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CONTENTS

List of symbols and abbreviations

A-Index	Attained Subdivision Index
ALARP	As Low As Reasonably Practicable
CBA	Cost Benefit Assessment
EMSA	European Maritime Safety Agency
FSA	Formal Safety Assessment
IACS	International Association of Classification Societies
IMO	International Maritime Organization
GAP	General Arrangement Plan
GISIS	Global Integrated Shipping Information System
GM	Metacentric Height
GT	Gross Tonnage
PoB	Persons on Board
RoPax	RoRo-Passenger ship
SOLAS	International Convention for the Safety of Life at Sea
TTC	Time To Capsize
TTE	Time To Evacuate
TTS	Time To Sink

1 EXECUTIVE SUMMARY

The risk models developed in GOALDS and EMSA III for collision and grounding/contact accidents and for the purpose of evaluating the need for improving passenger ship's damage stability requirements have been reviewed with respect to structure and methods used for quantification. These risk models are based on historical accident data and contain a number of assumptions, simplifications and expert judgements. This review was performed by a workshop with experts from FLARE project. The starting point for the revised structure forms an identification of influences on flooding risk that were grouped according to probability of accident, probability of damage extent, probability of survivability and consequences. The revised flooding risk model is defined by a sequence characterising the risk to persons on board, including a more detailed description of the quantification of consequences. Means for quantification of the elements are specified, considering the input by FLARE as well as data sources used in GOALDS and EMSA III.

2 INTRODUCTION

During previous projects, like GOALDS (Papanikolaou et al., 2013) and EMSA III (Konovessis et al., 2015), available information on collision and grounding accidents has been used to classify the accidents per se, based on the available accident reports. It is not envisaged to re-classify the data base again, but use the previous categories for the update accounting for the latest accidents.

The existing risk models are designed based on historical accident data and contain a number of assumptions, simplifications and expert judgements. Details on the structure and population of the existing risk models of GOALDS and EMSA III are presented in Section 3. A joint review of these event trees was done during the 1st workshop held in Hamburg (2019-09-03&04) and led to a revised structure of the event tree. New nodes were identified that need to be addressed in WP3, WP4, WP5, WP6, WP7 and WP8. Examples are the correlation between damage extent, time to capsize and fatality rate and appropriateness of the division of the events into collision, bottom grounding and side grounding/contact instead of using the location of an accident (open sea, near coast, terminal area, etc.) and also the consideration of navigational and operational measures during the accident.

The objectives of this work package are as follows:

- Review of event trees with respect to structure and further develop the risk models for flooding risk of Cruise and RoPax ships;
- Identify nodes for further consideration in WP 3, 5, 6, 7 and 8;
- Focus on risk related to sinking/capsizing due to collision, contact and grounding accidents/incidents.

In this context it is noted by the authors that:

- The FLARE risk model should characterise the "real" risk, i.e. all probable scenarios, and not only historical data, i.e. what has occurred, respectively, reported.

- The risk is measured in terms of fatalities, environmental pollution and loss of property. The focus in FLARE is put on human risk, i.e. risk to all persons on board a vessel.
- The casualty reports help to identify main factors triggering the consequences, i.e. factors influencing the risk but also helping to categorise the consequences.
- When developing the risk model, further investigations are necessary to consider influences on risk that do not occur so far, i.e. reported in casualty reports.

3 Method of work

In order to provide an unbiased starting point for the review of the existing risk models as developed by previous research projects, namely GOALDS and EMSA III, for collision, grounding and contact risks of Cruise and RoPax ships, the influences on this risk were collected in a brainstorming session (Workshop 2019-09-03&04). These are subsequently supplemented by more detailed investigation.

The influences are grouped into main elements characterising the risk, i.e. incident, damage extent, survival/loss of vessel and consequences.

Based on the characterising elements, the influencing parameter and existing risk models, a basic structure is developed, i.e. a generic risk model.

Subsequently, the following is assigned to the generic model:

- Influences
- Methods for quantification
- Relevant data for quantification related to method
- Input by work packages within the project.

The new risk model was presented and discussed on a second workshop (2019-10-16).

4 Collision and Grounding/Contact Risk Models

The development of the collision and grounding/contact risk models was initiated in the framework of the EU funded research project GOALDS and continued within the EMSA III Study and the eSAFE project. These risk models were developed for determining the actual risk level for persons on board relating to collision, contact and grounding accidents, and to verify if IMO damage stability requirements can be further improved by applying the ALARP process. In this respect, a database with data from relevant ship accidents was elaborated, starting with historical data extracted from the IHS Fairplay casualty database. The collected casualty records were thoroughly reviewed and verified. Subsequently, extensive search for additional data, including accident reports was carried-out in order (a) to verify the information of IHS database and (b) to amend the information provided by details relevant for the further processing of information. The casualty records were enhanced with additional information collected from all possible official sources including IMO-GISIS, Flag Administrations, Class Societies, Owners and Operators. Based on the analysis of the collected accidents information, the event sequences presented in Figure 1 and Figure 2 for the collision and grounding/contact accidents were elaborated and subsequently used as the basis for the development of quantitative risk models. Due the differences between the two ship types, among others with respect to operational profile and subdivision, these risk models are ship type dependent.

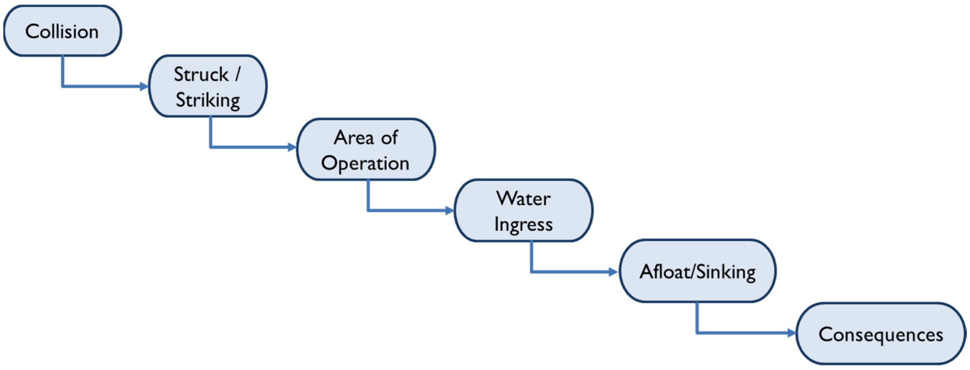

Figure 1: Collision accidents event sequence

For each type of accident (collision or grounding/contact) and each vessel type (Cruise or RoPax), initial frequencies were calculated based on available accident data: for Cruise ships based on accidents involving Cruise and Pure Passenger ships and for RoPax ships involving RoPax and RoPax Rail ships. The accidents as well as the figures of the active fleet used for the determination of the initial accident frequencies were identified applying the following filtering[1]:

- Ship types: Cruise and Pure Passenger ships or RoPax and RoPax Rail
- Casualty time period: 2000-2012

[1] These filtering characteristics were selected based on a comprehensive analysis of the fleet development and accidents of the type collision, contact and grounding.

- GT ≥ 1000
- Length ≥ 80 m
- Built ≥ 1982
- IACS classed ships
- Accident type: Collision – Serious cases
- Froude number ≤ 0.5 – to eliminate HSC from the study.

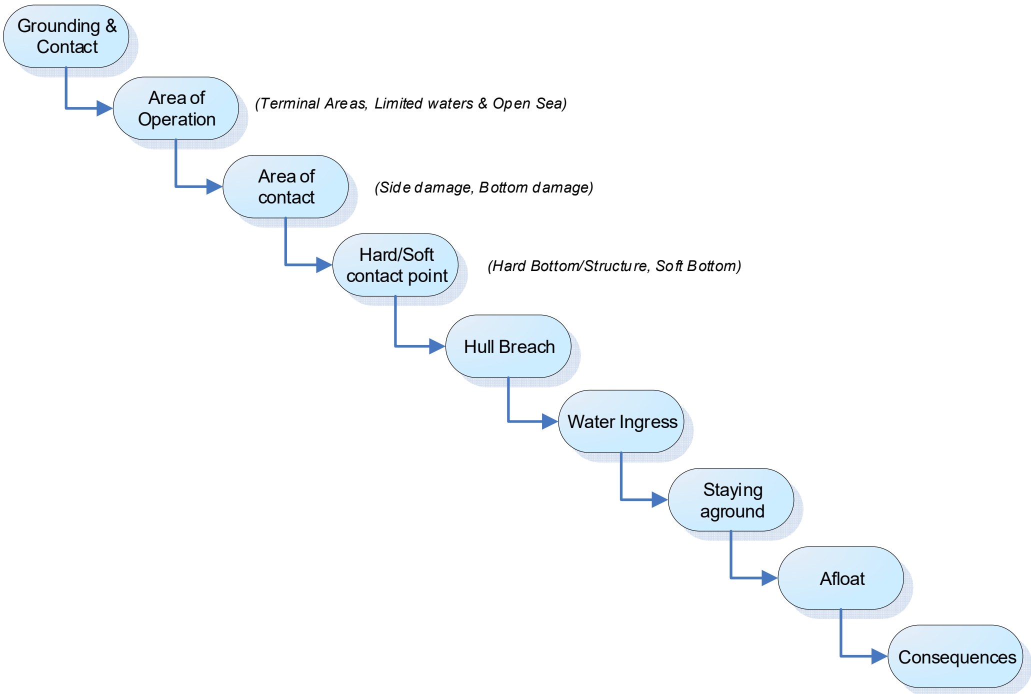

Figure 2: Grounding/contact accidents event sequence

The corresponding fleet at risk was calculated using the same filtering, on a monthly basis for the corresponding time period. It is noted that, even though the focus is on "serious" accidents not all casualties have the potential to lead to the loss of vessel, however, all accidents together are the "experience" of maritime industries. Thus, for building the bridge between experience and the focus of the risk models, these, "not relevant" cases were "de-selected" by the sequences shown in Figure 1 and Figure 2. For instance, probability of sinking/capsizing of a striking vessel in a collision accident tend to be zero, i.e. for about 50% of the vessel involved in a collision no consequences are considered. Likewise, in grounding/contact via "hull breach" only the scenarios with water ingress are considered for further computation of the risk.

The conditional probabilities within each risk model were calculated based on historical data from the casualty database, applying the following filtering:

- Ship types: Cruise and Pure Passenger ships, AND RoPax and RoPax Rail
- Casualty time period: 1990-2012

- GT ≥ 1000
- Length ≥ 80 m
- Built ≥ 1982
- IACS and non-IACS classed ships
- Accident type: Collision – classified serious according to IHS Fairplay specification
- Froude number ≤ 0.5 – to eliminate HSC from the study

In this respect, the initial probabilities were calculated separately for each type of vessels: (a) Cruise and Pure Passenger ships and (b) RoPax and RoPax Rail. However, in order to increase confidence, the conditional probabilities within each model have been calculated using the full set of data, collected from accidents pertaining to both ship types. This was decided due to the small size of the data, not allowing the population of each branch of the risk model with sufficient number of accidents without merging the data from both ship types. For the same reason, it was decided to expand the casualty time period and also to include non-IACS ships. It should be noted that, even with the relaxed filtering and after merging the data from accidents including both ship types, the total sample size is relatively small compared to other FSAs and it is further gradually reduced from one node to another, resulting to probabilities with very low confidence in several cases (see Annex B).

The Probability of "Afloat/Sinking" is estimated on the basis of the Attained Subdivision Index A, calculated according to SOLAS for collision accidents and according to the method developed in the framework of the EMSA III Study for grounding/contact (see Figure 1 and Figure 2). It is noted that the probability of "Afloat/Sinking" for the accident category under consideration is a conditional probability, e.g. given that the ship is struck, water ingress occurred.

Finally, the probability of "Fast/Slow Sinking", as well as the assumptions on human fatalities were estimated by expert judgment as follows:

- Probability of fast sinking
    - Cruise: 18%
    - RoPax: 50%
- Percentage of human fatalities with respect to POB (persons on board)
    - Fast Sinking: 80%
    - Slow Sinking: 5%
    - Fatalities in Terminal areas: 5%

The Fatality Rates in case of fast sinking/capsizing or in case of slow sinking (progressive flooding) were estimated by expert judgment considering historical data from past accidents. In this respect, it might be noted that the assumed fatality rate in case of fast sinking is in good agreement with that of the Estonia accident with a fatality rate of ~85%. For terminal area the expert judgement is based on (a) the possibility to escape/evacuate directly to shore and (b) limited water depth reducing the probability to sink, respectively, complete capsize. Reference is made to the case of the Herald of Free Enterprise that capsized only partly when leaving harbour (on a sandbank, 9 m water depth) and to the design of modern ships, the majority of which has a beam of 25 m or more (79%).

A more detailed discussion of the background of the development of the risk models for collision and grounding/contact accidents, along with a detailed description of the data sample used for the evaluation of the conditional probabilities is given in Annex B.

5 Further development of flooding risk model

5.1 Influences on flooding accidents

As basis for the review of the risk models developed within previous projects related to damage stability, influences on the risk to people on board passenger ships due to flooding accidents were collected in a workshop with FLARE experts taking place at 2019-09-03 and 04 in Hamburg. It is noted that for FLARE project this discussion is focusing on flooding in general in order to develop one generic model that may help to overcome the shortcomings of the accident category based approach, i.e. independent models for collision and contact/grounding risk.

Influences identified in the workshop are assigned to the main characteristic elements:

- Probability of incident/accident;
- Probability of survival, respectively sinking (damage extent – impact of damage);
- Consequences (probability of certain consequences for FLARE conditional probability of fatality rate with respect to PoB).

It is noted that this collection of influences does not consider all details.

In the following the influences identified are summarised and grouped according to the main characteristic elements. An overview of all influences can be found in Figure 4 to Figure 7.

5.1.1 Probability of incident/accident

Probability of incident/accident is influenced by two aspects (a) system failure (~reliability) and (b) navigation error. Losing the manoeuvring or navigation capability gives rise to the potential for collision or contact/grounding accident. However, probability also depends on the operational area. For instance, a failure of the steering system in a harbour has a high probability of leading to contact accidents whereas the same failure in the middle of the ocean will have a low probability. Navigational error is understood as human related error, i.e. underperformance of crew, assuming that crew acting and performing in accordance to the regulation will not make any navigational errors. Typically, in accident investigation reports human error (insufficient performance) is mentioned as the dominating cause. Human performance depends on various influences (positively and negatively) such as:

- Personal situation: daytime, fatigue, training
- Work environment: ergonomy (bridge design, design of equipment), communication problems
- Actual situation: daytime, operational area, traffic density and weather conditions.

In general, these influences can be grouped into operational area related, weather related, equipment / systems and operation / management as shown in Figure 3. As shown, some of these influences relate to more than one category. For instance, wind, current and waves depend mainly on weather but also on the operational area, e.g. wave height in restricted water or terminal area. Furthermore, the influences can be grouped into those mainly acting on the human element and system reliability related ones. For instance, high traffic density with many ship encounters is basically increasing the number of situations with potential of leading to collision and likely increase the probability of human error causing an incident.

Figure 5 shows the collected influences in the "probability of accident" branch of the cause and effect diagram.

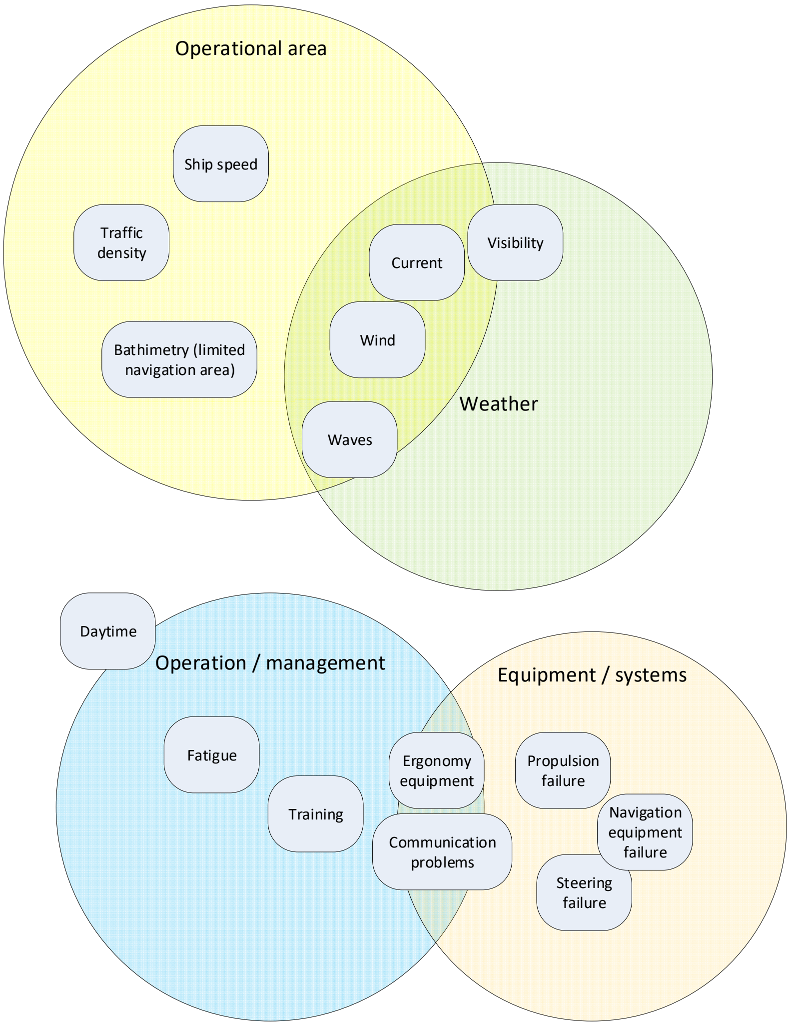

Figure 3 Grouping of influences on flooding accidents

5.1.2 Probability of survival, respectively sinking

Probability of survival relates to two aspects (a) damage extent and (b) impact of damage on ship stability, respectively, buoyancy. In this context damage extent covers the breach of hull, size of the opening and further deformation of ship's structure. The damage extent depends on the kinetic energy acting on ship structure and the structural resistance. The kinetic energy is characterised by the mass and speed, but also the angle of the impact is relevant. The effect on ship's structure of the kinetic energy relates to the strength and capability of energy absorption. Furthermore, the shape and size of the "object interacting" with the vessel under consideration (other ship in case of collision, wreck or structure in case of contact or "rock" in case of grounding) are relevant factors on the damage extent.

Flooding has a negative influence on the ship's stability and buoyancy. The impact on these depends on

- the amount of water flowed in and its distribution, both influenced by watertight subdivision and permeability of flooded rooms.
- the initial GM, freeboard and cargo shift are relevant factors, all relating to the loading conditions of the vessel; and,
- environmental influences like wind and waves.

Even if the vessel becomes unstable or is lacking sufficient buoyancy, the vessel may not sink because of

- Water depth (vessel will rest on sea bottom);
- Crew is able to beach the vessel (a scenario often observed for accidents in harbour or canals) or the vessel stays aground (grounding accident), either unintentionally or intentionally (i.e. when the vessel could be re-floated but staying aground was preferred for safety reasons).

Finally, operational or active measures may be applied in order to prevent the vessel from capsizing/sinking.

5.1.3 Consequences

Consequences mainly relate to the time available for abandoning the vessel, i.e. the relation between the time the vessel stays afloat and the time required for abandonment which means that consequences relate not only to the probability of sinking as estimated in section 5.1.2 but also to the

- time to sink,
- availability of life-saving appliances (functioning, not damaged),
- accidents in abandoning,
- time to evacuate for the given conditions (ship motions/list, visibility, daytime etc.), and
- the number of persons on board (PoB).

Availability of life-saving appliances relates to scenarios of damaged appliances, not functioning appliances (reliability) and ship conditions not allowing their usage (availability), e.g. lowering lifeboats impossible due to excessive heel (> 20°).

The first factors TTS[2] and TTC[3] are dependent on the flooding process (again dependent on permeability and GAP/subdivision), the remaining stability in relation to weather (wind, waves), loading conditions (GM, freeboard, cargo shift) and operational measures increasing stability. Water depth is not influencing TTS to TTC but is influencing the consequences

[2] TTS: Time To Sink
[3] TTC: Time To Capsize

(expected fatality rate) if it does not allow complete capsizing or sinking ("Herald of Free Enterprise").

Time to evacuate (TTE) depends on influences acting on the time PoB need for abandonment:

- Evaluation of situation (crew) and decision to abandon;
- Mustering;
- Preparation of LSA;
- Move to embarkation location;
- Embarkation, lowering and cast off;
- Manoeuvring to safe distance to parent vessel and marshalling.

Time to evacuate (TTE) depends on weather conditions, ship motions, condition of the ship (list angle, power availability), daytime, vessel layout, training of crew etc. Furthermore, the consequence depends on subsequent event that could be initiated by the accident, like fire or explosion. Such events may have a direct impact on the available LSA capacity and/or r significantly influence the evacuation process and thus TTE. Due to the focus of FLARE project such influences are not taken into consideration, however the risk models may easily be applied for such an expanded assessment, in particular, the part for the consequences

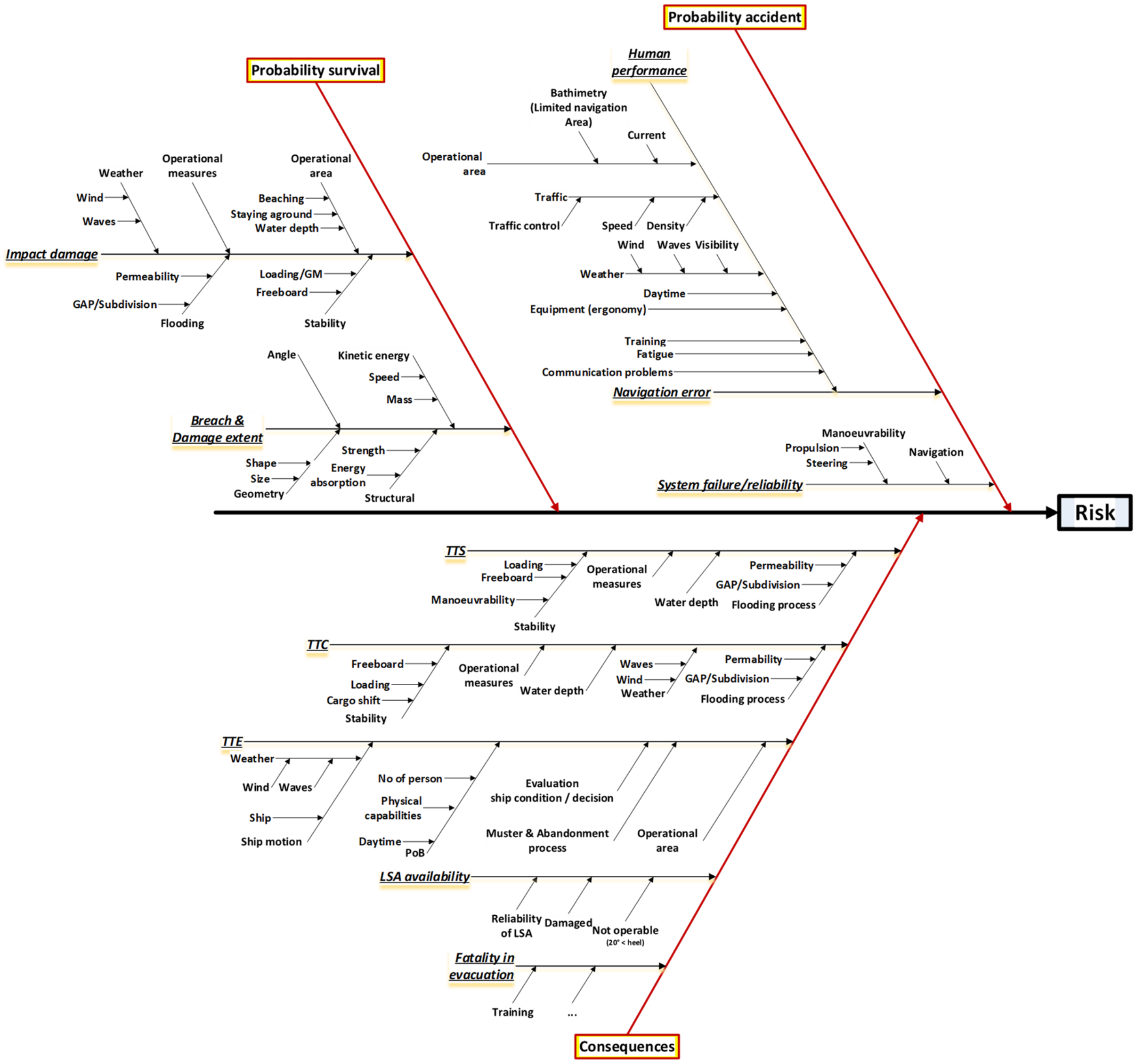

Figure 4 Overall Cause and Effect diagram specifying influences on the risk relating to flooding incidents (more details shown in Figure 5 to Figure 7 below)

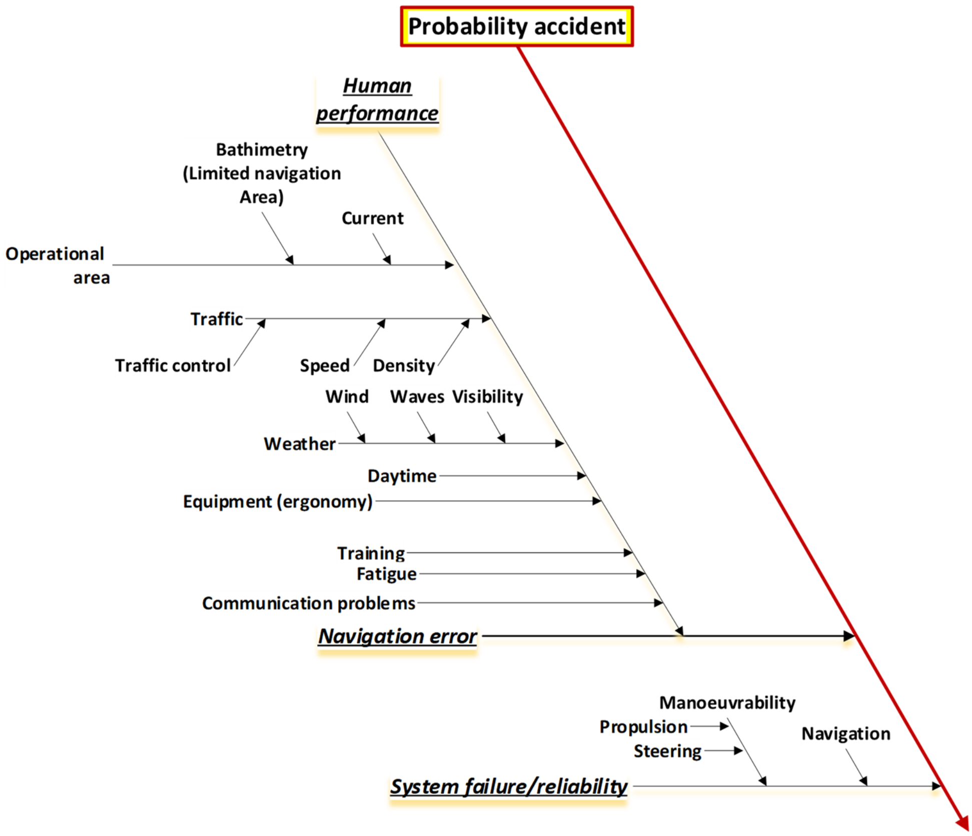

Figure 5 Influences on probability of incident/accident

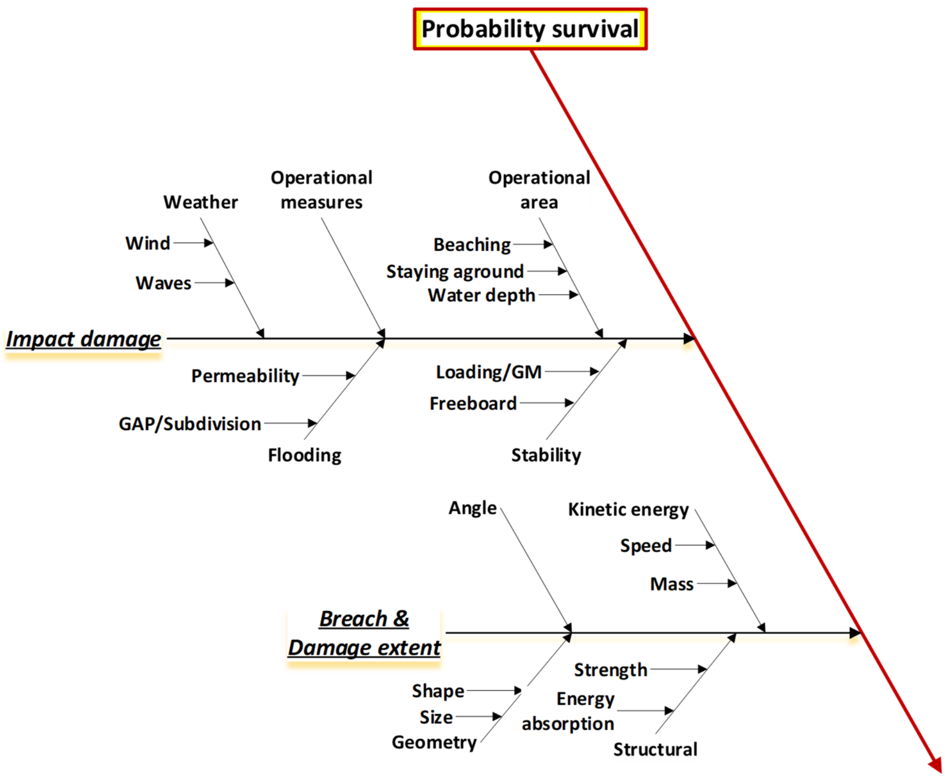

Figure 6 Influences on probability of survival

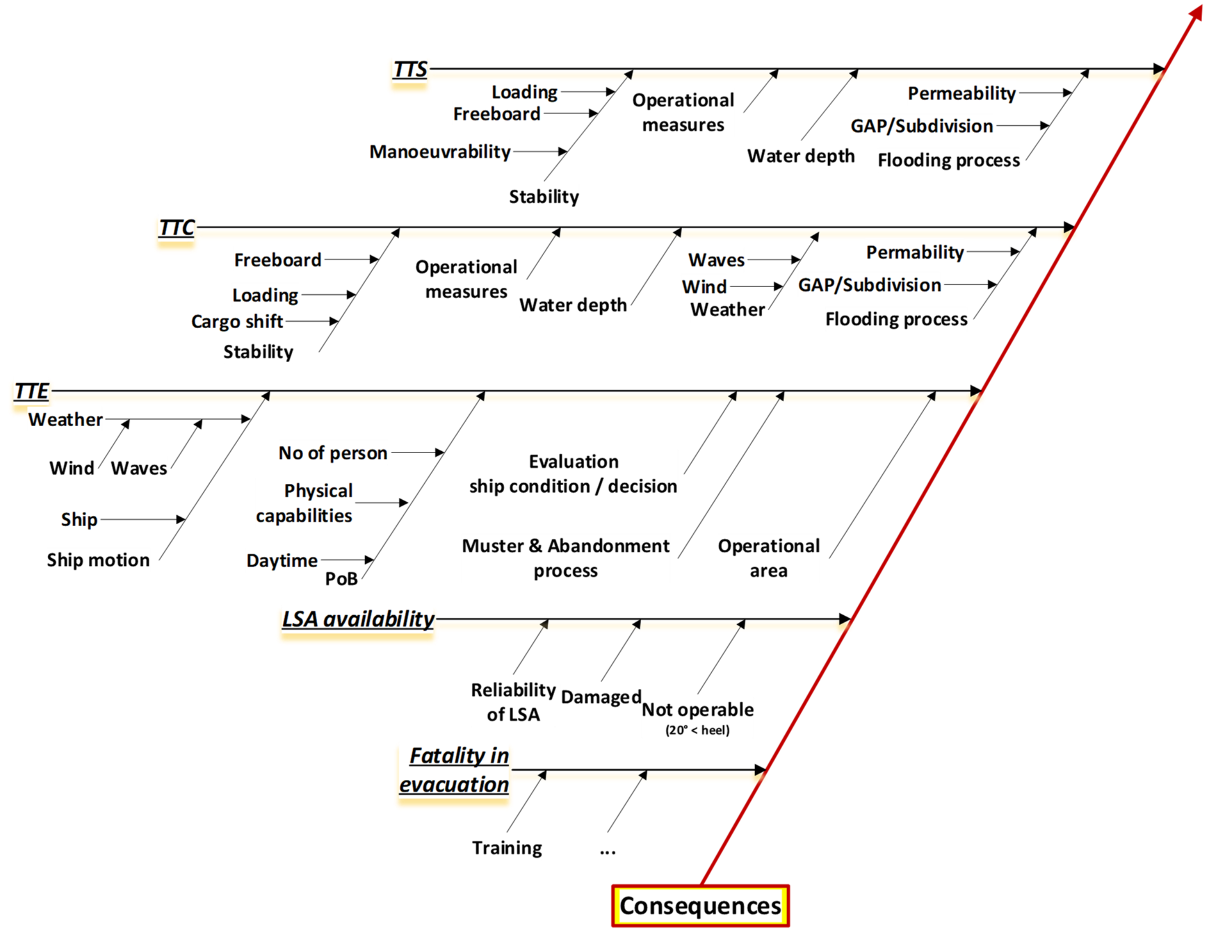

Figure 7 Influences on consequences

5.2 Generic risk model

Based on the investigation of the influences characterising the risk due to flooding accidents, the generic structure of the risk model is developed considering the main elements probability of incident/accident, probability of survival and consequences as shown in Figure 8. This figure shows a sequence of "decisions" characterising the risk considering the elements:

- Combined node accident category/damage location (side and bottom);
- Hull breach[4];
- Damage extent;
- Beaching or staying aground;
- Survival; and,

[4] In the context of the present risk model a breach of hull is always associated with water ingress, i.e. hull breaches high above the waterline which are usual particularly in contact accidents are thereby not included.

- Consequences.

Operational area and ship type act on various instances of the decision sequences and are thus put in front. Via the *placeholder* operational area, the influences relating to traffic density, speed etc. as well as influences on consequences are incorporated into the risk model. Figure 9 shows which influences are represented by which *placeholder*.

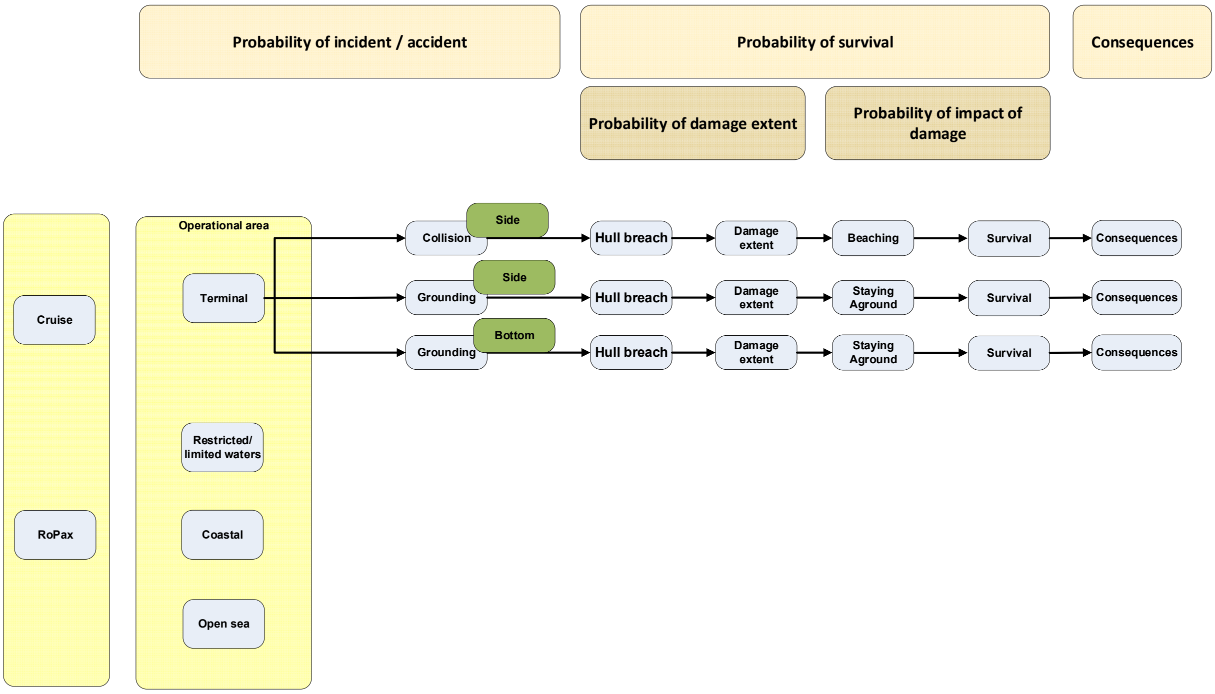

Figure 8: Generic flooding risk model: high-level structure.

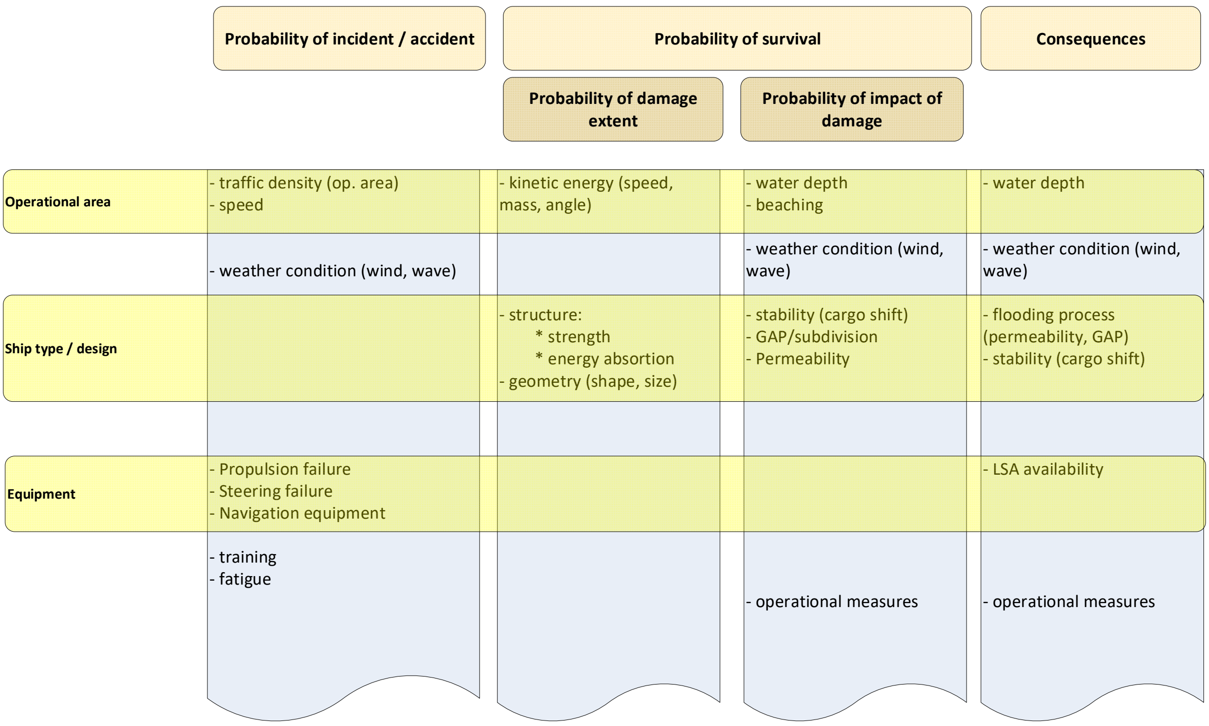

Figure 9: Correlation between influences and main elements.

More details for the consequence part are summarised in Figure 10. It is noted that the generic risk model considers only main elements, however based on this model more detailed models in form of decision trees can be developed in order to adequately determine related probabilities.

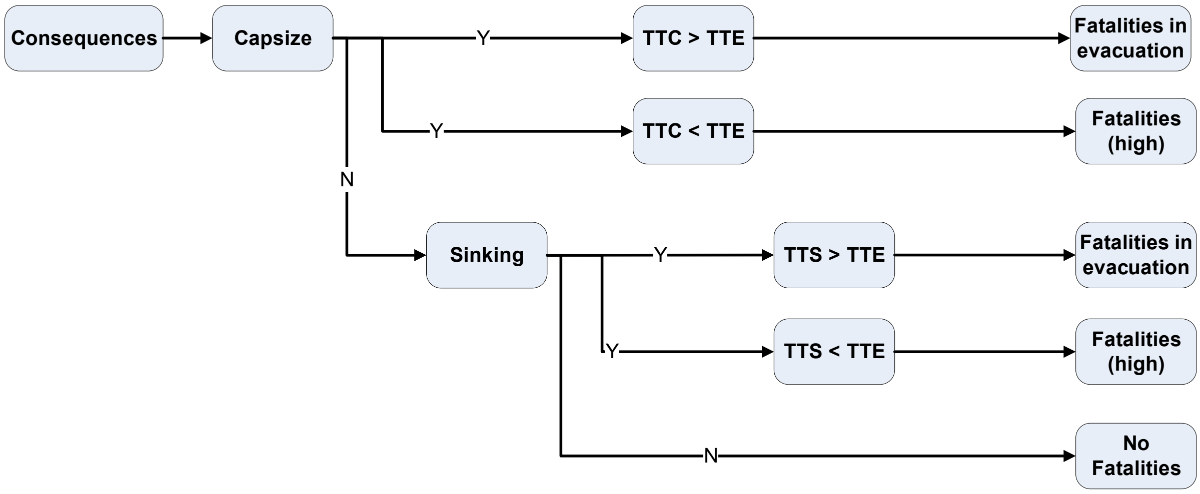

Figure 10: Generic consequence model (decision tree).

5.3 Quantification of flooding risk model

Like in GOALDS, EMSA III etc. a quantitative risk model will be developed in FLARE and this section of the deliverable will specify the correlation between the generic model and the work packages providing the data for quantification. An overview is presented in Figure 11 showing the generic decision sequence, potential sources and methods used for quantification and the FLARE work packages that will provide the data.

The risk models of GOALDS, EMSA III and eSAFE were mainly based on a combination of accident statistics (including analysis of casualty reports for details of accident scenarios) and expert judgements in particular for the elements *probability of accident*, *operational area*, *hull breach* and *staying aground* (grounding/contacts), as well as for the consequences. Damage extent and impact of damage were calculated by means of SOLAS damage stability calculation model for the collision accidents. For grounding/contact accidents a probabilistic model for the damage extent and an innovative "non-zonal" procedure for the calculation of the probability of survival were developed in the framework of the EMSA III study. The "non-zonal" approach has been extended to collision damages in the eSAFE project (Luhmann et al., 2018).

As mentioned in the introduction, one of the objectives of FLARE is to apply more sophisticated methods for quantification, such as traffic simulation for determining the probability of accidents, structural collision and grounding simulation for estimating damage extent (depth and opening), transient flooding and stability calculation and, finally, evacuation simulation for more detailed estimation of fatality rates.

In FLARE **initial accident probability** will be determined based on traffic simulations using AIS data and assumptions for identifying the situation with potential of leading to collision, contact or grounding. As discussed in section 5.1.1 (see also Figure 5) human performance has an essential influence on the probability of accident and need to be adequately determined, respectively justified. Information to be used in the traffic simulation will be provided by WP 2.4 and WP 2.6. Probability of accident will be determined for the three categories collision damage, side grounding damage and bottom grounding damage, distinguishing the two ship types under consideration (due to different operational profile) and operational areas. If deemed appropriate, some of the categories may be merged.

The effect of the accident on structural integrity and the effect of the structure to the extent of damage will be estimated by means of collision/grounding simulations (WP 3.2 and WP 3.3), providing probability density distributions for the damage location and extent, i.e. "**hull breach**" and "**damage extent**" (i.e. p-factors). Relevant for the risk to PoB are only accidents leading to water ingress. Influences on the hull breach & damage extent are summarised in section 5.1.2 and it is expected that operational area as well as ship type are relevant. Depending on the final calculation process, the two nodes "hull breach" and "damage extent" may be merged.

Probability density distributions for the damage location and extent will be the input for calculating the **probability of survival**, respectively, the probability of capsizing or sinking. Ship design (subdivision), loading conditions, weather conditions and operational mitigation measures are factors to be taken into consideration. The probabilities for beaching and staying aground will not be treated separately.

Finally, the **consequences** for person on board (PoB) will be calculated by means of evacuation simulations linked to the time domain simulations of flooding process and calculation of probability of sinking/capsize.

In parallel to enhanced simulation tools, some of the conditional probabilities can be evaluated based on historical data derived from the existing accidents database. The initial frequencies of the various types of accidents (collision, side grounding/contact and bottom grounding/contact) for the considered operational areas may be evaluated from the number of accidents registered in the database involving Cruise or RoPax ships (either the database of EMSA III or WP 2.6) and the corresponding "overall" fleet at risk (no information is available on the fleet at risk at each operational area considered in the risk model). The conditional probabilities should be once again calculated using the enhanced accidents sample, derived by including accidents to both ship types and the relaxed filtering used for the EMSA III Risk Models. In this respect, the conditional probability of "hull breach" can be evaluated counting all the accidents in the database for which a hull breach with water ingress is explicitly reported, divided by the total number of accidents for which relevant information is available (i.e. omitting accidents for which it is not clearly registered whether a hull breach or water ingress actually occurred). The same procedure will be followed for the calculation of the conditional probability of beaching or staying aground. For the bottom grounding/contact, the probability of a vessel staying aground (either intentionally or unintentionally) has been already considered in the development of the existing risk models. For the side grounding/contact and collision accidents, the database will be revisited to verify whether this information is available. For the damage extend in case of a collision accident and the corresponding survival probability, use can be made of the formulation for the "p-factors", the "s-factors" and the A-Index in SOLAS 2009/2020, the non-zonal approach for collision developed in eSAFE and numerical flooding simulations. For the damage extend in case of a grounding/contact accident and the corresponding survival probability, the evaluation can be based on the damage probabilistic models and the "non-zonal" approach for the calculation of the corresponding A-Indices, developed in the framework of the EMSA III study (Zaraphonitis et al., 2013) as well as numerical flooding simulations. The consequences to human life may be evaluated based on the GOALDS/EMSA III probabilities of fast/slow sinking and the corresponding fatality rates derived by expert judgment, respectively, more detailed evacuation analyses.

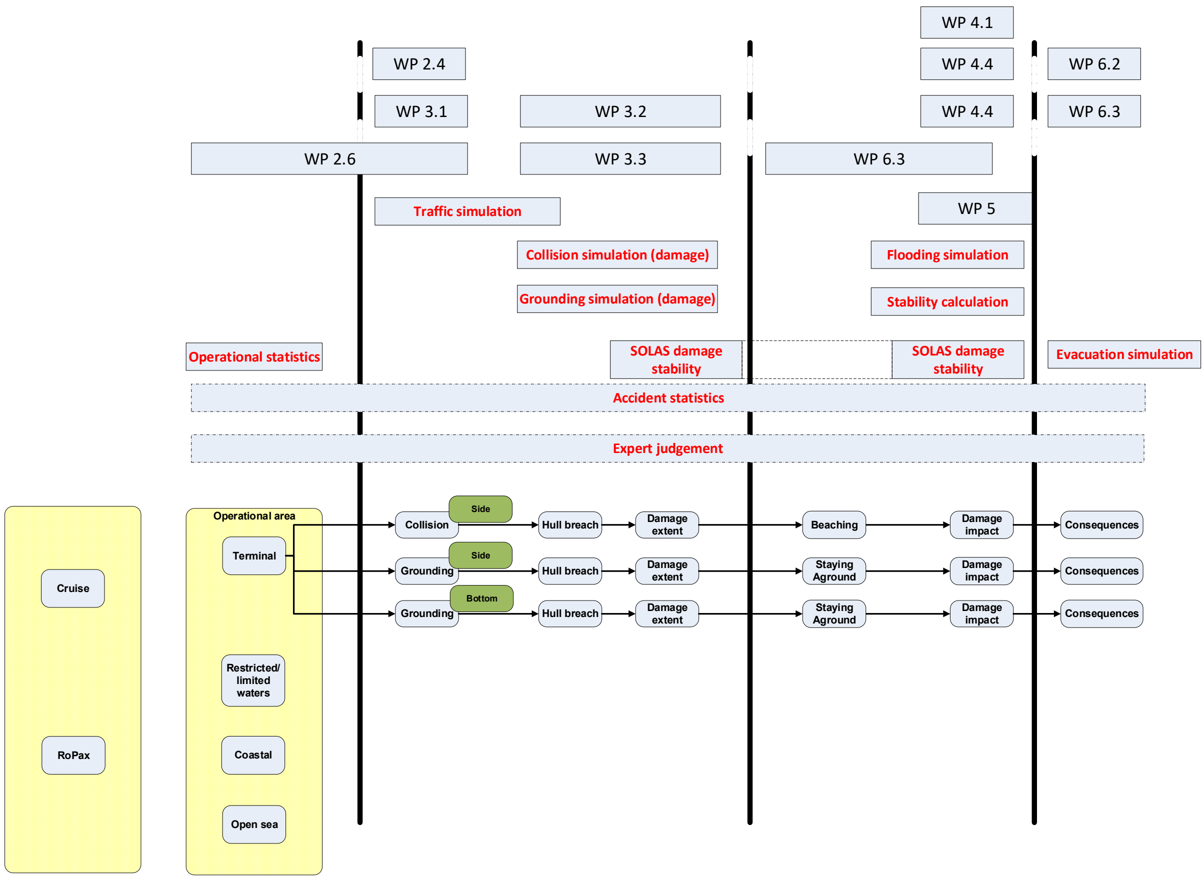

Figure 11 : Generic flooding risk model including potential source for quantification.

It is noted that details of the whole calculation process and, in particular, the reporting of intermediate results need to consider the purpose of the risk model, i.e. risk calculation within ship design process will be different to that for regulation development.

For instance, according to IMO FSA Guidelines (MSC-MEPC.2/Circ.12/Rev.2, 2018), recommendations should be justified by a cost-benefit assessment (CBA) if risk should be made ALARP[5]. For CBA a risk model that adequately characterise the risk to PoB or environment for the area the recommendation should be used is necessary, e.g. the risk model for cruise ship in world-wide operation needs to be representative for this. Typically, IMO reviews FSAs by an IMO Expert Group before considering the recommendations. In order to facilitate this review, detailed reporting is essential; in particular the risk model needs to be explained in detail including data allowing at least rough calculation of the risk and risk

[5] ALARP: As Low As Reasonably Practicable

reduction. Thus, intermediate probabilities and/or probability density distributions for the elements of the decision sequence need to be provided by FLARE work packages.

6 Summary

Risk models developed and used for previous studies on damage stability requirements are reviewed in order to reflect more appropriately the state-of-the-art in quantification and finer distinguishing consequences of flooding accidents. Based on an identification of relevant influences on risk to PoB due to flooding accidents and subsequently grouping of influences, a generic risk model for flooding accidents is developed which can be regarded as an evolution of the EMSA III risk model. The updated risk model considers all accidents leading to flooding together and provides a more consistent (homogeneous) structure. For the elements of this modular risk model the input has been specified from both FLARE work packages and historical data as used in pervious projects.

It is noted that intermediate probabilities (for the nodes of the decision tree) need to be provided, at least for the presentation at IMO. Further, due to the objectives of FLARE this risk model focus on flooding accidents and does not consider subsequent escalation relevant for the consequences, e.g. due to fire/explosion initiated by a collision.

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ANNEX A Public summary

A.1 Public summary

The risk models developed in GOALDS and EMSA III for collision and grounding/contact accidents has been reviewed with respect to structure and methods used for quantification. for the purpose of evaluating the need for improving passenger ship's damage stability requirements. These risk models are based on historical accident data and contain a number of assumptions, simplifications and expert judgements. The review was performed in a workshop with experts from FLARE project. The starting point for the revised structure forms an identification of influences on flooding risk that were grouped according to probability of accident, probability of damage extent, probability of survivability and consequences. The revised flooding risk model is defined by a sequence characterising the risk to person on board including a more detailed description for the quantification of consequences. Means for quantification of the elements are specified considering the input by FLARE as well as data sources used in GOALDS and EMSA III.

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ANNEX B Collision and Grounding Risk Models

This Annex outlines the background of the development of the EMSA III Risk Models for collision and grounding/contact accidents. This work was started in the framework of the EU research project *GOALDS* and continued within the *EMSA III* study and the Cruise Ship Safety Forum project *eSAFE*. These risk models were developed for determining the actual risk level for person on board relating to collision, contact and grounding accidents, and to verify if IMO damage stability requirements could be further increased by applying the ALARP process. In this respect, a database with data from relevant ship accidents was elaborated in Microsoft Access, starting with historical data extracted from the IHS Fairplay casualty database. At first, the casualty records from IHS Fairplay were thoroughly reviewed and verified. During the review process, the accident type was revised, where necessary, in accordance with IMO relevant document MSC/Circ.953. Captured accidents were assigned to one of the predefined main incident categories according to the last "accidental event": collision, grounding and contact. Subsequently, extensive search for additional data, including accident reports was carried-out. In this respect, the casualty information was enhanced with additional information collected from all possible official sources including IMO-GISIS, Flag Administrations, Class Societies, Owners and Operators. The collected information was cross-checked and registered in the accidents database in a way facilitating its retrieval and systematic analysis with respect to risk. Based on the analysis of the collected information, the event trees and risk models for collision and grounding/contact accidents were elaborated.

B.1 Collision Risk Model

The event sequence used for the development of the collision risk model is presented in Figure 12. The resulting risk model is presented in Figure 13.

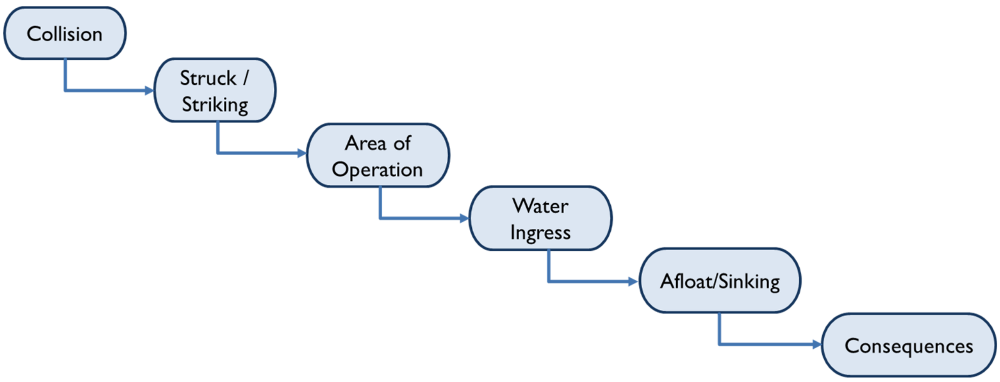


Figure 12: Collision accidents event sequence

The first node of the Risk model corresponds to the initial frequency of a collision event. Initial frequencies for Cruise ships were based on collision accident data pertaining to the sampling plan of Cruise and Pure Passenger ships. Respectively, the initial frequencies for RoPax ships were based on accident data pertaining to RoPax and RoPax Rail ships. The accidents as well as the figures of the active fleet used for the determination of the initial accident frequencies were identified after applying the following filtering:

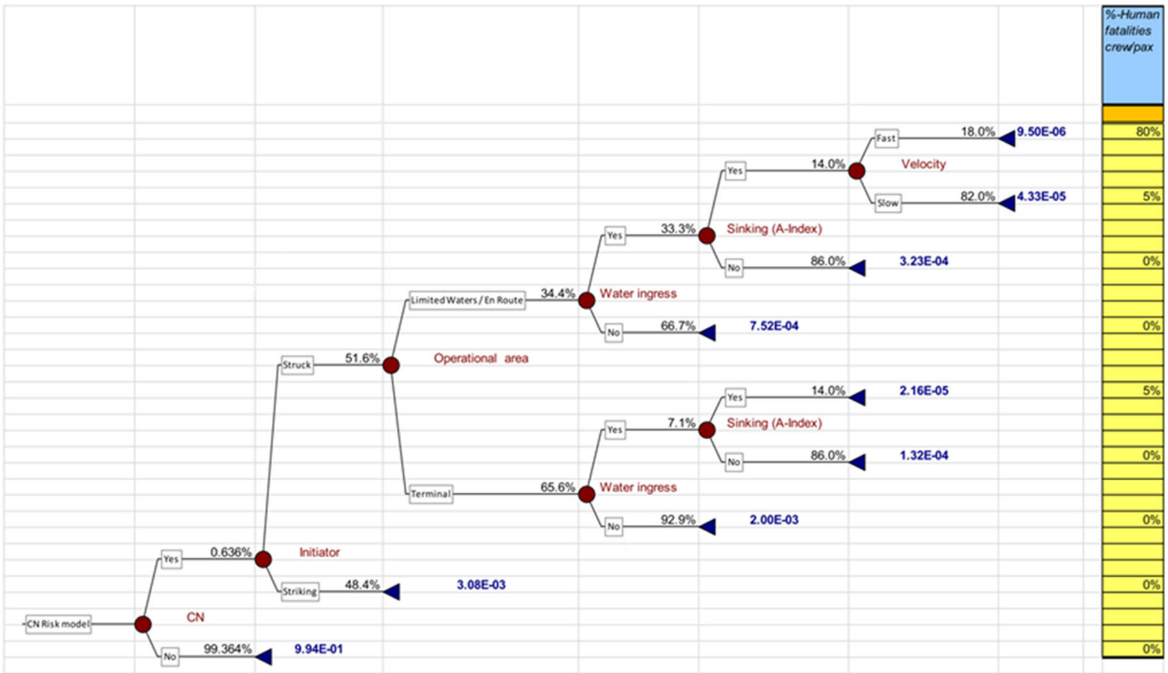
- Ship types: Cruise and Pure Passenger ships or RoPax and RoPax Rail

- Casualty time period: 2000-2012
- GT ≥ 1000
- Length ≥ 80 m
- Built ≥ 1982
- IACS classed ships
- Accident type: Collision – Serious cases
- Froude number ≤ 0.5 – to eliminate HSC from the study.

The corresponding Fleet at Risk was calculated using the same filtering, on a monthly basis for the corresponding time period. Within the time period of 2000-2012, from the total number of accidents registered in the database, 17 collision accidents involving Cruise ships and 53 accidents involving RoPax ships were identified after applying the agreed filtering. The corresponding Fleets at Risk are 2,673 for Cruise ships and 5,328 for RoPax ships. Therefore, the initial frequency of collision accidents is calculated as follows:

Cruise ships: 6.36E-03

RoPax ships: 9.95E-03



Collision risk model for Cruise and RoPax ship

Figure 13: Collision accidents risk model

The conditional probabilities within the risk model (i.e. the probabilities of "Struck/Striking", "Area of Operation" and "Water Ingress") were calculated based on historical data from the casualty database applying the following filtering:

- Ship types: Cruise and Pure Passenger ships, and RoPax and RoPax Rail
- Casualty time period: 1990-2012

- GT ≥ 1000
- Length ≥ 80 m
- Built ≥ 1982
- IACS and non-IACS classed ships
- Accident type: Collision – Serious cases
- Froude number ≤ 0.5 – to eliminate HSC from the study.

In this respect, the initial probabilities were calculated separately for each type of vessels: (a) Cruise and Pure Passenger ships and (b) RoPax and RoPax Rail. However, in order to increase confidence the conditional probabilities within each model have been calculated using the full set of data, collected from accidents including both ship types. This was decided due to the small number of accidents, not allowing the population of each branch of the risk model with sufficient number of accidents without merging the data from both ship types. For the same reason, it was decided to expand the casualty time period and also to include non-IACS ships. It should be noted that, even after merging the data from accidents including both ship types, the total sample size is relatively small, e.g. compared to other FSAs and it is further gradually reduced from one node to another, resulting to probabilities with very low confidence in several cases.

<u>Probability of "Struck/Striking"</u> (sample: 86 casualty records):

In the database, 86 casualty records were registered as collision events complying with the specified relaxed filtering. These include the 17 accidents involving Cruise ships and the 53 accidents involving RoPax ships used for the calculation of the corresponding initial frequencies and 16 more accidents occurring because of the modified filtering that was applied for the calculation of the conditional probabilities. From the recorded 86 casualties, in 32 cases the ship is struck, in 30 cases the ship is the striking one and in the remaining 25 cases no relevant information is available in order to register them properly. Consequently, the sample that was finally used for the calculation of the probability of particular node is reduced to 62 cases. The estimated conditional probability that a ship is struck is (32/62). Furthermore, since the problem under investigation is focusing on struck ships, the potential sample for the next node is 32 casualty cases.

<u>Probability of "Area of Operation"</u> (sample: 32 casualty records):

Two different operational states, associated with different operational speed ranges, were identified as the basic categorization for the risk analysis of different events, namely "Limited Waters/En Route" and "Terminal Areas". According to the historical data, out of the 32 casualties in 11 cases (34.4%) the ship was struck in a collision event during operation in Limited Waters or En Route. The remaining 21 cases (65.6%) occurred in Terminal Areas.

<u>Probability of "Water Ingress"</u>

- In Limited Waters or En Route (sample: 11 casualty records)

In 5 cases out of 11, there is no available information on the existence or not of water ingress. In 2 cases, water ingress because of the accident was reported and in 4 cases there was no water ingress. Therefore, the estimated conditional probability of water ingress in Limited Waters or En Route is set equal to 33.3%.

- Terminal Areas (sample: 21 casualty records)

In Terminal Areas, there was 1 registered case with water ingress, 13 cases with no water ingress and 7 cases with no available information. Therefore, the estimated conditional probability of water ingress in Terminal Areas is set equal to 7.1%.

<u>Probability of "Sinking/Capsizing"</u>

The probability of Sinking or Capsizing depends on the particular characteristics of each vessel. In the risk model this probability is set equal to 1-A, where A is the Attained Subdivision Index according to the SOLAS 2009/2020 damage stability regulation.

<u>Probability of "fast / slow sinking" and corresponding fatalities</u>

In case of a ship sinking or capsizing due to a collision accident occurring in Limited Waters or En Route, the probability of fast/slow sinking and corresponding fatalities are estimated based on expert judgment:

- Probability of Fast Sinking:
    - Cruise: 18%,f
    - RoPax: 50%
- Percentage of human fatalities with respect to POB
    - Fast Sinking: 80%
    - Slow Sinking: 5%
    - Fatalities in Terminal areas[6]: 5%

The Fatality Rates in case of fast sinking/capsizing or in case of slow sinking (progressive flooding) were estimated by expert judgment considering historical data from past accidents. In this respect, it might be noted that the assumed fatality rate in case of fast sinking is in good agreement with that of the Estonia accident with a fatality rate of ~85%. For terminal area the expert judgement is based on (a) the possibility to escape/evacuate directly to shore and (b) limited water depth reducing the probability to sink, respectively, complete capsize. Reference is made to the case of the Herald of Free Enterprise that capsized only partly when leaving harbour (on a sandbank, 9 m water depth) and to the design of modern ships, the majority of which has a beam of 25 m or more (79%).

B.2 *Grounding/Contact Risk Model*

The event sequence used for the development of the grounding/contact risk model is presented in Figure 14. The resulting risk model is presented in Figure 15.

Similarly to the collision model, the initial frequencies of grounding/contact accidents for Cruise ships were based on accident data pertaining to the sampling plan of Cruise and Pure Passenger ships. Respectively, the initial frequencies for RoPax ships were based on accident data pertaining to RoPax and RoPax Rail ships. The accidents for each ship type, used for the

[6] In case of a ship sinking or capsizing due to a collision accident occurring in Terminal Areas, the fatalities as a percentage of POB are estimated equal to 5%, again based on expert judgment.

determination of initial frequencies were identified after applying the same filtering used in the collision risk model except for the "Accident type" where "Grounding/Contact – Serious cases" was used. The Fleet at Risk was calculated using the same filtering, on a monthly basis for the corresponding time period.

Within the time period of 2000-2012, from the total number of accidents registered in the database, 48 grounding or contact accidents involving Cruise ships and 123 accidents involving RoPax ships were identified after applying the agreed filtering. The corresponding Fleets at Risk are 2673 for Cruise ships and 5328 for RoPax ships. Therefore, the initial frequency of grounding and contact accidents is calculated as follows:

Cruise ships: 1.80E-02

RoPax ships: 2.31E-02

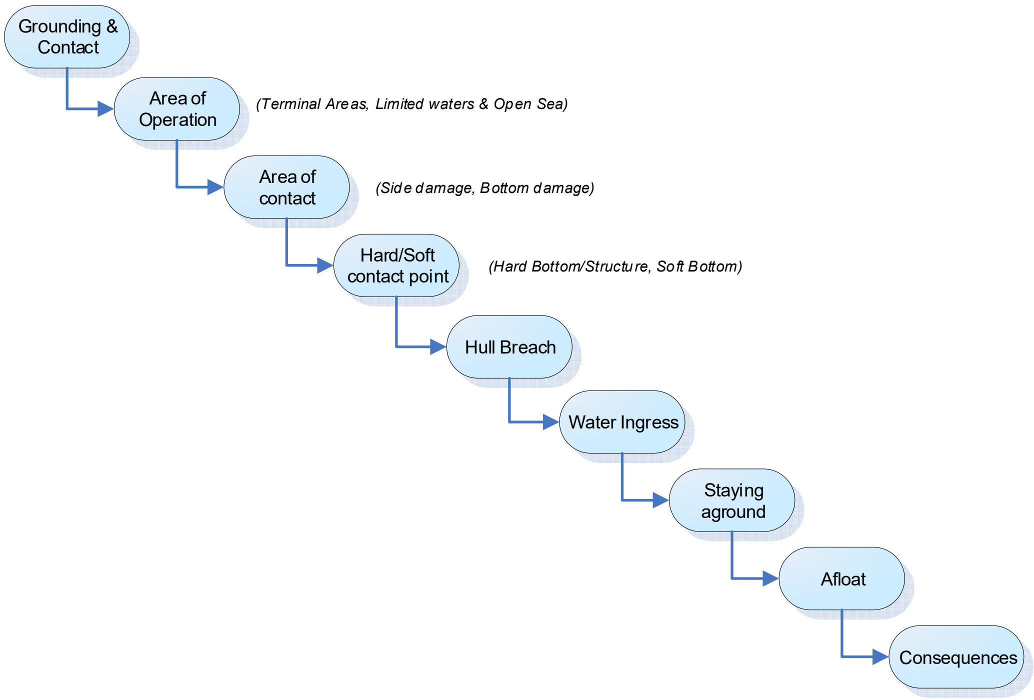


Figure 14: Grounding/contact accidents event sequence

Once again, the conditional probabilities within the risk model (i.e. the conditional probabilities of "Area of Operation", "Area of Contact", "Contact Point", "Hull breach", "Water Ingress" and "Staying aground") have been calculated using the combined set of data, collected from accidents including both ship types and with the same relaxed filtering also used for the collision risk model, i.e.an extended casualty period (1990-2012), and inclusion of both IACS and non-IACS classed ships.

Probability of "Area of Operation" (sample of 218 cases)

In the database, 218 casualty records were registered as grounding/contact events complying with the specified relaxed filtering. These include the 48 accidents involving Cruise ships and the 123 accidents involving RoPax ships used for the calculation of the corresponding initial frequencies and 47 more accidents occurring because of the modified filtering that was applied for the calculation of the conditional probabilities. From the recorded 218 casualties, in 125 cases the accident occurred in Terminal Areas, in 92 cases it occurred in Limited Waters/En Route and in 1 case there is no available information. Therefore, the conditional probabilities are estimated as follows:

- Terminal Areas: 57.6%
- Limited Waters/En Route: 42.4%

Probability of "Area of Contact" (sample of 217 cases)

- Terminal Areas: out of 125 casualties, in 69 cases the accident was registered as a side grounding/contact, in 6 cases as a bottom grounding/contact, in 11 cases the contact area was somewhere in the bow, stern or outfitting and in 39 cases the area of contact was unclear. Therefore, the conditional probabilities are estimated as follows:
    - Side grounding/contact: 92.0% (69/75)
    - Bottom grounding/contact: 8.0% (6/75)
- Limited Waters/En Route: out of 92 casualties, in 21 cases the accident was registered as side grounding/contact, in 22 cases as bottom grounding/contact, in 15 cases the contact area was somewhere in the bow, stern or outfitting and in 34 cases the area of contact was unclear. Therefore, the conditional probabilities are estimated as follows:
    - Side grounding/contact: 48.8% (21/43)
    - Bottom grounding/contact: 51.2% (22/43)

Probability of "Hull Breach" and "Water Ingress"

- Terminal Areas and side area of contact (69 cases): in 56 cases (81%) there was a hull breach in the side area of the vessel. From the 56 cases with hull breach, in 14 cases water ingress was registered, in 13 cases there was no water ingress and in the remaining 29 cases there is no available information. Therefore the estimated probability of water ingress given a hull breach is 51.9% (14/27).
    - Terminal Areas and bottom area of contact. In total 6 cases are registered in the database. For one of them no clear information was available. The remaining 5 cases are as follows:
    - Hard Bottom (4 cases, 80%): in all cases (100%) there was a hull breach and water ingress
    - Soft Bottom (1 case, 20%): there was no hull breach and water ingress and the ship stayed aground
    - Limited Waters/En Route and side area of contact (21 cases): In one case the relevant information was not clear. From the remaining 20 cases, in 18 cases (18/20=90%[7]) there was a hull breach in the side area of the vessel and in 2

[7] At the time when the EMSA study was carried out, the corresponding probability was calculated equal to 86.4% (19/22), however, based on later information some casualties were excluded from the sample.

cases (2/20=10%) there was no hull breach. From the 18 cases with hull breach, in 13 cases water ingress was reported and for the remained 5 cases there was no available information. The corresponding probability of water ingress was assumed equal to 100%.

- Limited Waters/En Route and bottom area of contact (22 cases). In one case the relevant information was not clear. From the remaining 21 cases:
- Hard Bottom in 18 out of 21 cases (18/21=85.7%).

In 16 out of the 18 cases water ingress was explicitly reported. In the remaining two cases no water ingress was reported. Based on expert judgment, the probability of water ingress was set equal to 100%.

- Soft Bottom in 3 out of 21 cases (14.3%=3/21)

In all cases there was no water ingress and the ship stayed aground.

Probability of "Staying aground"

- Terminal Areas, side damage, hull breach and water ingress: No available information. Assumption:
- No staying aground 100%
- Staying aground 0%
- Terminal Areas, bottom damage, hard obstacle and hull breach (consequently and water ingress):
- No staying aground: 2 cases (50%=2/4)
- Staying aground: 2 cases (50%=2/4)
- Limited Waters/En Route, side damage, hull breach and water ingress:
- No staying aground: 6 cases (66.7%=6/9)
- Staying aground: 3 cases (33.3%=3/9)
- Limited Waters/En Route, bottom damage, hard obstacle and hull breach (consequently and water ingress):
- No staying aground: 3 cases (20%=3/15)
- Staying Aground: 12 cases (80%=12/15)

Probability of "Afloat/Sinking"

The probability of Sinking or Capsizing depends on the particular characteristics of each vessel. In the Risk Model this probability is set equal to 1-A, where A is the Grounding/Contact Attained Subdivision Index A for side or bottom damage as proposed in EMSA III study.

Probability of "fast/slow sinking" and corresponding fatalities

In case of a ship sinking or capsizing due to a collision accident occurring in Limited Waters or En Route, the probability of fast/slow sinking and corresponding fatalities are estimated based on expert judgment:

- Probability of Fast Sinking:
    - Cruise: 18%,
    - RoPax: 50%
- Percentage of human fatalities with respect to POB

- Fast Sinking: 80%
- Slow Sinking: 5%
- Fatalities in Terminal areas: 5%

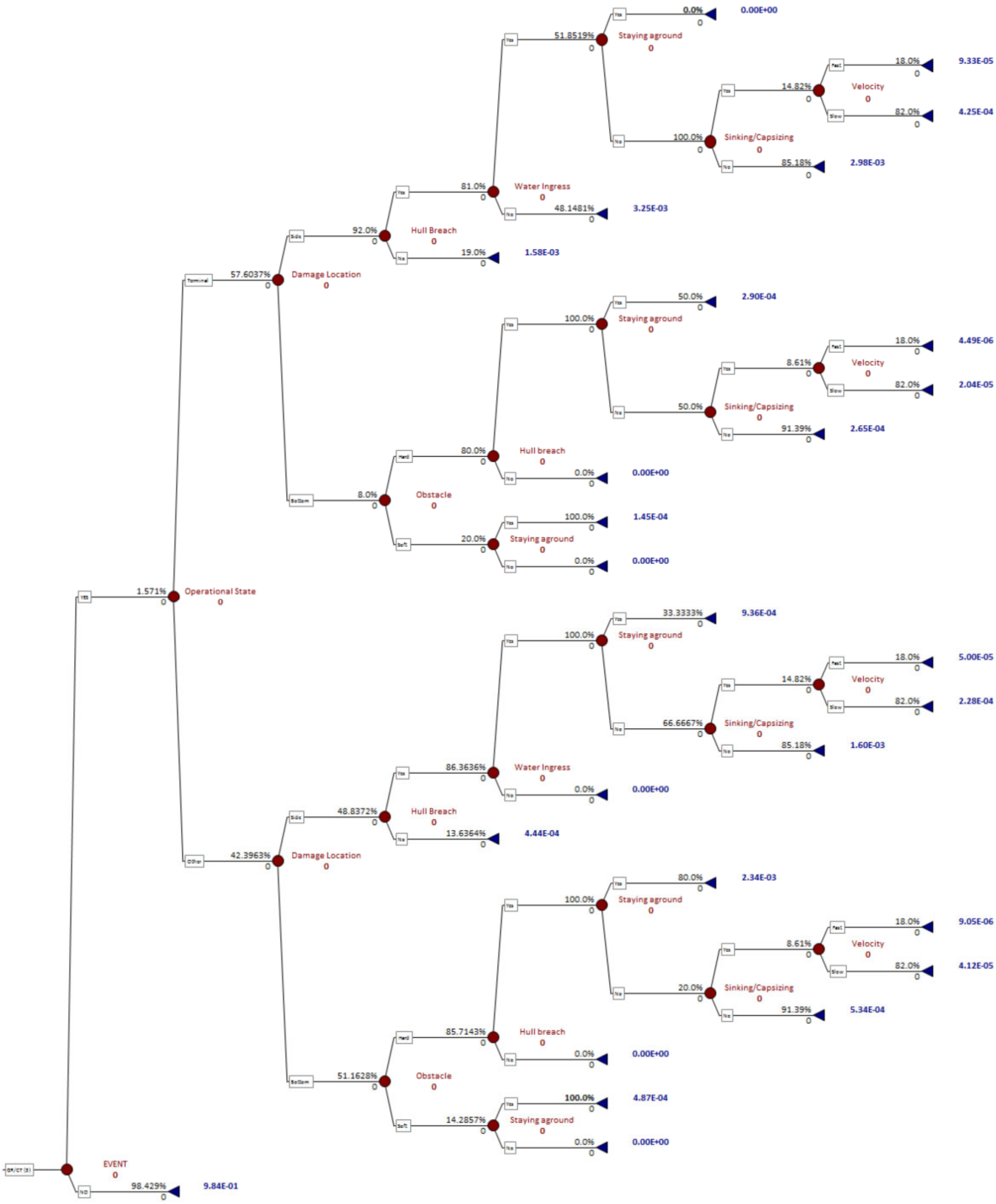


Figure 15: Grounding/contact risk model