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Analysis of Navigation Safety Regarding Tankers in Narrow Waterways

Summary:

Sailing of tanker ships in specific navigation areas, such as narrow waterways, is a particularly delicate navigational venture, where one of the greatest related risks is grounding. Grounding of a tanker in a narrow waterway is an event that can cause many adverse consequences, the most important among them being environmental pollution, explosion or onboard fire damaging the ship, injuries and lost lives of crewmembers. Factors affecting the safety of tanker navigation in narrow waterways can be principally divided into geometric, traffic, meteorological and oceanological factors, ship design factors and marine equipment faults as well as human-related factors. With a view to minimizing the possibility of grounding or contact, the assessment of risks is to be considered indispensable and primarily aimed at influencing accident probability and/or consequence factors as its most important objective.
The paper analyses the safety of tanker navigation in narrow waterways based on the assessment of risk of grounding. The event influential probability factors that are taken into consideration comprise the narrow waterway category, meteorological and oceanological conditions, traffic density and VTS coverage of the navigable area, while factors such as ship speed, bottom type, hull quality and loading condition are factors related to consequences. Using the risk assessment matrix, estimated values used for evaluation of the safety of tanker navigation in narrow waterways are assigned to probability factors and factors of consequences.

Key words: narrow waterway, grounding, contact, tanker, risk assessment

1. Introduction

Tankers are ships of a specific type that represent a major threat to the natural environment and human lives themselves, due to the amount of liquid cargo they can carry on board. Navigation of tankers in narrow waterways represents certain risks such as the risk of collision, grounding or contact with a fixed object that may have catastrophic consequences such as environmental pollution, explosion, fire, human casualties, as well as possible closure of the narrow waterway for navigation. The safety of navigation of tankers in the narrow waterway is generally influenced by human factors, factors of the ship itself, factors of the narrow waterway, and meteorological and oceanological factors.

For the purpose of the paper, probability and consequence factors for the navigation of tankers of a certain size in the narrow waterway are defined and assigned appropriate values in order to enable the grounding or contact risk estimate. The risk assessment does not take into account human factors that are very difficult to foresee and evaluate and it is generally considered that good voyage planning, including monitoring of the voyage plan by all bridge team members and verifying the plan by the master, can significantly reduce possible human error.

2. Risk of tanker grounding in narrow waterways

Tankers navigating in narrow waterways are exposed to eventualities of various accidents, among which ship grounding is the one that primarily causes greatest consequences, followed by collision, contact, explosion, fire and ship structural problems as accidents with potential serious consequences. In order to reduce the risk of grounding, the procedure presented in this paper is proposed for the assessment of tanker grounding risk during navigation in a narrow waterway.

Generally, grounding is an event characterized by a contact of a ship and the sea bottom in which ship loses its floating ability and cannot continue sailing [11]. In shipping, the risk is generally defined as a multiplicity of probabilities of an unwanted event (for example grounding) and its consequence. For the purpose of this paper, the risk is taken as a multiplicity of the probability of running aground and the consequences that this event can produce.

Factors influencing grounding and their classification are important in determining the likelihood of grounding and the corresponding consequences; therefore, there are influencing factors and probabilities of grounding and its possible consequences presented in the paper as well.

2.1. Grounding factors

Studies published so far have shown that causes of ship grounding can be classified, in principle, into the following four main categories [7]:

1. Manoeuvring error including incorrect positioning and poor lookout,
2. Inability of a deck officer to manoeuvre a ship as a result of drunkenness, fatigue, sudden weakness or other task performance. Fatigue has been identified as one of the main causes of groundings,
3. Technical problems with the engine, steering gear or navigational instruments,
4. Environmental factors such as poor visibility, strong wind or high waves.

Grounding causes under 1 and 2 can be classified as human error factors. Serious accidents usually occur with a basic human error, but the seriousness of the accident is a complex technical error, operator error, design error, or management error [6].

Factors that should have the most important effect on ships' navigation in narrow waterways or on the occurrence of grounding can be shown considering the above-mentioned causes.

Factors that can cause grounding can generally be divided into the following categories [7]:

- **Geometric factors**: length, width, depth of the narrow waterway and marking of the waterway with navigation markings (buoys, lighthouses, ATON (*Aid to Navigation*), AIS (*automatic identification system*), RACON (*Radar beacon*).
- **Traffic factors**: traffic density, traffic speeds, types of floating objects on the waterway.
- **Meteorological and oceanological factors**: visibility, wind direction and speed, direction and speed of the sea currents, the influence of the tides.
- **Ship design factors and ship equipment error factors**: radar error, steering gear error, structural error, GPS error.
- **Human factors**: lack of communication on the navigating bridge, fatigue, lack of situation awareness, complacency, inadequate voyage planning, pilot error.

2.2. Probability and consequences of grounding

According to the data from IMO (*International Maritime Organization*), in the period from 1980-2007, there were 424 tanker groundings in total, 40 of which caused pollution of the marine environment, with a total of 360.962 tons of oil spilled in the sea[8]. There was only one casualty, actual or disappearance of a crew member, that occurred in all the mentioned groundings. At the same time, the accident rate was $1{,}11 \cdot 10^{-2}$, i.e. the occurrence of environmental pollution rate was $1{,}05 \cdot 10^{-3}$ [8]. It should also be noted that data were taken at the time when the latest technologies (AIS, ATON, ECDIS- *Electronic Chart Display and Information System*) that make maritime traffic safer were not yet in existence, while double hull tankers were only introduced in the 1990s, so it can be considered with certainty that nowadays the chance of grounding or loss of cargo (oil spill) is even lower. Statistics have also included contacts with fixed and floating objects with no casualty recorded. During the same period, there occurred 269 contacts, out of which 26 resulted in oil spillage or pollution, with 37.548

tons of oil in the sea. The contact frequency was 7.04* 10^{-3}ships per year while the oil spill frequency due to the contact was 6.80*10^{-4} ships per year. According to statistical data from 1990-2007 the frequency of grounding was 7.45* 10^{-3} ships per year, and frequency of contact was 3.61 * 10^{-3}ships per year [8].

Grounding is the second and contact is statistically the fourth accident by numbers (Figure 1), and the introduction of new navigational aids and ship systems (ECDIS, ATON, redundancy of the steering gear ...) have reduced the likelihood of grounding/ contact itself. In addition, the introduction of larger height and width of double bottom tanks and better distribution of cargo tanks have reduced the consequences of grounding/contact [9].

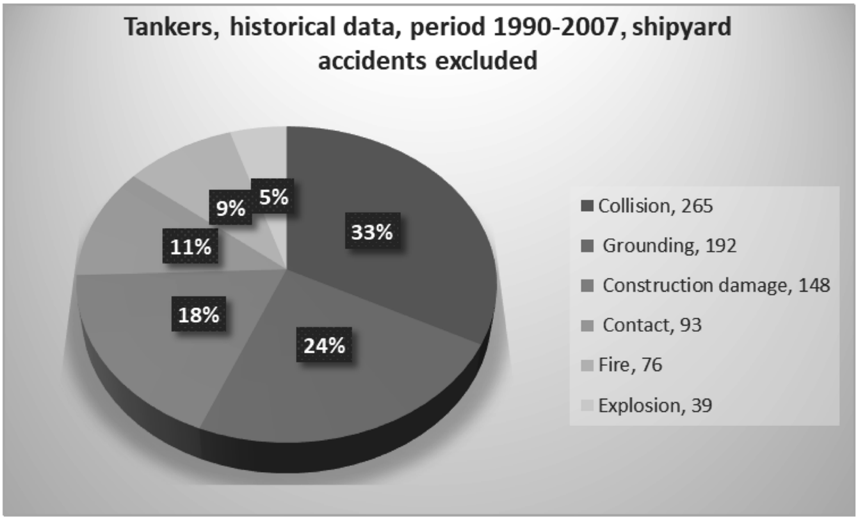


Figure 1 – Accident categories of tankers larger than 60.000 DWT [9]

Important characteristics of narrow waterways as well as tankers themselves will be explained on the following pages in order for probability factors and consequences of grounding or contact to be presented.

3. Characteristics of narrow waterways

A narrow waterway can be an approachable waterway, a coastal waterway or a canal within the harbour itself.

From the point of view of the safety of navigation and the assessment of the risk of the occurrence of grounding, characteristics of narrow waterways can be divided into several different groups [6].

Geometric features represent dimensions (width, depth and length), markings of the narrow navigational waterway with navigation marks, the presence of shallow waters, fixed or floating objects and bridges. The width of the narrow waterway is the horizontal distance between the boundaries of the waterway within which the ship can safely navigate without the risk of grounding, provided that there are no shallow waters/obstacles within the waterway. The depth of the narrow waterway represents the vertical distance from the bottom of the sea to the sea surface (the navigation chart usually depicts the depth during the lowest mean sea level). The length of the narrow waterway represents the distance between the two extreme points on the narrow waterway (usually marked by buoys or fixed objects). The marking of the waterway is a very important factor in the safety of navigation. Markings can be buoys equipped with light/sound signals, with RACON and/or AIS, lighthouses, ATONs.

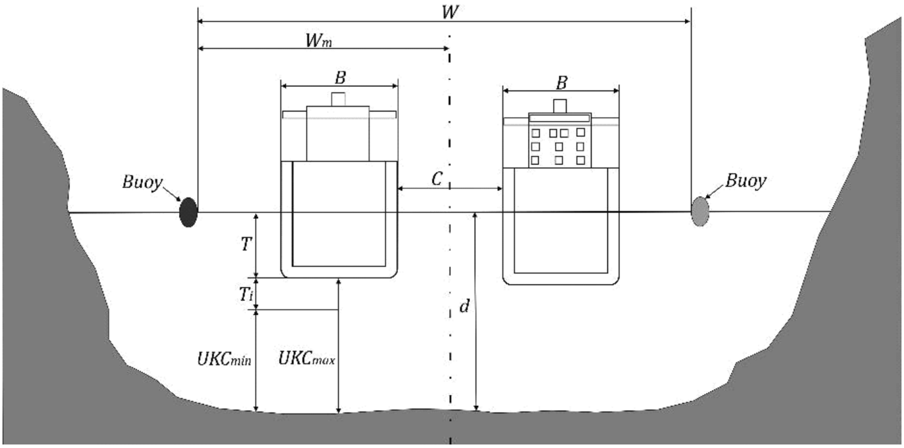


Figure 2 – Geometric features of waterway (Source: Authors)

Where figures correspond to the following:

W – width of waterway
W_m – width of a lane of a two-way waterway
B – ship breadth
C – distance between ships within waterway
T – static ship draft
T_i – increase of draft
d – depth of waterway
UKC_{max} – distance from the lowest point of the keel to the bottom of waterway
UKC_{min} – distance from the lowest point of the keel (total draft) to the bottom of waterway

Increase of the ship draft (*Ti*) is a variable derived from the sum of the value of the influence of waves, rolling and pitching of the ship due to waves, the change of the draft due to the density of the water in which ship navigates and the squat of the ship.

$$T_i = ID + f_{max} + \frac{H}{2} + T_n + S \quad (1)\ [2]$$

The influence of rolling on the ship can be determined from the following formula

$$ID = 0.5\, x\, B\, x\, sin\alpha - (T - T\, x\, cos\alpha) \quad (2)\ [2]$$

where *ID* represents the increase of draft due to rolling, *B* width of the ship, *T* ship draft, and α inclination angle of the ship. The influence of pitching on a ship (f_{max}) can be determined using the following formula:

$$f_{max} = 2\, x\, C_B x \frac{V_k 2}{100} meters \quad (3)\ [2]$$

where C_B represents the block coefficient of the ship - approximately 0.82 for a tanker[17],while V_k represents the speed of the ship in knots. The influence of waves counts as *H/2*, i.e. half wavelength.

The change of the draft due to water density is determined using the following formula:

$$T_n = \frac{FWA\, x(1.025 - \delta)}{25} \quad (4)\ [2]$$

where *FWA* (*Fresh Water Allowance*) presents the increase of draft in freshwater that is determined in shipyard and is taken from the hydrostatic tables of the ship, and δis the water density the draft is to be calculated for.

The type of sea bottom is one of the important characteristics of a narrow waterway. The seabed can be rocks, mostly rocks, sand with rocks and sand or mud [5]. Grounding of a tanker would have the highest estimated value of consequences, i.e. oil spill in the rocky seabed [16].

Traffic density is determined as the number of ships per unit of the waterway in the unit of time. With the increase of traffic density, safety of navigation decreases, and vice versa. For the purpose of the paper, authors divided traffic density into three categories (Table 1).

Table 1 – Distribution of traffic density

Low traffic density	0-1 ship per hour
Medium traffic density	1-3 ships per hour
High traffic density	>3 ships per hour

Source: Authors

Coverage of VTS service (*vessel traffic service)* is an important factor in the safety of navigation in narrow waterways. When navigating the area covered by the VTS service, the movement of the ships is monitored by the VTS operator and the safety of the navigation itself is increased. The VTS service issues navigational and safety warnings, weather forecasts and, in some cases, approaches to a pilot station, anchorage, and similar. Ships within the coverage area of the VTS service are obliged to listen to a particular VHF channel and report to VTS service when passing specific locations (if so specified).

Hydro and meteorological characteristics include the prevailing wind and wind direction, sea currents and tidal streams, waves and visibility, while traffic characteristics are traffic density, ship speed, ship movement direction and VTS coverage.

The wind has a significant impact on ships, especially in narrow waterways where ships' speed is usually lower and the wind effect is higher. The stronger the wind and the slower speed of the ship, the greater the ship's drift or the angle between the ship's heading and the course over ground [14]. Also, wind gusts can have a major impact on the safety of navigation in narrow waterways since they can produce an unexpected effect especially in situations of dangerous proximity to other ships or a near isolated danger. Wind has a particularly significant impact on ships with a large freeboard (VLCC - Very Large Crude Carrier or ULCC - Ultra Large Crude Carrier in ballast condition) [14].

Waves also have a significant impact on the safety of navigation in narrow waterways, especially on smaller ships. As the subject of the paper deals with the navigation in narrow waterways that are relatively sheltered from the open sea and have relatively low depths, it can be considered that the waves will not exceed the height of 2 meters.

Sea currents, same as wind can heavily affect the safety of navigation. Sea currents can be divided into steady currents and tidal streams. Both are constant and with the help of the tables and atlases their direction and rates can be precisely determined and in that way their impact on the safety of navigation can be reduced. Sea currents will have a greater impact on ships with deeper drafts.

For the purpose of this paper, authors have divided hydro and meteorological conditions that are present on certain narrow waterways into three groups: hydro-meteorological conditions A, B and C (Table 2).

Group A is characterized by calm winds, good visibility, low rate sea currents and barely wavy sea which practically do not present a danger to the navigation of tankers. Group B is characterized by a stronger wind (moderately strong to very strong winds), poorer visibility than in group A (but still good), slightly stronger sea current rates and slightly higher waves. The hydro-meteorological conditions of group B have an impact on the navigation of tankers and should be taken into account. Group C are hydro-meteorological conditions that can cause significant drift of the ship, reduce ship's speed, increase draft and make ship manoeuvring more difficult, thereby significantly reducing the safety of navigation and increasing the risk of grounding or contact.

These conditions are gales or storms with accompanying waves, poor visibility, and high rate sea currents.

Values of hydro-meteorological factors for the defined categories A, B, C are shown in the following table.

Table 2 – Categories of hydro and meteorological conditions

Group A	Wind speed up to 4 Beaufort (wind speed less than 16 knots), waves up to 1 meter, visibility more than 5 M, and sea current rate less than 0.5 knots.
Group B	Wind speed between 4 and 7 Beaufort (wind speed between 16 and 33 knots), waves between 1 and 3 meters, visibility between 2 and 5 M and sea current rate between 0.5 and 1.5 knots.
Group C	Wind speed more than 7 Beaufort (wind speed more than 33 knots), waves more than 3 meter, visibility less than 2 M and sea current rate more than 1.5 knots.

Source: Authors

For the purpose of this paper, four categories of narrow waterways with corresponding characteristics have been defined based on previously mentioned features in order to analyse the safety of navigation.

1. Narrow waterway category I:
   a. Sea depth ≥ 1.5 draft of the ship
   b. Well-marked waterway (buoys, lighthouses, AIS, ATON, ...)
   c. Width sufficient for two or more ships to safely pass (CPA 0.5 M (*closestpoint of approach*))
   d. Lengths up to 10 M
   e. There is no danger within the waterway itself
   f. ECDIS, CATZOC (*Category Zone of Confidence*) A1, A2

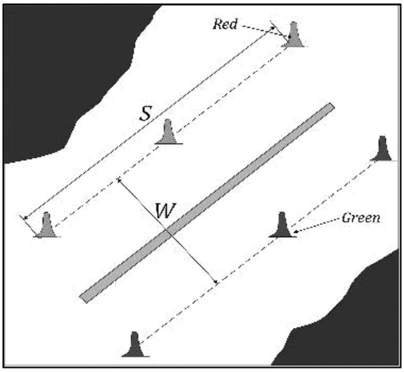
2. Narrow waterway category II:
   a. Sea depth ≥ 1.5 draft of the ship
   b. Well-marked waterway (buoys, lighthouses, AIS, ATON, ...)
   c. Width sufficient for two or more ships to safely pass (CPA 0.5 M)
   d. Lengths up to 10 M
   e. There is no danger within the waterway itself
   f. ECDIS, CATZOC A1, A2
   g. There is a need to alter the course of the ship within the waterway

3. Narrow waterway category III
   a. 1.2< sea depth < 1.5 ship's draft
   b. Well-marked waterway (buoys, lighthouses, AIS, ATON, ...)
   c. Width sufficient for two or more ships to safely pass (CPA 0.5 M)

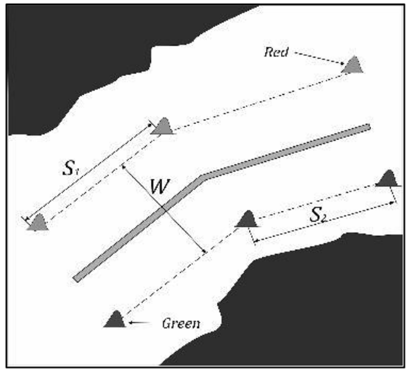
d. Lengths up to 10 M
e. There are dangers within the waterway itself (shoal, fixed object, ...)
f. ECDIS, CATZOC A1, A2

4. Narrow waterway category IV:
a. 1.2< sea depth < 1.5 ship's draft
b. Well-marked waterway (buoys, lighthouses, AIS, ATON, ...)
c. Width sufficient for two or more ships to safely pass (CPA 0.5 M)
d. Lengths up to 10 M
e. There are dangers within the waterway itself (shoal, fixed object, ...)
f. ECDIS, CATZOC A1, A2
g. There is a need to alter the course of the ship within the waterway

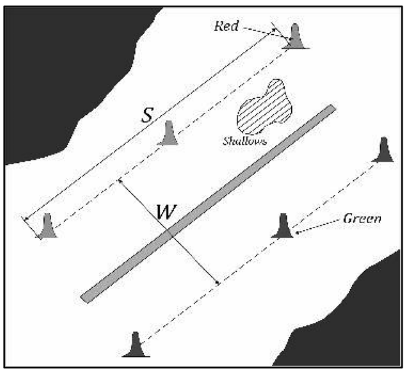
For categories I and II, the sea depth shall be equal to or greater than 1.5 times the draft of the ship, which does not significantly affect the manoeuvring characteristics of the ship; while for groups III and IV, the sea depth is 1.2 to 1.5 times greater than the ship's draft, what significantly affects the manoeuvring characteristics of the ship and the safety of navigation [3]. Furthermore, it is specified that in categories I and II there is no danger within the narrow waterway (e.g. shoal), while in category III and IV there is a danger within the waterway itself, and the risk of grounding is increased. Alteration of courses includes waterways of categories II and IV which also increase the risk of grounding/contact [1] [4] [6]. The CPA value of 0.5 M is taken as a safe value for two ships passing in the narrow waterway, which is a common practice in the navigation of tankers [12]. An essential feature of all categories of narrow waterways is exploration of the sea bottom, ie. the accuracy of depth data on ECDIS [10]. The CATZOC represents the category of reliability of the area on the electronic navigational chart. CATZOC A1 and A2 are the most reliable categories in which the sea bottom in a given area is fully explored and the depth accuracy is quite high [19] [20].



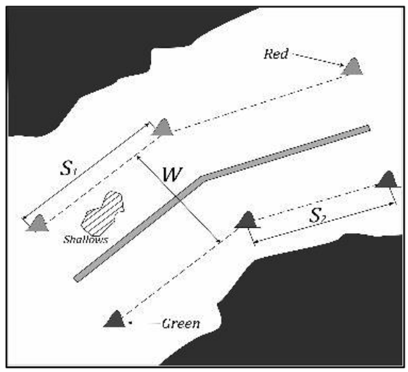
Category I



Category II



Category III



Category IV

Figure 3 – Graphical illustrations of the narrow waterways' categories, Source: Authors

The assumption is that all narrow waterways are well marked with navigational markings which facilitates navigation and allows navigational officers to determine the position of the ship in several ways, thus reducing the probability of the position error [1]. Differences for a particular category of waterway are represented by differences in traffic density, navigational dangers within narrow waterways, depths and lengths of waterways, and by whether they change direction of navigation. The assumed categories of narrow waterways are shown in previous figures.

4. Tanker characteristics

A tanker is a ship intended for the carriage of liquid cargoes by sea. In general, oil tankers are divided into categories by the size and their technical and technological characteristics ranging from smaller offshore tankers to the largest ones (*Handysize, Panamax, Aframax, Suezmax*, VLCC and ULCC) [17]. The paper will deal with the navigation of the *Aframax* oil tanker sizes.

Generally, tankers are specific ships that are characterized by inferior manoeuvring characteristics compared to other ships (e.g. container ships or passenger ships) [15]. The tactical diameter of the turning circle of most tankers is long between 2.5 and 3.5 times their length, which meets the IMO criterion of five times the length of the ship. If the tanker moves at a reduced speed in the area of small depths, the tactical diameter of the turning circle increases (Figure 4). Thus, in the case where the ratio of water depth and tanker draft is 1.2, the tactical diameter of the turning circle increases almost twice [3]. Therefore, when avoiding objects or shoals within a narrow waterway and when altering the course, attention should be paid to the diameter of the turning circle to avoid any dangerous situation.

When it comes to manoeuvring characteristics of tankers, it should be mentioned that stopping distance is about two nautical miles for the VLCC tanker (depending on whether the ship is loaded or not and on hydro-meteorological conditions). It is important to note that at reduced sea depths (sea depths 1.3 times the ship's draft) the stopping distance of the ship is reduced [3]. Most tankers have only one propeller and are powered by a slow-moving diesel engine [13].

Aframax tankers are the second most common type of tankers (*Handysize* tankers are the most numerous) and their sizes range from 80,000 to 119,999 tonnes of deadweight [8]. The main characteristics of Aframax tankers are shown in the table below.

Table 3 – Main characteristics of AFRAMAX tankers

Length over all	248.00 m
Length between perpendiculars	238.00 m
Extreme breadth	43.00 m
Extreme depth	21.00 m
Width of double hull	2.18 m
Height of double bottom	2.30 m
Summer draft	14.30 m
Summer draft deadweight	105,357 mt
Number of cargo tanks	12 tanks plus two slop tanks
Typical volume of cargo tanks	No.1 P/S each 8,003 m^3, No.2 P/S 10,796 m^3, No.3 P/S each 10,872 m^3, No.4 P/S 10,872 m^3, No.5 P/S each 10,872 m^3, No.6 P/S 9,976 m^3, Slop tanks each 1,212 m^3

Source: [9]

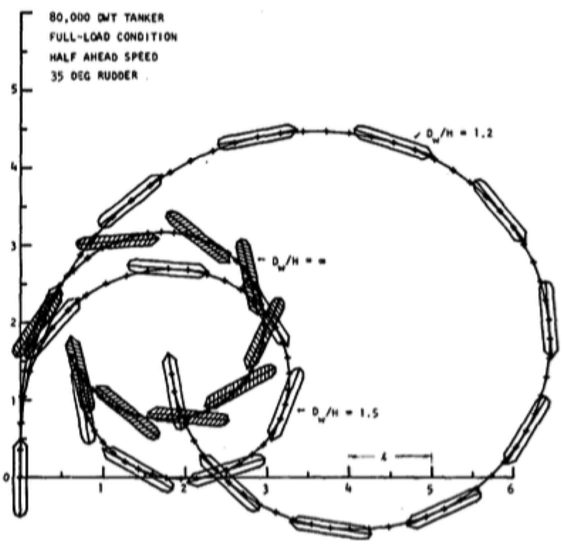


Figure 4 – Effect of water depth on tactical diameter of turning circle [3]

The quality of navigational equipment on the navigating bridge has also a significant impact on the safety of ships navigating in narrow waterways and although it varies from one shipping company to another, it can be generally considered that *Aframax* tankers are provided with high level equipment and its proper usage makes navigating in narrow canals safer. The introduction of ECDIS as a navigational aid has significantly increased the safety of navigation and its adequate handling can significantly reduce the possibility of grounding/contact [9].

The probability of environmental pollution as a consequence of grounding or contact has been considerably reduced with the introduction of double hulled tankers. Redundancy of steering gear reduced the probability of its failure [9].

From the above mentioned, it is concluded that large quantities of oil transported by tankers, their relatively large dimensions and slightly weaker manoeuvring characteristics than in other ships put tankers in a high risk group of ships for which the assessment of safety of navigation and the risk of grounding/contact in narrow waterways is necessary in order to minimize potential catastrophic consequences of grounding or contact.

5. Grounding and contact risk assessment

A risk matrix has been created for the purpose of the paper in order to assess the risk of grounding or contact and the probability and consequence factors have been assigned values between one and four.

The value of the risk of grounding or contact with a fixed or floating object is estimated by using the risk matrix. The estimated values of probability factors are summed up and divided by the mean value and with that value the matrix is entered from the left side. Then, the estimated value of consequence factors is added and divided by the mean value and with that value the matrix is entered from the bottom. In the interception, the value of the risk of grounding or contact is estimated. This method significantly simplifies the risk assessment and can quickly and easily assess whether the estimated risk value is small enough for the ship to safely continue the voyage or additional measures are needed to reduce the likelihood and/or any negative consequence to an acceptable level.

Here follow the most important factors of the probability of grounding (V) that have the greatest influence on the occurrence of grounding [7]:

- narrow waterway (V_1),
- hydro and meteorological conditions (V_2),
- traffic density (V_3),
- VTS service coverage (V_4).

For the purpose of estimating probabilities, each factor is assigned the estimated value ranging from 1 to 4.

Table 4 – Grounding or contact probability factors

Estimated value	V_1	V_2	V_3	V_4
1	Category I	Group A	Low traffic density	Compulsory or voluntary reporting to VTS
2	Category II	Group B	Medium traffic density	/
3	Category III	Group C	High traffic density	/
4	Category IV	/	/	No VTS

Source: Authors

The above-mentioned factors of the likelihood of accident are associated with consequence factors (P). The following consequence factors are taken in consideration:

- ship speed immediately before the grounding or contact (P_1)
- type of sea bottom (P_2),
- type of tanker hull (P_3),
- condition of tanker –loaded or ballast (P_4).

Table 5 – Valuing grounding or contact consequence factors

Estimated value	P_1	P_2	P_3	P_4
1	Less than manoeuvring speed	Sand or mud/floating object	Double hull	Ballast
2	Manoeuvring speed	Sand and rocks	/	/
3	Sea speed	Mostly rocks	/	/
4	/	Rocks/Fixed object	Single hull	Cargo

Source: Authors

Table 6 – Risk assessment matrix of tanker grounding or contact in narrow waterways

High	**4**	**8**	**12**	**16**
Medium	**3**	**6**	**9**	**12**
Low	**2**	**4**	**6**	**8**
Very low or negligible	**1**	**2**	**3**	**4**
Probability/ Consequence	Very low or negligible	Low	Medium	High

Source: Authors

Risk Matrix Legend:

1–7 Negligible to low risk (acceptable)

8–9 Medium risk (acceptable but additional measures required)

12–16 High risk (unacceptable - it is necessary to reduce the probability of event and/or consequences)

For example, for a tanker navigating in a narrow waterway category II where reporting to VTS service is voluntary, with the medium traffic density and the predominant hydro-meteorological conditions of group B, the derived mean value results:

$$V = \frac{(V_1 + V_2 + V_3 + V_4)}{4} = \frac{(2+2+2+1)}{4} = 1.75 \approx 2$$

Furthermore, if the bottom is rocky, the tanker is in ballast and has a double hull, and runs with the manoeuvring speed, the following could be derived:

$$P = \frac{(P_1 + P_2 + P_3 + P_4)}{4} = \frac{(2+4+1+1)}{4} = 2$$

When the estimated probability value (2) and the consequence value (2) are entered into the risk assessment matrix, the obtained value is 4, indicating that the estimated risk of grounding or contact is the lower acceptable one and that the precautionary and risk reduction measures already in place are sufficient, provided that none of the conditions taken are changed.

In case the value of the estimated risk is above 8, it is recommended to reduce the values of factors or the consequences in such a way as to affect the variable parameters or to delay the passage in the narrow waterway until the values of the factors are reduced to acceptable levels. In case of impossibility of mitigating the value to an acceptable level, additional safety measures such as the compulsory pilotage or an escort tug-boat may be introduced, as well as any other measures that will have an impact on reducing the risk to the proposed acceptable limit.

The method of assessing the risk of tanker navigation in a narrow waterway provides a simple tool that primarily enables a rapid risk assessment, and at the same time even provides a risk assessment option that can introduce special safety measures for a particular narrow waterway. The method can be used by shipping companies within their safety management system as a useful way of assessing risks of navigating their ships in certain channels.

The presented factors may be additionally extended by an individual and more detailed description of each of them, or by adding new ones, whereby the accuracy of risk assessment would be improved, yet the time required for the assessment would be prolonged.

6. Conclusion

Tanker grounding or contact damage within a narrow waterway can cause catastrophic consequences to the environment and people. In order to avoid such disasters, it is necessary to apply efficient methods that will reduce the likelihood of such accidents. The method of estimating the risk of grounding may be taken as one of such methods. The risk of grounding of an *Aframax* tanker navigating in a narrow waterway is shown in this paper.

It is proposed to divide narrow waterways into four categories that are clearly defined by the waterway characteristics, hydrometeorological conditions, traffic density with different values given and their linkage to probability factors of grounding and to consequence factors. The assessment of the risk of grounding is determined by means of a risk matrix that includes the assessment using probability and consequence factors with the risk estimation and risk mitigation measures.

Using the proposed risk assessment method, estimation of the risk of grounding by assigning values to defined factors of the risk of grounding can be determined in a simple and rapid way. Also, by modifying the parameters used for the specified type of tanker, it is possible to apply the method to other types of tankers and to other types of ships as well. The method can easily be applied by shipping companies and can be used as a safety assessment tool within a built-in safety management system.

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