RESEARCH REPORT

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Collision and grounding frequency analyses in the Gulf of Finland

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Confidentiality: Public

Baltic Sea Safety

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Summary

The main objective of the study was to estimate the collision and grounding frequencies of ship traffic in the Gulf of Finland. The second objective was to further exploit the usability of GRISK software in risk analyses as part of the Formal Safety Assessment process. The calculations are based on AIS data from 2008.

According to the calculations, the highest accident frequency areas are concentrated along the entire routeing system in the Gulf of Finland. The expected frequency of ship-to-ship collisions is 0.243 incidents per year, which is fairly consistent with the number of occurred collisions of 0.22 accidents per year. However, because of the small number of relevant accidents, the historical collision frequency is an imprecise estimate of the expected collision frequency. The expected "hot spots" of bend collisions in the areas of the two westernmost TSSs in the Gulf of Finland seem odd, because the lanes of opposite traffic are quite far apart. However, the expected high overtaking collision frequencies in the narrow Traffic Separation Scheme areas of the eastern Gulf of Finland are realistic due to the big speed differences of the ships. The expected frequency of powered groundings is 0.572 incidents per year, which is barely one third of the average annual number of occurred groundings in the Gulf of Finland. One reason for the low frequency estimates could be that the route legs nearest the ports were omitted from the calculation model. Another reason could be the insufficient information reported from the accidents. Some of the grounding accidents selected for verification should perhaps be classified as drift groundings, which are not taken into account in the calculation model. Based on the calculations, the most probable ship type is general cargo ship in collisions and container ship in groundings, which makes sense as these two ship types are the most common in the Gulf of Finland.

Roughly 80% of the traffic is included in the traffic model used in the calculations. The main ship traffic consisting of passenger vessels, cargo vessels and tankers is well represented in the model, compared with only about 25% of traffic in the categories support ships, fishing ships and leisure boats. This is attributed to the route network creation process of the traffic model, in which route legs are placed in high traffic density areas. Vessels like support ships, fishing ships and leisure boats often stay away from high-density routes.

Confidentiality	Public

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1 Introduction

The Gulf of Finland is a sea area between Finland and Estonia bordering Russia in the east. The gulf has an area of 29,500 km^2, length of 428 km and width of up to 120 km. The deepest parts of the gulf are at its mouth, where there is a deep with a depth of 80–100 metres. There are depths of over 100 metres at the southern coast, while the depth at the northern coast never exceeds 60 metres. Much of the northern shoreline is fairly shallow and rocky, making it difficult or even dangerous to navigate the coastal waters there without accurate charts. The deepest point, 121 m, is at the Estonian coast, just northeast of Tallinn. About 5% of the water mass in the Baltic Sea is located in the Gulf of Finland.

The main concern in the Gulf of Finland is the rapid increase in oil tanker traffic. In 2008 the annual amount of oil transport was about 145 million tons, almost sevenfold compared with 1995, and is expected to reach 250 million tons by 2015 (Figure 1). Oil tanker traffic crosses the Gulf of Finland mainly in the east-west direction, intersecting the routes of frequent passenger traffic between Helsinki and Tallinn and increasing the risk of serious accidents.

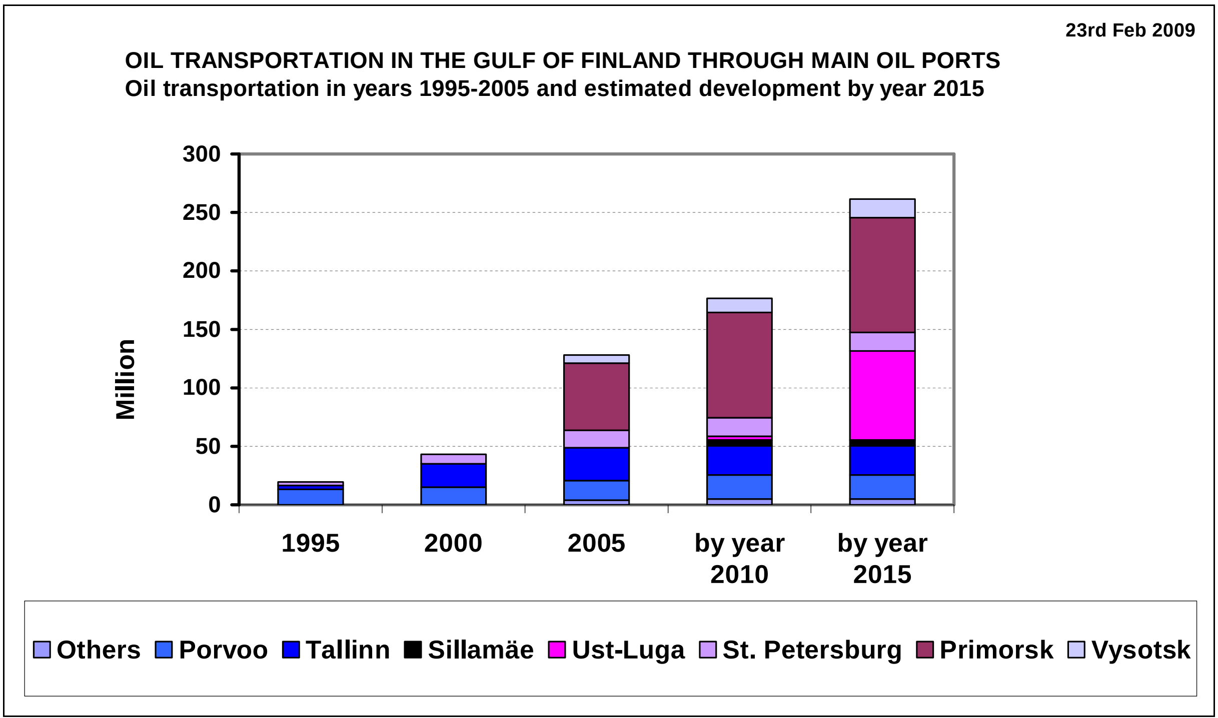


Figure 1 Oil transportation in the Gulf of Finland based on port statistics [Source: SYKE and VTT].

In order to reduce the risk of ship accidents, ship traffic in the Gulf of Finland is monitored both by the national VTS stations and the GOFREP system managed in Finland by Helsinki Traffic, in the Russian Federation by St. Petersburg Traffic, and in Estonia by Tallinn Traffic. The monitoring areas are shown in Figure 2.

The traffic in the Gulf of Finland is organised in accordance with traffic separation schemes dividing eastbound and westbound traffic along their own lanes (Figure 2).

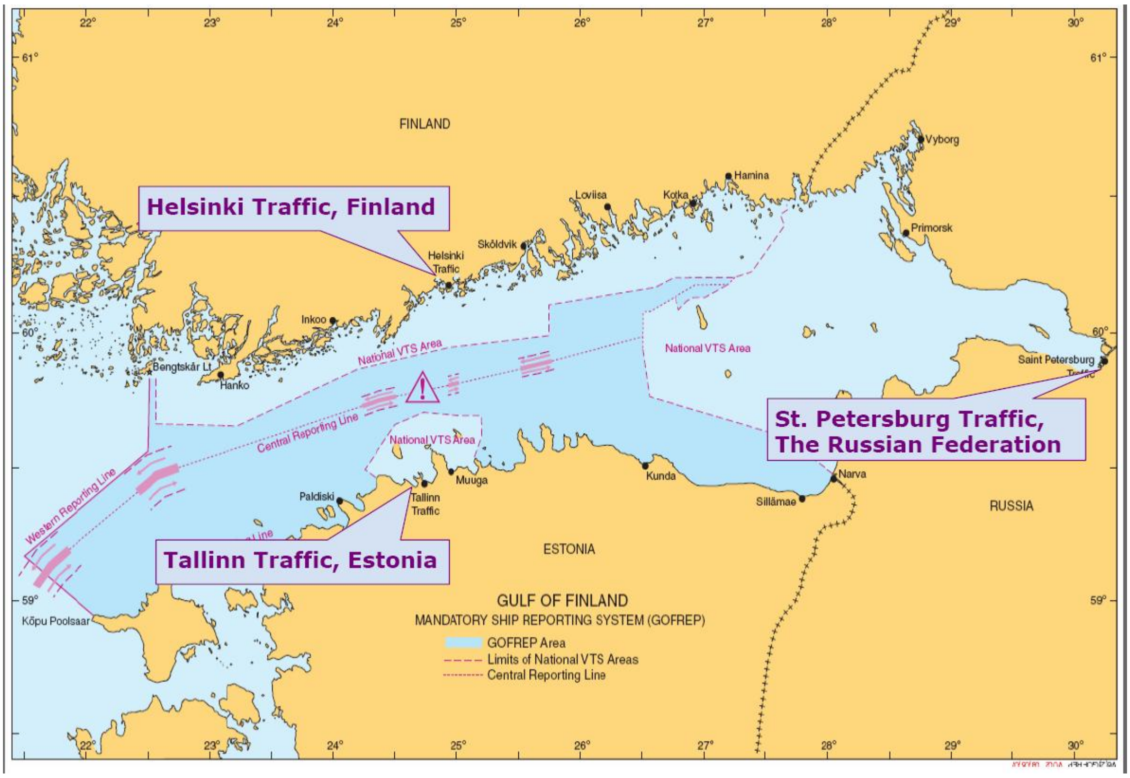


Figure 2 GOFREP and national VTS areas in the Gulf of Finland [Source: Finnish Maritime Administration].

The accident frequency and traffic analyses reported here are based on the traffic situation of 2008.

The Gulf of Finland freezes each year but the extent of ice cover varies from winter to winter; in 2008 it was the smallest ever recorded (Figure 3). The thickness of fast ice in the western and middle parts of the gulf was 1-10 cm and in the eastern part 15-30 cm.

This study is part of the Nordic BaSSy project (Baltic Sea Safety). One of the objectives of the project is to develop harmonised principles for the Formal Safety Assessment (FSA) process to be applied in the Baltic Sea. The project is formed by the following organisations: SSPA Sweden AB (SSPA), MSI Design, Chalmers Shipping and Marine Technology (Chalmers) from Sweden, VTT Technical Research Centre of Finland (VTT) from Finland, and the Technical University of Denmark (DTU) and Gatehouse from Denmark. In addition to national funding, the project is also financed by the Nordic Council of Ministers. The GRISK software, which was partly developed within the BaSSy project by DTU and Gatehouse, was used for calculation of the collision and grounding frequencies in this study. Development of the GRISK software has subsequently continued under the name IWRAP Mk2 (IALA Waterway Risk Assessment Program).

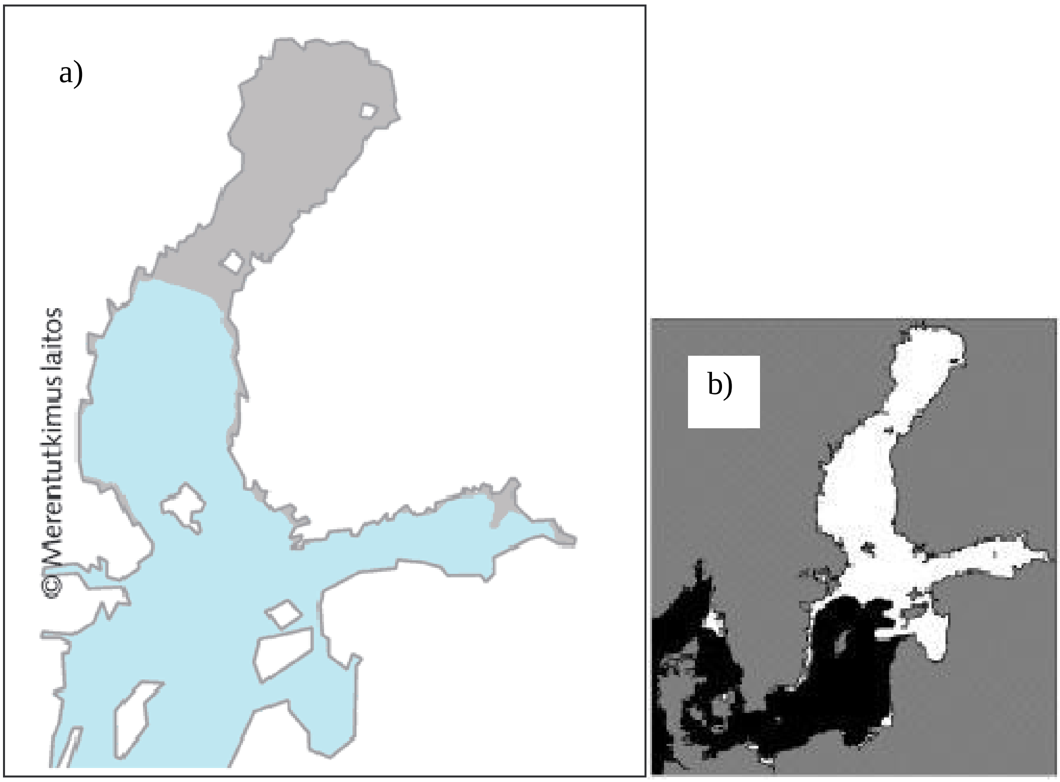


Figure 3 a) The maximum extent of ice cover on the whole Baltic Sea (49 000 km²) in 2008 was recorded on March 24th. b) The maximum extent of ice cover on the Baltic Sea in a normal winter is about 200 000 km².

2 Goal

The main objective of the study was to estimate the collision and grounding frequencies of ship traffic in the Gulf of Finland. The second goal was to further exploit the usability of GRISK software in risk analyses needed in the FSA process. The calculations are based on AIS data from 2008.

3 Limitations

In the ship collision and grounding frequency calculation model, only open sea areas were modelled. The harbour areas and fairways inside the archipelago were excluded. Because the winter of 2008 was extremely mild the same traffic model was used for the whole year.

As the calculation software uses historical AIS data in the analysis, vessels smaller than 300 GT were excluded. This leaves groundings of or collisions with leisure or other small crafts outside the analysis.

4 Methods

4.1 GRISK

Actual calculations to estimate collision and grounding frequencies were performed using the GRISK software version 2.1.1. which was partly developed by DTU and Gatehouse as part of the BaSSy project. The software succeeds the GRACAT software (Grounding and Collision Analysis Toolbox), which was validated in case studies by the developers. Development of the GRISK software has subsequently continued under the name IWRAP Mk2 (IALA Waterway Risk Assessment Program).

In the collision and grounding analysis, the latent accident frequency is first calculated from the traffic data. The latent frequency represents the amount of theoretically possible collision situations per unit time, assuming blind navigation. The *expected* frequency of an accident type is then obtained by multiplying the latent accident frequency by the expected value of the causation factor related to the accident type.

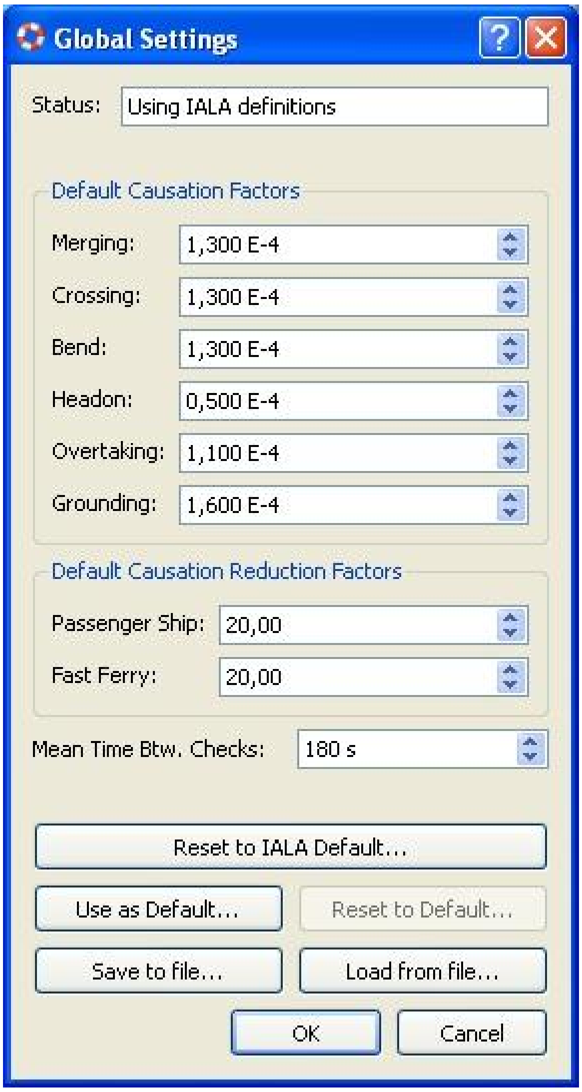
The causation factor represents the capability of vessels to notice the presence of a dangerous encounter situation in time and to react by taking sufficient steps to avoid an accident. The causation factor depends on several functions related to traffic perception, communication and avoidance actions. It also depends on external factors such as the vessel types involved in the accident, weather conditions, physical manoeuvre options, etc. The smaller the causation factor, the better is the capability of the navigators to avoid potential accidents.

With respect to ship-to-ship collision situations, GRISK examines five collision scenarios separately, namely:

1. *Overtaking collision*, in which two vessels moving in the same direction collide on a straight leg of a fairway as a result of one overtaking the other
2. *Head-on collision*, in which two vessels collide on a straight leg of a fairway as a result of two-way traffic on the fairway
3. *Crossing collision*, in which two vessels using different fairways collide at the fairway crossing
4. *Merging collision*, in which two vessels using different fairways collide at the merging of the fairways
5. *Bend collision*, in which two vessels moving in opposite directions on the same fairway collide on a turn of the fairway as a result of one of the vessels neglecting or missing the turn (error of omission) and thus coming into contact with the other vessel

GRISK enables the use of different causation factor values for each collision type. In this study, the default causation factor values of GRISK version 2.1.1 were used and are given in Table 1. In addition, a reduction factor of 20 is applied to passenger ships and fast ferries in the default settings, which means that the causation factor is divided by 20 for these ship types.

Table 1 Default causation factor values of GRISK version 2.1.1.



Grounding frequencies were estimated in similar manner as the collisions: first, the latent grounding frequencies were derived, i.e. number of ships on a grounding course, which were then multiplied with the corresponding causation factor. Two types of powered groundings were examined:

1. *Ships following the ordinary direct route at normal speed.* Accidents in this category are mainly due to human error, but may include ships subject to unexpected problems with the propulsion/steering system that occur in the vicinity of the fixed marine structure or ground.

2. *Ships that failed to change course* at a given turning point near the obstacle.

For grounding type 1, the causation factor represents the fraction of the grounding candidates which fail to avoid the obstacle, whereas for type 2 the causation factor represents the fraction failing to change course at the given point. In type 2, the vessel can still avoid grounding after failing to make a turn if it is able to detect the error in time. The officer of the watch is assumed to check the position of the ship randomly following a Poisson process. The checking frequency is determined by a modelling parameter called the *average time between checks*. The collision and grounding analysis methodology is further described in [1]. The drift grounding calculation module was not used in the analysis.

GRISK takes into account different characteristics of ships such as length, width, speed etc. by categorising ships according to ship type and length. The ship types used are crude oil tanker, oil products tanker, chemical tanker, gas tanker, container ship, general cargo ship, bulk carrier, Ro-Ro cargo ship, passenger ship, fast ferry, support ship, fishing ship, pleasure boat and other ship.

Water depth information was needed in the grounding risk analysis module in the GRISK software. For this analysis, electronic nautical chart material including coastlines and water depth curves were received from the FMA. The chart material was converted from ESRI Shapefile (.shp) format into XML for use in the GRISK software. The conversion process is described in Appendix 1.

4.2 Modelling of the sea area

Calculation of the collision frequencies is based on careful specification of the operational environment of the ship traffic considered. The ship routes relevant to the present study were based on a density plot of the 2008 AIS data covering the examined sea area (Figure 4). The routes consist of legs that are defined as straight lines between given waypoints (Figure 5).

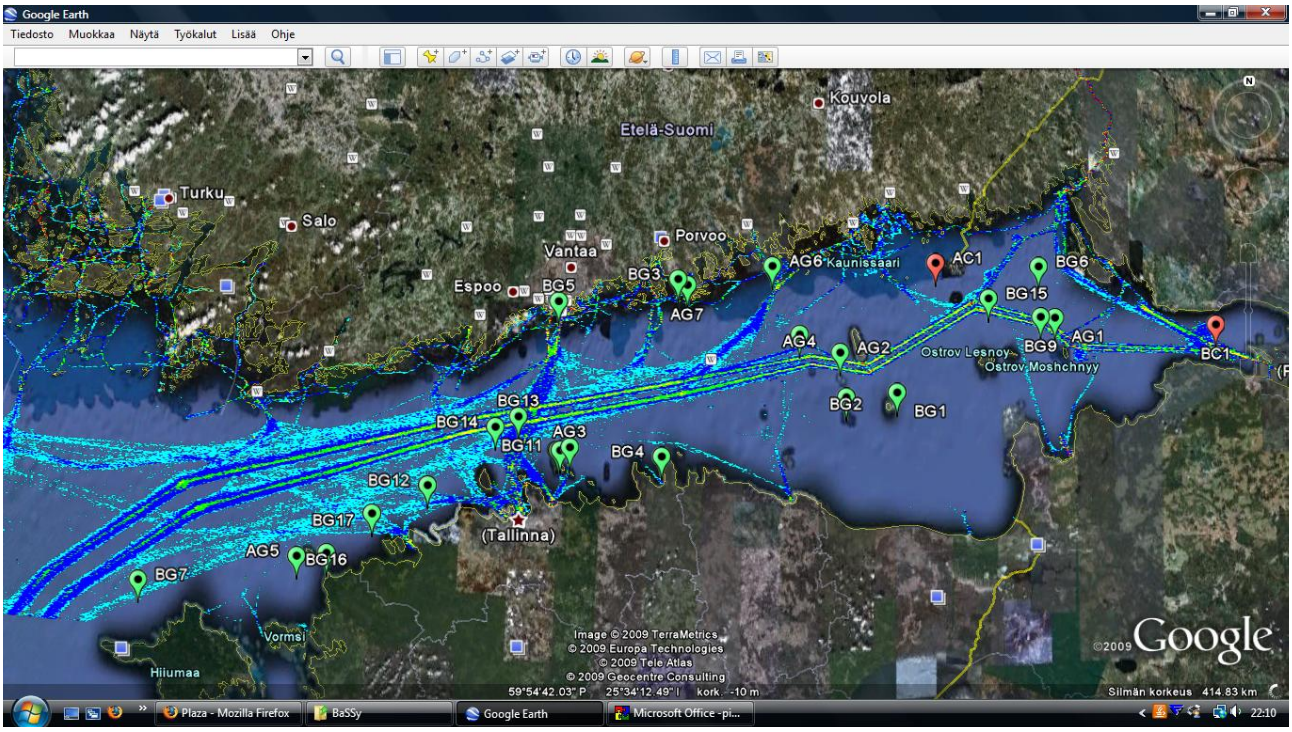


Figure 4 Ship traffic density plot and locations of the selected accidents in the Gulf of Finland. The red markers denote the position of a collision; the green markers denote grounding sites. Letter "A" in the marker denotes accidents that occurred after and letter "B" before implementation of the GOFREP system.

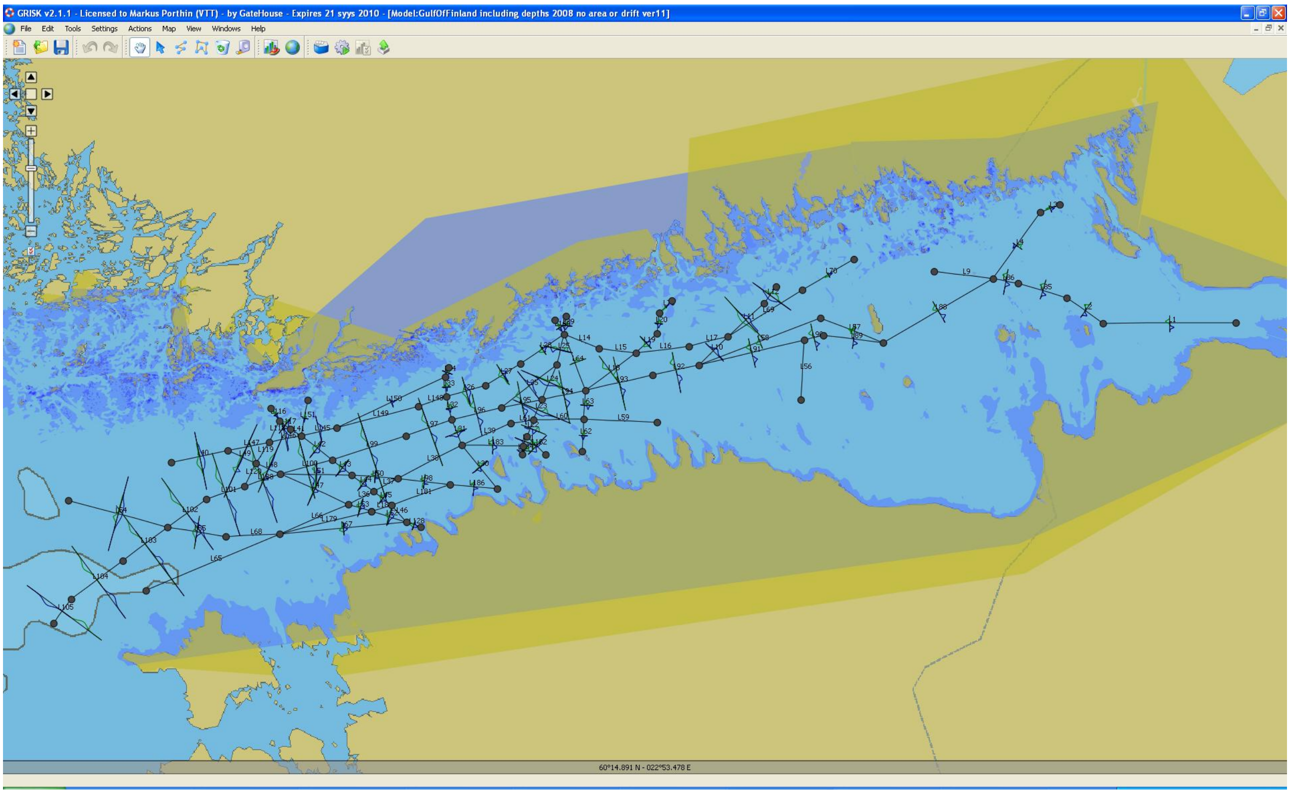


Figure 5 Traffic model used in the study.

AIS traffic data for 2008 were also used for estimating the annual numbers of vessels of different types and lengths on the various routes. The AIS signals were allocated to the route net by defining reference lines to each traffic leg. All ships that cross a reference line with less than a 20° angle to the leg are associated with that leg. A relatively small proportion of the total traffic does not fulfil the given conditions and is therefore discarded from the analysis. However, this is judged not to have any significant effect on the analysis. The ship types were ascertained from the Lloyd’s Database.

The lateral distribution of traffic on each route leg was specified based on AIS data. Histograms of the traffic crossing the reference line of each leg was processed from the AIS data as shown in the example in Figure 6. Theoretical distributions consisting of a mixture of either a normal distribution and a uniform distribution or two normal distributions were then fitted to the histograms as shown in Figure 7.

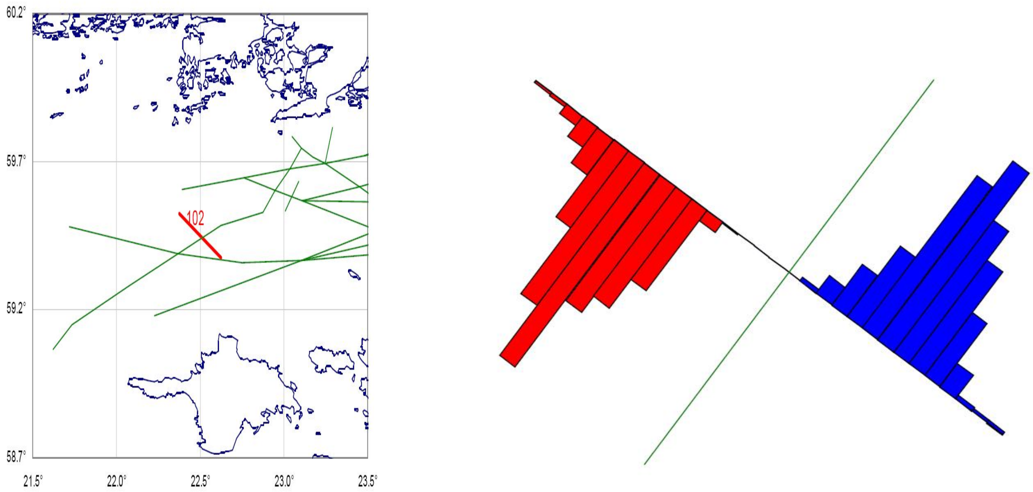


Figure 6 Example of a histogram showing the observed lateral distribution of traffic on a leg.

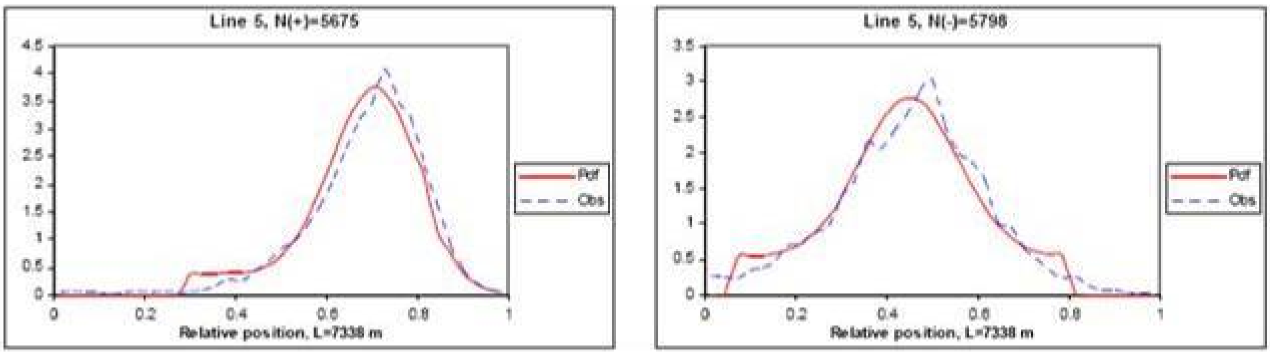


Figure 7 Example of a theoretical distribution (solid red line) fitted to the observed traffic (dashed blue line). Southbound traffic on the left and northbound on the right.

5 Results

5.1 Traffic analysis

Traffic analyses in this study were performed using the GRISK software and are based primarily on historical AIS data recorded in 2008. In addition, HELCOM AIS statistics were used in the analysis as a comparison.

The majority the ship traffic in the longitudinal direction on the Gulf of Finland follows the routeing system based on a sequence of Traffic Separation Schemes established on the Gulf of Finland (green line in Figure 8). According to the traffic analysis the annual number of vessels sailing along this route is almost 28000 vessels (including both directions) at the western end, decreasing eastwards to about 14500 vessels in the easternmost leg. The traffic consists mainly of container and general cargo ships (about 50% of vessels), but Ro-Ro cargo ships and oil product tankers are a significant part of the traffic on the western half of the route. About 5% of the vessels are crude oil tankers, most of them over 225 m in length, sailing the entire longitudinal route on the Gulf of Finland. The amount of traffic divided into different ship types on six legs along this route is shown in and . The location of the selected legs is shown in .

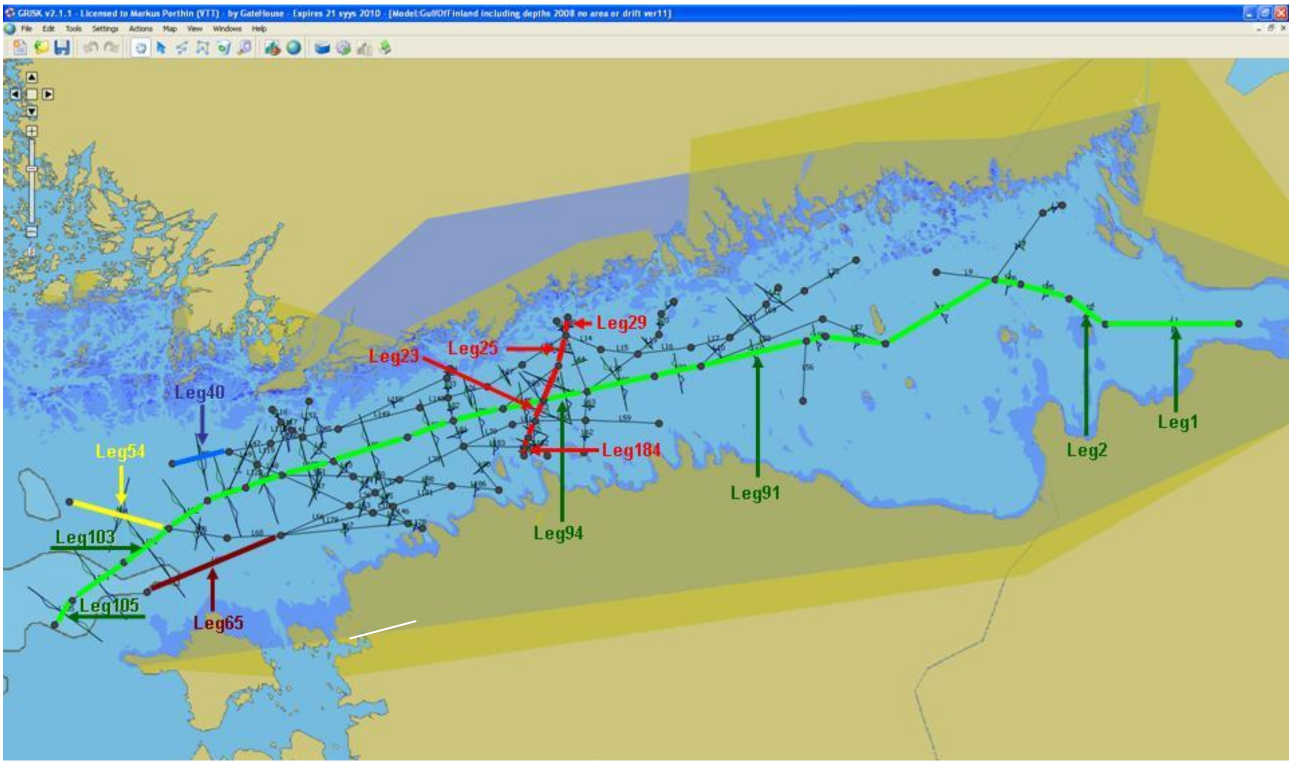


Figure 8 Main traffic routes in the Gulf of Finland used in the calculation model. Main route in the east–west direction along the Traffic Separation Schemes (green line) and the main route between Helsinki and Tallinn (red line).

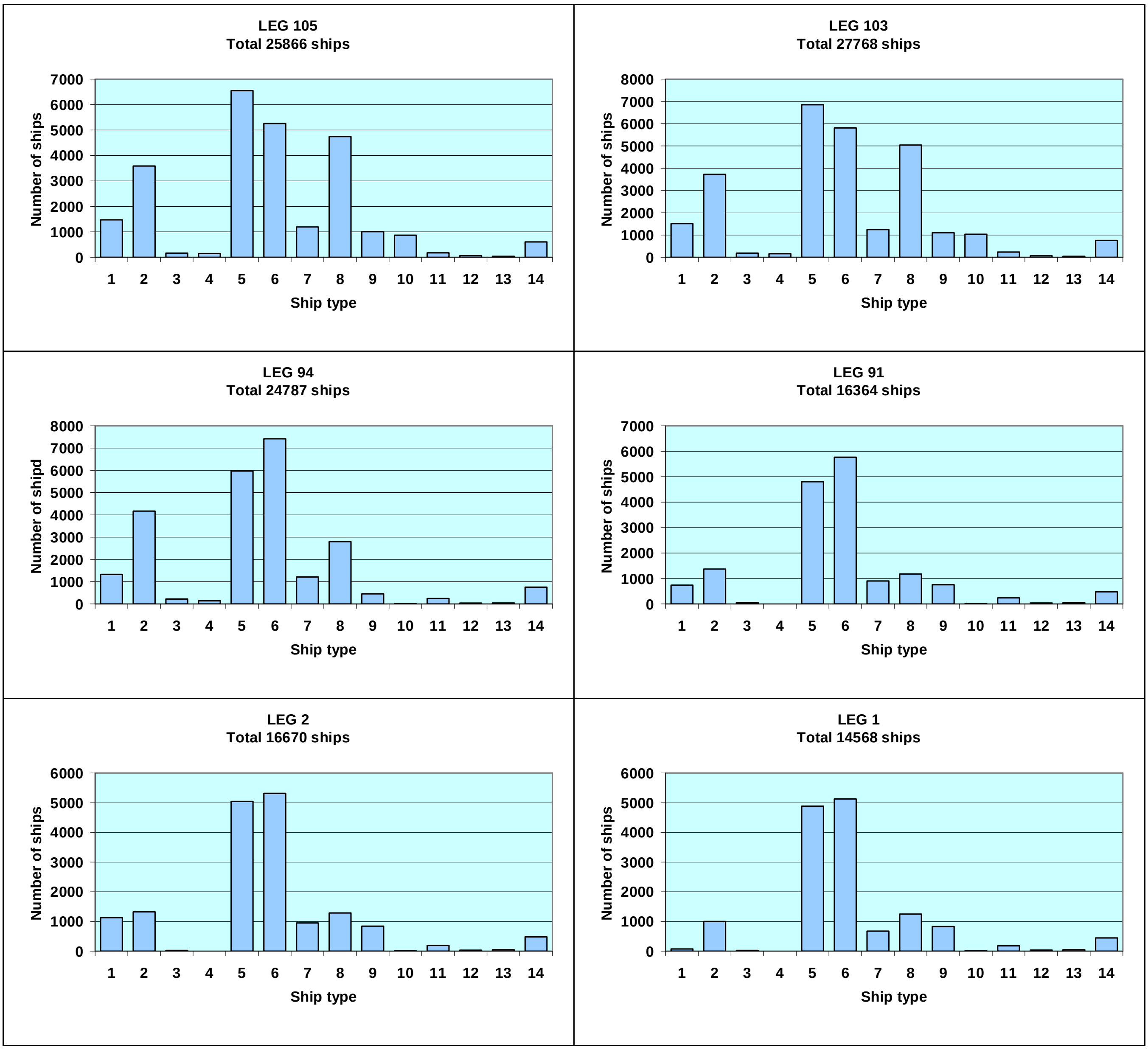


Figure 9 Main longitudinal traffic flow in the Gulf of Finland (green line in Figure 8). Number of vessels divided by ship type crossing Legs 105, 103, 94, 91, 2 and 1 in both directions. The column numbers are as follows: 1 = crude oil tanker, 2 = oil products tanker, 3 = chemical tanker, 4 = gas tanker, 5 = container ship, 6 = general cargo ship, 7 = bulk carrier, 8 = Ro-Ro cargo ship, 9 = passenger ship, 10 = fast ferry, 11 = support ship, 12 = fishing ship, 13 = pleasure boat and 14 = other ship.

Table 2 Number of ships divided by ship type on different legs of the longitudinal main route in the Gulf of Finland.

Ship type	Ship type	Number of ships					
		Leg 105	Leg 103	Leg 94	Leg 91	Leg 2	Leg 1
Crude oil tanker	1	1471	1515	1328	737	1128	73
Oil products tanker	2	3586	3726	4168	1369	1323	999
Chemical tanker	3	164	186	217	51	24	24
Gas tanker	4	147	159	140	0	0	0
Container ship	5	6548	6854	5971	4803	5042	4883
General cargo ship	6	5258	5809	7419	5766	5314	5124
Bulk carrier	7	1192	1244	1212	902	949	674
Ro-Ro cargo ship	8	4744	5040	2796	1175	1286	1248
Passenger ship	9	1008	1101	452	756	840	828
Fast ferry	10	868	1036	7	6	11	8
Support ship	11	175	234	242	238	192	180
Fishing ship	12	63	65	40	39	33	34
Pleasure boat	13	39	41	42	48	47	47
Other ship	14	603	758	753	474	481	446
Sum		25866	27768	24787	16364	16670	14568

Ship traffic in the transverse direction across the Gulf of Finland runs mostly between Helsinki and Tallinn (red line in Figure 8). The annual number of vessels on this route is about 13500 vessels (including both directions) in the north, decreasing to about 10000 vessels in the south. Roughly half of the traffic consists of fast passenger ferry traffic between Helsinki and Tallinn, the other half being mostly container and passenger ships. On the northern part of the route, Ro-Ro cargo ships sailing between Helsinki and ports around the Baltic Sea and North Sea form a significant part of the traffic. The results of the traffic analysis are shown in greater detail in Figure 10 and Table 3.

In addition to the traffic on the main routes mentioned above, there is significant traffic from the Finnish ports to Sweden following the Finnish coastline on the north side of the routeing system. Passenger-car ferry traffic between Helsinki and Stockholm is an important part of this traffic. Also joining this flow is the passenger-car ferry traffic between Tallinn and Stockholm via Mariehamn. Totally this comes to 5000 vessels sailing annually through Leg 40 in Figure 8. Half of the traffic is passenger vessels and one quarter is container ships (Figure 11).

Another significant longitudinal traffic flow outside the main traffic routes in the Gulf of Finland is traffic following the Estonian north coast on the south side of the routeing system and being directed towards ports around the Baltic Sea and elsewhere in Europe. This traffic (Leg 65 in Figure 8) consists of about 4300 vessels. Some 60% of these are general cargo ships, 13% container ships and 13% Ro-Ro cargo ships (Figure 12).

The third traffic flow outside the main traffic routes of the Gulf of Finland moves westwards from the port of Paldiski in Estonia, crossing the routeing system and consisting of about 1500 vessels (Leg 54 in Figure 8). Of this traffic, 40% is passenger ships sailing daily between Paldiski and Kapellskär, 28% is oil products tankers, and 20% is general cargo ships (Figure 13).

The annual numbers of vessels of different types and lengths on each leg in the traffic model are presented in Appendix 2.

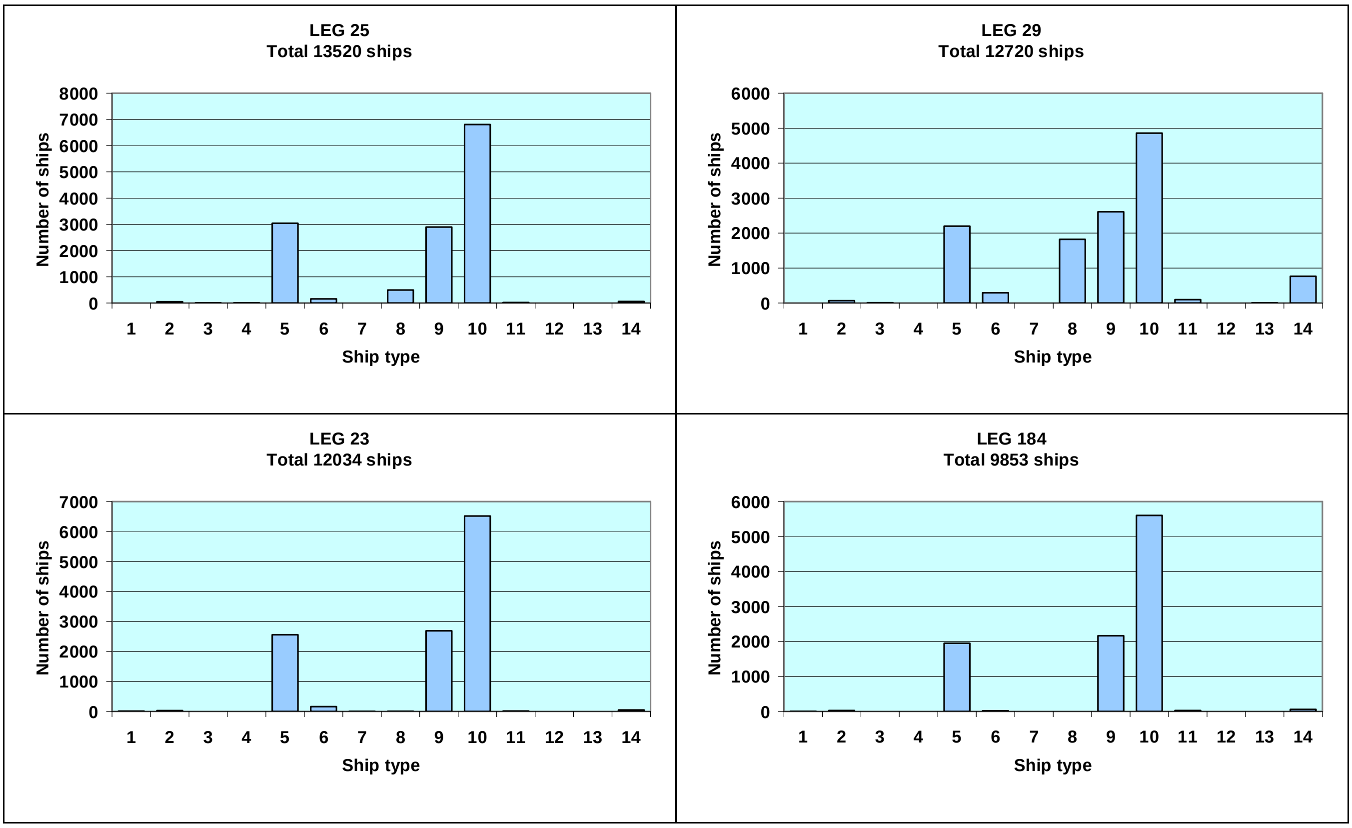


Figure 10 Main traffic flow in the transverse direction on the Gulf of Finland (red line in Figure 8). Number of vessels divided by ship type crossing Legs 25, 29, 23 and 184 in both directions. The column numbers are as follows: 1 = crude oil tanker, 2 = oil products tanker, 3 = chemical tanker, 4 = gas tanker, 5 = container ship, 6 = general cargo ship, 7 = bulk carrier, 8 = Ro-Ro cargo ship, 9 = passenger ship, 10 = fast ferry, 11 = support ship, 12 = fishing ship, 13 = pleasure boat and 14 = other ship.

Table 3 Number of ships divided by ship type on different legs of the transverse main route in the Gulf of Finland.

Ship type	**Ship type number**	**Number of ships**			
		Leg 25	**Leg 29**	**Leg 23**	**Leg 184**
Crude oil tanker	1	0	0	9	2
Oil products tanker	2	49	68	27	26
Chemical tanker	3	2	8	1	1
Gas tanker	4	2	0	0	0
Container ship	5	3040	2199	2560	1949
General cargo ship	6	155	292	159	19
Bulk carrier	7	0	0	2	0
Ro-Ro cargo ship	8	495	1822	6	1
Passenger ship	9	2896	2610	2690	2164
Fast ferry	10	6804	4857	6518	5605
Support ship	11	19	97	14	25
Fishing ship	12	0	0	0	0
Pleasure boat	13	1	4	1	1
Other ship	14	57	763	47	60
Sum		13520	12720	12034	9853

LEG 40
Total 5166 ships

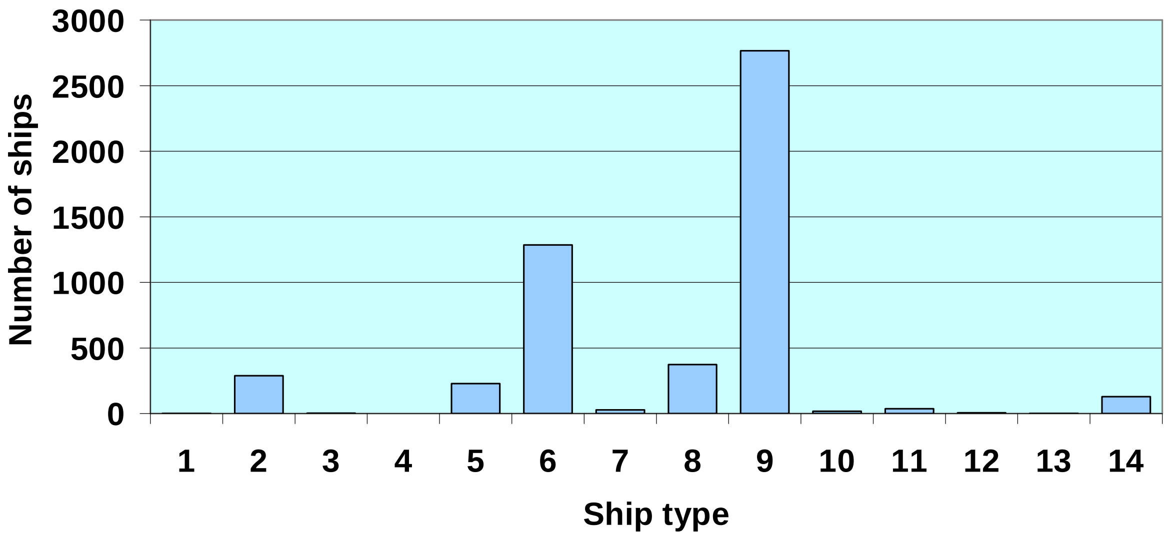


Figure 11 Traffic flow on Leg 40 in (blue line in Figure 8) consisting mainly of vessels going from Finnish and Estonian ports to Stockholm and vice versa.

LEG 65
Total 4312 ships

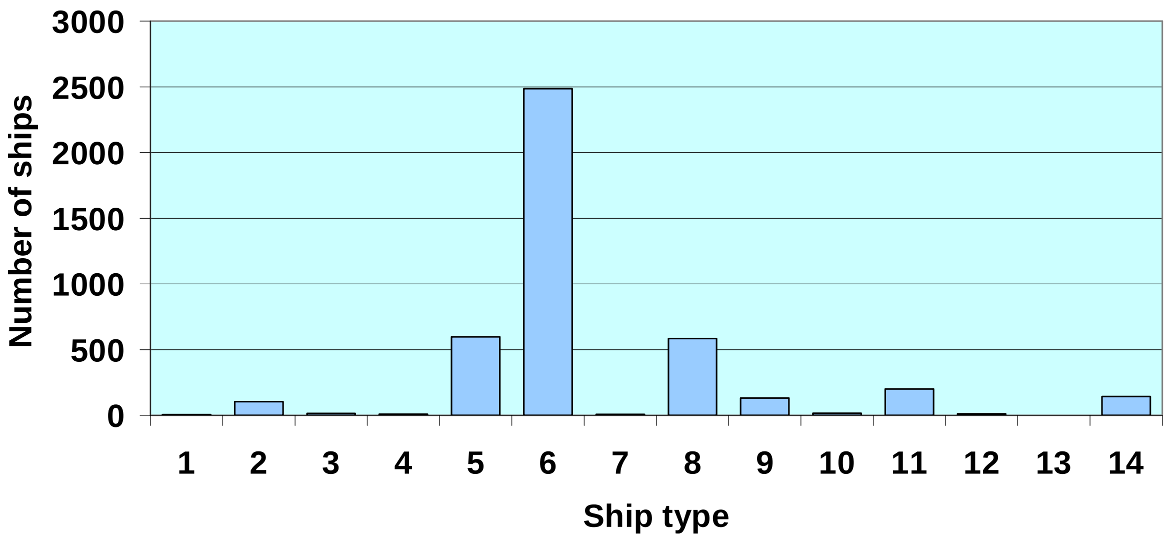


Figure 12 Traffic flow on Leg 65 in (brown line Figure 8) consisting mainly of vessels going from Estonia to ports around the Baltic Sea outside the Gulf of Finland and European ports and vice versa.

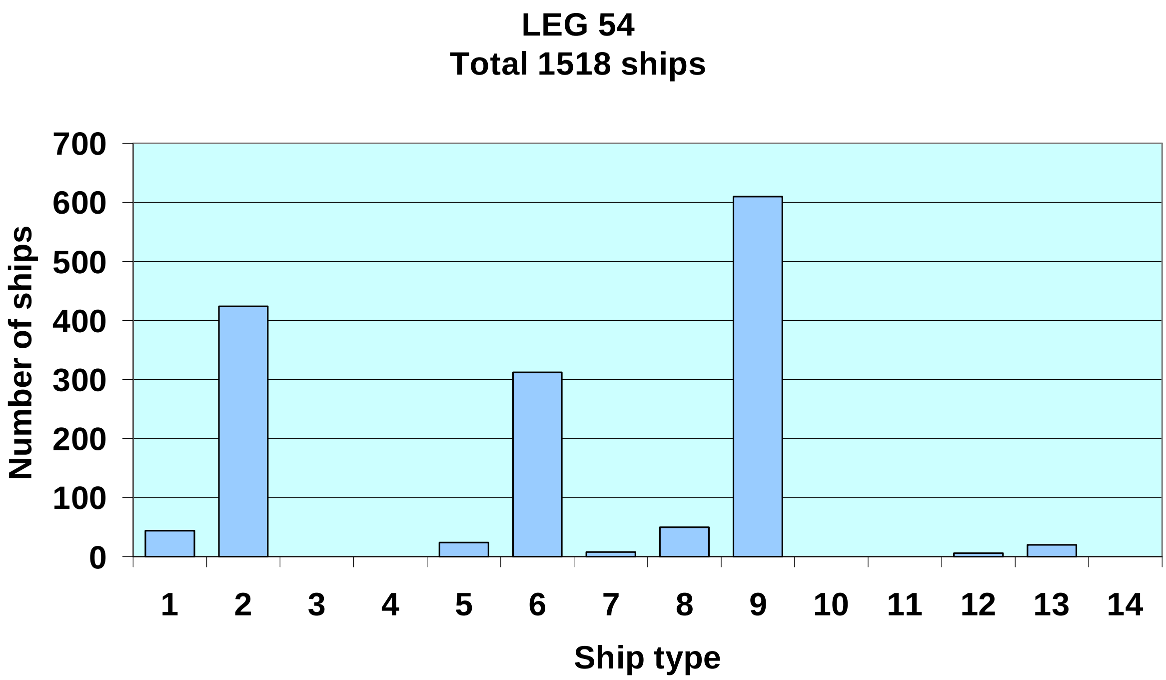


Figure 13 Traffic flow on Leg 54 in (yellow line in Figure 8) consisting mainly of vessels going westwards from the port of Paldiski in Estonia crossing the routeing system.

5.2 Collision and grounding frequency analysis

An overview of the results of the collision and grounding calculations is shown on the map in Figure 14. The red colour shows the locations of high accident frequency areas. These are concentrated along the entire routeing system in the Gulf of Finland.

According to the calculations, the highest bend collision risk is in the areas of Traffic Separation Schemes “Off Köpu Peninsula” (Label 1 in Figure 14) and “Off Hankoniemi Peninsula” (Label 2), whereas the overtaking collision risk is the highest on the leg between the islands Gogland and Sommers (Label 4) and on the leg east from Seskar island (Label 5). The powered grounding risk is the highest in the area of the southern point of Gogland island (Label 3).

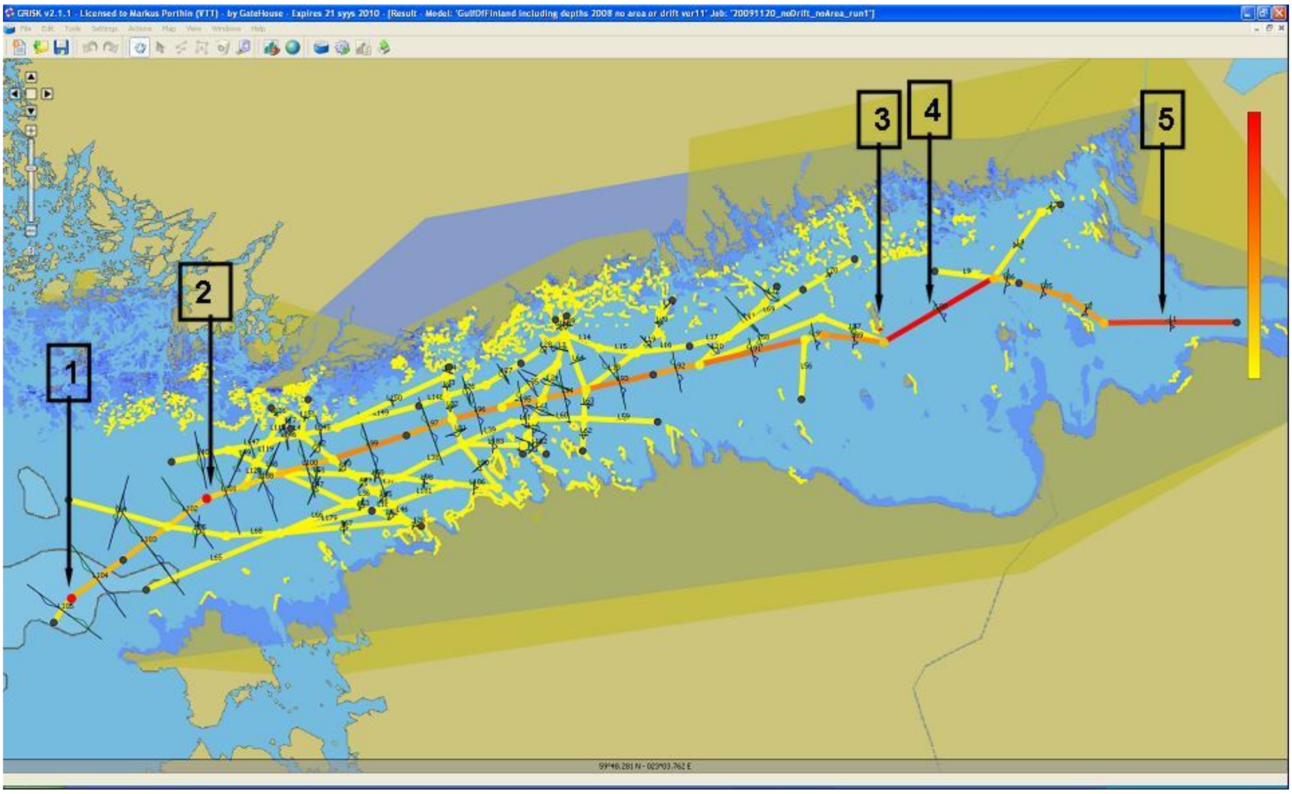


Figure 14 Results of collision and grounding frequency analysis. The legs, waypoints and shoreline areas with the highest accident frequencies are shown in red. Positions 1 and 2 are waypoints with a high frequency of bending collisions, position 3 denotes a high frequency of powered groundings, and positions 4 and 5 denote legs with a high frequency of overtaking collisions.

The estimates of expected accident frequencies are shown in Figure 15 - Figure 17 and in Table 4 - Table 6. The expected frequency for ship-to-ship collision is 0.243 incidents per year and for powered grounding more than double at 0.572 incidents per year (Table 4). Among collision types the bend collision is the most probable, with 0.144 incidents per year. The next most probable type is the overtaking collision, with 0.069 incidents per year.

According to the calculations, the most probable ship type suffering collision is general cargo ship, followed by container ship (Figure 16, Table 5), and the most probable ship suffering grounding is container ship, followed by general cargo ship (Figure 17, Table 6). This is unsurprising as these two ship types are the most common in the Gulf of Finland.

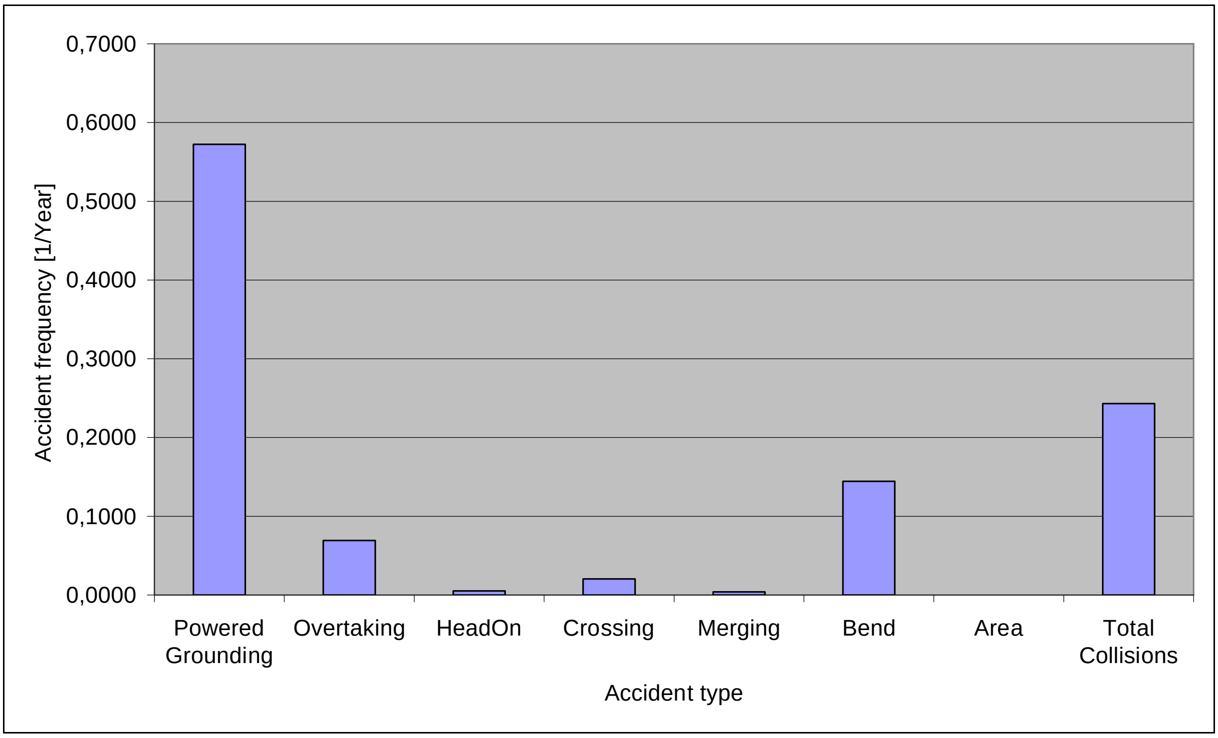


Figure 15 Expected accident frequencies per year by collision type.

Table 4 Expected accident frequencies per year by collision type. Highest collision values shadowed.

Accident type	Accident frequency [Accidents/Year]
Powered Grounding	0.5724
Overtaking	0.0693
HeadOn	0.0050
Crossing	0.0203
Merging	0.0040
Bend	0.1443
Area	0.0000
Total Collisions	0.2430

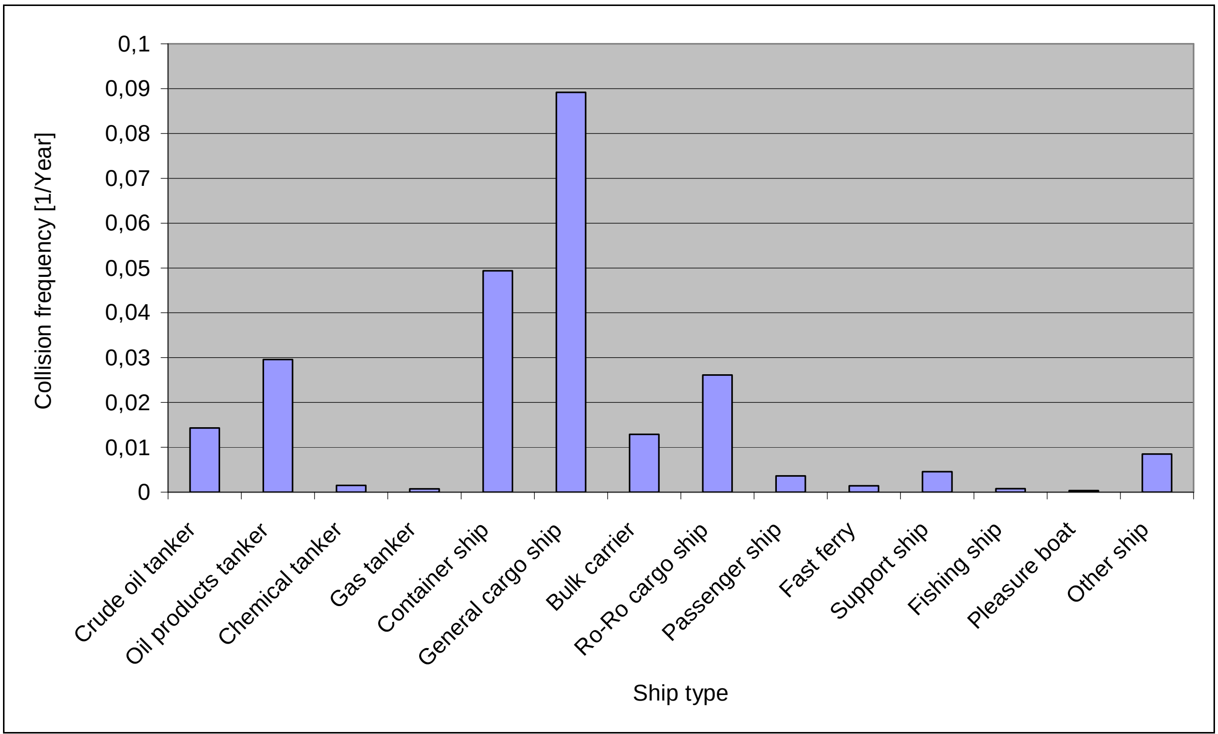


Figure 16 Expected collision frequencies per year by type of struck vessel.

Table 5 Expected collision frequencies per year by type of struck vessel. Highest values shadowed.

Ship type	**Collision frequency [Incidents/Year]**
Crude oil tanker	0.0143
Oil products tanker	0.0296
Chemical tanker	0.0015
Gas tanker	0.0007
Container ship	0.0494
General cargo ship	0.0892
Bulk carrier	0.0129
Ro-Ro cargo ship	0.0261
Passenger ship	0.0036
Fast ferry	0.0014
Support ship	0.0046
Fishing ship	0.0008
Pleasure boat	0.0003
Other ship	0.0085
Sum	**0.2430**

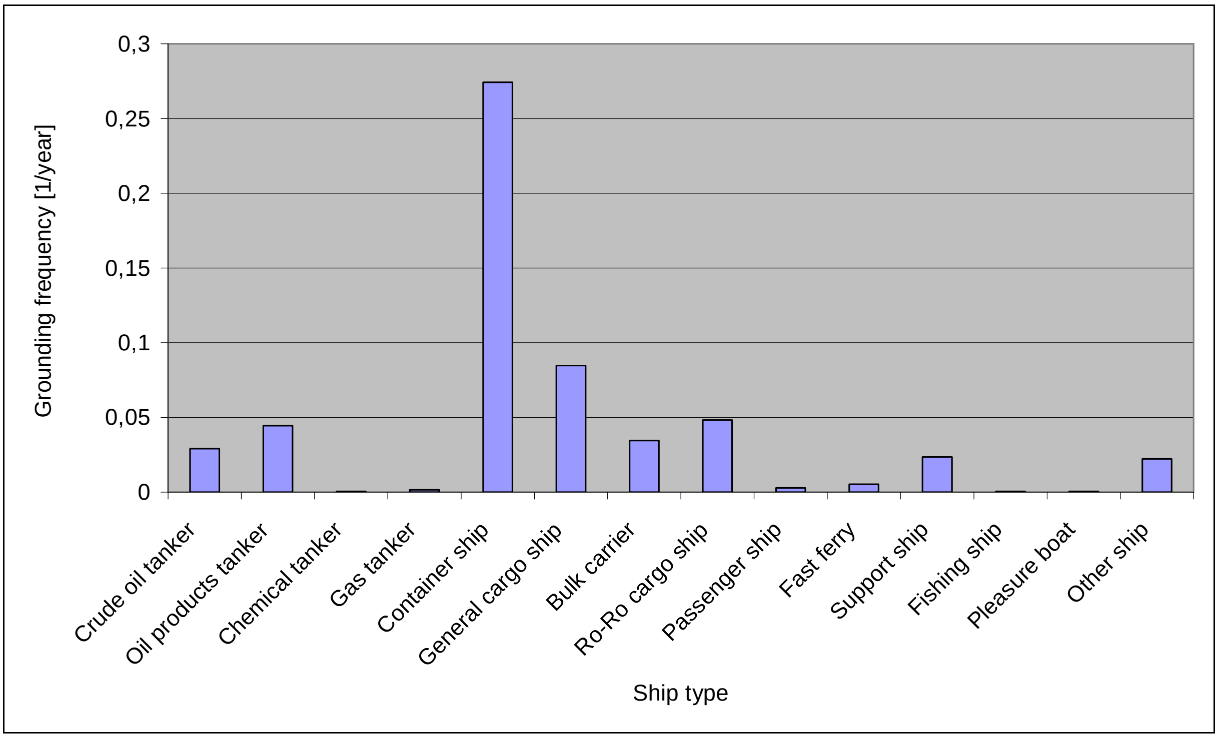


Figure 17 Expected grounding frequencies per year by type of vessel.

Table 6 Expected grounding frequencies per year by type of vessel. Highest values shadowed.

Ship type	**Grounding frequency [Incidents/Year]**
Crude oil tanker	0.0291
Oil products tanker	0.0445
Chemical tanker	0.0005
Gas tanker	0.0016
Container ship	0.2743
General cargo ship	0.0848
Bulk carrier	0.0345
Ro-Ro cargo ship	0.0482
Passenger ship	0.0029
Fast ferry	0.0053
Support ship	0.0236
Fishing ship	0.0005
Pleasure boat	0.0005
Other ship	0.0223
Sum	**0.5724**

6 Validation of the results

6.1 Background

In the following, the validation of the estimated collision and grounding frequencies is performed by comparing them with the frequency of registered accidents that have occurred in the Gulf of Finland. The accident statistics were obtained primarily from the Baltic Sea accident statistics reports compiled by HELCOM [3] and the Finnish accident database DAMA, which consists of the marine casualty reports given to FMA. Also used in the validation were the statistical analyses of accidents [4], [5] and [6] and the reports of the Finnish Accident Investigation Board [7].

The criteria for selecting the relevant accidents were as follows:

– Only accidents that occurred in the Gulf of Finland were taken into account.

– Accidents that occurred during the period 1.7.2004 – 31.12.2008 were taken into account primarily. The accident statistics of 2009 were not yet available. The GOFREP system was introduced at the beginning of July 2004; thus conditions in the Gulf of Finland are not comparable before and after that time. However, as a comparison also accidents that occurred before implementation of the GOFREP system during the period 1.1.1999 – 30.6.2004 were checked.

– Accidents that occurred due to ice conditions were rejected because the accident models in the GRISK software were developed only for open water conditions.

– Accidents that occurred in the port area were rejected.

– The accident frequency estimation performed using the GRISK software is based on historical AIS data from 2008. Thus only accidents involving vessels of gross tonnage 300 upwards were taken into account. (According to the IMO regulation this is the size limit for vessels in international traffic that have to be equipped with the AIS system.)

– As regards collisions only ship-to-ship collisions were taken into account.

– As regards groundings only powered groundings were taken into account.

6.2 Accidents

During the four-and-a-half year period following implementation of the GOFREP system (1.7.2004 – 31.12.2008), altogether 57 accidents were registered in the Gulf of Finland – 19 collisions and 38 groundings (Table 7). Following the above-mentioned criteria, altogether eight accidents, one collision and seven groundings were selected for use in verification of the calculated accident frequencies. As a comparison, accidents before the GOFREP system were also compiled. During the five-and-a-half year period from 1.1.1999 to 30.6.2004 there were 66 accidents registered in the Gulf of Finland – 22 collisions and 44 groundings. One of the collisions and 17 of the groundings were evaluated as relevant. However, due to insufficient data reported on the accidents, selection of relevant accidents was difficult and categorising the accidents into different types was impossible. The locations of accidents in the Gulf of

Finland can be seen in Figure 4 and other information in Table 8 for collisions and in Table 9 for groundings. When translating the numbers of accidents into accident frequencies the following values were obtained:

- After GOFREP (4.5 year period):
  - Collision frequency 0.22 accidents/year
  - Grounding frequency 1.56 accidents/year
- Before GOFREP (5.5 year period):
  - Collision frequency 0.18 accidents/year
  - Grounding frequency 3.09 accidents/year

In one collision that occurred after implementation of the GOFREP system a Panamanian 4128 GT refrigerated vessel and a Russian 2500 GT bulk carrier collided near the border between Finland and Russia northwest of the Sommers lighthouse. In another collision that occurred before the GOFREP system a Russian 53700 dwt timber carrier and a Panamanian 16582 dwt bulker collided near the pilot boarding position at the eastern end of the recommended route to St. Petersburg. The locations are shown on the map in Figure 4. The type of the collision was not reported in the statistics.

As for groundings, the most common ship types involved after implementation of the GOFREP system were general cargo ships (three accidents) and container ships (two accidents). Those involved before GOFREP were general cargo ships (five accidents), tankers (four accidents) and bulk carriers (four accidents) (Table 10). In the table all tanker types are listed under Tanker.

None of the accidents resulted in oil pollution.

Table 7 Registered accidents before (1.1.1999 – 30.6.2004) and after (1.7.2004 –31.12 2008) implementation of the GOFREP system.

	1.7.2004- 31.12.2008		1.1.1999 – 30.6.2004	
	Collisions	Groundings	Collisions	Groundings
Qualified	**1**	**7**	**1**	**17**
Due to ice conditions	1		10	1
Port area accident	16	15	8	14
Collision with object	1		2	
Drift grounding				2
Location outside the modelled area		16	1	10
Total number of accidents	19	38	22	44

Table 8 Relevant collisions in the Gulf of Finland. "A" in the collision number indicates that the accident occurred after, and "B" before, implementation of the GOFREP system.

No	Date	Lat.	Lon.	Ship1	Ship1 category	Ship1 size	Ship2	Ship2 category	Ship 2 size	Cause	Pilot onboard	Offence	Damage
AC1	31.5.2007	60,2530	27,5080	BEAUTY SONG Panama	Cargo, refrigerated vessel	4128 GT	Nevskiy-34 Russia	Cargo, bulk carrier	2500 GT	Other factor, reduced visibility	ship 1: Yes ship 2: n.i.	weather restriction	hole
BC1	5.11.2003	60,0333	29,4167	PIONER YAKUTII Russia	Cargo timber carrier	53700 dwt	HANDY RUBY Panama	Cargo, bulk carrier	16582 dwt	n.i.	n.i.	n.i.	n.i.

Table 9 Relevant groundings in the Gulf of Finland. "A" in the grounding number indicates that the accident occurred after, and "B" before, implementation of the GOFREP system.

No	Date	Lat.	Lon.	Ship	Ship type	Ship size	Ship draught (m)	Cause	Pilot on-board	Offence	Damage
AG1	12.8.2004	60,0667	28,3167	Shuya Russia	Dry cargo vessel	2889 GT	5	Human factor	No	navigation rules, ship order	no
AG2	6.10.2004	59,9500	26,8667	Amur-2521 Russia	Dry cargo vessel	3086 GT	4	Human factor	No	navigation rules	damage to hullleakage
AG3	9.11.2004	59,6116	25,0806	MSC Lieselotte Panama	Container ship	21586 GT	10	Human factor absent	Yes	operation of the ship	hull damaged
AG4	9.2.2007	60,0090	26,5930	Propontis Greece	Crude oil tanker	117055 dwt	15				cracks in bow dents in right side
AG5	25.3.2007	59,2000	23,3100	BALTIYSKIY-102 Russia	General cargo	1926 GT		Human factor	Yes	n.i.	
AG6	2.4.2008	60,2376	26,4027	Anne Sibum Cyprus	Container ship	10585 GT	9	Human factor	no		propeller, rudder damage
AG7	9.6.2008	60,1680	25,8330	Sabina Finland	Dry bulk	2006 GT	< 7m	Human factor	No	n.i.	dents and tears in hull
BG1	1.4.1999	59,8170	27,2500	Eotums Great Britain	Tanker	22000 dwt	n.i.	n.i.	n.i.	n.i.	n.i.
BG2	1.11.1999	59,8000	26,9101	Voshod Russia	Other	234 dwt	n.i.	n.i.	n.i.	n.i.	n.i.
BG3	8.12.1999	60,1870	25,7690	Spanvik	Other	650 dwt	n.i.	n.i.	n.i.	n.i.	n.i.
BG4	28.2.2000	59,5900	25,6900	Shuya Russia	Tanker	5082 dwt	n.i.	n.i.	n.i.	n.i.	n.i.
BG5	6.3.2000	60,1000	24,9700	Aurora Norway,	Cargo Ro-Ro	20381 GT	n.i.	n.i.	n.i.	n.i.	n.i.
BG6	11.3.2000	60,2400	28,2100	Kontula Finland	Cargo Dry bulk	19854 GT	n.i.	n.i.	n.i.	n.i.	n.i.
BG7	6.9.2000	59,0800	22,2700	Aldebaran Russia	Other Fishing vessel	748 dwt	n.i.	n.i.	n.i.	n.i.	n.i.

Table 10 Comparison of calculated grounding frequencies with grounding frequencies registered in the Gulf of Finland.

Ship type	Calculated grounding frequency [Inc./Year]	After GOFREP		Before GOFREP	
		Number of groundings	Grounding frequency [Inc./Year]	Number of groundings	Grounding frequency [Inc./Year]
Tanker (crude oil-, oil products-, chemical- and gas tanker)	0.0757	1	0.22	4	0.73
Container ship	0.2743	2	0.44		
General cargo ship	0.0848	3	0.67	5	0.91
Bulk carrier	0.0345	1	0.22	4	0.73
Ro-Ro cargo ship	0.0482			1	0.18
Passenger ship	0.0029				
Fast ferry	0.0053				
Support ship	0.0236				
Fishing ship	0.0005			1	0.18
Pleasure boat	0.0005				
Other ship	0.0223			2	0.36
Sum	**0.5724**	**7**	**1.56**	**17**	**3.09**

6.3 Qualitative validation

Qualitative validation of the calculated accident results was performed first by comparing the “hot spot” areas identified by the calculations with the locations of accidents that occurred in the Gulf of Finland. Next the “high risk” ship types identified by the calculations were compared with the ship types actually involved in accidents.

Only two collisions occurred in the Gulf of Finland that were relevant for comparison. One of them took place in “hot spot” area No. 5 in Figure 14, which was identified by calculations. Due to insufficient information it is not known whether this was an overtaking collision as predicted by the calculations. In addition, the collision occurred before implementation of GOFREP, which slightly decreases its relevance.

According to the calculations, the powered grounding “hot spot” is at the southern point of Gogland island. However, no accidents have been reported in that area. Powered groundings are concentrated in three areas of the Gulf of Finland: in the Finnish coastal area east of Helsinki, in the coastal area between Mohni lighthouse and Hiiumaa island in Estonia, and in the central area of the eastern Gulf of Finland (Figure 4). The entire Finnish coast in Figure 14 is marked in yellow, indicating a slightly increased risk for powered groundings, whereas groundings have occurred only near the coastline east of Helsinki (Figure 4).

The parties involved in the collisions were a refrigerated vessel and a bulker in the collision that occurred after GOFREP, and a general cargo ship and a bulker in the collision before GOFREP. General cargo ship is the ship type having the highest collision risk according to the calculations, whereas bulkers are only in sixth position.

Most of the grounded vessels both after and before GOFREP were general cargo ships, the ship type with the second highest grounding risk according to the calculations. The calculations showed container ships to have the highest grounding risk whereas this ship type was in second place in the grounding statistics collected after GOFREP.

6.4 Quantitative validation

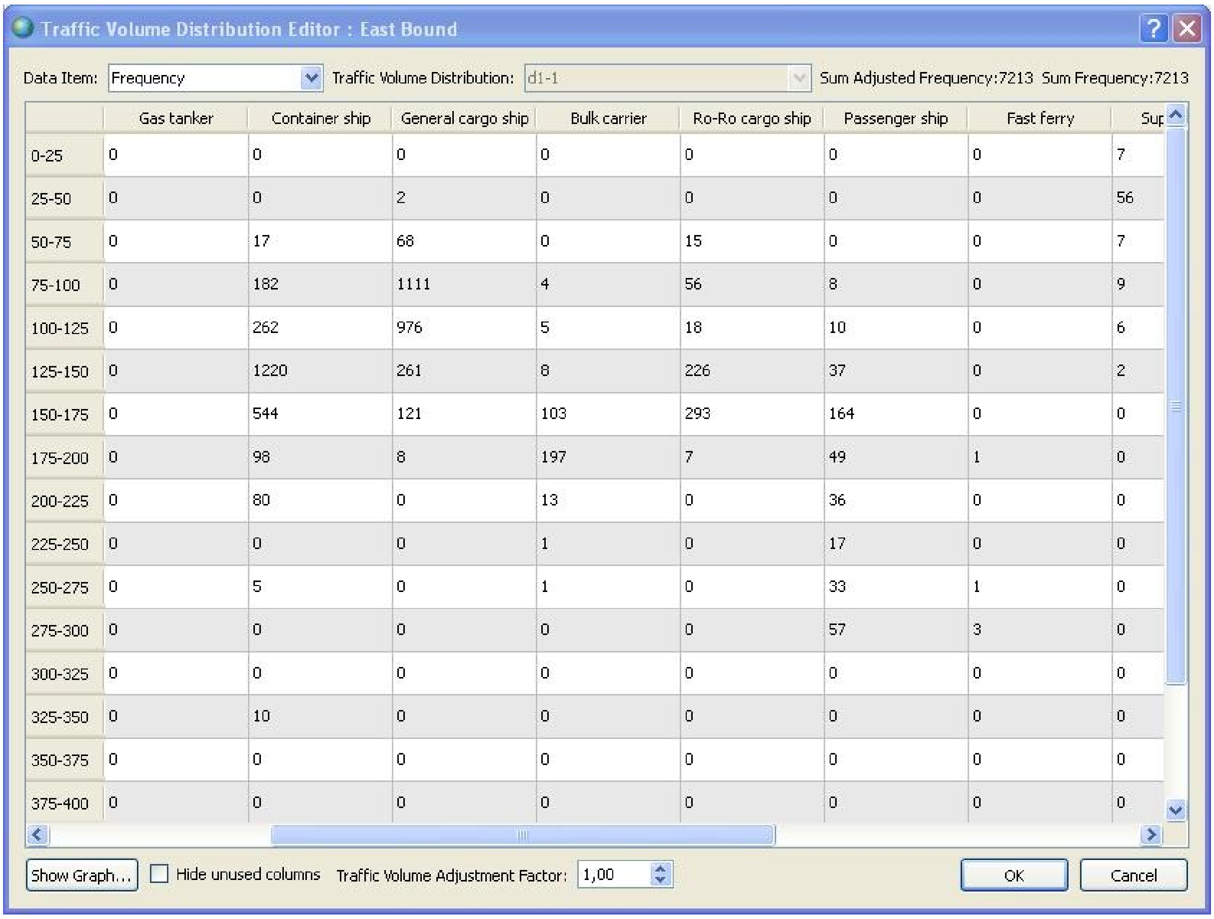
Performing calculations with the default causation factor values and with the presented traffic model gives an expected total collision frequency of 0.243 per year and powered grounding frequency of 0.572 per year, i.e. one collision in 4 years and one powered grounding in 1.7 years.

The accident statistics show one collision for the 4.5 year period after implementation of the GOFREP system, or 0.22 collisions per year. As a comparison, before GOFREP there was one collision in 5.5 years or 0.18 collisions per year. The predicted total collision frequencies based on the calculations are fairly consistent with the actual number of accidents. However, because of the small number of relevant accidents, the historical collision frequency is an imprecise estimate of the predicted collision frequency.

Next, the types of expected collisions were studied in more detail. The high frequencies of overtaking collisions on legs 4 and 5 in Figure 14 can be explained by the big speed difference between the two major vessel groups — container ships and general cargo ships — and the narrow Traffic Separation Scheme (TSS). For example, on the easternmost leg (label 5), based on the table in Figure 18 the annual number of container ships was 2418 vessels and that of general cargo ships 2547 vessels. Their weighted average speeds were 21.6 knots and 14.7 knots, respectively, taking into account in the calculations the number of vessels and average speed (table in Figure 19) in each ship type and size category.

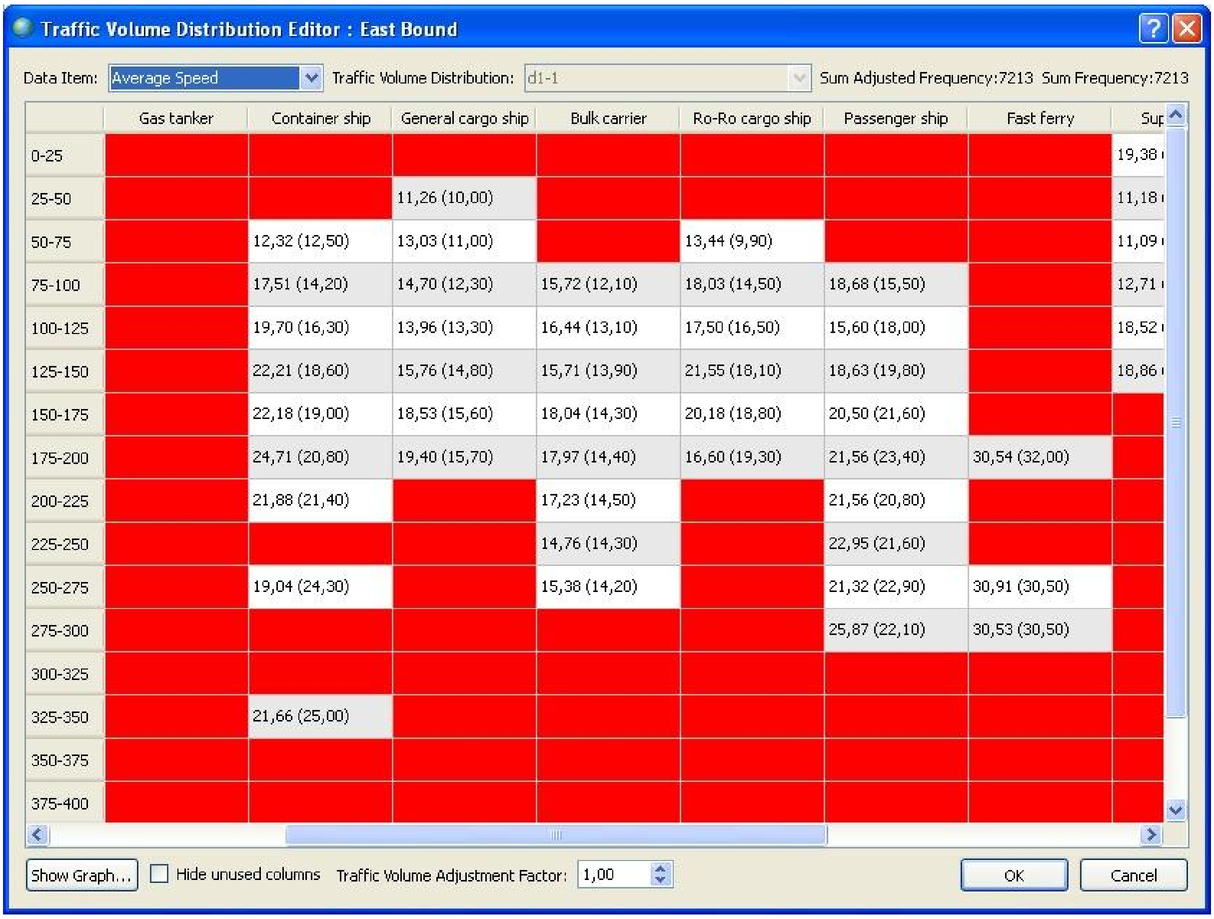
By contrast, the predicted high frequency of bending collisions on waypoints 1 and 2 in Figure 14 seem somewhat surprising due to the long distance between opposite traffic lanes in the TSS areas, as shown in Figure 4. The expected values would be more understandable if the calculation model took in to account not only bend collisions between vessels in opposite directions, but also those in which the vessels are going in the same direction and one of them neglects or misses the turn.

According to the accident statistics there were seven groundings in the Gulf of Finland during the 4.5 year period following implementation of the GOFREP system. This translates to 1.56 groundings per year. The predicted grounding frequency is 0.572 accidents per year, i.e. the GRISK software underestimates the number of groundings by a factor of 2.7. As a comparison, during the 5.5 year period before GOFREP there were 17 groundings, i.e. 3.09 per year which is 5.4 times the expected frequency. At least two reasons for under-predicted grounding frequency estimates can be identified. First, due to insufficient information about reported accidents some of the selected powered groundings may in fact have been drift groundings. Second, if the outermost legs reaching as far as the ports were included in the fairway network used in the calculations, the expected grounding frequency would be somewhat higher.



	Gas tanker	Container ship	General cargo ship	Bulk carrier	Ro-Ro cargo ship	Passenger ship	Fast ferry	Sup
0-25	0	0	0	0	0	0	0	7
25-50	0	0	2	0	0	0	0	56
50-75	0	17	68	0	15	0	0	7
75-100	0	182	1111	4	56	8	0	9
100-125	0	262	976	5	18	10	0	6
125-150	0	1220	261	8	226	37	0	2
150-175	0	544	121	103	293	164	0	0
175-200	0	98	8	197	7	49	1	0
200-225	0	80	0	13	0	36	0	0
225-250	0	0	0	1	0	17	0	0
250-275	0	5	0	1	0	33	1	0
275-300	0	0	0	0	0	57	3	0
300-325	0	0	0	0	0	0	0	0
325-350	0	10	0	0	0	0	0	0
350-375	0	0	0	0	0	0	0	0
375-400	0	0	0	0	0	0	0	0

Figure 18 Number of ships in different ship type and size categories on Leg 1 (label 5 in Figure 14).



	Gas tanker	Container ship	General cargo ship	Bulk carrier	Ro-Ro cargo ship	Passenger ship	Fast ferry	Sup
0-25								19,38
25-50			11,26 (10,00)					11,18
50-75		12,32 (12,50)	13,03 (11,00)		13,44 (9,90)			11,09
75-100		17,51 (14,20)	14,70 (12,30)	15,72 (12,10)	18,03 (14,50)	18,68 (15,50)		12,71
100-125		19,70 (16,30)	13,96 (13,30)	16,44 (13,10)	17,50 (16,50)	15,60 (18,00)		18,52
125-150		22,21 (18,60)	15,76 (14,80)	15,71 (13,90)	21,55 (18,10)	18,63 (19,80)		18,86
150-175		22,18 (19,00)	18,53 (15,60)	18,04 (14,30)	20,18 (18,80)	20,50 (21,60)		
175-200		24,71 (20,80)	19,40 (15,70)	17,97 (14,40)	16,60 (19,30)	21,56 (23,40)	30,54 (32,00)	
200-225		21,88 (21,40)		17,23 (14,50)		21,56 (20,80)		
225-250				14,76 (14,30)		22,95 (21,60)		
250-275		19,04 (24,30)		15,38 (14,20)		21,32 (22,90)	30,91 (30,50)	
275-300						25,87 (22,10)	30,53 (30,50)	
300-325								
325-350		21,66 (25,00)						
350-375								
375-400								

Figure 19 Average speeds of different ship types and sizes on Leg 1 (label 5 in Figure 14).

According to the HELCOM AIS database, the number of ships crossing in both directions the reference line at the entrance to the Gulf of Finland seen in Figure 20 was 47584 vessels in 2008 [2]. Legs 40, 54, 65 and 103 in the GRISK traffic model (Figure 14) are in the area of the HELCOM AIS reference line. Summing up the traffic on these legs gives a total of 38764 vessels, i.e. 81% of the HELCOM value. In Figure 21 the HELCOM traffic and traffic obtained from the GRISK traffic model in the same area is divided into main ship categories. The number of ships in the categories passenger vessels, cargo vessels and tankers is almost equal, whereas in the category other ship the difference is significant, being four times bigger in the HELCOM AIS. Category other ship consists of the GRISK ship types support ship, fishing ship, pleasure boat and other ship, which often does not follow the routes of the main traffic and was thus omitted from the GRISK model.

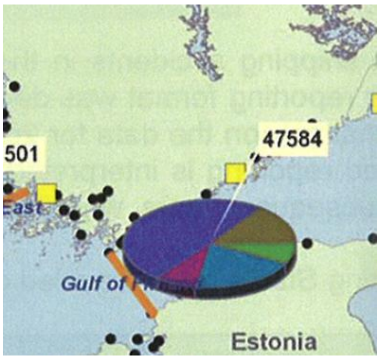


Figure 20 Location of the reference line.

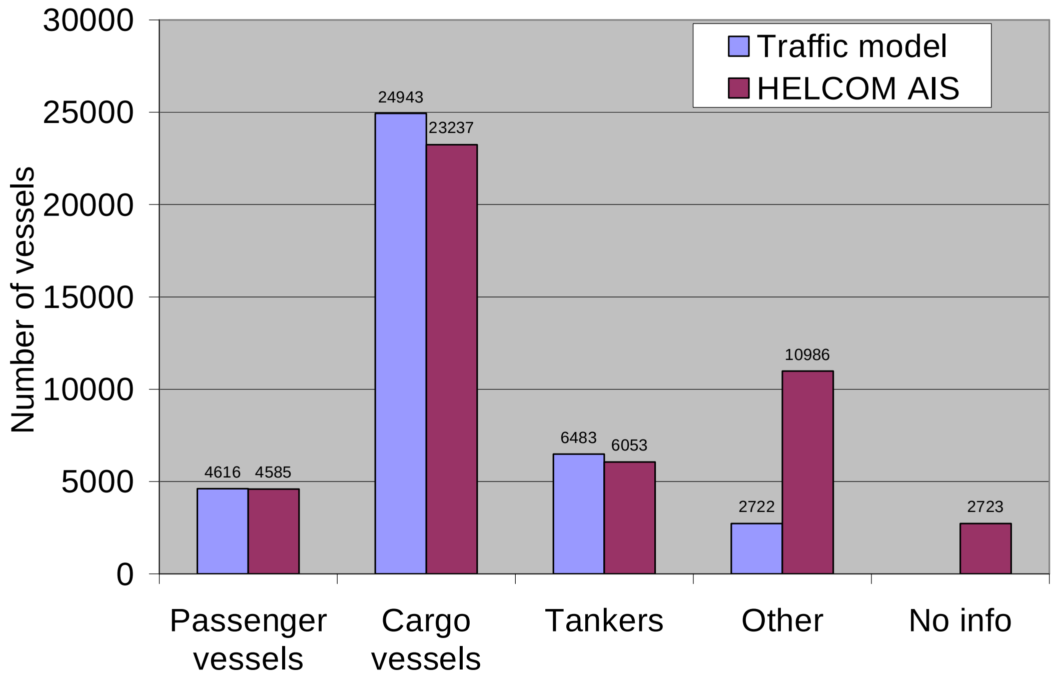


Figure 21 Number of ships in 2008 according to type of vessel crossing a fixed line at the entrance to the Gulf of Finland [2].

7 Conclusions

The main objective of the study was to estimate the collision and grounding frequencies of ship traffic in the Gulf of Finland. The second objective was to exploit the usability of the GRISK software in risk analyses needed in the FSA process. The calculations are based on AIS data from 2008.

According to the calculations, the highest accident frequency areas are concentrated along the whole routeing system in the Gulf of Finland.

The expected frequency for ship-to-ship collisions is 0.243 incidents per year, which is fairly consistent with the number of occurred collisions of 0.22 accidents per year. However, because of the small number of relevant accidents, the historical collision frequency is an imprecise estimate of the expected collision frequency. The predicted “hot spots” of bend collisions in the areas of the two westernmost TSSs in the Gulf of Finland seems odd, because the lanes of opposite traffic are quite far apart. However, the predicted high frequencies of overtaking collisions in the narrow TSS areas in the eastern Gulf of Finland are realistic due to the big speed differences of ships.

The expected frequency of powered groundings is 0.572 incidents per year, which is barely one third of the average annual number of groundings in the Gulf of Finland. One reason for the low frequency estimates could be that the route legs nearest the ports were omitted from the calculation model. Another reason could be insufficient information reported from the accidents. Some of the grounding accidents selected for verification should perhaps be classified as drift groundings, which are not taken into account in the calculation model.

The most probable ship type according to the calculations is general cargo ship in collisions and container ship in groundings, which makes sense as these two ship types are the most common in the Gulf of Finland.

About 80% of traffic is included in the traffic model used in the calculations. The main ship traffic consisting of passenger vessels, cargo vessels and tankers is well represented in the model, compared to about 25% of traffic in the categories support ship, fishing ship and leisure boat. This is due to the route network creation process of the traffic model, in which route legs are placed in the high traffic density areas. Vessels like support ships, fishing ships and leisure boats often keep away from high-density routes.

Appendices

1 Electronic chart data conversion from shapefile format to xml format

2 Traffic volumes on legs

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