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NAVIGATIONAL RISK ASSESSMENT OF SHIPS

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Abstract. This paper describes new methodology of creating the criteria for assessing navigational risk. Various factors influencing the navigational risk assessment are described. The method of calculating and evaluating ship risk probability is presented in this paper. Practical methods of ship navigational risk probability and assessment with the explanation for particular regions are described. The paper concludes with identifying sea regions with more risk based on a large number of factors.

Keywords: transportation; ships' navigational risk; risk probability; risk assessment.

1. Introduction

Transportation by ship is constantly increasing. Every year the transportation of crude oil, oil products and other dangerous goods in seas and oceans increases and very often terminals for dangerous goods are constructed in very complicated navigational sea regions which create potential navigational risk. Many oil terminals undergo a very rapid development and every year or every other year new oil terminals appear in Europe and elsewhere.

A large number of the existing oil and other dangerous goods terminals and very fast increasing of transportation of crude oil, oil products and chemical products in closed seas, such as the Baltic Sea, the Black Sea and others, increase the probability of accidents for ships with dangerous goods. This probability varies for different seas and sea regions.

Surveys of navigational risk and accident probability for oil tankers and other ships that transport dangerous goods are important in order to make it possible to take special precautionary measures in different places for decreasing the probability of navigational risk and accidents, since some places cannot be recommended for handling of oil or for the development of terminals for other dangerous goods, including handling of dangerous goods, because the risk is too high.

2. Main dangerous goods terminals in the east Baltic

Terminals for oil and other dangerous goods in the East Baltic were researched. In the eighties crude oil and oil products terminals started developing in Ventspils, Klaipeda, Gdansk, Rostock, and other ports and a gas terminal was developed at Ventspils port.

In the nineties new oil terminals started developing and old terminals in Klaipeda, Ventspils, and Tallinn were renovated; chemical bulk terminals were constructed in Kaliningrad, Klaipeda, Ventspils, Riga, Tallinn, St.-Petersburg and other smaller ports. In this century new terminals for handling dangerous goods were constructed in Butinge, Primorsk, Vysock and other ports. The dynamics of transportation of crude oil and oil products via the Baltic ports and terminals from Poland to Russia (Finnish Bay) is displayed in Table 1 [1].

The following ports can be considered the main South and East Baltic ports involved in crude oil and oil product transportation during the above-mentioned period: Gdansk (G); Kaliningrad (Kl); Klaipeda (K); Butinge (B); Ventspils (V); Riga (Ri); Tallinn (T); St.-Petersburg (St.-P) and Primorsk (P). They are presented in Table 2 [1].

Most transportation of crude oil, oil and chemical products from the South and East Baltic ports heads for destinations outside the Baltic Sea. In this case it is possible to select one main point to be crossed by the majority of tankers and other ship routes. Skagen cape is chosen in this project as the main point to be crossed for the South and East Baltic ports. The distances from Skagen cape to the main oil and other dangerous goods terminals in the East Baltic Sea are shown in Table 3.

In Table 3, distances in narrow places mean the total distance in channels and other narrow waters

Table 1. Crude oil and oil product transportation via the Baltic ports in 1996 – 2003

Year	Quantity, mil. tons	Different from previous year, %	Different from year 1996, %
1996	47,5	-	-
1997	52,8	+11,1	+11,1
1998	56,7	+7,4	+19,4
1999	60,7	+7,0	+27,8
2000	73,7	+21,4	+55,2
2001	83,9	+13,8	+76,6
2002	98,1	+16,9	+106,5
2003	117,2	+19,5	+146,7

Table 2. Crude oil and oil product transportation via the main South and East Baltic ports in 1996 – 2003 (mil. tons)

Year	G	Kl	K	B	V	Ri	T	St.-P	P	Total	Δ with previous year,%	Δ with year 1996, %
1996	5,0	0,5	4,2		29,0	1,0	5,8	1,4		46,9	-	-
1997	5,2	0,6	3,6		28,6	2,2	8,1	3,7		52,0	+10,5	+10,9
1998	8,3	0,8	2,2		27,5	1,0	11,1	4,6		55,5	+6,7	+18,3
1999	7,0	0,9	3,9		25,7	2,4	14,5	4,9		59,3	+6,8	+26,4
2000	7,4	1,0	5,2	3,6	27,3	3,0	17,8	7,3		72,6	+22,4	+54,8
2001	7,2	1,9	5,1	5,1	29,5	3,6	21,0	9,1		82,5	+13,6	+75,9
2002	6,0	4,9	6,7	6,3	20,5	5,3	24,3	10,6	12,0	96,6	+17,1	+106,0
2003	10,0	6,3	6,6	10,7	19,0	8,0	26,0	11,0	17,7	115,3	+19,4	+145,8
2003/ 1996	2,0	12,6	1,6		0,7	8,0	4,5	7,8		2,45		

Table 3. Distances from the main East Baltic oil terminals to the main point near Skagen cape

Port	Turnover oil in 2003, mil. tons	Distance to Skagen cape, n.m.	Distances in narrow places, n.m.
Gdansk	10,0	460	260
Kaliningrad	6,3	480	260
Klaipeda	6,6	510	260
Butinge	10,7	515	260
Ventspils	19,0	550	260
Riga	8,0	725	310
Tallinn	26,0	825	330
Primorsk	17,7	970	550
St-Petersburg	11,0	990	570
Vysock	-	960	540
Total	115,3		

Note: n.m. – nautical miles.

where there are districts, such as mandatory piloting service places, special routes and so on.

A good situation in oil and chemical goods business market has stimulated crude oil, oil and chemical product outputs in oil and chemical goods produced in countries like the Baltic States, Russia, Belarus, Kazakhstan and countries of Middle Asia.

3. Ships navigational risk assessment theory

Navigational risk assessment for ships can be evaluated through a multi-criteria analysis and on the basis of probability theory. Navigational risk based on multi-criteria analysis can be expressed through these factors:

- geographical conditions;
- traffic conditions;
- ship conditions;
- other conditions.

Geographical conditions depend on particular geographical places marked with the existence of abounding navigational obstacles like islands, narrow channels, rocks etc., create natural difficulties for navigation. These sub-factors can be considered to be geographical conditions:

- the distance between the selected main point and the port;
- natural channels and other difficult places (rocks, islands, narrow places and others) on the particular route;
- channels and other obstacles at the entrances to ports;
- ports entrance configurations;
- safety conditions in ports beside the quay walls;
- other geographical aspects.

Traffic conditions are highly important in channels and other places with traffic density. Ships accidents like collisions, groundings and so on tend to happen in areas with dense traffic. At the same time these traffic conditions are linked with accidents such as the above. Mistakes are also made during maneuvers and they also have a strong effect by imposing environmental pollution risk.

These main sub-factors fall into traffic conditions category:

- traffic density in different zones (number of zones);
- traffic separation in different zones with dense traffic;
- conditions near traffic separation zones;
- main ports near dense traffic zones;
- navigational obstacles in dense traffic zones;
- hydro meteorological conditions in dense traffic zones;
- fishing regions on routes and density of fishing ships;
- other problems of traffic conditions.

Conditions of a ship are mainly related to the typical physical state of a ship, such as a ship stability, durability, draft in ports and other shallow waters, etc. In multi-criteria analysis conditions of a ship can go under the following sub-factors:

- ship hull (double or single);
- ship stability (in ballast and loaded);
- ship durability under sea and port conditions;
- situation of ballast tanks (separate or not);
- ship grounding risk;
- ship maneuvering possibilities;
- other factors related to each individual ship.

Other conditions influencing ship navigational and environmental pollution risk can be evaluated in any particular situation and the main sub factors can be listed as follows:

- ice conditions in winter time;
- ships passing very close to moored tankers in ports;
- the safety of ship mooring under storm conditions;
- other specific conditions.

A complex evaluation of the concrete route between the selected main point and any port can be done as follows:

$$E = \eta_k (k_1 \cdot K_1 + k_2 \cdot K_2 + k_3 \cdot K_3 + k_4 \cdot K_4 + \ldots), \qquad (1)$$

where η_k – correlation coefficient which can be calculated on the basis of special surveys or it can be taken as standard for the same tasks; k_i – weight of factors; K_1 – geographical conditions factor; K_2 – traffic conditions factor; K_3 – ship condition factor; K_4 – other conditions factor.

The correlation coefficient in a multi-criteria analysis depends on the number of factors included in the evaluation. In the case where all possible factors and sub-factors are included in the evaluation, the correlation coefficient in transport processes is about 0,85 – 0,90 [2]. In the case where there are limitations to the factors, the correlation coefficient can be higher, and in the case where just a single factor is evaluated, the correlation coefficient will come close to one (Fig 1).

The weight of the factors can be obtained on the basis of special surveys, for example, expert's evaluation or probability assessment. In transportation the weight of the given factors can be distributed on the basis of their importance. At the same time the importance of the factors can imply a change in the conditions; for instance, the influence of winter in the regions with severe ice conditions.

On the basis of special research that has been carried out for the Baltic Sea, the recommended weight of the factors mentioned in this paper can be broken down as follows:

- for the geographical conditions factor – 0,1 – 0,3;
- for the traffic conditions factor – 0,1 – 0,3;
- for the ship condition factor – 0,1 – 0,2;
- for the other conditions factor – 0,1 – 0,2.

The weight of the geographical conditions factor in the Baltic Sea for all ports, including the Baltic channels, mainly depends on the distances. The example of the weight of the geographical conditions factor is shown in Fig 2.

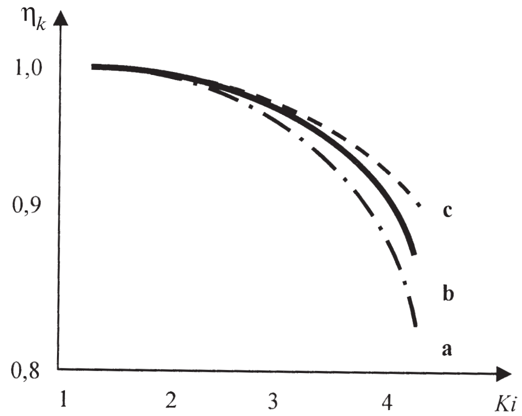

Fig 1. The correlation coefficient trend depends on the included surveyed factors and sub-factors:
a – include all possible sub factors for a certain route;
b – standard correlation coefficient with typical sub factors;
c – in case of limitation of sub factors

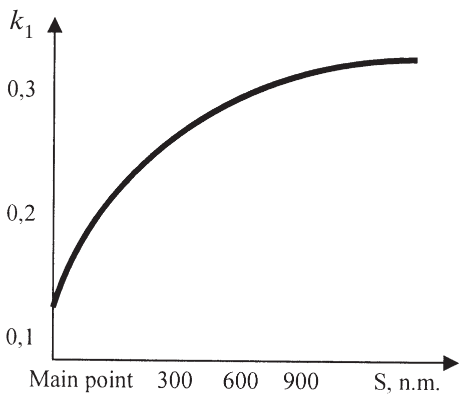

Fig 2. Trend of the weight of the geographical condition factor for the Baltic Sea

The weight of the traffic condition factor mainly depends on the number of available zones of high traffic density. The following can be considered as the main zones of high traffic density connected with the Baltic Sea (between the selected main point and the rest of the Baltic Sea):

- Kattegat strait;
- Belt strait;
- Oresund strait;
- South and southwest from Born Holm island region;
- Northwest from Born Holm island region;
- Irben strait;
- Tallinn – Helsinki route region;
- Ports entrance regions.

An example of the weight of the traffic condition factor for the Baltic Sea is displayed in Fig 3.

The ship condition factor mainly depends on the ship age, since the older ships sailing in this particular route are, the higher the above-mentioned factor is. An example of the weight of the ship condition factor is shown in Fig 4.

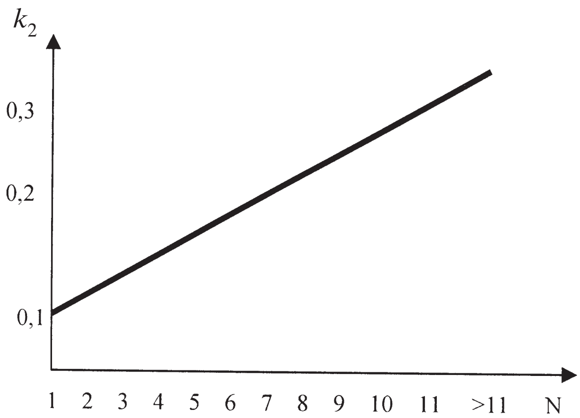

Fig 3. Trend of the weight of the traffic conditions factor for the Baltic Sea (N – number of highly dense traffic zones)

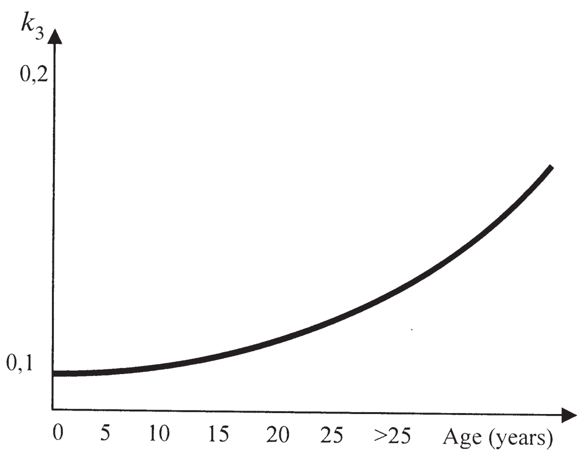

Fig 4. Trend of the weight of the ship condition factor depends on the age of the ship

The weight of other conditions factor depends on the real special conditions of the route and should be additionally investigated for each individual situation. In the same manner it is possible to find some special conditions to compare ports. For example, it could be winter features (ice conditions) in the Baltic Sea. The example of the weight of other conditions factor depending on winter conditions in the Baltic Sea is shown in Fig 5.

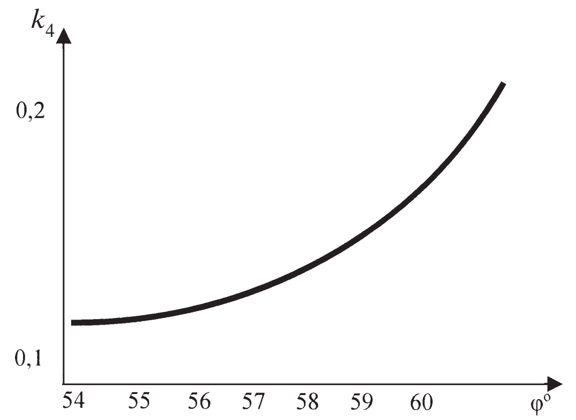

Fig 5. Trend of the weight of other conditions factor depending on the latitude

The sub-factors should be investigated individually, yet every factor must be calculated on the basis of sub-factors. In general each of the factors can be calculated as follows [3]:

$$K_i = \sum m_i \cdot q_i , \qquad (2)$$

where m_i – weight of the sub-factors; q_i – sub-factors real figure to be calculated as the difference between maximum possibility and real possibility.

Here is an example, which contains the following sub-factors of the geographical conditions factor:

- distance between selected main point and ports (q_s);
- channels (number of channels) (q_{ch});
- ports entrance distances (q_p).

In this case, K_1 can be calculated as follows:

$$K_1 = m_1 \cdot q_s + m_2 \cdot q_{ch} + m_3 \cdot q_p , \qquad (3)$$

where m_i – weights of sub-factors which can be evaluated on the basis of relative importance can be calculated as follows:

$$m_i = \frac{1}{\sum q_i} . \qquad (4)$$

The distance sub-factor can be calculated as follows:

$$q_s = \frac{S_i}{S_{\max}} , \qquad (5)$$

where S_i – the distance between the selected main point (Skagen cape for the Baltic Sea) and the target port; $S_{\max}$ – the maximum distance between the selected main point and the port farthest from the main point, for the target cargo flow and the port where the mentioned cargo is to be handled.

The channel sub-factor can be calculated as the total distance in the channels between the main point selected and the target port, and the port located at the maximum distance from the main point and it can be calculated as follows:

$$q_{ch} = \frac{S_{chi}}{S_{ch\max}} , \qquad (6)$$

where S_{chi} – total distances in channels between the main point and the target port; $S_{ch\max}$ – total distances in channels between the main point and the port located at the maximum distance from the main point.

The sub-factor for the ports channels can be calculated as follows:

$$q_p = \frac{S_{pi}}{S_{p\max}} , \qquad (7)$$

where S_{pi} – length of the entrance channel in the target port from the port entrance up to the quay wall; $S_{p\max}$ – distance of the entrance channel into the port having the longest entrance channel from the port entrance up to the quay wall.

In the same manner all the sub-factors and the weight of the sub-factors and the factors can be calculated and finally it is possible to obtain concrete results of the differences between ports as follows:

$$\Delta = \frac{E_i}{E_j} , \qquad (8)$$

where E_i – comparison result of target ports; E_j – comparison result of other ports.

Differences between ports show which port or ports are in a more favorable position regarding navigational risk.

Existing risk probability for the target port can be calculated on the basis of positive and negative probability of the same factors that were shown before. In this case, the typical formula could be used [4]:

$$P_i = \frac{1}{\eta_p}(1 - Q_i) , \qquad (9)$$

where η_p – the probability correlation coefficient; P_i – positive probability of the surveyed factors that can be found in the typical way in probability theory; Q_i – negative probability of the surveyed factors, to be assessed on a statistical or other basis for the particular regions or sub-factors.

Negative probability can be obtained as statistical results depending on certain sailing conditions, or accidents, or sea pollution results. Negative probability depending on sailing conditions, for example, includes the following conditions [5, 6]:

- sailing in the open sea;
- sailing in channels and other highly dense regions;
- sailing in complicated navigational places with banks, rocks and so on;
- sailing in port areas;
- sailing under ice conditions;
- sailing under complicated hydro-meteorological conditions;
- other complicated conditions.

The above-mentioned conditions could be divided into sub-conditions including the following:

- the probability of collision of ships;
- the probability of grounding;
- the probability of loss of ship stability;
- the probability of ship technical problems;
- other negative probabilities depending on the individual situation.

Based on the evaluation models presented in this paper, navigational risk and other risks for the individual port can be assessed, which can help to arrive at the right decision regarding the development of ports or terminals.

4. Examples of the evaluation of some East Baltic ports

In this study some typical East Baltic ports handling crude oil and oil products located at different places and being subjected to different hydrometeorological and navigational conditions were selected.

Table 4. Geographic, navigational and other parameters between the main point and the East Baltic ports

Parameters	Gdansk	Klaipeda	Butinge	Ventspils	Riga	Tallinn	Primorsk
Distances from the main point, n.m.	460	510	515	530	725	825	970
Number of channels	5	5	5	5	6	6	8
Distances of port entrance channel, n.m.	5	3	3	5	5	8	15
Navigational obstacles in sea	-	-	-	-	+	+	++
Highly dense traffic zones	6	5	5	5	7	6	8
Fishing regions on sea routes	2	2	2	3	4	5	6
Distances in ice conditions, n.m.	20	15	10	40	140	230	380
Average age of ships	20	20	15	20	25	20	20
Distances in channels between the main point and target port, n.m.	260	260	260	260	310	330	390

Table 5. Compared results of navigational safety among the ports

Parameters	G	K	B	V	Ri	T	P
η_k	0,92	0,92	0,92	0,92	0,92	0,92	0,92
m_1	0,2	0,2	0,2	0,2	0,2	0,2	0,2
q_s	0,41	0,52	0,53	0,57	0,75	0,85	1,0
m_2	0,35	0,35	0,35	0,35	0,35	0,35	0,35
q_{ch}	0,67	0,67	0,67	0,67	0,79	0,85	1,0
m_3	0,45	0,45	0,45	0,45	0,45	0,45	0,45
q_p	0,33	0,20	0,20	0,33	0,33	0,53	1,0
K_1	0,46	0,46	0,43	0,49	0,58	0,71	1,0
k_1	0,24	0,25	0,26	0,27	0,28	0,29	0,30
K_2	0,57	0,50	0,50	0,57	0,78	0,78	1,0
k_2	0,22	0,20	0,20	0,22	0,29	0,29	0,30
K_3	0,8	0,9	0,8	0,9	0,9	0,9	0,9
k_3	0,18	0,19	0,18	0,19	0,19	0,19	0,19
K_4	0,05	0,04	0,03	0,10	0,37	0,61	1,0
k_4	0,10	0,11	0,11	0,14	0,14	0,16	0,17
E	0,39	0,38	0,36	0,44	0,61	0,71	0,94
Δ_1	0,41	0,40	0,38	0,47	0,65	0,76	1,0
Δ_2	0,71	0,69	0,66	0,80	1,12	1,30	1,72

Table 6. Navigational risk for the selected ports

Parameters	G	K	B	V	R	T	P
η_k	0,99	0,99	0,99	0,99	0,99	0,99	0,99
Collision	0,000335	0,00033	0,000325	0,00036	0,000527	0,000648	0,001035
Grounding	0,00027	0,00027	0,00027	0,000275	0,000337	0,000367	0,000606
Stability and endurance	0,00004	0,00005	0,00005	0,000055	0,000072	0,000082	0,000092
Technical problems	0,00033	0,00033	0,00032	0,00036	0,000528	0,000648	0,001035
$1-Q_1$	0,999665	0,999670	0,999675	0,999640	0,999473	0,999352	0,998965
$1-Q_2$	0,99973	0,99973	0,99973	0,999725	0,999663	0,999633	0,999394
$1-Q_3$	0,99996	0,99995	0,99995	0,999945	0,999928	0,999918	0,999903
$1-Q_4$	0,99967	0,99967	0,99968	0,99964	0,999472	0,999352	0,998965
P	0,999025	0,999020	0,999035	0,998950	0,998536	0,998256	0,997229
Δ, %	–0,0010	–0,0015	0,0	–0,0085	–0,050	–0,078	–0,181

These are the ports:

- Gdansk (G);
- Klaipeda (K);
- Butinge (B);
- Ventspils (V);
- Riga (Ri);
- Tallinn (T);
- Primorsk (P).

The main geographic, navigational and other parameters for the selected ports are presented in Table 4.

Based on the models discussed in this paper, the results of comparing certain conditions factors and complex comparison results for the target ports were obtained. The results of calculation and evaluation comparison between the ports are presented in Table 5.

Table 5 Δ_2 indicates the difference between average results and the result of the individual port.

Navigational risk probability based on statistical average results in certain sailing areas for the selected ports is presented in Table 6.

In Table 6 Δ (%), the differences between the best safety means in Butinge terminal and other selected ports are shown. Based on the obtained results which are presented in Tables 5 and 6 it is possible to discover more exact differences of navigational safety and take additional precautionary measures to minimize navigational risk and along with that, to prevent the risk of pollution.

5. Conclusions

1. Increased oil and oil products transportation in the Baltic Sea increases navigational accident risk for tankers and along with that, sea pollution risk.

2. New oil terminals constructed under more difficult navigational conditions, dramatically increase navigational and sea pollution risk carrying oil and oil products.

3. The method presented in this paper can be applied for discovering areas of actual risk and places of increased risk.

4. Based on the method of navigational risk assessment evaluation presented in this paper, areas of higher danger in sea can be determined as risk regions.

5. Based on the risk region selections additional precautionary measures such as mandatory pilot services and the assistance of tugs must be taken in order to minimize the probability of ships accidents.

6. Navigational risk assessment presented in the paper can be considered as indication means for guidance, but additional research has to be carried out for individual areas.

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