



KRZYSZTOF MARCJAN, LUCJAN GUCMA
Maritime University of Szczecin, Poland

**DETERMINATION OF THE RISK
OF LOCATION THE QUAY FOR LARGE
STEEL COMPONENTS HANDLING IN VICINITY
OF THE FAIRWAY USING THE FAST-TIME
SIMULATION METHOD**

ABSTRACT

The paper presents the use of the Fast-Time navigational simulator to verify the location of designed elements of navigational infrastructure in vicinity of a high traffic fairway. The aim of the study is to perform the analysis of navigational safety in vicinity of newly constructed quay placed to the east of the island Ostrow Brdowski. The Quay is intended handling of large steel structures. The Fast-Time simulation is performed to evaluate the safety of the navigation passage through the fairway along the quay for the future use of vessels which length may exceed 260 m. This kind of simulation method has been implemented to make a statistical analysis based on a large amount of data, the collection of which would be very expensive and time consuming using a Real-Time simulator.

Keywords:

Risk of collision, Fast-Time simulation, safety of navigation, statistical analysis, ship manoeuvring simulation

1. INTRODUCTION

Ship navigation and maneuvering simulation systems have been developed to effectively evaluate and optimize the horizontal design of a navigation in narrow passages like channels, port approaches or harbor basins. There are two main types of navigational simulations:

- Fast-time simulation
- Real-time simulation

Both simulation systems are composed of simulation software, mathematical ships maneuvering models, geographical area databases and analysis tools. The main difference is that fast-time simulation uses autopilot algorithms to control the ship and tugs, whereas real-time simulation systems use a real mariners or pilots to control the simulated ships and tugs [PIANC, 2014]. The use of real-time and fast-time ship maneuvering simulators in the design of harbor areas (e.g. navigation channels and basins) provides a realistic tool for verification of navigation safety under specific environmental conditions and infrastructure layout, thus preventing unexpected port operation problems for the future [Arndal, 1999]. An example of a research based on real-time simulation was introduced in [Gucma L., 2014] where this method was used to design a new Port in Mielno. The real-time simulation interactive with captains and pilots engaged in ships manoeuvring trials was applied as the most reliable and suitable in this kind of research studies [Gucma L., 2005].

A fast-time navigation simulator is also referred to as an off-line or track-keeping simulator. It generates data without a real pilot operating the ship, as it is not possible to do so when running in fast-time. Such simulators operate through the use of a number of equations which represent the behaviour of a pilot navigating a vessel or a tug in such a manner so that it is kept on a reference track. The simulations run at accelerated speed which generates large volumes of output data which are analyzed to form meaningful conclusions. Using a fast time simulation model gives an efficient cost effective way of evaluation which can help forming important decisions at an early stage. In order to make a statistical analysis where a large amount of data is needed, the collection of which would be both too expensive and time consuming using a real-time simulator.

The paper presents the results of simulation associated with the analysis of navigational safety in vicinity of newly constructed quay intended handling of large steel structures. The study has been performed to evaluate the safety of the navigation passage through the fairway along the quay, for the future use of larger vessels than are used nowadays, using a Fast-time simulation method. In the beginning the IRMSym

Fast-time simulation model will be presented on which the simulations have been performed next the construction and operation diagram of model of ships intended for use on the fairway in the future. Finally the results of the simulation analysis will be presented.

2. THE STUDY AREA

The aim of the study is to perform the analysis of the safety of ships proceeding the fairway along the newly constructed quay to the east end of the island Ostrow Brdowski. The area covered by the analysis is leading along the quay with a gantry for loading large steel structures is shown in Fig. 1. The dimensioning of the fairway in the time of the analysis was performed (D = 90m, H = 10.5 m) and planned (D = 110m, H = 12.5 m) that is shown in Fig. 2.



Figure 1. Analyzed area with approximate positions of loading quay, gantry and dolphins indicated. Source: Authors based on Google Earth.

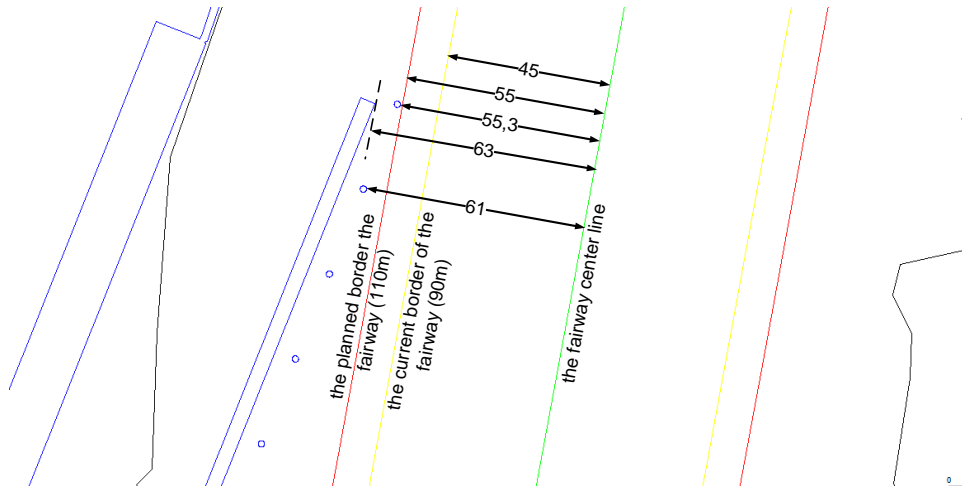


Figure 2. The area of analysis with borders of the current fairway and planned one.
Source: Authors.

3. EVALUATION OF THE NAVIGATIONAL SAFETY IN THE SELECTED PART OF THE FAIRWAY

Presented investigation has been conducted for evaluation of the navigational safety in the selected part of the fairway having regard to the planned maximum size of ships based on the Fast-Time simulation. The Fast-Time simulation method is an established process of surveys of the navigational safety on the fairways with a low degree of complexity [Gucma L. 2005]). This form of simulation is considered appropriate for representing the behavior of a pilot in certain circumstances, where the actions of the pilot are relatively straightforward and where the concept of a reference track is valid, such as for the design of relatively straight channels or fairways without complex bends [PIANC 2014] This method is considered to be sufficient for analyzing those sections of fairways where a vessel performs maneuvers without a tug assistance. The simulation method described in this paper is based on IRMSym ship traffic model which is equipped with a specially built autopilot which is a simplified model of a navigator.

This method reflects the dynamics of the ship, the external interferences and the impact of the water area, but instead of a human an autopilot controls the ship similar to his performance. In the analysis it was assumed that in straight sections of the waterway often better than the helmsman performs the autopilot due to the accuracy of

control and the inability to commit mistakes. The general functional diagram of IMRSym Fast-Time simulation model is shown in Fig. 3. The same method was used when planning the width of the North approach fairway for LNG tankers in Swinoujscie [IIRM AM, 2007].

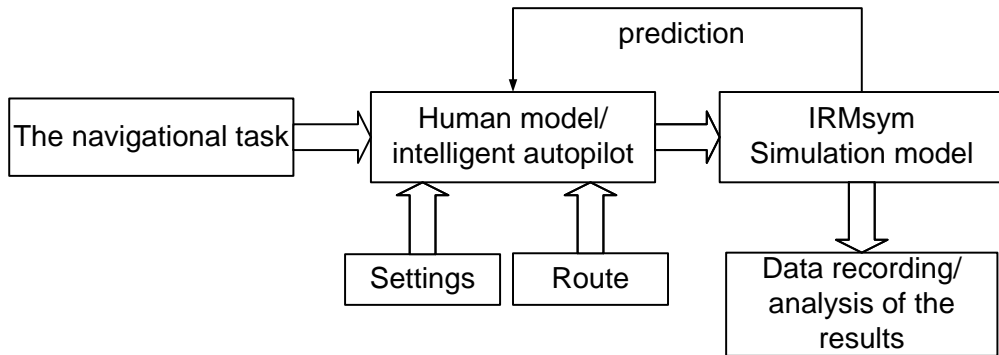


Figure 3. IMRSym Fast-Time simulation model used for the analysis. Source: Authors.

A Fast-Time Simulator is often called a Simulator of course maintenance because there is no human (pilot) and instead of him it simulates his behavior using mathematical equations generally consisting of two blocks. First block is an autopilot for 3 or more constants (generally working on the principle of PID proportional-integral-derivative controller) and second block is the element of prediction. One of the first steps is to enter the geographic coordinates of a planned route to the IMRSym model on which you want to keep the vessel. The autopilot-human model does not include the ability to control the tugs, as in the chosen section of the fairway vessel is able to maneuver independently. As autopilot a model in the form of the following equation has been applied:

$$\delta = c_1(K - K_z) + c_2(\omega - \omega_z) + c_3(x/L_{pp}) \quad \dots(1)$$

where:

- δ - set rudder angle,
- K - current course,
- K_z - set course,
- ω - ROT (Rate Of Turn) that equals $(g/L_{pp})^{1/2}$,
- ω_z - set ROT,
- c_1, c_2, c_3 - gain factors,
- x - Cross Track Error (XTE),
- L_{pp} - Length between perpendiculars.

4. THE CONSTRUCTION OF SHIP MODEL INTENDED FOR THE FUTURE USE ON THE FAIRWAY

Two ship models were built with maximum dimensions for future fairway:

- container ship: LOA =210m; Lpp=190m, B =30,0m; T =11,0m.
- cruise ship: LOA =260m; Lpp=220m; B =33,0m; T =9,0m.

The models were built as typical on the basis of existing vessels with similar characteristics in their class. The exact parameters of vessels and parameters of models constructed on their basis are shown below.

Table 1. Container ship parameters (based on class: *Maersk Newport*).

Sign.	Parameter	<i>M/V Maersk Newport</i>
LOA	Length – overall	207 m
Lpp	Length between perpendiculars	197m
B	Breadth	30 m
T	Draft	11 m
Cb	Block Coefficient	0,62
DWT	Deadweight Tonnage	35 100 t
	Propeller	1 variable pitch 21.770 kW
	Speed	22 kn
	Bowthruster	1100 kW
	Capacity	2478 TEU
Fp	Lateral wind area Fp	3500 m ²

Source: Authors.



Figure 4. M/V Mears Newport. Source: https://www.marinetraffic.com/en/ais/details/ships/shipid:156502/mmsi:219223000/imo:9356127/vessel:MAERSK_NEWPORT (15.07.2018)

Table 2. Cruise ship (based on class: *Carnival Fantasy*).

Sign.	Parameter	M/V <i>Carnival Fantasy</i>
LOA	Length - overall	262 m
Lpp	Length between perpendiculars	222 m
B	Breadth	31.5 m
T	Draft	7.8 m
Cb	Block Coefficient	0,66
DWT	Deadweight Tonnage	35 100 t
	Propulsion	2 x ABB Azipod propulsion units (together 47.520 kW)
	Speed	22 kn
	Bowthrusters	3 x 1500 kW
	Guest Capacity / Onboard Crew	2052 / 920
Fp	Lateral wind area	8000m ²

Source: Authors.



Figure 5. M/V *Carnival Fantasy*.

Source: <https://i.pinimg.com/736x/15/fb/f9/15fbf99ed317228dfe4ce3dae52d7b8f--carnival-fantasy-the-carnival.jpg> (15.07.2018).

For the analysis a model that repeatedly verified as an application while developing ports in Poland, Sweden (Ystad) and Slovenia (Koper) was used. The model is operating in the loop where the input variables are calculated instantly (settings and disturbances) as the forces and moments acting on the hull and momentary accelerations are evaluated and speeds of movement surge, sway and yaw [Gucma S. et. al, 2008].

The most important forces acting on the model are:

1. thrust of propellers,
2. side force of propellers,
3. sway and resistant force of propellers,
4. bow and stern thrusters forces,
5. current,
6. wind,
7. ice effects (neglected),
8. moment and force of bank effect,
9. shallow water forces,
10. tug forces.

Application interface on which the analysis of navigational safety was made is shown in Fig. 6 and 7 the main functional diagram of simulation model is presented.

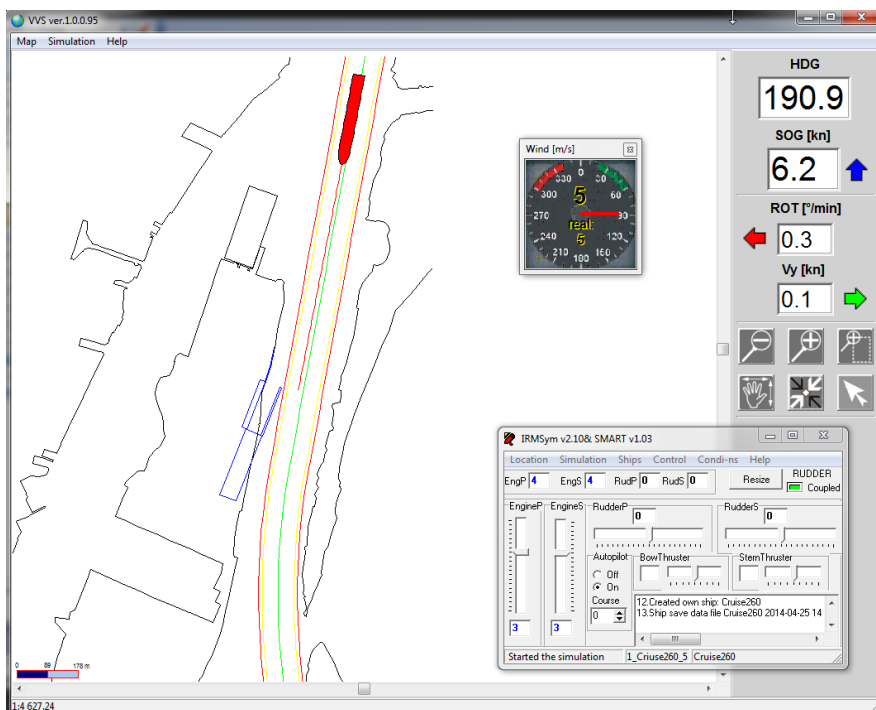


Figure 6. The interface of ship traffic simulation model. Source: Authors.

The following series of experiments of one-way passage along the selected section of the fairway were chosen for analysis:

Table 3. Trial scenarios for container ship and for cruise ship for fairway passage.

No.	Ship	Wind	Current	No of passages
1	Container ship 210	5m/s	0,5 from aft	15
2	Container ship 210	10m/s	0,5 from aft	15
3	Cruise ship 260	5m/s	0,5 from aft	15
4	Cruise ship 260	10m/s	0,5 from aft	15

Source: Authors.

The manoeuvres were performed using ships rudders, main propulsions to maintain the speed of 8 kn during the passage without the tug assistance.

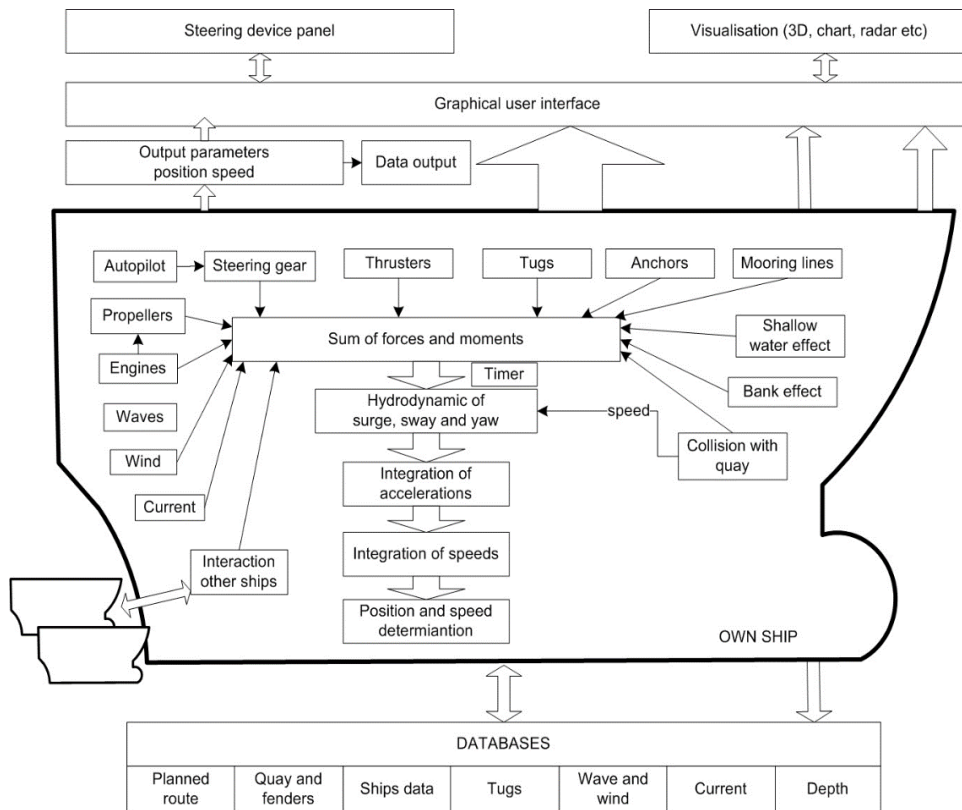


Figure 7. The main functional diagram of simulation model. Source: Authors.

5. ANALYSIS OF THE RESULTS FROM THE SIMULATION TRIALS

The data from the simulation trials was recorded and analyzed and as a final result it has been presented as ship maneuvering lanes widths (horizontal safe maneuvering area dimension) and which have been graphically depicted in the figures (Fig. 8, 9, 10, 11). Each graph presents three lanes:

- The maneuvering lane obtained on 95% level of confidence, marked with red colour line,
- Maximum obtained maneuvering lane, marked with pink colour line,
- An average maneuvering lane, marked with green colour.

The safe maneuvering areas on given level of confidence (usually 95%) are widely used in analysis and for designing the waterways and hydrotechnical structures in Polish ports by the IRM team of Maritime University of Szczecin [Gucma S., 2004]. On the mentioned graphs can be noticed that in any of them ship maneuvering lanes on 95% level of confidence did not exceed even the current fairway of 90m width.



Figure 8. The maneuvering lanes obtained from the container vessel trials with wind speed 5m/s and East direction. Source: Authors.

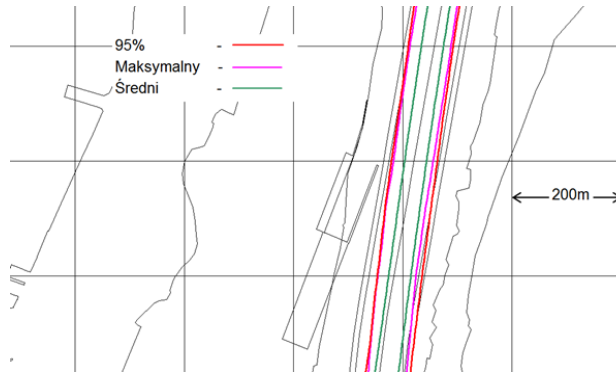


Figure 9. The maneuvering lanes obtained from the container vessel trials with wind speed 10m/s and East direction. Source: Authors.

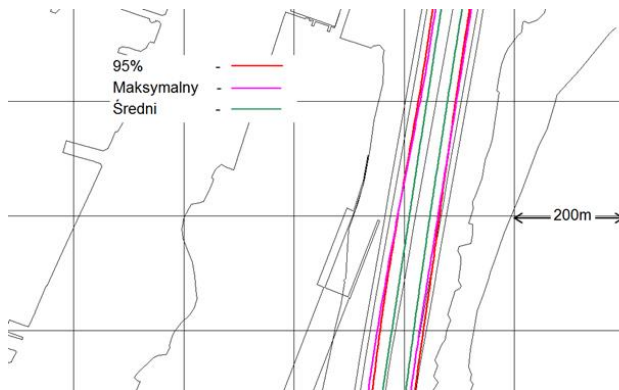


Figure 10. The maneuvering lanes obtained from the cruise vessel trials with wind speed 5m/s and East direction. Source: Authors.

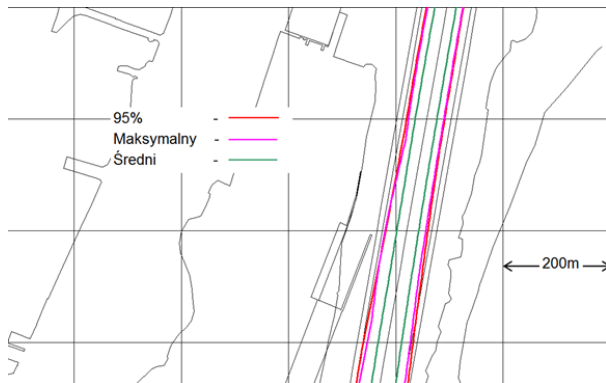


Figure 11. The maneuvering lanes obtained from the cruise vessel trials with wind speed 10m/s and East direction. Source: Authors.

In the Fig. 12 both maneuvering lane obtained for container vessel on 95% level of confidence are depicted. Neither of them does exceed the 80m (which is almost 2,5 of her breadth) in vicinity of the new built quay. These results indicate that there shouldn't be any problem with maneuvering on the selected part of the waterway by a container vessel of 260m LOA and by a cruise vessel of 210m LOA (Fig. 13).

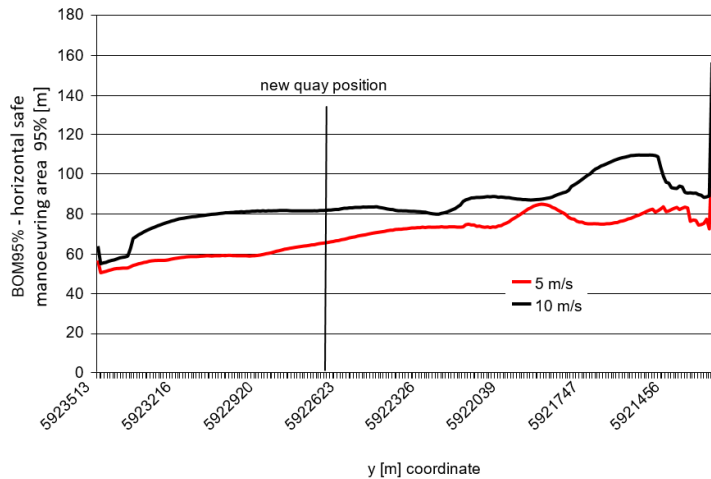


Fig. 12. The horizontal safe maneuvering area dimension on 95% level of confidence (BOM95%) for a container vessel and the wind speed of 5 m/s (red color) and 10 m/s (black color). Source: Authors.

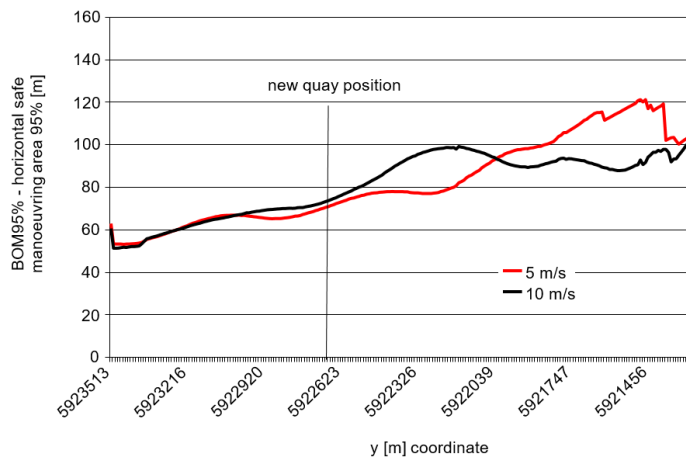


Fig. 13. The horizontal safe maneuvering area dimension on 95% level of confidence (BOM95%) for a cruise vessel and the wind speed of 5 m/s (red color) and 10 m/s (black color). Source: Authors.

The probability of collision between the chosen vessels and the base part of the gantry has been calculated basing on the generalized simulation analysis method (which equations are shown below) with the use of standard deviations and the mean values obtained in the simulation trials. There are also several statistical parameters which are describing the maneuvering lanes and the maximum safe maneuvering area.

The width of the safe maneuvering area (BOM) on the α level of confidence can be determined using the equation (2) in meters:

$$BOM_{\alpha} = m + 2k_{\alpha}s \quad \dots(2)$$

Where k_{α} is a parameter which value depends on the confidence level, it determines what percentage of the population is to be included in the estimation.

In this example $\alpha = 0.95$ (95% probability) so $k_{\alpha} = 1.94$.

Assuming normality of ships starboard position, the probability of collision with the structure is (3):

$$P_{wp} = \int_{x_p}^{+\infty} f_{RN(m_p,s)}(x)dx \quad \dots(3)$$

where

m_p - the average position of the extreme points of the starboard side of the ship, defined as:

$$m_p = +(m/2) \quad \dots(4)$$

x_p – position of danger (at the edge of the waterway)

I_R – the intensity of the annual traffic of large vessels

lam_R – the intensity of annual collisions with objects situated on the border of the waterway located at the point of x_p ($lam_R = I_R P_{wp}$)

n_w – the average number of passages during which a collision may occur ($n_w = I/P_{wp}$)

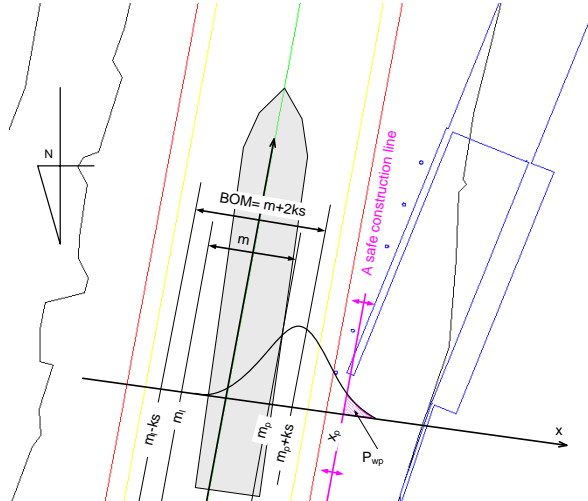


Figure 14. Explanatory illustration of the terms and parameters used in the method of generalized simulation analysis. Source: Authors.

For the examined vessels the value of the x_p parameter is being changed so that the intensity of annual accidents lam_R is smaller than the criterion of 0.07 light and heavy accidents [Gucma S. 2001]. This changes the location of a safe construction line (pink color in Fig. 13).

Table 4. The maximum values of the parameters determining safe maneuvering area.

Lp	B	L	m	s	$k_{95\%}$	$BOM_{95\%}$	m_p	x_p	P_{wp}	n_w	I_R	lam_R
1	30	210	39.2	9.7	1.94	76.8	19.60	+50.6	0.000697	1435	100	0.069703
2	30	210	41.1	12.2	1.94	88.4	20.55	+59.5	0.000705	1419	100	0.070493
3	33	260	41.2	11.0	1.94	83.9	20.60	+55.7	0.000709	1410	100	0.070913
4	33	260	42.9	13.9	1.94	96.8	21.45	+65.4	0.000710	1409	100	0.070977

Source: Authors.

In the table 4 are shown the largest existing parameters of the maneuvering lane (mean m and standard deviation s) in the area of 100m before and behind the new quay. The table shows the values calculated on the basis of simulation trials for both vessels (the container vessel 260m and the cruise vessel 210m) obtained for the two scenarios with the most unfavourable east wind. The value of x_p parameter has been adopted so that the annual risk of collision with construction was smaller than the criteria (0.07 accident per year). This value is maintained at a distance of $x_p = 65m$ from the middle of the fairway.

CONCLUSIONS

The presented study confirms the possibility of using the Fast-Time IRMsym to assess the location of newly built quay in terms of navigational safety on the adjacent fairway. The use of an autonomous simulator type Fast-Time has been substantiated by the fact that the selected section of the fairway can be treated as rectilinear.

It should be noted that the calculated risk at the level of 0.07 means that one (light or heavy) accident is being accepted in 15 years, this period of time is established as a life time or the time to modernize the port structure or the ship. Historical analysis performed by many authors including one of the authors of this paper [Gucma L. 2009] indicate that the heavy accident happens with 10% probability in relation to all accidents, which means that by the location of the farthest part of the quay at the distance of $x_p = +65\text{m}$ from the center of the fairway we accept one heavy accident for 150 years.

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KRZYSZTOF MARCIAN

Maritime University of Szczecin
Wały Chrobrego 1-2, 70-500 Szczecin, Poland
e-mail: k.marcjan@am.szczecin.pl

LUCJAN GUCMA

Maritime University of Szczecin
Wały Chrobrego 1-2, 70-500 Szczecin, Poland
e-mail: l.gucma@am.szczecin.pl

STRESZCZENIE

W artykule przedstawione zostanie wykorzystanie symulatora nawigacyjnego typu Fast-Time w celu weryfikacji lokalizacji projektowanego nabrzeża w pobliżu uczęszczanego toru wodnego. Celem opracowania jest wykonanie analizy nawigacyjnej dla nowobudowanego nabrzeża na wschodniej części wyspy Ostrów Brdowski przeznaczonego do załadunku wielkogabarytowych konstrukcji stalowych. Zaprezentowano ocenę bezpieczeństwa nawigacyjnego przejścia przez tor wodny prowadzący wzdłuż nabrzeża, dla przyszłościowych jednostek o długości 260 m, wykonana metodą symulacyjną Fast-Time. W badaniu wykorzystano model czasu przyspieszonego ze względu na dużą ilość danych (przejazdów) potrzebnych do wykonania analizy statystycznej, użycie symulatora czasu rzeczywistego do uzyskania wystarczającej ilości danych byłoby zbyt drogie i zbyt kosztowne w czasie.