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The quantitative assessment of marine traffic safety in the Gulf of Finland, on the basis of AIS data

Ilościowa ocena bezpieczeństwa ruchu morskiego w Zatoce Fińskiej z wykorzystaniem danych systemu AIS

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Key words: risk assessment, marine traffic, ships collision

Abstract
Navigational risk assessment is a complex process, which aims to determine the level of safety over the analyzed area. Usually two approaches are used: qualitative and quantitative. Engineers tend to view risk in an objective way in relation to safety, and as such use the concept of risk as an objective safety criteria. Among engineers risk is defined as a product of probability of occurrence of an undesired event and the expected consequences in terms of human, economic and environmental loss. These two components are equally important; therefore appropriate estimation of these values is a matter of great significance. This paper deals with one of these two components: the probability of vessels' collision assessment. A new approach for probability estimation of collision between vessels is presented, rooted in aviation experiences. The presented model for collision frequency estimation takes into account historical traffic data from AIS, generalized vessel dynamics and uses advanced statistical and optimization methods (Monte-Carlo, Genetic Algorithms).

Słowa kluczowe: szacowanie ryzyka, ruch statków, kolizje statków

Abstrakt
Szacowanie ryzyka nawigacyjnego jest złożonym procesem, którego celem jest określenie poziomu bezpieczeństwa na analizowanym akwenie. Zazwyczaj stosowane są dwa podejścia: jakościowe i ilościowe. Inżynierowie definiują ryzyko jako prawdopodobieństwo wystąpienia niepożądanego zdarzenia oraz wynikających z niego konsekwencji tj. utraty życia ludzkiego, aspektów ekonomicznych oraz zanieczyszczenia środowiska. Te dwa komponenty są w równym stopniu ważne; dlatego odpowiednie oszacowanie wartości ma bardzo duże znaczenie. W artykule zaprezentowano jeden z dwóch czynników: prawdopodobieństwo szacowania kolizji statków. Przedstawiono nowe podejście dotyczące szacowania prawdopodobieństwa kolizji pomiędzy dwoma statkami, które zostało zaczerpnięte z doświadczeń lotnictwa. Opisany model szacowania częstotliwości kolizji bierze pod uwagę dane otrzymane z systemu AIS, uogólnioną charakterystykę dynamiki statku przy użyciu zaawansowanych metod statystycznych i optymalizacyjnych (Monte-Carlo, algorytmy genetyczne).

Introduction

The Gulf of Finland is the easternmost arm of the Baltic Sea; it is situated between Finland (north), Russia (east) and Estonia (south). The gulf extends for 215 nautical miles from east to west, but only 10 to 70 nautical miles from north to south. The bottom varies between deep and shallow, to a maximum depth of 115 m at its western end, and many shallow waters and underwater rocks dominate the Finnish archipelago area. Due to its low salinity (six parts per thousand) the gulf freezes over for three to five months in winter. The gulf is an important shipping route for its main ports: Porkkala, Helsinki, and Kotka in Finland; Vyborg, St. Petersburg, and Primorsk in

Russia; and Tallinn in Estonia. In the year 2007 approximately 53 600 ship calls were made in the ports of the Gulf of Finland, and 263 M tones of cargoes were transported. In the recent years rapid increase in oil transportation is evident, mostly due to establishment of new oil harbors in Primorsk and Ust Luga. The forecast for the traffic in 2015 assumes the "average growth" scenario, which would mean a growth of 64% in maritime transportation tones compared to the year 2007. Such a rapid growth could occur due to the strong development of Russia [1]. The high density of traffic and large numbers of tanker vessels at present and even higher figures predicted pose a certain hazard to the sea and coastal areas in the Gulf of Finland.

Several reports and articles appeared recently that considered the analysis of safety of marine traffic in the Gulf of Finland [2, 3] and navigational risk modeling [4], but the overall risk of maritime transportation is to be estimated. For risk modeling purposes (probability of collision and grounding estimation) these reports used a well-known scenario-based approach proposed by Pedersen (1995), which is simple and robust but has serious limitations. This paper presents another approach, derived from the concept of modified two-dimensional gas molecular collision model combined with vessel domain theory. The model takes into account vessel dynamics, unlike Pedersen's model. The presented gas model is utilized to assess the collision frequency on the junction of the waterways between Helsinki and Tallinn, which is a high-density traffic sea area. The results obtained from the GAS model are compared with Pedersen's model as well as available accidents and data from near misses.

The probability of collision is a product of geometrical probability and causation probability. This paper deals with geometrical probability and human factor, which affects the causation probability, has not been a subject of research.

Marine traffic and accidents

Marine traffic profile

Vessel traffic profiles over the analyzed area are described using the data derived from the AIS transmission recorded in March and July 2006. The registered data does not fully reflect the existing traffic, mostly due to AIS carriage requirements limitation [5]. Regulation 19 of SOLAS Chapter V requires AIS to be fitted aboard: all ships of 300 gross tonnage and upwards engaged on international voyages, all cargo ships of 500 gross tonnage and upwards not engaged on international voyages and all passenger ships irrespective of size. Due to this, all "small" traffic is not included in the present study, although a large number of pleasure crafts and fishing boats navigate in the Gulf of Finland, especially in summer. These boats, despite their small dimensions, in some situations may complicate the traffic, and raise the already high risk of collision and grounding in the area. For further research that kind of traffic should be estimated as well. Another reason behind the difference between registered traffic and existing situation is incomplete AIS information transmitted by vessels. Transmissions without MMSI number, latitude or longitude were not stored in the database. Thus, the total number of recorded vessels in area is smaller than the actual.

The area in question is a junction of two main waterways; one is leading N–S and another E–W. The N–S stream consists mainly of passenger vessels, cruising between Helsinki and Tallinn, whereas E–W stream consists of cargo vessels bound to and from harbors located in the Gulf of Finland. To estimate the number of vessels that arrive to and depart from the Gulf of Finland, the counting gate number 1 was established along meridian $\lambda = 023°30'$E. To compute the traffic volumes of the streams in the junction another two counting gates were established. Gate number 2 was established along parallel $\varphi = 60°$N to count N-S traffic, and gate number 3 along the meridian $\lambda = 026°$E to count E–W traffic (fig. 1).

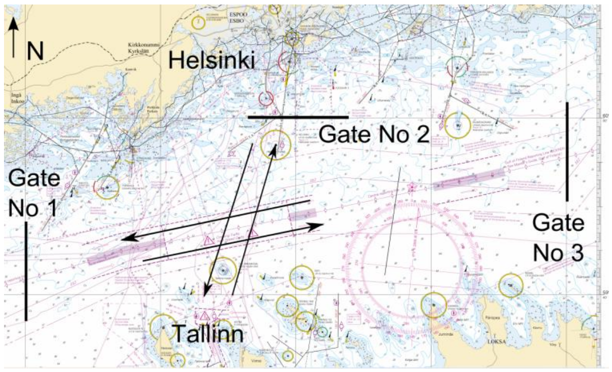

Fig. 1. Analyzed waterways' junction with counting gates and main traffic flows marked

Rys. 1. Analizowany akwen – przecięcie się dwóch torów wodnych z oznaczonymi bramkami liczącymi oraz oznaczonymi głównymi strumieniami ruchu statków

The types of vessels and their percentage share of the traffic in the Gulf of Finland are presented graphically in figure 2. The diagram constitutes the results of two months AIS transmission recordings, carried out in March and July 2006 in counting gates number 1 (all vessels) and 2 (passenger vessels only). The traffic recorded in March is considered winter profile of traffic, whereas traffic registered in July is a summer profile of marine traffic in the Gulf of Finland.

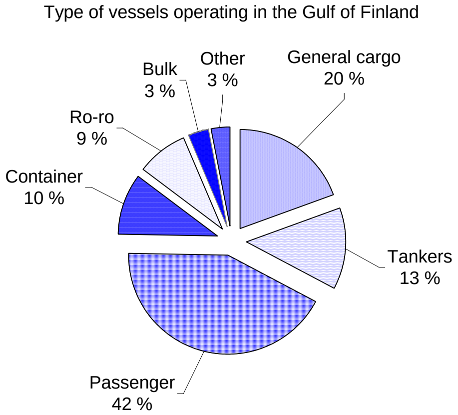

Fig. 2. Types of vessels operating in the Gulf of Finland
Rys. 2. Typy statków pływających w Zatoce Fińskiej

In the diagram above the group labeled "other" consists of tug boats, icebreakers, research vessels, support vessels, sailing yachts, and vessels for which AIS transmission was not complete. In case of messages with MMSI number, but without vessel details, the missing information was extracted from the external vessels database. That external database was very helpful to categorize vessels other than passenger and tankers, the AIS status of which was "cargo vessels" (containers carriers, general cargo, ro-ro, bulk carriers). The size of typical (frequently recorded) and maximal vessels operating in the Gulf of Finland in the period of investigation are gathered in table 1.

Table 1. Types and sizes of typical and maximal vessels operating in the Gulf of Finland in the year 2006
Tabela 1. Typy i wielkości statków charakterystycznych oraz maksymalnych żeglujących w rejonie Zatoki Fińskiej w roku 2006

Vessel type	L	L max	B	B max	T	T max
Tankers	239.0	320.0	27.3	58.0	11.2	22.0
Passenger	171.3	266.2	28.7	36.0	5.0	8.5
Containers	124.5	192.7	22.5	25.4	8.7	10.5
Gen. cargo	85.0	173.5	12.5	27.6	5.3	10.9
Ro-ro	162	195	20.6	28.1	6.7	10.0

The total number of vessels registered in gates 1 and 2 is presented in table 2. There are no significant differences in the number of vessels passing gate 1 each season (winter, summer). However such differences exist for gate 2, where the number of vessels in summer is marked with asterisk and for winter with double asterisks. The main reason for the difference is that during winter time the operations of high speed crafts between Helsinki and Tallinn are suspended, therefore number of passenger vessels on above route is reduced.

Table 2. Number of vessels passing gate 1 (E–W traffic) and gate 2 (N–S traffic), registered in March (**) and July (*) 2006
Tabela 2. Liczba statków przechodzących przez bramkę nr 1 (ruch E–W) oraz przez bramkę nr 2 (ruch N–S), zarejestrowana w marcu i lipcu 2006 r.

Vessel type	Gate number 1		Gate number 2	
	East	West	North	South
Tankers	618	607		
Ro-Ro	397	400		
Passenger	505	502	1140* 488**	1140* 488**
Containers carrier	470	464		
General cargo vessels	895	929		
Bulk carriers	153	145		
TOTAL	3038	3047		

Although the number of vessels passing gate 1 is similar through the year season, the spatial distribution of traffic is different, which depends mostly on icing conditions in the area. As an example, the histograms of the winter and summer traffic are presented in figures 3 and 4 respectively. The differences in distributions are significant and cannot be omitted in risk analysis. The above relations remain in force for the other gates as well.

For the purposes of risk analysis and traffic modeling the traffic spatial distributions might be approximated either by statistical distribution or by histograms in case the registered traffic poorly fits any known distribution.

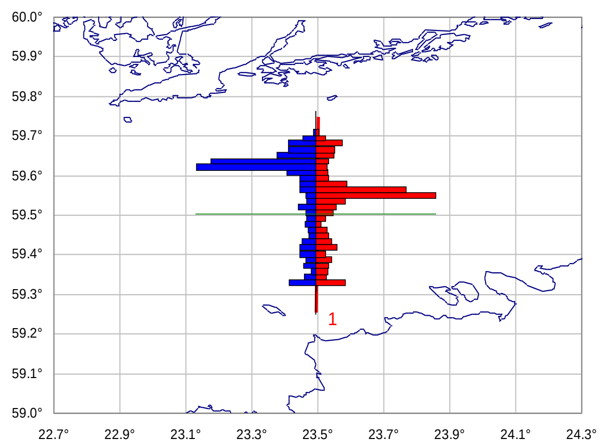

Fig. 3. Traffic flow at gate no 1 in March
Rys. 3. Strumień statków na bramce nr 1, marzec

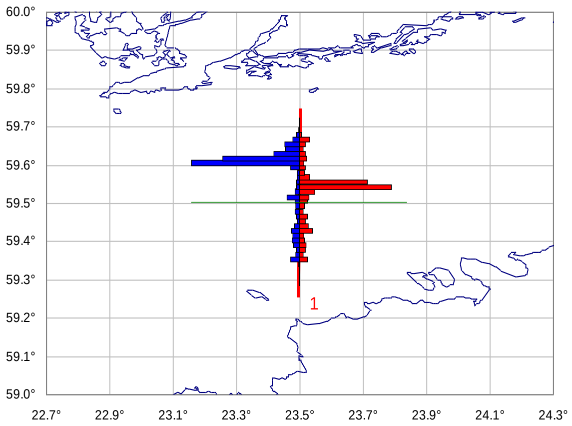

Fig. 4. Traffic flow at gate no 1 in July
Rys. 4. Strumień statków na bramce nr 2, lipiec

Marine traffic modeling

Marine traffic in the analyzed area is assumed to consist of four main flows: east, west, north, and south, while the north and south flows are assumed to contain passenger vessels only. Each flow is modeled with the following input parameters:

- overall number of vessels,
- type of vessels,
- number of vessels of given type,
- size of vessel of given type (distribution),
- speed of vessels of given type (distribution),
- course of vessel (distribution or histogram),
- position of vessel across the waterway (single or mixture of distributions or histogram).

According to analysis of traffic composition shown in figure 3, the following main groups of vessels are concerned:

- container carriers,
- tankers,
- general cargo vessels,
- ro-ro,
- passenger:
  - cruiser,
  - speed craft.

In Figures 5 and 6 discreet values of vessels' speed and courses are presented. For modeling purposes these values are approximated by continuous distribution. The distributions were chosen according to results of the χ^2 test. Those which fit best (obtained the highest value of χ^2 test) were selected as inputs for the model.

The outputs of the model are:

- number of encounters (crossing, overtaking, head-on),
- geometrical probability of collision for specified type of encounter,
- mean time between accident (collisions).

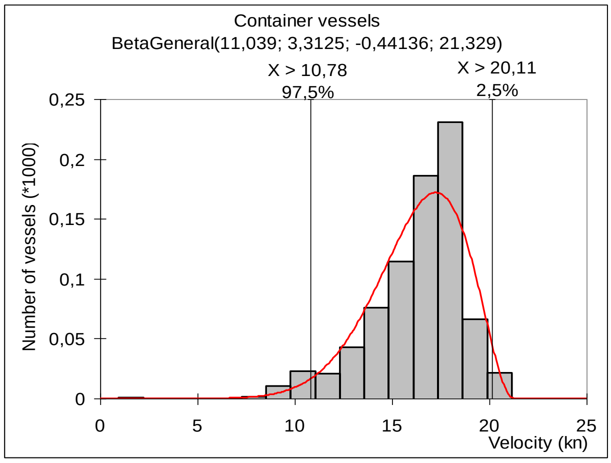

Fig. 5. Histogram of velocities of container vessels with distribution fitted
Rys. 5. Histogram prędkości statków kontenerowych wraz z rozkładem

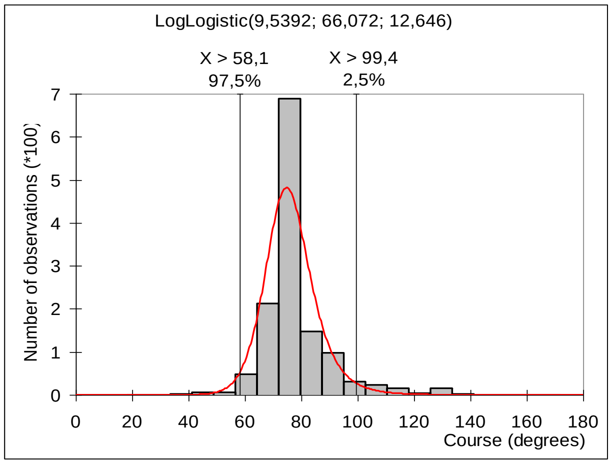

Fig. 6. Histogram of courses of eastbound flow registered in gate 1, with distribution fitted
Rys. 6. Histogram kursów statków płynących na wschód, zarejestrowany na bramce nr 1, wraz z rozkładem

Due to the complexity of traffic over the junction, it was divided into crossing areas, as shown in figure 7, and each area was analyzed separately.

The following main interactions between flows were analyzed:

- crossing situations in four crossing areas, as marked in figure 7, named respectively NE, NW, SW, SE;
- overtaking situations in four traffic lanes – North, South, East and West;
- head-on situations between lanes heading East-West and North-South.

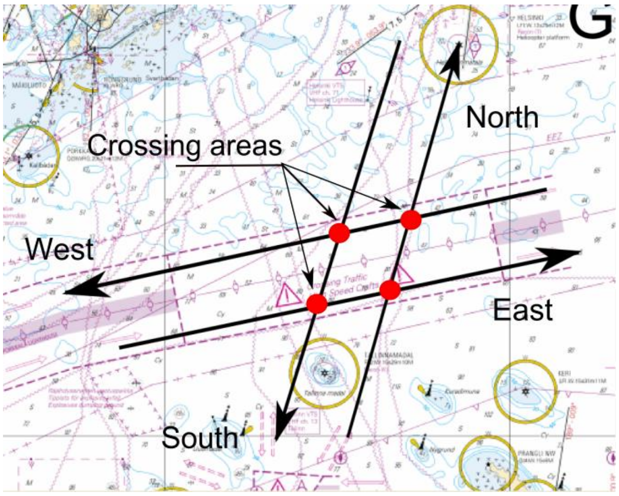

Fig. 7. Analyzed junction with four main crossing areas marked
Rys. 7. Analizowane skrzyżowanie strumieni ruchu statków z oznaczonymi czterema głównymi miejscami ich przecięcia się

Marine accidents

Data about marine accidents in the Gulf of Finland was extracted from HELCOM accidents database. The base covers the period between 1988 and 2008, and includes all marine accidents that occurred in the Baltic Sea area. According to this database, in the junction between Helsinki and Tallinn there were 3 collisions during last 20 years. Due to this very rare occurrence, inference based on the number of accidents is quite difficult and highly uncertain. Therefore it seems justified to analyze the near miss situations, which may better reflect the collisions hazard. Berglund & Huttunen in their report (2008) analyzed the meeting situations in the Gulf of Finland for the summer traffic (May, July, July) in 2006, 2007, and 2008. They provided data concerning near misses for crossing, overtaking and head on encounters. The near miss situation was defined there as a meeting of two vessels with distance less than 0.3 Nm. The abridged results of the analysis are collected in table 3.

Table 3. Number of near misses, according to type of encounter, summer traffic (May–July) in Gulf of Finland in 2006
Tabela 3. Liczba potencjalnych sytuacji grożących wypadkiem zgonie z typem spotkań, ruch w okresie letnim (maj–lipiec), zatoka Fińska, rok 2006

Encounter / Number	Head-on	Crossing	Overtaking
Total	8	419	943
Per month	2.8	142.7	321.1

Navigational risk modelling

The engineers define the risk as a product of probability of occurrence of an undesired event and the expected consequences according to formula [6]:

$$R = P \cdot C \tag{1}$$

where: P – probability of unwanted event (collision, grounding, etc); C – consequences.

These two components are equally important; therefore appropriate estimation of these values is a matter of great significance. This paper deals with modelling of one of these two components, the probability of vessels' collision.

Modelling the collision probability

The model presented in this paper for collision probability prediction is based on well-known gas molecular collision model. For the purposes of marine navigation, the model is simplified from its original three dimensions to two dimensions. In 2D GAS model, the vessel is represented as a particle surrounded by a disk of given radius (Fig. 8a), which constitutes the "no go area" for other objects. Some researchers define in the similar way the vessel's static domain [7, 8] while others call it the bumper [9], or guarding ring [10]. The domain is defined as the area around the vessel that the navigator wants to keep clear of other vessels or objects [11, 12, 13], therefore the violation of a vessel's domain is not tantamount to collision. The violation of the disk in GAS model is equal to collision. The collision between two vessels is described as an overlap of two disks, which represent the vessels. The occurrence of such overlapping is equivalent to the event, that a point representing a centre of one vessel enters the disk whose radius is twice as large as original (fig. 8b). A similar approach is presented by Fowler & Sørgråd (2000): they define the critical situation as the situation when two vessels come to close quarter crossing within 0,5 Nm of each other. In the GAS model that critical distance is not fixed, but changes with the situation.

The diameter of the greater disk (fig. 8b) is computed for each type of encounter individually. The value of that disk diameter is called Minimum Distance To Collision (MDTC) and shall be understood as the minimum distance between centres of two navigating vessels, being in close quarters, when it is still feasible to perform efficient collision avoidance manoeuvres by these two vessels together (fig. 9). The following assumptions were made: vessels manoeuvrability is a factor which determinate the MDTC value; vessels are performing manoeuvres simultaneously; human factor is not considered.

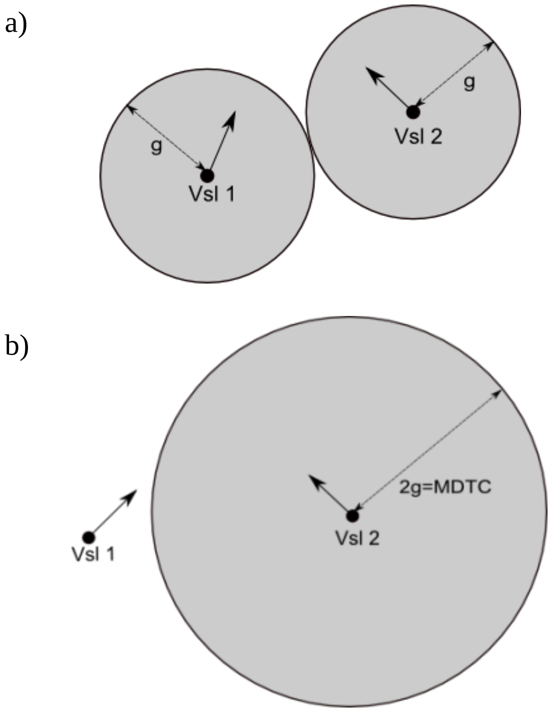

Fig. 8. Representation of vessels as disks and collision situation
Rys. 8. Statki przedstawione jako „dyski" i sytuacje kolizyjne

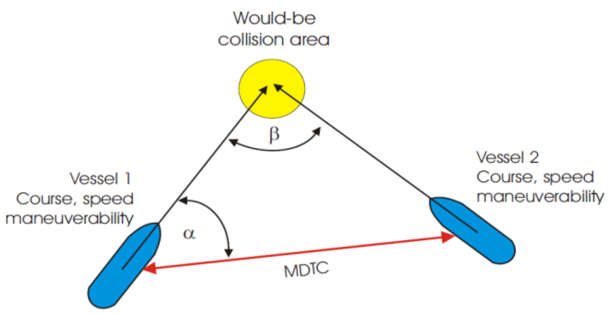

Fig. 9. Definition of MDTC, and factors affecting value of MDTC
Rys. 9. Definicja MDTC oraz czynniki wpływające na tę wartość

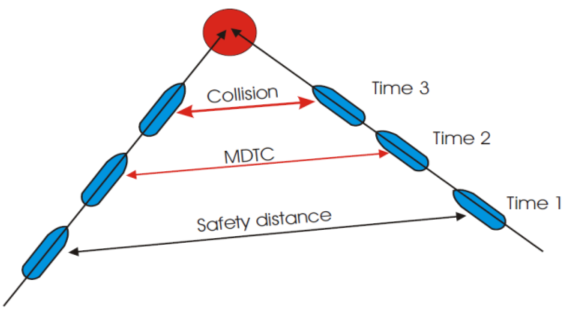

Fig. 10.The relationship between MDTC, safety passing distance, and collision
Rys. 10. Związek pomiędzy MDTC, odległością bezpiecznego minięcia oraz kolizją

If the distance between these two vessels becomes less then MDTC (fig. 8b), it means that collision may not be avoided by any manoeuvres, and the vessels will collide (fig. 10).

In other words, as long as the two disks of radius 0.5 MDTC each do not overlap the collision will not take place.

This paper presents the results of analysis of three main types of vessel encounters:

– overtaking,
– head-on,
– crossing.

Vessels on parallel courses – overtaking. In this case, vessels are navigating along the same route, on courses mutually parallel (the difference between courses does not exceed 5 degrees), but with different velocities. To estimate the probability of potential collision, one should calculate two parameters: overtaking rate (T) and probability that the vessels' domains are violated while overtaking (P_O). Overtaking rate (T) is the number of vessels which will overtake one another while on parallel courses irrespective of the passing distance. Overtaking rate is not a collision frequency, unless the waterway width is zero. The probability that the vessels' domains are violated while overtaking (P_O) equals the probability of the event that two vessels will pass each other with distance less than the adopted value. Overtaking rate is calculated with the following formulae:

$$T = \frac{N^2}{2L} E\left[V_{ij}\right] \tag{2}$$

where: N – expected number of vessels in waterway; L – length of waterway; $E(V_{ij})$ – expected relative velocity over all pairs of vessels of type i and j.

Expected relative velocity is determined as follows:

$$E\left[V_{ij}\right] = \sqrt{\left(V_i^2 + V_{ij}^2 - 2V_i\, V_j\, \cos\theta\right)} \tag{3}$$

where: V_i – velocity of vessel's group i [m/s]; V_j – velocity of vessel's group j [m/s]; Θ – difference between courses of vessels group i and j (angle of intersection).

Expected relative velocity taken all over possible pair of vessels is computed as follows:

$$E'\left[V_{ij}\right] = \frac{1}{N-1} \sum_{i,j}^{N} E\left[V_{ij}\right] \tag{4}$$

Probability of the event that the two vessels will pass each other with distance less than the adopted value (P_O) is expressed as follows:

$$P_O = P\left(x \le \frac{B_1 + B_2}{2}\right) \quad (5)$$

where: x – passing distance; B_1 – breadth of vessels' class 1; B_2 – breadth of vessels' class 2.

To assess value of P_O, one should follow the algorithm:

- on the basis of formerly known lateral distribution of vessels' positions across a waterway, pick up randomly positions of two vessels;
- compute the distance between these position;
- if the computed distance is less than or equal to the adopted value (e.g: 0.5(B1+B2)), define it as a success (1), otherwise as failure (0);
- store in memory if success, reject if failure;
- repeat procedure n times from 1 to 4;
- after adopted numbers of repetitions, compute the ratio of success to number of repetitions.

The geometrical probability of collision of two vessels while overtaking also referred to as the numbers of candidates for collision during overtaking, is expressed as follows:

$$N_{\text{overtaking}} = TP_O \quad (6)$$

where: T – overtaking rate; P_O – probability that vessels will pass each other with distance less than adopted value.

Vessels on parallel courses – head-on. The number of collision candidates during head-on meetings is calculated using formulas 2–6. It is assumed that differences between the two vessels' courses are to be within: 175–185° to consider such situation as a head-on meeting.

Vessels on crossing courses. To calculate the collision rate at the waterways intersections it is assumed that vessels are entering the waterway according to the Poisson process, with given velocity and given intensity, and processes of vessels' flows into waterways are independent. Number of collision candidates is determined on the basis of following equation:

$$N_{\text{crossing}} = \sum_{i,j} \frac{2gE\left[V_{ij}\right]\lambda_i \lambda_j}{V_i V_j \sin\alpha} \quad (7)$$

where: $2g$ – value of MDTC [m]; $E[V_{ij}]$ – expected relative velocity [m/s]; λ – intensity of which vessels enter the waterways; V – velocity of vessels according to type.

The number of collision candidates at waterways' intersections depends on vessels' velocities, vessels' dimensions, traffic intensities, angle of intersection. The rate does not depend on vessels' distribution across the waterway, whereas it was crucial in case of overtaking and head-on situations.

MDTC assessment

To determine the value of MDTC and factors that might affect it, the experiment using the hydrodynamic model of ship motion was conducted and several vessels' crossing meeting scenarios were simulated. Analysis was carried out for the following scenarios:

- 3 type of vessels (container carriers, passenger vessels and tankers),
- 6 meeting scenarios,
- 17 crossing angles varying from 10 to 170 degrees, with 10 degrees step,
- 4 types of maneuvers conducted by both vessels to avoid collision, as follows:
  - both vessels are changing their courses to port,
  - both vessels are changing their courses to starboard,
  - vessel 1 changes her course to port, while vessel 2 is turning to starboard,
  - vessel 1 changes her course to starboard, while vessel 2 is turning to port.

The following assumptions were made:

- vessels are proceeding with full sea speed;
- vessels are fully laden;
- vessels are performing maneuvers simultaneously;
- initial course of vessel 1 is always 360° and vessel 2 changes her initial course in each consecutive trial by 10° starting from 175° until 355°, producing therefore 17 crossing angles and 17 trials for each meeting scenario;
- the relative bearing from vessel 1 to vessel 2 equals 45±2 degrees (the most unfavorable meeting scenario);
- for the further analysis only the "turning away maneuvers" are concerned;
- the influence of weather conditions is omitted.

The "turning away maneuver" implies course alteration away from each other to avoid collision and to shorten the time being in close quarters. Data presented in table 4 define the turning away maneuvers depending on the initial course of vessel 2 (initial course of vessel 1 equals 360°).

Table 4. Away turning maneuvers
Tabela 4. Manewry „obejścia" statku

Type of maneuver / Vessel's 2 course	Vsl_1 to port Vsl_2 to stbd	Both to port	Both to stbd	Vsl_1 to stbd Vsl_2 to port
<185°–270°)	No	Yes	Yes	No
<270°–355°>	Yes	No	No	No

Recent research reveals that the vessel's safety domain, which might be comparable to MDTC, has a relatively low correlation with the sea state and wind force [10]. Therefore the hydro-meteorological conditions are not considered. The most intriguing question is: if and how the types of meeting vessels affect the value of MDTC. For that purpose the following meeting scenarios were simulated and appropriate nomenclature was adopted, used then in figure 11:

- two containers of same size (Cont_Cont),
- two containers of different size (Cont_diff),
- two tankers of same size (Tanker_Tanker),
- two tankers of different size (Tankers_diff),
- passenger – tanker (Tanker_Pass),
- two passenger vessels (Pass_Pass),
- passenger – container (Pass_Cont),
- LNG – container (LNG_Cont),
- LNG – LNG (LNG_LNG).

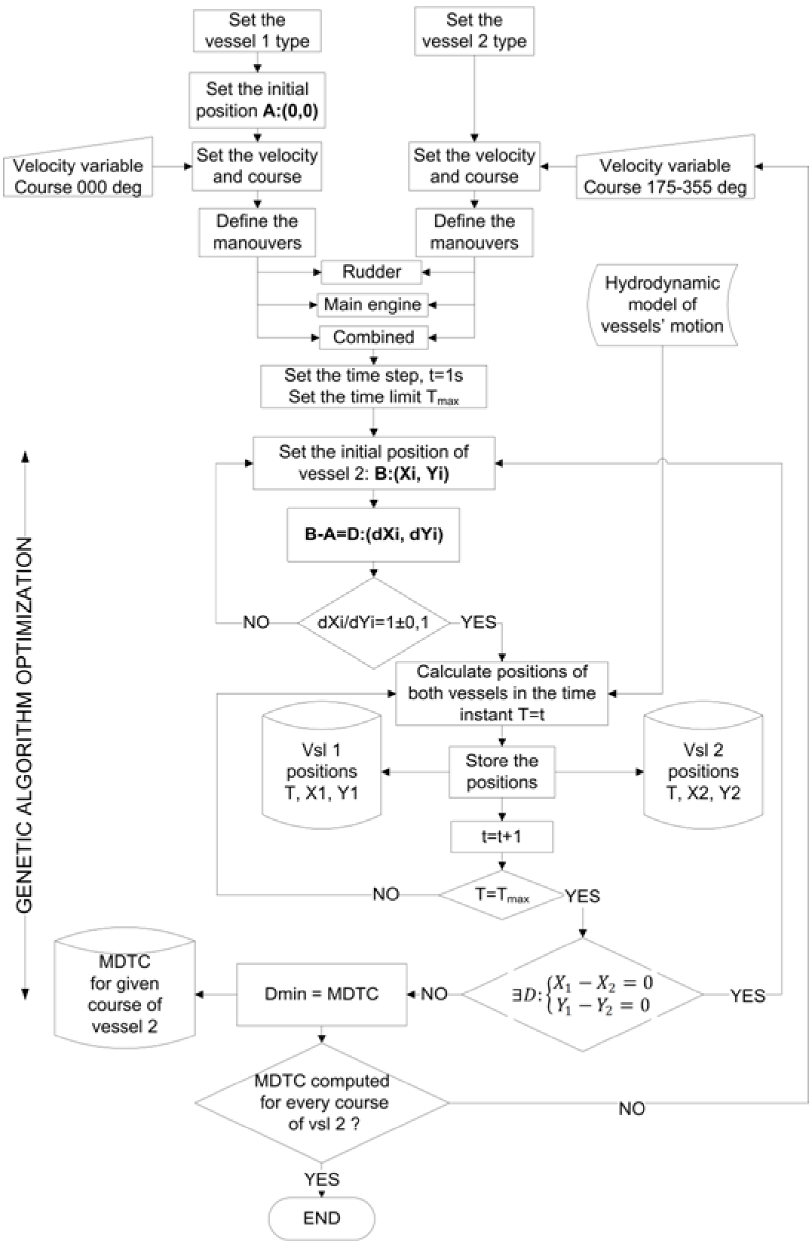

Fig. 11. The block diagram of algorithm for MDTC assessment
Rys. 11. Schemat blokowy algorytmu szacowania MDTC

As the analyses were conducted for the Baltic Sea, typical "Baltic" vessels were concerned, according to table 1. The algorithm for MDTC assessment is presented in figure 11. The optimization process, the aim of which is to obtain the minimum distance between two maneuvering vessels (MDTC), with steady maneuvering parameters (constant rudder angle, constant main engine settings, lack of wind and sea influence), is done with the use of genetic algorithms.

As evasive manoeuvres the following three actions may be considered: rudder action (hard to port/starboard) or main engine action (full astern) or combined action (rudder hard to side and full astern). However due to the relatively long response-time in case of engine manoeuvres performed on sea going vessels, they were omitted in the further analysis. Only rudder manoeuvres are concerned. Vessel's manoeuvrability is estimated by generalized hydrodynamic model of the vessel's motion, based on Abkovitz's model [14].

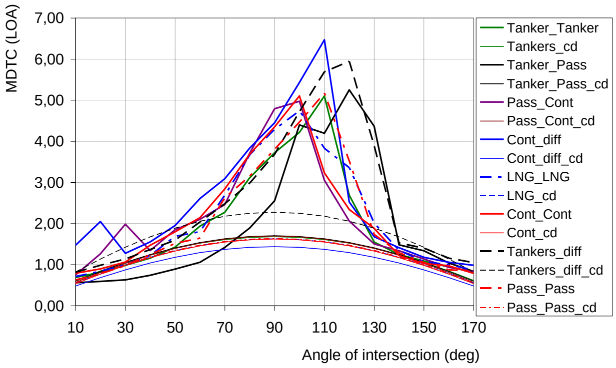

Fig. 12. Values of MDTC obtained for all meeting scenarios, with corresponding values of collision diameters

Rys. 12. Wartości MDTC określone dla wszystkich scenariuszy spotkaniowych wraz z wartościami średnicy kolizji

The results of this experiment are presented in figure 12, together with corresponding values of "collision diameter" used in Pedersen's model [15]. The collision diameter (CD) and MDTC may be considered equivalent in the principle. The figure 11 consists of a number of curves, which represent meetings of different types of vessels, according to the legend, the values of MDTC and CD are expressed in average length of vessels involved. Depending on the types of vessels engaged in meeting there are slight differences in MDTC values, therefore statistical analysis was done. An assumption was made, that each MDTC curve was treated as drawn from different population. To prove it a nonparametric Kruskal-Wallis test of the equality of medians for two or more populations was performed. The test's hypotheses are H_0: the population medians are all equal versus H_1: the medians are not all equal. In all analyzed cases the test statistic's had a *p*-value higher than adopted α-value ($p > 0.05$), indicating that null hypothesis can not be rejected. Therefore the results allow to assume all MDTC values be drawn from the same population. Due to limited survey sample, the further analysis was based on the Monte Carlo simulation, and both mean and standard deviation values were obtained. Afterwards, both MDTC and CD values at 95% confidence level were calculated, and the results are presented in figure 13.

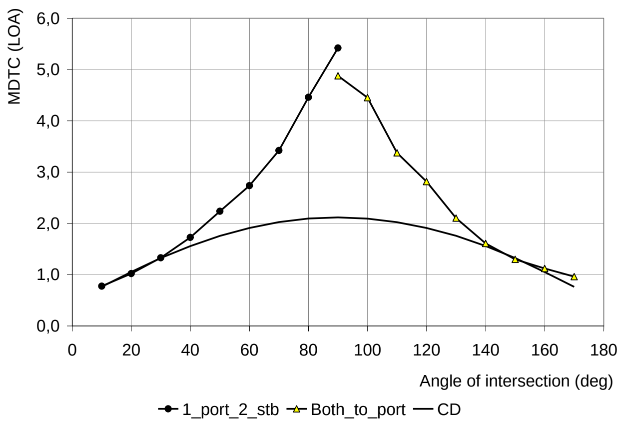

Fig. 13. MDTC and CD's values computed at 95% confidence level by use of Monte Carlo simulations

Rys. 13. Wartości MDTC oraz CD obliczone metodą Monte Carlo na 95% – poziomie prawdopodobieństwa

Results

Using the GAS model described above, the number of encounters per month for three types of vessel meeting situations are obtained. These values are compared with the number of encounters observed [2] and number of encounters computed by means of Pedersen's model. The results of this experiment are shown in table 5.

Table 5. Monthly number of encounters according to observation and models

Tabela 5. Miesięczna liczba sytuacji spotkaniowych statków, w zależności od obserwacji i modelu

Data source	Type of meeting		
	Crossing	Over-taking	Head on
Observation (Berglund&Huttunen)	142.7	321.1	2.8
GAS model	169.0	407.0	6.8
Pedersen	46.8	146.4	6.4
Pedersen_MDTC	104.3	146.4	6.4

The variances between estimated and observed values are presented in figure 14. They are expressed as a percent of observed values according to formula:

$$\Delta = \left(\frac{N_{GAS} - N_{OBS}}{N_{OBS}} \right) 100(\%) \qquad (8)$$

where: N_{GAS} – number of encounters obtained by use of the GAS model; N_{OBS} – number of encounters observed.

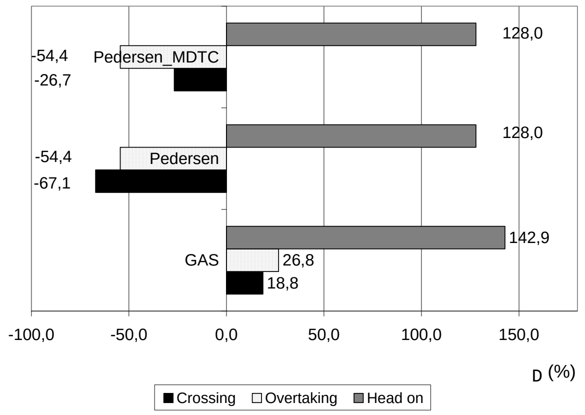

Fig. 14. The variance between estimated number of encounters and observed numbers
Rys. 14. Różnica pomiędzy szacowaną liczbą spotkań, a liczbą obserwowanych

Discussion

This paper presents new approach of probability of collision modeling. Innovative use of a ship's motion model to determine the Minimum Distance To Collision may be recognized, as this approach meets the demands expressed in recent works [4] and the obtained results are very promising. The number of encounters in the Gulf of Finland for the summer traffic obtained by means of the GAS model is very close to observed values. The GAS model overestimates the number of crossing situations by 19%, whereas Pedersen's model underestimates this number by almost 70%. The number of encounters computed by a modified Pedersen model, with MDTC module applied, is still 27% less than observed value.

In case of overtaking GAS model overestimates the result, but even though it seems reasonable (27%). On contrary Pedersen model's result are underestimated (–55%).

Number of head on meetings is overestimated by both GAS and Pedersen's models, and in that case the results are comparable. It should be mentioned that only E–W traffic was considered, and N–S traffic was rejected. The assumption was made, that vessels cruising in N–S flow, which are passenger liners, are operated by highly skilled crew, and head on meetings do not occur (and are controlled if they do).

Slight overestimation of the results by GAS model seems natural. In real traffic ships have the possibility to avoid each other, which is not included in geometrical model. One may hazard a guess that models should give larger results than what can be get by observation of real traffic.

The modeling of MDTC should be continued; present analysis concerns chosen types of vessels, typical for Baltic Sea, equipped with typical propulsions and steering gears. The ship's motion model implemented into the MDTC assessing algorithm uses generalized data, dependant on the ship's type, which might also raise some uncertainties in case of specialized vessels (vessels with non conventional propulsion). As more AIS data becomes available, successive analysis for the years 2008 and 2009 are expected to be carried out.

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