrowest part of the section of Zakręt Mańków had positive results for each of the trial had been made. In terms of impacts of ship-to-shore, ship-to-ship and difficulties in the maintenance on the track, it was the least demanding stretch. Analyzed values achieved the highest levels of the entire study sample.

Table 5. Mean values of parameters of ships passing encounter in the seaway section between Zakręt Mańków – Ina-S

No.	1	2	3	4	5	6	7
Vessel 1	Magdalena	Ferry30L	Ferry30L	CNTNR16L	CNTNR16L	PRODCT03L	CNTNR16L
Max bow squat	0.22	0.64	0.43	0.39	0.4	0.4	0.28
Max stern sqaut	0.38	0.55	0.35	0.35	0.35	0.34	0.24
Minimum bow under keel clearance	5.32	0.02	2.39	1.01	1	1.02	1
Minimum stern under keel clearance	1.69	1.18	2.47	0.45	0.45	0.47	0.45
Vessel 2	Magdalena	Magdalena	Ferry30L	Ferry30L	CNTNR16L	CNTNR16L	Ferry30L
Max bow squat	0.23	0.24	0.47	0.43	0.39	0.41	0.34
Max stern sqaut	0.35	0.36	0.39	0.33	0.35	0.35	0.27
Minimum bow under keel clearance	5.02	4.47	0.01	0.63	0	0.62	1.5
Minimum stern under keel clearance	1.35	0.76	0.44	0.49	0.45	0	1.16
Average minimum lateral distance between vessels	76.7 m	56.2 m	59.1 m	40 m	37.4 m	11.6 m	35.3 m

Table 6. Mean values of parameters of ships passing encounter in the seaway section between Ina-S – Przesmyk Orli

No.	1	2	3	4	5	6	7
Vessel 1	Magdalena	Ferry30L	Ferry30L	CNTNR16L	CNTNR16L	PRODCT03L	PRODCT03L
Max bow squat	0.18	0.42	0.55	0.35	0.36	0.33	0.32
Max stern sqaut	0.27	0.33	0.45	0.31	0.32	0.28	0.27
Minimum bow under keel clearance	6.04	1.6	0.53	0.96	0.42	0.6	0.45
Minimum stern under keel clearance	2.4	1.43	0.24	0.23	0.01	0.53	0.38
Vessel 2	Magdalena	Magdalena	Ferry30L	Ferry30L	CNTNR16L	CNTNR16L	CNTNR16L
Max bow squat	0.19	0.2	0.4	0.38	0.35	0.31	0.33
Max stern sqaut	0.27	0.3	0.33	0.31	0.3	0.27	0.26
Minimum bow under keel clearance	6.63	6.62	2.42	2.44	1.05	0.74	1.1
Minimum stern under keel clearance	3.37	3.07	1.34	1.37	0.5	0.42	0.52
Average minimum lateral distance between vessels	46 m	55.6 m	68.6 m	44.7 m	40.6 m	37.5 m	26.9 m

Table 7. Mean values of parameters of ships passing encounter in the seaway section between Przesmyk Orli – Basen Górniczy

No.	1	2	3	4	5	6	7
Vessel 1	Magdalena	Ferry30L	Ferry30L	CNTNR16L	CNTNR16L	PRODCT03L	CNTNR16L
Max bow squat	0.17	0.49	0.41	0.38	0.39	0.42	0.44
Max stern sqaut	0.29	0.41	0.34	0.34	0.34	0.37	0.36
Minimum bow under keel clearance	6.49	2.38	1.31	1.03	1.02	0.61	0.0
Minimum stern under keel clearance	2.49	2.42	0.32	0.47	0	0	0.54
Vessel 2	Magdalena	Magdalena	Ferry30L	Ferry30L	CNTNR16L	CNTNR16L	Ferry30L
Max bow squat	0.16	0.18	0.42	0.41	0.4	0.39	0.43
Max stern sqaut	0.32	0.32	0.34	0.34	0.35	0.34	0.34
Minimum bow under keel clearance	6.63	6.57	2.41	2.16	1.16	1.09	0.98
Minimum stern under keel clearance	3.07	2.97	1.58	0	0.49	0.5	0.44
Average minimum lateral distance between vessels	43.6 m	35.2 m	32.7 m	23.3 m	18.9 m	14.2 m	30.7 m

The seaway section between Zakręt Mańków – Ina-S

The ships passing manoeuvre at the narrowest part of the section between Zakręt Mańków to Ina-S had negative results in the fifth and sixth trial variant.

The variants with container – container passing encounter showed a strong bank effect which is a tendency of the stern of a ship to swing toward the near bank of the waterway. The value of the under keel clearance of each vessel was insufficient for safe passage in all attempts. A similar situation was observed for variant of passing between product tanker – container.

The seaway section between Ina-S – Przesmyk Orli

The ships passing manoeuvre at the narrowest part of the section between Ina-S – Przesmyk Orli had positive results for each of the trial had been made. Similarly, as described in subsection, there were no activities here of excessive external forces and moments, acting on the hull of the ship. Characteristics of navigable water area (sufficient width of the fairway), allows for easy passing of the vessels with a draft of 7.5 m.

The seaway section between Przesmyk Orli – Basen Górniczy

The results of ships passing manoeuvre at the narrowest part of the section between Przesmyk Orli and Basen Górniczy does not allow for a safe manoeuvre for the greatest number of studied variants. At the narrowest point, the available width of the waterway, with a required depth for safe navigation is not sufficient variants from four to seven. Ship groundings are not the result of the strong interactions ship-to-ship or ship-to-shore, nor inability to maintain the ship on course. Value of the UKC = 0 is a result of insufficient cross-sectional width of the track at the keel level of passing vessels.

Conclusions

This paper presents an analysis of the parameters of vessel passing encounters on the seaway Świnoujście–Szczecin. Analyzing the presented data, it is clear that in terms of simulation capabilities of the existing waterway, the possible capacity of large vessel two-way traffic, is used only to a small extent.

All over the world there is a tendency to increase the size of vessels entering and operating in ports. It happens very often that the port regulations implement a very large safety margins. An example is discussed in this article for ships passing manoeuvre. The parameters of vessel draft and her overall length is strictly limited for the passing vessels in the seaway Świnoujście–Szczecin. Port regulations are often created based on the user experience and for obvious reasons are designed to minimize the risk of hazardous events.

It may be noted that the development of technology and the development of marine traffic engineering methods offer modern tools that can and should be used to update this type of studies, regulating the intensity of traffic streams. Statistical analysis of research results shows that the use simulation studies, the same as the model of other navigation analyzes for area Świnoujście–Szczecin port, may as a result: increase throughput path by updating the port existing legislation, to verify for the correctness of the deployment of existing and new navigational aids and other aspects that define security of navigation in that water area.

The traffic volume in Port Szczecin is high. Unnecessary slow down of vessel traffic, due to the inability of ships passing in accordance with the prevailing port regulations may result in the decrease in ports competitiveness.

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