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Assessing the Frequency and Material Consequences of Collisions with Vessels Lying at an Anchorage in Line with IALA iWrap MkII

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ABSTRACT: This paper proposes a collision model for ships underway and temporary objects as an extension to state-of-the-art maritime risk assessment like IALA iWrap MkII. It gives a brief review of frequency modeling's and consequence calculation theory as well as its applications, before it analogously derives a model to assess the risk of anchorage areas. Subsequently, its benefit is demonstrated by an example scenario.

1 INTRODUCTION

Maritime traffic volumes and ship dimensions are expected to increase further, requiring fairway and port designs being adapted to the new situation. In general, these design processes should be accompanied by an assessment of the risk of collision and grounding.

According to IMO (2007), "risk" is defined as the combination of number of occurrences per time unit and the severity of their consequences. The occurrence might be a collision or a grounding event. Its consequence is e.g. an oil leakage or a sinking ship, which is mostly measured in monetary values. Thus, it implies the common risk definition as probability of a collision multiplied by its expected damage (Pedersen 2010).

To quantify the risk, the International Association of Marine Aids to Navigations and Lighthouse Authorities IALA recommends a probabilistic methodology based on frequency modeling (IALA 2009). Basically, the methodology distinguishes collisions between ships underway and grounding, which includes collisions between ships and fixed objects (in the following, "collision" includes grounding events, as they are methodologically similar to collisions with fixed objects).

However, in this specific case the risk of mooring dolphins in relation to an anchorage has to be assessed. While the former is clearly a fixed object, vessels lying at an anchorage are neither underway nor completely fixed objects. Thus, the anchorage's risk is difficult to determine with the proposed IALA methodology.

Based on a risk assessment formula in section 2, a brief review of frequency modeling's theory and consequence calculation are given in section 3 and 4. The collision type "ship-anchorage" is defined in section 5, for which a frequency and a consequence model are derived in section 6 and 7 in line with current maritime risk models. Section 8 applies the models on an example scenario and compares the results with alternative modeling based on current methodology. In section 9 conclusions are drawn.

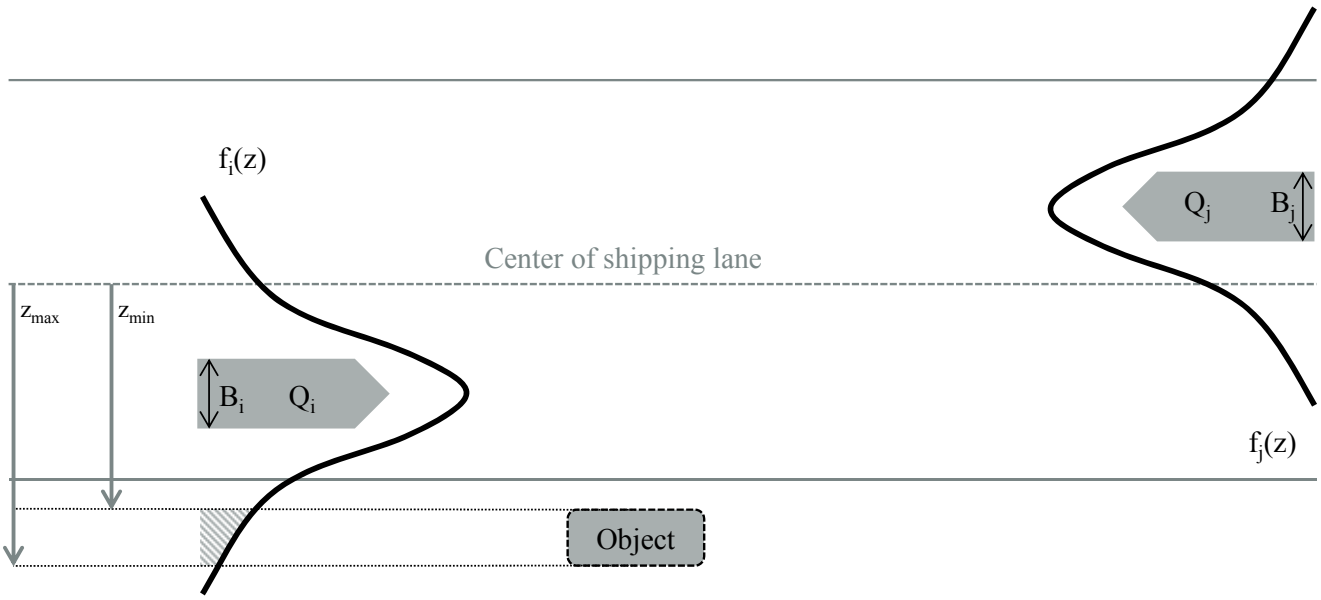

Figure 1. Head-on and fixed object category I situation (based on Pedersen 1995)

2 THEORY OF RISK ASSESSMENT

Referring to the definition of the term "risk" in section 1, the risk is composed of the frequency or probability P_i that a consequence C_i results from the hazard H_i as well as an utility function U converting the consequence to a monetary value. The risk can be formulated as (Pedersen 2010, IMO 2007):

$$Risk = \sum_i P_i\left(H_i, C_i\right) \cdot U\left(C_i\right) \tag{1}$$

3 THEORY OF FREQUENCY MODELS

Collision probabilities are mostly determined by frequency models, which are based on the work of Macduff (1974), Fujii (1983) and Pedersen (1995). The methodology has been applied in several analyses e.g. in the Canary Islands (Otto et al. 2002), in the Øresund (Rambøll 2006) or in the Gulf of Finland (Kujala et al. 2009, Hänninen et al. 2012).

In these models, the frequency corresponds to the number of collision events N in a specific time. In principle, this number is calculated by multiplying the number of collision candidates N_a with the causation probability P_C:

$$N = P_C \cdot N_a \tag{2}$$

3.1 *Collision candidate*

A "collision candidate" is a situation, which results in a collision, if no aversive maneuvers are made. For vessels underway, its number is calculated based on the geometric specification of the investigated sea area, the traffic volumes, vessel specifications and their lateral distribution under the assumption of "blind navigation". The latter implies, that initially a vessel choses its route independently of the current situation. Depending on the type of meeting situation:

- Passing a fixed object,
- Head-on meeting,
- Overtaking,
- Crossing or
- Merging

different models are commonly accepted to determine the number of collision candidates (Pedersen 2010, IALA 2012). In case of object collisions, Pedersen (1995) proposes four categories to further classify the type of accident:

1 Ordinary, direct route at normal speed,
2 Fail to change course at given turning point,
3 Collision as result of evasive actions or
4 Other (e.g. drifting).

The situation of the first category is displayed on the bottom of figure 1. According to basic statistics, the number of collision candidates in a specific timeframe for this type can be estimated by:

$$N_a^I = \sum_i Q_i \cdot \int_{z_{min}-\frac{B_i}{2}}^{z_{max}+\frac{B_i}{2}} f_i\left(z\right) dz \tag{3}$$

given that Q_i represents the number of passing vessels of type i in this time, B_i is the breadth of vessels of type i, $f_i(z)$ stands for their lateral distribution and z_{min} and z_{max} characterizes the dimensions of the fixed object.

The number of head-on collision candidates can be estimated in a similar way by:

$$N_a^{head} = L_W \cdot \sum_{i,j} \frac{v_i + v_j}{v_i \cdot v_j} \cdot Q_i \cdot Q_j \cdot P_{i,j}^{head} \tag{4}$$

with j representing types of meeting vessels, v_i is the speed of vessels of type i and L_W is the length of the route or fairway, where head-on meetings are

expected (see also figure 1). Finally, the probability $P_{i,j}^{head}$ for meeting vessels can be calculated by:

$$P_{i,j}^{head} = \int_{-\infty}^{\infty} \int_{z_i-(B_i+B_j)/2}^{z_i+(B_i+B_j)/2} f_i(z_i) \cdot f_j(z_j) \cdot dz_j dz_i \quad (5)$$

Analogously, estimation for the further types of collision can be derived, but as they are not further needed in this work, it is referred to Pedersen (1995).

3.2 *Causation probability*

The causation probability is defined as the fraction of collision candidates that results in a collision. In general, these factors differ depending on the situation types and are mainly derived from analytical methods or Bayesian networks.

As this paper focuses on collision candidate determination and not on causation probability modeling in the context of frequency modeling, it is referred to e.g. IMO (2007), Hänninen & Kujala (2010), Pedersen (2010) and IALA (2012) for further information. For grounding and object collisions, IALA (2012) suggests a default causation factor of $1.6 \cdot 10^{-4}$.

4 THEORY OF CONSEQUENCE CALCULATION

Consequences of ship collisions can generally be related to damaged material even leading to a sinking ship, environmental damages mainly due to an oil leakage as well as fatalities.

As this paper only focusses on material damages as possible consequences, collision problems can be divided in the external dynamics and the internal mechanics of the collision. The external dynamics considers the global motion of the vessels and the interaction with the surrounding water, while the internal mechanics deals with the response of the ships' structure (Lützen 2001). Thus, the internal mechanics refers to the deformation of the colliding vessels.

Methods to analyze the external dynamics of collisions range from empirical or analytical solutions thus closed form solutions, to time-stepped simulations (Brown 2002). In the context of risk analysis, a great variety of collision scenarios is considered, for which reason analytical solutions are mostly favored over time-stepped simulations.

The internal mechanics can be studied by two classes of theoretical methods: Finite element methods as well as analytical methods (Lützen 2001). Finite element methods allow calculating the internal mechanics by detailed modeling of ship structures that can be involved in the collision, such as the bow of the striking vessel and the lateral ship hull structure of the struck vessel (Zhang 1999). Due to very different types of ships and the resulting inhomogeneous distribution of bow shapes and steel structures, analytical methods are again favored over finite element methods for application in maritime risk assessment.

The analytical approach to determine the damaged material volume, considering both external dynamics and internal mechanics, generally relates the damage size to the dissipated kinetic energy and links it to a monetary value (e.g. Pedersen 2010).

4.1 *Absorbed Energy*

The amount of kinetic energy absorbed by the deformation of the ships' hulls can be calculated assuming a totally inelastic collision (Brown 2002, Minorsky 1959, Zhang 1999). Although the impact response is usually neither totally inelastic nor totally elastic, a more exact calculation requires detailed knowledge and modeling of ship structures. Assuming that the maximum possible percentage of the initial kinetic energy is absorbed by the ships' hulls in a totally inelastic collision, it presents a conservative approach.

The absorbed energy can, thus, be obtained from the difference between the initial kinetic energy of both ships before the collision and the kinetic energy in the system after the collision. The energies are calculated based on the principle of energy conservation and the momentum equation. Rotational energies are not considered.

The absorbed energy can be derived using the ships' displacements Δ_i and Δ_j, velocities v_i and v_j and added mass coefficients m_{ax} and m_{ay} considering the water in surge or sway motion due to the ship's motion, as well as the angle of encounter θ:

$$E = \frac{1}{2}(1+m_{ax}) \cdot \left(\Delta_i v_i^2 + \Delta_j v_j^2\right) - \frac{1}{2}(1+m_{ax})^2 \cdot \frac{\Delta_i^2 v_i^2 + \Delta_j^2 v_j^2 + 2\Delta_i v_i \Delta_j v_j \cos\theta}{(1+m_{ax}) \cdot \Delta_i + (1+m_{ay}) \cdot \Delta_j} \quad (6)$$

The index *i* indicates the striking ship, while *j* stands for the struck ship.

4.2 *Damage Size*

The damage size or volume of destroyed material can be related to the absorbed energy. The most common empirical approach for ships on crossing routes considering external dynamics and internal mechanics has been developed by Minorsky (Brown 2002, Zhang 1999).

Minorsky (1959) examined data from 26 full-scale ship collisions, where vessel speed, angle of encounter and damage size were known. For wider applicability as well as greater accuracy, this linear approach has been modified several times and has been developed further amongst others by Pedersen & Zhang (2000):

$$E = 0,77 \cdot \varepsilon_C \cdot \sigma_0 \cdot R_j + 3.5 \cdot \left(\frac{t}{d}\right)^{0.67} \cdot \sigma_0 \cdot R_i \quad (7)$$

The first term describes the damage of the ruptured or tensioned side structure, thus the damaged material volume of the struck ship R_i, taking into account the flow stress of the material σ_0 and the critical rupture strain ε_c. The second term refers to the damaged material volume at the bow of the striking ship R_i assuming a crushing or folding damage type. It includes the average thickness of crushed plates t and the average width of the plates in the cross section d (Zhang 1999).

4.3 *Monetary Value*

In the third step, the damaged material volume is translated into a monetary value. The repair costs $C_{Material}$ not only depend on the damaged volumes R_i and R_j, the density of steel ϱ and the costs for a typical repair job C_{Repair}, but also on the location of the repair yard leading to costs for the voyage to the yard C_{Yard} and the probability that a repair in a yard is required P_{Yard}:

$$C_{Material} = (R_i + R_j)\rho \cdot C_{Repair} + C_{Yard} P_{Yard} \quad (8)$$

P_{Yard} amounts to zero in case of low energy collisions, and to one for high energy collision. In case of low energy collisions the ship's hull is only deformed but not ruptured. Thus, it is assumed that a ship's classification certificate can be maintained and a stay at a yard is not required. This depends on a critical kinetic energy, which can be derived from the ship's displacement and a critical speed.

In case the resulting monetary value is higher than the building costs, total loss can be assumed.

5 RISK FACTOR ANCHORAGE

Anchorages pose a risk to navigational safety, as there often anchor vessels, which then are an obstacle that others might collide with. Notwithstanding improving navigational aids and crew qualification, collisions still occur, like e.g. the collision between the "Katharina Siemer" and anchoring "Angon" on the Elbe River in November 2012 or between "Jinggangshan" and anchoring "Aeolos" near Gibraltar in May 2011. Thus, an appropriate consideration of anchorages during maritime risk assessments should be aspired.

5.1 *Anchorage characteristics*

An anchorage is a limited area that is suitable for vessels to anchor. Those areas are highlighted in sea charts and might also be marked with buoys (BSH 2011). However, if the anchorage is not in use, it is not an obstacle for shipping as it normally does not necessitate any fixed infrastructure (except in the case of buoys).

The actual obstacles are the vessels lying at an anchorage, which one may collide with. In contrast to a berthed ship, those ones change their position by swinging at anchor depending on wind, waves and tide.

5.2 *Collision types on an anchorage*

Types of collision that may occur in relation to an anchorage are collisions between:

1 Anchored vessels,
2 Anchored vessel and vessel underway (e.g. with a transiting vessel),
3 Vessels underway (e.g. transiting vessel and a vessel leaving the anchorage) or
4 Other (e.g. drifting).

While the collision candidates for the third type can be determined with the help of a crossing or merging model, none is available for the upper categories, as the anchored vessels are neither fixed objects nor permanent obstacles. In the following, the first one is called "anchorage-" and the second one "ship-anchorage-collision".

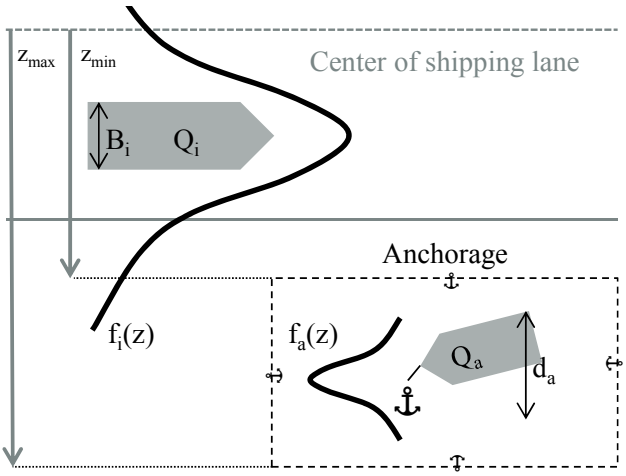

Figure 2: Ship-anchorage-collision

6 PROBABILITY OF SHIP-ANCHORAGE-COLLISION

6.1 *Mathematical model for collision candidates*

To determine the ship-anchorage collision candidates similar to (3) and (4) first all meeting situations in a given timeframe must be calculated. If $\tau_{use,a}$ is the fraction of time that the anchorage is used by at least one vessel of type a and Q_a is the mean number of vessels of type a, which lay at the anchorage at the same time, then the total number of collision candidates is given by:

$$N_a^{S-A} = \sum_{i,a} Q_i \cdot \tau_{use,a} \cdot Q_a \cdot P_{i,a}^{S-A} \quad (9)$$

where the first three elements determine the number of all meeting situations.

Afterwards, the probability $P_{i,j}^{S-A}$ of the underway vessel heading towards an anchored ship has to be calculated. This is done by $f_a(z)$, which is the probability density function of the anchoring ship's distance to the center of the shipping lane, and d_a representing its obstacle dimensions including paid out anchor chain perpendicular to the other vessel's moving direction (see also figure 2). If the vessels

underway are described as in (3), then the collision candidates can be estimated similar to (4) by:

$$P_{i,\mathrm{a}}^{\mathrm{S-A}} = \int_{-\infty}^{\infty} \int_{z_i-(B_i+d_a)/2}^{z_i+(B_i+d_a)/2} f_i(z_i)\, f_a(z_a) \cdot dz_a dz_i \qquad (10)$$

6.2 *Causation probability*

This work focuses primarily on modeling of collision candidates. Thus, in the first instance the causation probabilities for fixed object collision could be used as an approximation for calculating the number of collision events.

6.3 *Model variables*

Of course, the different types of anchoring vessels allow modeling different sizes of ships. However, it furthermore allows incorporating swinging circle effects, as d_a and $f_a(z)$ depend on the actual weather and tidal constraints. Therefore, the ship of type a is split into several types with different obstacle characteristics, while its likelihood is controlled by $\tau_{use,a}$, which is set according to the tidal conditions' fraction of time.

As the boundaries z_{min} and z_{max} of the anchorage are not part of the model, it has to be ensured by the chosen distribution function that the anchoring vessels are positioned within the anchorage area. However, the tails of $f_a(z)$ outside the anchorage could be used to model meeting situations between vessels underway and ships adrift because of a broken anchor or with ships swinging at anchor into the shipping lane.

7 CONSEQUENCE OF SHIP-ANCHORAGE-COLLISION

In order to estimate the consequences of ship-anchorage collisions swinging circle effects have to be taken into account. Due to the varying angle of encounter, ship-ship collisions can be orthogonal, parallel or in between, thus leading to bow-side-structure collisions, head-on collisions or intermediate encounters.

Moreover, the speed of the anchored ship is assumed to be zero. Based on formula (6) the absorbed energy for orthogonal collisions of two vessels can be calculated by:

$$E = \frac{1}{2}\left(1+m_{ax}\right)\Delta_i v_i^2 - \frac{1}{2}\frac{\left(1+m_{ax}\right)^2 \Delta_i^2 v_i^2}{\left(1+m_{ax}\right)\cdot\Delta_i + \left(1+m_{ay}\right)\cdot\Delta_j} \qquad (11)$$

In contrast to orthogonal collisions, where the struck ship is assumed not only to have a forward speed but also a sway velocity after the collision, head-on collisions with an angle of encounter of 0° or 180° principally only lead to a surge motion of both ships. Hence, only the added mass coefficient for surge motion has to be considered when calculation the absorbed energy resulting in the following expression based on (6):

$$E = \frac{1}{2}\cdot\left(1+m_{ax}\right)\cdot\frac{\Delta_i\Delta_j}{\Delta_i+\Delta_j}\cdot v_i^2 \qquad (12)$$

8 RISK ASSESSMENT EXAMPLE

Due to confidentiality reasons the original case that inspired the extension can't be presented here. However, a simplified virtual decision situation shall demonstrate the utility of the ship-anchorage-collision model.

8.1 *Decision alternatives*

In an area of restricted tidal waters short-term berths are needed for ships waiting e.g. for a free berth at the pier or a locking. However, it is discussed to either display a narrow anchorage area next to the fairway or to construct several dolphins allowing for short-term moorings. As the second option is more costly its safety benefits should be analyzed.

8.2 *Frequency modeling as ship-anchorage-collision*

The principal layout of the dolphin alternative corresponds to figure 1 and the one of the anchorage to figure 2. Table 1 gives an overview about the scenario variables. It is assumed that during 75% of the time the anchorage area or the dolphins are in use. Furthermore, the berths at the dolphins are on the fairway side, thus the obstacle dimensions increase if a vessel is moored. If there are several ships, they are moored in series; consequently the obstacle dimensions stay constant.

Table 1. Scenario variables for frequency modeling.

Variable	Anchorage		Mooring dolphins	
Q_1, Q_2	20,000	Ships/a	20,000	Ships/a
B_1, B_2	20	m	20	m
$f_1(z)$	$N(50, 50^2)$		$N(50, 50^2)$	
$f_2(z)$	$N(-50, 50^2)$		$N(-50, 50^2)$	
z_{min}	150	m	300*	m
z_{max}	450	m	305	m
$\tau_{use,a}$	0.75	-	0.75	-
Q_a	2.5	Ships	2.5	Ships

* z_{min}=280m for dolphins if ships are moored

Due to tidal waters, the anchoring vessels swing at the anchor thus having different obstacle positions and dimensions over time. The latter strongly depends on the vessels angle to the fairway. If further weather effects are neglected and a tidal current parallel to the fairway is assumed, then the obstacle dimension of the anchoring vessel (perpendicular to the fairway) over time follows approximately the solid line in figure 3.

It can be seen, that shortly after slack tide, when the dotted current line crosses the axis of abscissae, the changing current direction turns around the vessel

until it lays again parallel to the fairway according to the new tide. During this time, the obstacle dimensions are of course much higher than in the dolphin case, where the vessels stay parallel independently of the tide.

Within this example, a turning rate of 5 degrees per minute is assumed and the turning process is divided into three different relations. Their characteristics are given in table 2 considering that the likelihood of anchored vessels outside the anchorage (e.g. due to drifting because of broken anchor) is below 1.0%. In reality, the position distribution as well as the lateral dimension should of course be derived by available information, as e.g. data from the Automatic Information System AIS.

Table 2. Obstacle dimensions in anchorage scenario

Relation	Orthogonal	In between	Parallel
Fraction of time	0.04	0.06	0.90
d_a	100 m	60 m	20 m
$f_a(z)$	N(300, 40^2)	N(300, 20^2)	N(300, 10^2)

8.3 *Frequency modeling as fixed-object-collision*

Even though anchoring vessels do not fit the definition of fixed object collision models, two alternatives are presented based on the methodology described in Pedersen (1995) to allow for a comparison with the proposed model.

In the first alternative "Fixed Object: Anchorage" the whole anchorage is modeled as an object for 75% of the time, while the second one "Fixed Object: Anchored vessel" assumes that all obstacles lay in a row in the middle of the anchorage similar to the dimensions in table 2. Of course, the latter implies that not the whole anchorage area is used.

8.4 *Comparison of frequency modeling results*

Table 3 shows the estimated collision candidates for the decision alternatives. Using (3), the estimation of the collision candidates for the dolphin scenario can be performed directly according to accepted methodology and results in 0.084 collision candidates per annum.

Indeed, it is observable that the results for the anchorage scenario widely differ depending on the chosen model. If e.g. the whole anchorage area is modeled as a fixed object, then this results in 540 estimated collision candidates. This seems to be a very conservative approach as underway vessels traveling through this area are not necessarily on collision course with an anchoring ship.

Table 3.Collision candidate results of example

Model	Collision candidates	
Ship-Anchorage-Collision	2.472	p.a.
Fixed Object: Anchorage	54 0.040	p.a.
Fixed Object: Anchored vessel	0.111	p.a.
Fixed Object: Mooring dolphins	0.084	p.a.

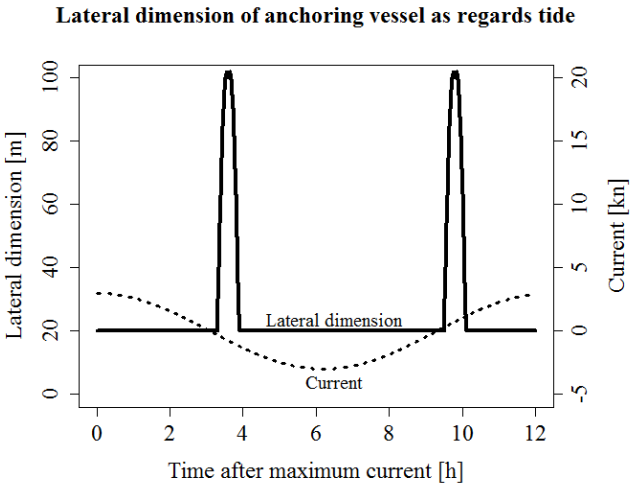

Figure 3. Lateral dimension of anchoring vessel (idealized)

In contrast to that assuming a fixed anchoring position might be too subjective due to the fact that the chosen position could strongly bias the results. As commonly used lateral probability distributions decline in the tails, assuming a more distant anchoring position would strongly affect the calculated collision candidates, and thus the risk assessment. If it is e.g. anticipated in this example, that all anchoring vessels lay next to the fairway-side border of the anchorage, the expected number of collision candidates would be close to the one in the "Fixed object: Anchorage" case.

As the result reacts very sensitive to the assumed anchoring position, it can be considered to be the most objective way to include the probability density function $f_a(z)$ of the anchoring position directly in the risk assessment by using the proposed model. Therefore, frequency distributions derived from recorded AIS-data provide an accurate base to determine the required functions $f_a(z)$ and $f_i(z)$.

8.5 *Consequence calculation*

On the basis of the frequency modeling results the consequences are calculated for ship-anchorage-collisions in comparison to the dolphin scenario. For the calculation, a ship with the dimensions in table 4 and building costs of around 16.78 million € is assumed. The ship at the anchorage or mooring dolphins has the same dimensions.

Typical repair costs are assumed as 6,000 €/t (Otto et al. 2002), which include the full repair process, such as cutting-building-fitting of the damaged volume. Furthermore, costs for the voyage to the shipyard C_{Yard} of about 50,000 €/repair job including fuel, crew and tug costs are added (Otto et al. 2002). Costs for a damaged mooring dolphin are approximated with 200,000 €.

Regarding the calculation of the damaged material volume of both vessels using formula (7) normal strength hull structural steel is used with a flow stress σ_0 of 460 N/mm² and a density ϱ of 7.85 t/m³. For the critical rupture strain ε_c a mean value for stiffened and unstiffened plates of 7% is assumed according to Paik & Pedersen (1996). The relation of average thickness of crushed plates to average width of the

plates in the cross section t/d is 1/83 referring to (Zhang 1999).

Table 4. Scenario variables for consequence calculation.

Variable	Anchorage		Mooring dolphin	s
L_1, L_2	120	m	120	m
B_1, B_2	20	m	20	m
T_1, T_2	8	m	8	m
Δ_1, Δ_2	15,700	t	15,700	t
v_1, v_2	8;0	kn	8;0	kn
C_{Ship1}, C_{Ship2}	16.78	mil €	16.78	mil €
$C_{Dolphin}$			200,000	€
ε_c	7	%	7	%
σ_0	460	N/mm²	460	N/mm²
t/d	1/83		1/83	
ϱ	7.85	t/m³	7.85	t/m³

Table 5 summarizes the results of the consequence calculation based on the three-step approach relating the damaged material volume to the absorbed energy and linking it to a monetary value. The results are only shown for ship-anchorage collisions compared to the mooring dolphin scenario.

Table 5. Consequence results of example

Model	Consequence
Ship-Anchorage-Collision	139,828 €
Fixed Object: Mooring dolphins	264,042 €

Taking into account the fraction of time for orthogonal, parallel and in between collision situations as well as the fraction of time particularly the dolphins are in use, it can be seen that the consequences are on average almost twice as high for the mooring dolphin scenario than for ship-anchorage collisions.

On the one hand this can be explained by higher energies to be absorbed in case of mooring dolphins as the moored vessels cannot experience a surge or sway motion after the collision, but needs to absorb the energy that could stay in the system due to the motion.

On the other hand, even more significant is the influence of the costs in case one mooring dolphin is damaged by a ship crushing head-on into it, because there is no ship at the mooring dolphins at the point in time of the collision.

8.6 *Risk assessment*

According to the definition of risk, the risk of the ship-anchorage scenario and the mooring dolphin scenario can be derived from the collision candidates or probabilities and the consequences using (1). The results are listed in Table 6.

Table 6. Risk results of example

Model	Risk	
Ship-Anchorage-Collision	55.31	€ p.a.
Fixed Object: Mooring dolphins	3.55	€ p.a.

The results emphasize the importance of risk assessment besides frequency modeling and consequence calculation. In this example the consequence results indicate that an anchorage area should be favored over mooring dolphins. Only looking at the frequencies, in contrast would give impression vice versa. The risk assessment relates both providing the basis for a sound decision.

Furthermore, the analysis of the different anchoring situations could also be of help by finding high risky situations. Table 7 shows the partial results of the ship-anchorage-collision-model in this example and it can be observed, that nearly all collision candidates are expected during the orthogonal situation.

Table 7. Collision candidates' situation depending on tide

Relation	Orthogonal	In between	Parallel
Fraction of time	0.04	0.06	0.90
Collision cand.	2.257	0.108	0.107
Consequence	145,871 €	89,239 €	63,625 €
Risk	52.67 €	1.55 €	1.09 €

9 CONCLUSION

Within this work additional collision types than those used in IALA (2012) have been defined, which are related to anchorage areas. A model for estimating collision candidates between vessels underway and vessels lying at an anchorage has been proposed, which is capable of taking into account information on the anchoring position's frequency distribution. Notwithstanding, the proposed model suffers similar drawbacks as frequency models in general, e.g. that vessel movements are not taken into account and that information about the exact collision situations is missing (Goerlandt & Kujala 2011).

Nevertheless, the proposed model goes in line with state-of-the-art frequency models for collisions between ships or ships and fixed objects to allow for comparison with other collision types. The method has been applied on an example case derived from a real problem to demonstrate the shortage of modeling anchorage areas as fixed obstacles. Additionally, the proposed model is capable to roughly consider swinging circle effects.

To fully assess the risk induced by an anchorage it can be seen that the consequences need to be evaluated. An analytical approach considering external dynamics and internal mechanics based on three steps relating the damaged material volume to the absorbed energy and subsequently linking it to a monetary value has been applied.

Although the approach assumes totally inelastic behavior besides other simplifications, such as neglecting rotational energies, it can be used for maritime risk assessment based on a variety of collision scenarios and ship types. Nevertheless, the approach only gives a rough estimation of the consequences. Where possible, additional information on the colliding vessels or more detailed modeling of ship structures should be integrated in the consequence calculation.

Indeed, further adjustments are necessary to establish a full risk model for anchorages. Next to the proposed geometric model, a deeper analysis of causation factors should be conducted for this type of accidents. Moreover, consequences not only refer to damaged material, but also to environmental damages, fatalities or loss of earnings (Pedersen 2010). However, this requires further investigation for ship-anchorage-collisions.

Considering the mentioned adjustments this paper presented a way to more accurately assess an anchorage's risk in line with IALA iWrap MkII.

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