

Safety at Speed - S@S  
**IMPLEMENTATION OF INTEGRATED  
MODEL FOR CONTROLLABILITY  
DELIVERABLE No. D1.3.4**

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## List of Acronyms

BE	Basic Event
FT	Fault Tree
HF	Human Factor
HFQ	Human Factor Quotient
HSC	High Speed Craft
MCA	Multi Criteria Analysis
ME	Manoeuvrability Error
M&A	Mechanical and Automation
PMM	Planar Motion Mechanism
RSM	Response Surface Methodology

## **1. EXECUTIVE SUMMARY SUITABLE FOR PUBLICATION**

The present document provides the methodological foundation of a 'design tool' that safety analysts may use in the preliminary design stage of a High Speed Craft. This tool is useful for evaluating risk and cost related to different design options that should diminish the probability of occurrence of Collision, Grounding and Striking events.

This tool implements a set of well defined models that tackle Human Errors, Mechanical and Automation Failure and Manoeuvring Errors that account for the majority of Collision, Grounding and Striking events.

This document represents the finalisation of the work carried out within the sub-tasks 1.3.1, 1.3.2 and 1.3.3 of the Safety At Speed project and, besides it acts as a 'user manual' for those who wish to make use of such a tool.

[S@S](#) is the acronym for Safety at Speed, a project supported by the European Commission under the Growth Programme of the 5<sup>TH</sup> Framework Programme. The support is given under the scheme of RTD, Contract No. G3RD-CT-2001-00331.

## 2. INTRODUCTION

The present document reports the work of integration of three distinct risk-and-cost models into a 'single' controllability model for the evaluation of different technical solutions that should reduce the risk of collision, grounding and striking events of a High Speed Craft at a given cost. These models deal with Human Factors, Automation and Mechanical Failures and Manoeuvrability Errors and have been developed and implemented respectively in subtasks 131, 132 and 133 of the project.

The controllability model allows tackling Human Factors, Automation and Mechanical Failures and Manoeuvrability Errors during the preliminary design phase of a High Speed Craft. The influence of these factors, which account for the majority of collision, grounding and striking events, can be limited by adopting and implementing 'ad-hoc' technical solutions. However, these solutions may contrast each other because of the different nature of influencing factors they should contain. Moreover, these conflicts may arise in a later stage of the design of a vessel, when other technical solutions have been already defined and consolidated.

In order to anticipate and solve these potential conflicts at the preliminary design stage, at least as long as the problems related to collision, grounding and striking events are concerned, an extended investigation (i.e., fault tree analysis) of these events was carried out. The objective was to identify at a detailed level (i.e., basic event) which are those factors that combined with others either of the same or of different nature can lead to any of these events.

This allowed the identification of those critical areas where a designer / safety analyst can intervene to reduce the probability of occurrence of these events. The benefit of this identification was that the three types of factors had been considered.

Following the general Safety @ Speed approach, a set of parameters the designer deals with at the preliminary design stage of a High Speed Craft were singled out and put in relationship with the relevant basic event. Likewise, the same parameters were coupled with the relevant heads of cost so as to allow the evaluation of risk and cost associated to a particular event (e.g., collision, grounding and striking), for a given configuration of parameters. This is what the three models, duly described in [R2], [R3] and [R4] respectively, are about.

The last part of the work was their final integration into a single approach aiming to minimise globally the probability of occurrence of unwanted events at a convenient cost. This common approach is documented in the present document and represents the integrated model for controllability.

This report is structured in two main sections, namely Section One and Section Two. While the former provides a synthetic description of the results achieved in each one of the three subtasks and how they have been combined into the model for controllability, the latter is more shaped as a user's guide that suggests how to exploit these results.

Section One consists of two parts where the two components of the model for controllability (i.e., risk and cost) are explained. The first part on risk provides at the beginning an overview of the fault trees (FTs) analyses that allowed the identification

of the Basic Events (BEs) leading to a potential collision, grounding and striking. Afterwards, the parameters the designer /safety analyst deals with for controlling such events are presented. The description of the relationships between parameters & basic-event terminates the first part of Section 1 and leads to the second part where the relationships between parameters & heads-of-cost are documented. In general, all these descriptions are not a repetition of the contents of deliverable D131 [R2], D132 [R3] and D133 [R4] but only an overview. Finally, the description of how these models have been integrated into a single approach providing the model for controllability of the vessel is detailed explained.

Section two of this document is about how to jointly exploit these models, i.e., how to use the tools that implement them and how these tools have to be fitted into the more general and integrating tool developed within WP5.

For the sake of clarity within this document, we will simply refer to the 'Model' when we talk about the model for controllability; this Model is composed of a Risk part and a Cost part. Both these parts are a synthesis of the three risk-and-cost models (i.e., Human Factors, Automation and Mechanical Failures and Manoeuvrability Errors) that have been developed and implemented respectively in subtasks 131, 132 and 133 of the project.

## **SECTION ONE**

### **Background Information of the Controllability Model**

### 3. RISK MODEL

The foundation of the Risk Model developed in WP1 for tackling collision, grounding and striking hazards is a fault tree analysis that was carried out in Task 1.2 and progressively refined along a number of iterations.

This fault tree analysis allowed the identification of critical areas where a designer / safety analyst can intervene to reduce the probability of occurrence of collision, grounding and striking hazards; these critical areas are represented by the Basic Events of the Fault Trees.

Specific Parameters used in the preliminary design stage of an High Speed Craft were identified and associated to these Basic Events with the objective of developing a set of Functional Relationships that designers can use for ‘controlling’ these Basic Events.

As a result, it can be affirmed that the main elements of this Risk Model are the followings:

- Fault Trees (FTs)
- Basic Events (BEs)
- Design Parameters
- Functional Relationships

These elements are briefly described in the following subchapters; further details can be found in other project documents (Ref. [R1], [R2], [R3], [R4]).

#### 3.1 Fault Trees & Basic Event

The analysis structure is a combination of semantic networks (i.e., classifications) in its upper part, and Fault Trees (FTs) in its lower (Figure 1), where the three main hazards Grounding, Collision and Striking are initially categorised according to likely scenarios and then analysed according to the fault tree logic.

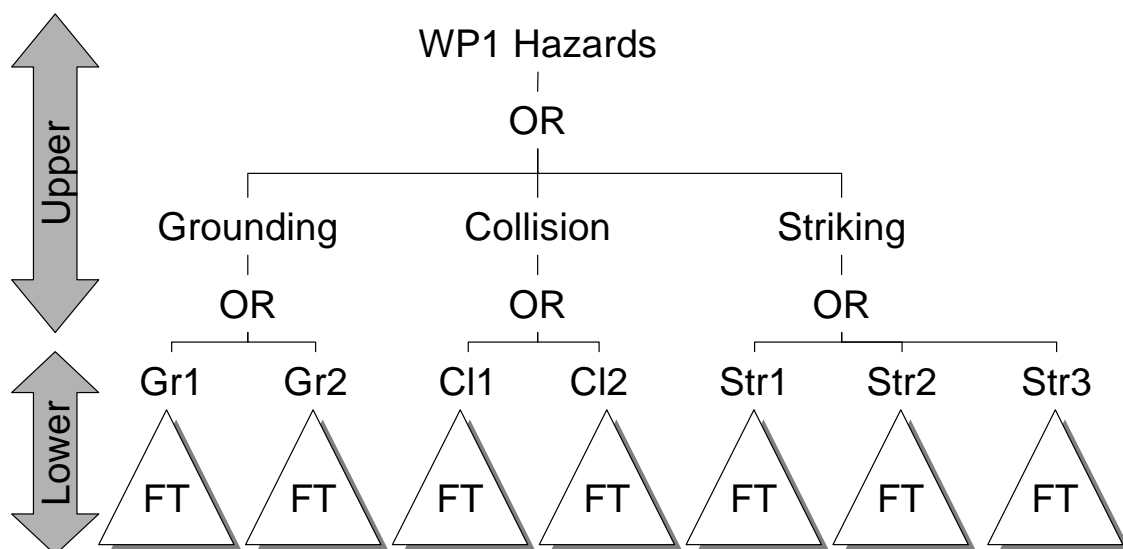


Figure 1 - Overall View of WP1 Hazards Structure.

The upper part of the structure is schematised in the following hierarchical list in which 7 Top Events are distinguished:

1. Grounding
  - 1.1. Powered grounding (Top Event "Gr1")
  - 1.2. Drift grounding (Top Event "Gr2")
2. Collision
  - 2.1. In open sea (Top Event "Cl1")
  - 2.2. In restricted waters (Top Event "Cl2")
3. Striking
  - 3.1. With a floating object (Top Event "Str1")
  - 3.2. With a fixed object/infrastructure
    - 3.2.1. In open sea (Top Event "Str2")
    - 3.2.2. In restricted waters (Top Event "Str3").

The lower part consists of 7 distinct FTs, related to the 7 Top Events, which are reported in Appendix 1: Fault Trees.

The FT analyses allowed the identification of critical areas where a designer / safety analyst can intervene to reduce the probability of occurrence of these Top Events; these areas are represented by the Basic Events (BEs) of the FTs, which were classified into three main categories:

1. Human Factors (HFs),
2. Mechanical and Automation (M&A) Failures,
3. Manoeuvrability Errors (MEs).

A fourth group of BEs was created which includes those BEs that could not be categorised under any of the three ones mentioned above and were tackled separately. All the BEs are reported in Appendix 2: Basic Events.

### 3.2 Design Parameters & Functional Relationships

Because of the diversity of the three areas covered (i.e., Human Factors, Mechanical and Automation Failures, Manoeuvrability Errors), different criteria were followed in the identification of the most relevant design parameters that may affect the probability of occurrence of the BEs singled out in the FTs. Similarly, different approaches were adopted for the development of the functional relationships aimed at coupling design parameters with BEs.

For each BE, a set of design parameters were identified and linked to the BE through functional relationships (e.g., formulas, tables of values, algorithms, etc.) allowing the calculation of the occurrence probability of the BE, according to the parameters setting. In general terms, these relationships can be represented as:

$$\text{Prob}(\text{BE}_i) = f(p_1, p_2, \dots, p_n),$$

where  $p_n$  represents the design parameters. The following subchapters provide an overview of the approaches followed in the three areas; for the other BEs, 'ad-hoc' relationships were developed. The set of functional relationships developed within each area is, ultimately, the specific model for that area.

### 3.2.1 Human Factors Risk Model

The model for calculating the occurrence probability of human factors BEs is based on a list of parameters that can be adjusted individually and independently of each other but whose global influence on the BE probability is mediated via the *Human Factors Quotient (HFQ)*. A detail description of the model is reported in [R2].

- The human factors parameters are divided into **design & operational** parameters. Each parameter has a scale at ordinal level with conceptually meaningful values (e.g. very low, low, medium, high and very high) and an unidirectional or bi-directional scale at interval level where these conceptual values are linked to corresponding quantifiable numerical values in the interval between 0 and 4. When adjusted, each parameter will have some kind of influence on the performance of the human operator in positive or negative direction. This list of parameters is reported in Appendix 3: Design Parameters.
- Since each parameter can be set independently, the effect of any adjustment could either outweigh each other or enhance each other, depending on the direction in which parameters are adjusted. Moreover, since these parameters have unequal importance with regards to human performance and human error, it is important that each of them is assigned with a coefficient describing its relative value compared to the other parameters. These coefficients are assigned empirically through the elicitation of experts who compare the importance of each parameter with respect to the probability of human error. Given the coefficients ( $C_{[1..n]}$ ) assigned to each parameter value ( $P_{[1..n]}$  where n is the total number of parameters), it is possible to calculate the overall effect on human performance and human error by means of the formula:

$$HFQ = \frac{(C_1 * P_1 + C_2 * P_2 + C_3 * P_3 + \dots + C_n * P_n)}{(4 * n)}$$

The HFQ can range between 0 and 1, where 0 represents the worst possible setting of human factors parameters and 1 is the best. The worst possible setting (0) generates an increased probability of human error compared to a residual value, while the best possible setting (1) generates a decreased probability of human error compared to the residual value. The BE probability is calculated as a single value expression corresponding to the setting of the parameters; the process is in two steps:

- Preparation of the model:
  1. Calculation of coefficients for each parameter (by means of expert judgement -- pair wise comparison);
  2. Coupling of probabilities of BE and HFQ level (by means of expert estimation).
- Application of the model:
  1. Parameters setting by the end user;
  2. Calculation of HFQ based on the parameters setting;
  3. Probabilities (intervals) assessment.

The probability of the BE is estimated as the number voyages per occurrence (of the BE), and the probability value is given as the number of occurrences (of the BE) per voyage.

### 3.2.2 Mechanical and Automation (M&A) Failures Risk Model

The model for calculating the occurrence probability of Mechanical and Automation Failures is based on a list of parameters whose value can be set individually and independently of each other with respect to every BE. However, the global influence on a specific failure probability is mediated through weights that differentiate the relative importance of some parameters with respect to others. A detail description of the model is reported in [R3].

Because of the large amount of parameters that interact with systems onboard ships, it was very difficult to establish hierarchies of importance between the parameters as data related to the reliability of the components are difficult to find. Nevertheless, according to a literature review it was possible to create a list of parameters that mostly influence the correct functioning of onboard systems. This list is reported in Appendix 3: Design Parameters.

The likely combination of parameters contributing to every BE is established in the model. These combinations are characterised in terms of number of parameters and possible states necessary when assessing the functioning of systems; the most common combinations are listed below:

1. Two parameters with 2 or 3 possible states each;
2. Three parameters with 2 or 3 possible states each;
3. Four parameters with 2 possible states each.

The Multi-Criteria Analysis (MCA) assess the most critical combinations of parameters and related states with respect to the occurrence of a BE.

Starting from an occurrence probability value of reference, which is assigned to a combination of parameters and related states, the model provides the variation of this occurrence probability according to the possible parameters combinations and related states.

### 3.2.3 Manoeuvrability Error Risk Model

The model for calculating the occurrence probability of Manoeuvrability Errors is based on Response Surface Methodology methods. According to the FT analyses, the relevant BEs that were tackled by the Manoeuvrability Errors Model are:

- Last minute avoidance too late, failed to turn in time to avoid collision, for encountered ship sea state, with actual ship speed, and accounting for manoeuvrability performance in open sea.
- Remaining distance too short for crash stop for encountered environment condition.

These BEs are exclusively related to the vessel manoeuvring capabilities in normal conditions of operation; they are not due either to human errors or mechanical failures. For the modelling purpose, it was necessary to take into account the BE position in the various FTs and to define specific scenarios in order to determine the associated parameters and the avoidance trajectories. These scenarios of last minute avoidance have been defined with respect to the rules of navigation when sailing (COLREGS rules). Parameters and scenarios are reported in Appendix 3: Design Parameters.

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The trajectories of the design vessel were modelled according to the IMO manoeuvring criteria and derived from the response surface model; these criteria are:

- For the stopping test:
- **Ds** (the stopping distance)
- For the initial turning ability:
- **Lt** (distance travelled along initial direction when the ship has turned 10°)
  - **Dt** (distance travelled transversely to initial direction when the ship has turned 10°)
- For the turning circle tests:
- **A** (the advance parameter)
  - **Td** (the tactical diameter)

From these criteria, the time dependent trajectory of the design vessel during a turning circle and a crash stop manoeuvre was derived allowing the calculation of the BE probability for all the scenarios. Indeed, the collision avoidance trajectory is supposed to be very close of the turning circle manoeuvre trajectory and therefore, it should be depending only on the criteria A and Td. The modelling of the crash stop manoeuvre is based on the knowledge of the stopping distance Ds. A detail description of the model is reported in D133.

## 4. COST MODEL

Unlike the Risk Model, the Cost Model only consists of two parts, respectively related to Human Factors and Mechanical and Automation Failures; no specific cost model has been developed for Manoeuvring Errors. As a matter of fact, the parameters that are relevant for manoeuvrability relate to the basic geometry of the vessel and are taken into account in cost models developed within other Work Packages. Nevertheless, a Power Prediction algorithm calculates fuel weight and cost on the basis of the required power determined on the basis of these parameter values.

Human Factors and Mechanical and Automation Failures basic events have been put in relation with costs through their design parameters. According to the costs estimation methodology proposed by WP5, the total cost ( $C_T$ ) associated to a parameter is split into:

- Build Cost ( $C_b$ );
- Through Life Costs ( $C_{tl}$ ).

The same approach was followed for Human Factors and Mechanical and Automation Failures, which is briefly described in the following sub-chapters; for a more detailed description the reader is invited to read [R2] and [R3].

### 4.1 Human Factors Cost Model

The majority of human factors related parameters have no impact on the build cost because they are entirely related to the operation of the vessel (operational parameters). A change in these parameters will therefore have no influence on the build cost whatsoever. However, a few parameters do have influence on the build cost, and this is further analysed and described in [R3].

The majority of human factors parameters have, due to their characteristics as operational parameters, influence on the operational costs of the vessel. This influence depends on the organisational structure of the shipping company, laws and regulations in the area of operations, official demands for manning as well as demands from labour organisations. Moreover, it has to be added costs for training and education of seafarers in the area of operation, procedures and administrative principals within the company, the general human factors standard of the company and so on. All these variables are unique to the given shipping company. The parameters' influence on the operational costs is therefore indefinable as one single, unified model. Actually a model should be tailor made for each and every shipping company. The shipping company must - each time the risk/cost model is in use - therefore recalculate the operational cost of the majority of the parameters. However, a few parameters do have influence on the operational cost, and this is further analysed and described in [R3]; these parameters are the same that have influence on the build costs as described earlier.

It is important to notice, that an increase in the level of the operational human factors related parameters will most probably require increase in operational costs such as (but not limited to):

- Increase in manning
- Increase in salaries
- Increase in expenses for training and education
- Increase in expenses for recruitment, testing and selection of personnel
- Increase in expenses for administration, on shore support etc.

## 4.2 Mechanical and Automation Failures Cost Model

A cost model has been developed for those systems whose failure had been identified as a BE in the FT analyses. The cost analysis of these systems was based on the same design parameters of the risk model; the starting point was the configuration of the mono-hull craft Super Sea Cat built by Fincantieri. The systems considered are the Propulsion system, the Stability system, the Electric Power system, the Navigation equipment, the Radar, and the Communication system. The cost model for every system is based on the general cost model developed for the whole project (Figure 2), and on the cost matrix (Table 1).

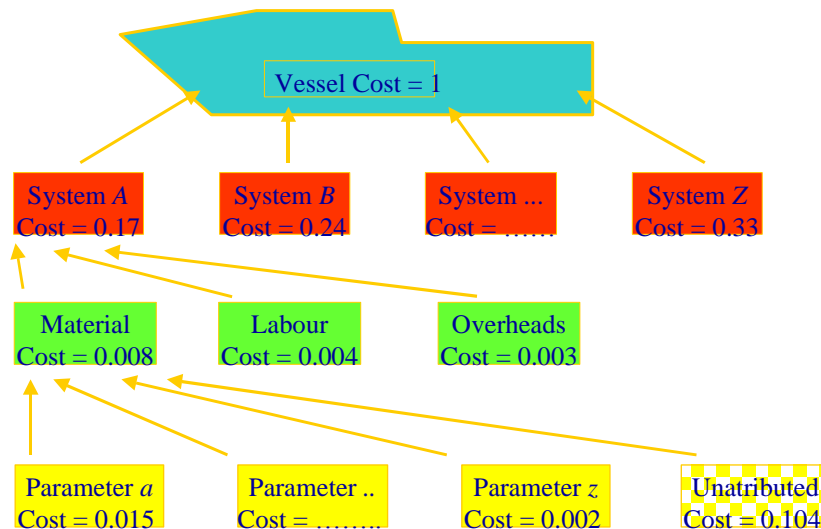


Figure 2: Cost Model

	Materials	Labour	Overheads
	Euros	Euros	Euros
Hull Structure and General	0.04	0.173	0.013333333
Propulsion Units	0.29	0.043	0.018333333
Electrical	0.025	0.022	0.013333333
Command and Control	0.01	0.012	0.015333333
Auxiliaries	0.09	0.06	0.026333333
General Outfitting	0.025	0.02	0.103333333
Totals	<b>0.48</b>	<b>0.33</b>	<b>0.19</b>

Table 1: Cost Matrix

The Cost Matrix for each system is built on the table extrapolated from the Risk-Matrix for the same system, and the identified design parameters that can affect the system failure. The configuration of the Super Sea Cat is taken as reference; the different cost

matrix values (identified for the whole cost model) have to be calculated with reference to this configuration. The approach is schematised in for the propulsion system; a detailed description of all the models is reported in [R3].

Configuration	Default Cost	N° of Components	Total Cost	1+d (whole)	d
	MEuro/Unit		MEuro		
Diesel Engine (DE)	1.30	4	5.2	1	0
DE	2.08	2	4.16	0.80	-0.20
DE	1.30	2	5.6	1.07	0.07
Gas Turbine (GT)	3	1			
DE	2.08	3	6.24	1.20	20
DE	1.30	2	6.4	1.23	0.23
GT	1.90	2			
DE	1.30	3	5.8	1.12	0.12
GT	1.90	1			

**Table 2: Cost matrix of the Propulsion system**

Figures indicated in Table 2 are for reference, they are not the real prices of engines. The aforementioned engine costs, include purchase and installation costs, but not maintenance and exercise costs. This is implicit in the price of each single engine. As a matter of fact, the designer receives from engines' manufacturer data about the reliability and maintainability of a particular engine; the higher the purchase cost is the lower exploitation and maintenance costs are.

### 4.3 Manoeuvring Errors Cost Model & Power Prediction Algorithm

The Power Prediction Algorithm calculates the propulsive power necessary to assure a certain speed of a HSC. Thus, it allows estimating the cost for the machinery in the manufacturing phase and the fuel costs for the ship in service.

This algorithm calculates the costs with a variation of the vessel length (waterline - for the Froude number), its draught, its displacement (for the general dependency of the power from the size), and the water depth. These 4 main inputs are used to calculate the power for the service speed. This is not the maximum power, which may be installed in the vessel. The power for the electrical generation may be either given as fixed value or calculated as percentage of the power for the propulsion.

For the calculation of the cost of the machinery for propulsion and electrical generation both the absolute and the relative method is available. The fuel costs use the fuel weight and the fuel price, which may be different for propulsion and electrical generation. The fuel weight uses the calculated power and the fuel consumption, for both values a distinction is made again between propulsion and electrical generation.

A detailed description is reported in Document No.: S101.31.10.58.001.

## **SECTION TWO**

### **How to Use the Controllability Model**

## 5. GENERAL OVERVIEW

The objective of this section is to explain how to use jointly the risk and cost models, which have been developed separately in Tasks 131, 132 and 133. The combined use of these models helps safety analysts in identifying the design parameters configuration that most minimise the probability of occurrence of collision, striking and grounding events, and the related costs. However, it's the final tool developed within the whole project that will enable more general considerations on risks and costs, once the whole set of design parameters will be considered.

At WP1 level, two approaches are proposed for calculating the occurrence probability and the cost of the three main hazard types (i.e., collision, striking and grounding). For the sake of simplicity we refer to them as:

1. The Basic Events driven approach (Figure 4), and
2. The Parameters driven approach (Figure 5).

These two approaches are not contradictory, they simply propose two applications of the individual risk and cost models within the Controllability Model frame. The Basic Events driven approach suggests tackling hazards one-by-one and adjusting the design parameters according to a desired probability value of the Top Event (i.e., hazard under analysis); costs are then calculated. The Parameters driven approach suggest setting all the parameters in one-shot and checking whether all the hazards (i.e., Top Events) probabilities satisfy a desired value before calculating the costs.

In both approaches, the parameters setting is done by considering the type of scenario in which the vessel will sail, the scenario is given by a combination of route difficulty and traffic density, as reported below in Figure 3.

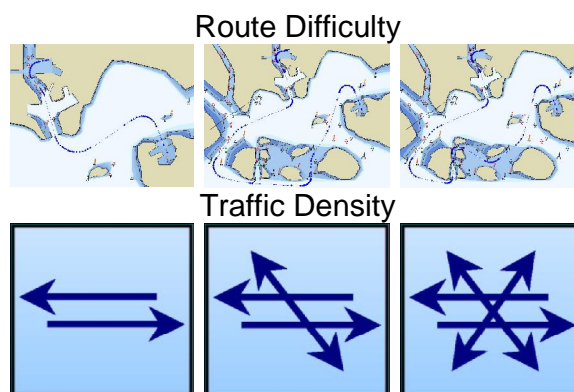


Figure 3: Scenarios

Moreover, as reported in Appendix 2: Basic Events, some BEs are not tackled by any of the three models and have been quantified separately; they now appear within the tool developed in Task 131.

In the following subchapters a brief description about the use of the individual models is reported; this description has to be read within the Controllability Model frame.

### 5.1 Basic Events driven approach

Figure 4 shows the Basic Events driven approach. For the sake of clarity, we've indicated as 'Orphan' the BEs that are not tackled by any of the three models developed in Tasks 131, 132 and 133.

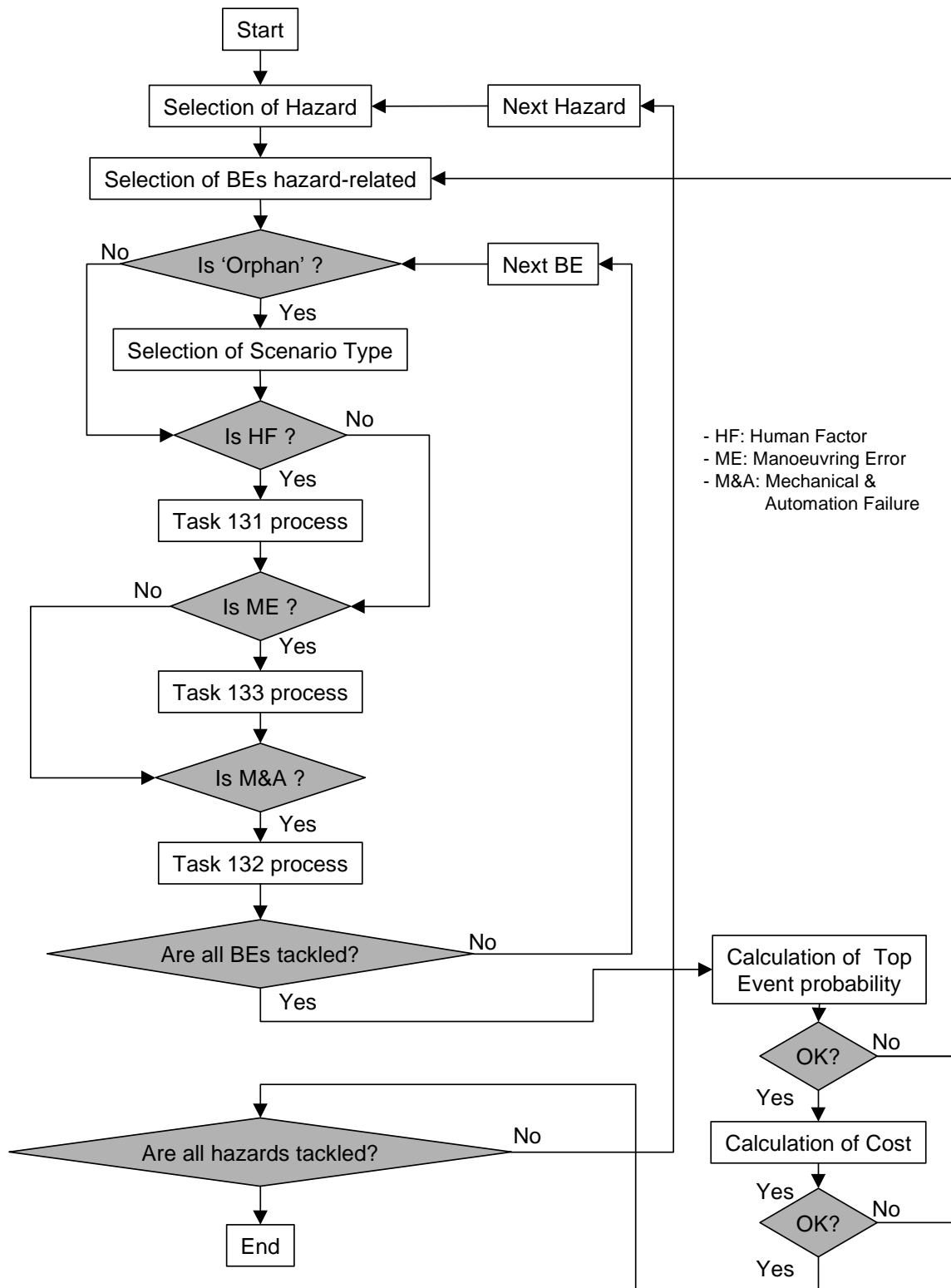


Figure 4: Controllability Model Use (Basic Events driven approach)

## 5.2 Parameters driven approach

Figure 5 shows the Parameters driven approach; the name of the Tasks are called slightly different.

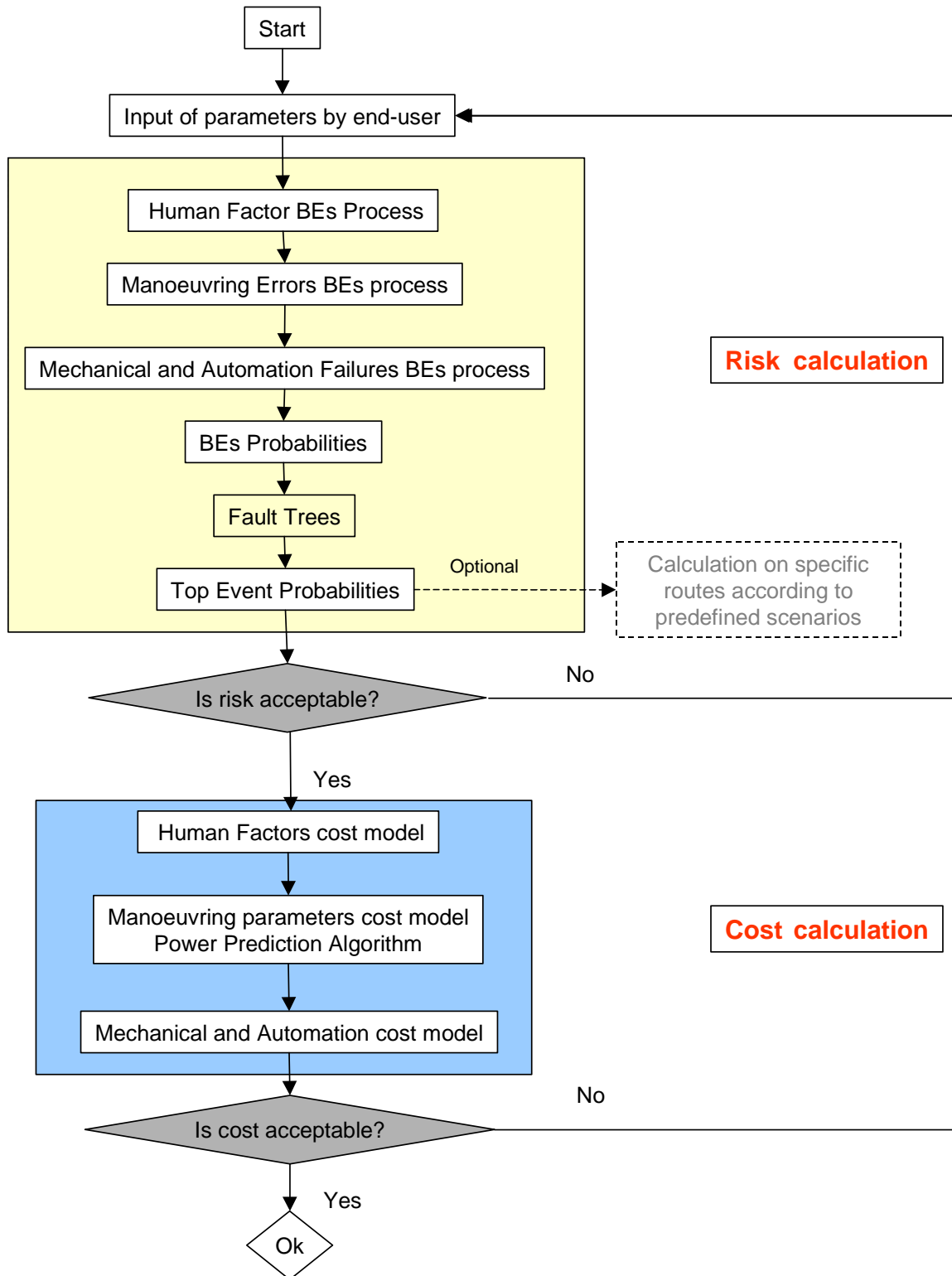


Figure 5: Controllability Model Use (Parameters driven approach)

### 5.3 Task 131 process

Task 131 deals with Human Factors and in [R2] a detailed description of the risk and cost model is reported. In the following, a brief overview of the models is provided; moreover, a tool implementing these models has been developed and its use duly documented in the User's Guide Documents (see [R5], [R6] and [R7]). For applying the risk and cost models for tackling Human Factors BEs, the user has to ...

1. ... Adjust all parameters according to the expected design and operation of the vessel. Operational parameters are set in co-operation with the ship owner according to the existing standards and principals in the company or the expected or planned standard for the human factors level on the new vessel.
2. ... Calculate the cost (building costs and operational costs) as described in [R2].
3. ... If the cost is acceptable continue to **step 4** otherwise resume **steps 1 and 2** with the appropriate corrections of parameters in order to change the cost to the desired level.
4. ... Calculate the Human Factors Quotient (HFQ) as described in the algorithm. Use the ordinal values corresponding to the settings of parameters made in **step 1**.
5. ... Find relevant intervals of probabilities of BEs by lookup in Table 4. Use the calculated HFQ to determine the entry column in the table.
6. ... Calculate the probability of grounding and/or collision by combined use of the probability intervals of the human factors related BEs and the probabilities of automation and mechanical failures ([R3]) and manoeuvrability errors ([R4]) as entry data in the computer based model of the fault trees.
7. ... If the calculated probability is unacceptable, resume **steps 1 through 6** with the appropriate corrections of parameters in order to change the probability to the desired level.

#### 5.3.1 Step 1 - Adjustment of parameters

Choose the appropriate setting of the nominal value of each sub-parameter in Table 3 according to the expectations for the design and operation of the vessel. The nominal value corresponds to an ordinal value according to the table. This ordinal value will be used in **step 4** for the calculation of the human factors quotient (HFQ).

PARAMETER	SUB-parameters	Code	Coefficient C <sub>1</sub> ...C <sub>32</sub>	Nominal value	Ordinal value
Training and education of Crew	Amount of training and education	A1	1	None Little Medium High Very high	0 1 2 3 4
	Overall quality of training and education	A2	1	Very low Low Medium High Very high	0 1 2 3 4

**Table 3: Extract of Parameters, sub-parameters and their associated coefficients, nominal and ordinal values**

### 5.3.2 Step 2 – Calculation of cost

Calculate the cost (building costs and operational costs) as described in Table 4 by consulting relevant sections of [R3] and by using input from the shipping company whenever it is required. The note “Data from ship owner” in the table indicates the requirement of calculations and recalculations.

The shipping company should be reminded, that an increase in the level of the operational human factors related parameters will most probably require increase in operational costs such as (but not limited to):

- Increase in manning;
- Increase in salaries;
- Increase in expenses for training and education;
- Increase in expenses for recruitment, testing and selection of personnel;
- Increase in expenses for administration, on shore support etc.

PARAMETER	SUB-parameters	Code	Nominal value	Building costs	Operational costs
Training and education of Crew	Amount of training and education	A1	None Little Medium High Very high		Data from ship owner
	Overall quality of training and education	A2	Very low Low Medium High Very high		Data from ship owner

**Table 4: Extract of Parameters, sub-parameters and their associated nominal values for building costs and operational costs**

## 5.4 Task 132 process

The process to be developed in order to build the model studied within the Task 132 can be easily resumed in the flow chart shown in Figure 6 and summarised in the following sub-chapters.

### 5.4.1 First Step: Selection of Hazard

Starting from the Fault Trees as basis, the first simple operation to be performed is the selection of the Hazard that we want to analyse. It is obvious that this choice must be made between the Hazard analysed along our work. This choice certainly depends on the environment that the Ferry under analysis will have to afford, especially with regard to the foreseen length of trips, to the traffic density and finally to the type of sea like narrow or open waters. Once the Hazard has been selected, we can proceed by listing the related BEs.

### 5.4.2 Second Step: Identification of Design Parameters related to the Ranked BEs

After the identification of the complete list of BEs, in order to evaluate how different choices can affect the characteristics of the HSC from either the point of view of risk or of cost, it is necessary to measure the influence exerted on each BE by different combinations of Design Parameters.

For each BE, a reference number which represents the rate of occurrence for a reference configuration of Design Parameters has been identified. In this context our procedure is aimed at evaluating how this number changes for different combinations of Design Parameters. For doing so, it is necessary to have a reference configuration which in our case is represented by the Super Sea Cat.

In this phase what we have to do is just to select the Design Parameters from the list and, one by one, to calculate the variations on the failure rate of the related BE. As detailed in Chapter 3.2.2, it is now necessary to use the MCA Method.

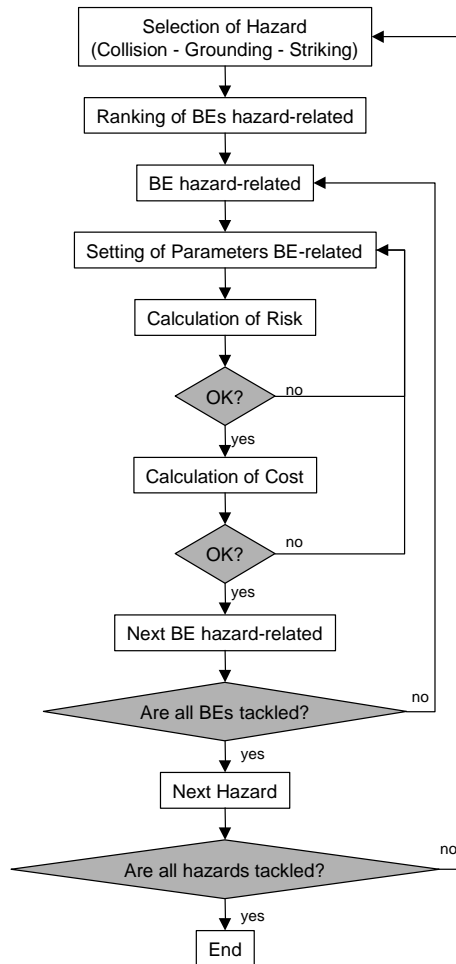


Figure 6: General Overview of the Process

### 5.4.3 Third Step: Application of the MCA Method

The starting point of this process is a normal matrix as that shown below:

Parameters (Design Parameters)	Parameter A		
	Parameter B		
<b>%Deviation</b>			<b>Ref. Value</b>

Table 5 - Example of Matrix

The scope is now to fill in the matrix with the values of deviations from the configuration chosen as basis.

In the Table below, acronyms used to develop the MCA Method are listed:

Ind	Parameter (Design Parameter)
Pind	Weight to be assigned to an Ind
Indcrit	Value assumed by an Ind
Rifind	Value used to index an Ind
Indcritot	Value related a combination

**Table 6 - Acronyms for the Application of the MCA Method**

For every Ind, it must be determined the worst value (Rifind). Such value might be either the maximum or the minimum, depending on the characteristics of the specific Ind.

This value will be used in order to index the pre-selected parameter so that values are comprised between 0 and 1 and, in particular, those more critical tense to assume 1 as value.

In this way, by using the Pind it is possible to associate a value (Indcritot) to a combination of parameters. It is clear that the most critical operation is that of assigning weights to the parameters. The reliability of this assignment depends on the capacity of the expert involved in the calculation.

The value of an Indcritot is calculated as follows:

$$\text{Indcritot} = \sum_{\text{Ind}=1}^{n\text{Ind}} \text{Pind} * f(\text{Indcrit}, \text{Rifind}).$$

The function  $f(\text{Indcrit}, \text{Rifind})$  can assume one of the following forms:

- $f(\text{Indcrit}, \text{Rifind}) = \frac{\text{Indcrit}}{\text{Rifind}}$  for parameters whose critical value is the maximum.
- $f(\text{Indcrit}, \text{Rifind}) = \frac{\text{Rifind}}{\text{Indcrit}}$  for parameters whose critical value is the minimum.

The most critical combinations are those which present the highest values.

Repeating all passages for every possible combination of Ind, we finally obtain a group of number each one tied only to one single combination. Now that every box in the table is filled, it is then possible to calculate the percentage deviation from the Reference Value, which is the value assigned to the reference configuration. That is made just performing a simple division between the present value and the reference one.

Finally, it has to be noted that the value of Pind must be chosen between 0 and 1 but the sum of Pind of different parameters can greater than 1.

**5.4.4 Fourth Step: Calculation of the variation of the Failure Rate**

The fourth and last step of the risk model is also the shortest to be performed. In fact, after having calculated all the percentage deviations we just have to multiply the reference value for the values of percentage coming from the matrix and to add or subtract this value to that of reference.

**5.5 Task 133 process**

The format of the manoeuvring error model is a spreadsheet with macros allowing calculating probabilities and launching the RSM program for estimating manoeuvring criteria. The calculation of the probabilities of the BEs is organised according to the following Top Events:

- Striking with a floating object
- Striking with a fixed object in open sea
- Striking with a fixed object in restricted water
- Collision in open sea
- Collision in restricted water
- Powered grounding

The procedure consists of the following three steps:

**First Step:** Calculating the manoeuvring criteria of the design vessel once the design and operational parameters are tuned.

**Second Step:** Tuning the specific parameters of each BE scenario according to other BE scenarios.

**Third Step:** Launching the Probability Calculations.

**5.5.1 Manoeuvring criteria calculation**

With respect to the spreadsheet Manoeuvring criteria, the end-user chooses the values of the RSM program inputs in the blue box at the left handside top corner:

The length overall: $L_{oa}$ (m)	Range: 100 to 150m
The breadth maximum: $B_{max}$ (m)	Range: 15 to 22.40m
The draft: $T$ (m)	Range: 2.03 to 3.05m
The displacement: $\Delta$ ( $m^3$ )	Range: 856.56 to 3524.29
The Speed of advance: $V$ (kts)	Range: 5 to 50kts
The depth: $D$ (m)	Range: $T*1.5$ to 100m

The RSM method needs  $L_{pp}$  and  $B_{wl}$  as inputs. These are obtained according to the following formula used by DMI for their simulations:

$$L_{pp} = 0.8765 * L_{oa}$$

$$B_{wl} = 0.755 * B_{max}$$

In order to respect the constraint on the geometry of the hull and to stay close to the basic design SuperSeaCat, constraints on the following ratios should be respected:

T/L  $\gamma$  [0.0162;0.0244];  
B/L  $\gamma$  [0.1197; 0.1795];  
B/T  $\gamma$  [5.8898; 8.8346].

The block coefficient should not be too modified:  $C_b \gamma$  [0.2813;0.3439]

The Froude in depth should not be superior to 1.

These constraints are verified by the program and the end user is alerted before the calculation is launched.

Then:

Click on the button: “**Manoeuvring Criteria Calculation**”

At this stage, the IMO Manoeuvring Criteria have been calculated by the RSM program for the set of inputs tuned by the end user. They appear in the Red table at the right handside.

#### **5.5.2 Basic Event Parameters:**

For some BE, specific parameters can be tuned by the end user in order to refine its risk evaluation. Nevertheless, one parameter is common and should be chosen once and for all, the distance between the obstacle and the design vessel when the avoidance manoeuvre is launched:  $d_0$ .

The choice of this distance is made once and for all in the excel sheet: “Probabilities”.

For each BE, the specific parameters to input are presented hereafter:

##### **Striking with a floating object:**

No other parameter is needed.

##### **Striking with a fixed object in open sea:**

No other parameter is needed.

##### **Striking with a fixed object in restricted water:**

No other parameter is needed.

##### **Collision in open sea:**

Traffic distribution index. Values: 1, 2 or 3 correspond to various distribution of ship types as previously described in paragraph 3.2.4 of [R4].

Scenario Percentage. Values: Numerical values between 0 and 100. The sum of the three should be equal to 100.

As described in paragraph 3.2.4 of [R4], three different scenarios can be considered for a collision in open sea. The choice of the percentage of scenarios allows adapting the model to specific known cases or specific area.

**Collision in restricted water:**

Traffic distribution index. Values: 1, 2 or 3 correspond to various distributions of ship types as previously described in paragraph 3.2.4 of [R4].

Scenario Percentage. Values: Numerical values between 0 and 100. The sum of the two should be equal to 100.

As described in paragraph 3.2.4 of [R4], two different scenarios can be considered for a collision in open sea. The choice of the percentage of scenarios allows adapting the model to specific known cases or specific area.

**Powered grounding:**

No other parameter is needed.

**5.5.3 Probabilities Calculation**

The final step consists in the choice of the distance  $d_0$  in the excel sheet "Probabilities" And to click on the button "**Calculation**".

Then the values of probabilities of the various BEs are available on this spreadsheet in the various related boxes.

## 6. CONCLUSIONS

This report has provided an integrated view of the risk and cost models that have been developed separately in Tasks 131, 132 and 133. The document has also explained how to use jointly these models for identifying the design parameters configuration(s) that most minimise the probability of occurrence of collision, striking and grounding events, and the related costs. However, it's the final tool developed within the whole project that will enable more general considerations on risks and costs, once the whole set of design parameters will be considered.

## 7. REFERENCES

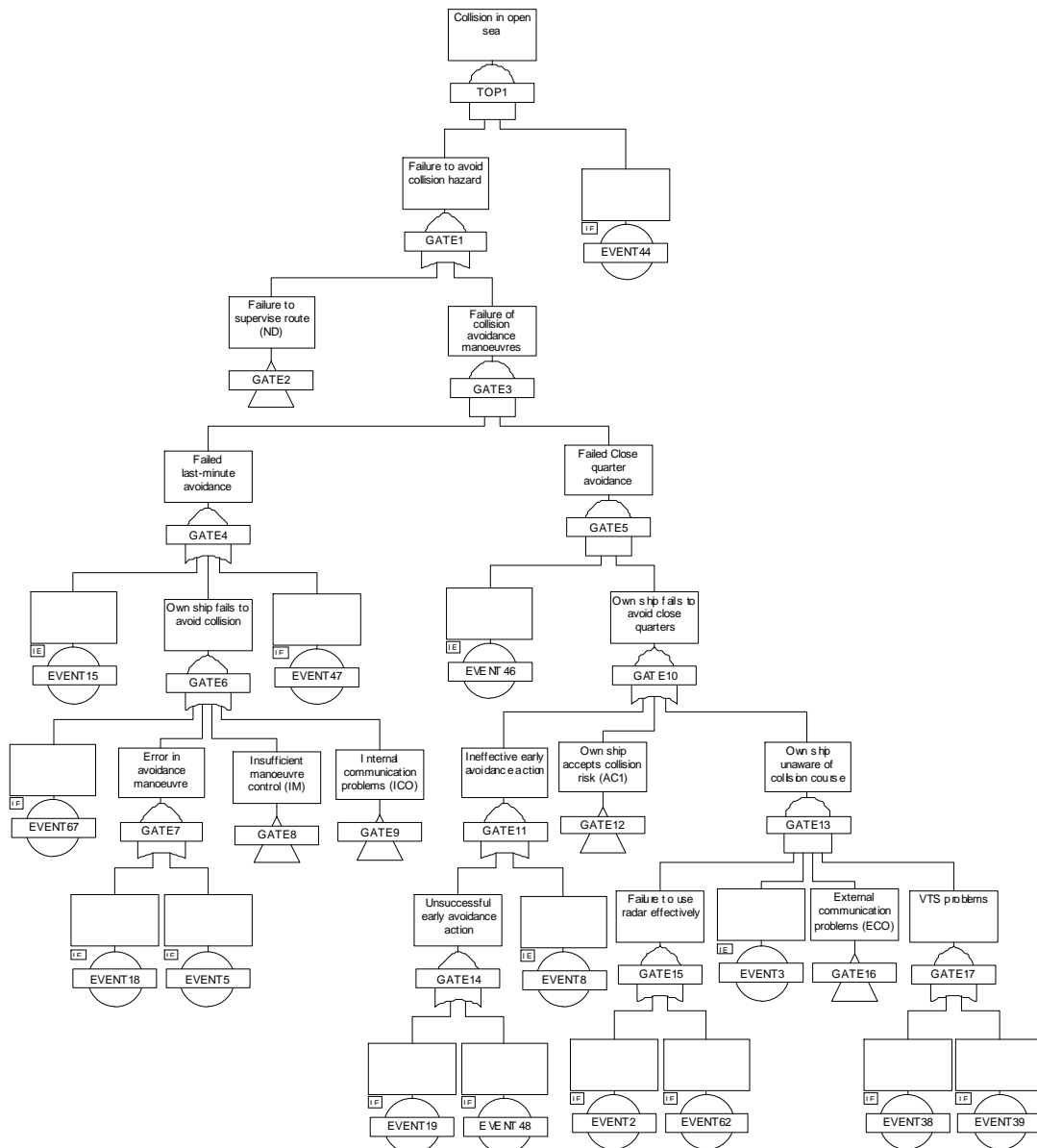
- [R1] D'Appolonia, D120, "Formulation of Models", ID-Code S101.20.03.054.001A, 2002.
- [R2] DMI, D131, "Implementation of Models for Human Errors", ID-Code S101.31.01.052.002, 2003.
- [R3] D'Appolonia, D132, "Implementation of Models for M&A Failures", ID-Code S101.23.03.051.001, 2003.
- [R4] SIREHNA, D133, "Implementation of Models for Manoeuvrability Errors", ID-Code S101.33.11.052.001B, 2003.
- [R5] DMI, "User Guide for the Model for the Human Error", ID-Code S101.31.01.052.002, 2003.
- [R6] D'Appolonia, "Risk and Cost Model Tool for M&A Failures, ID-Code S101.13.03.058.001, 2003.
- [R7] SIREHNA, "Manoeuvring Model-User Guide", Version number 1, 2003.

## 8. APPENDICES

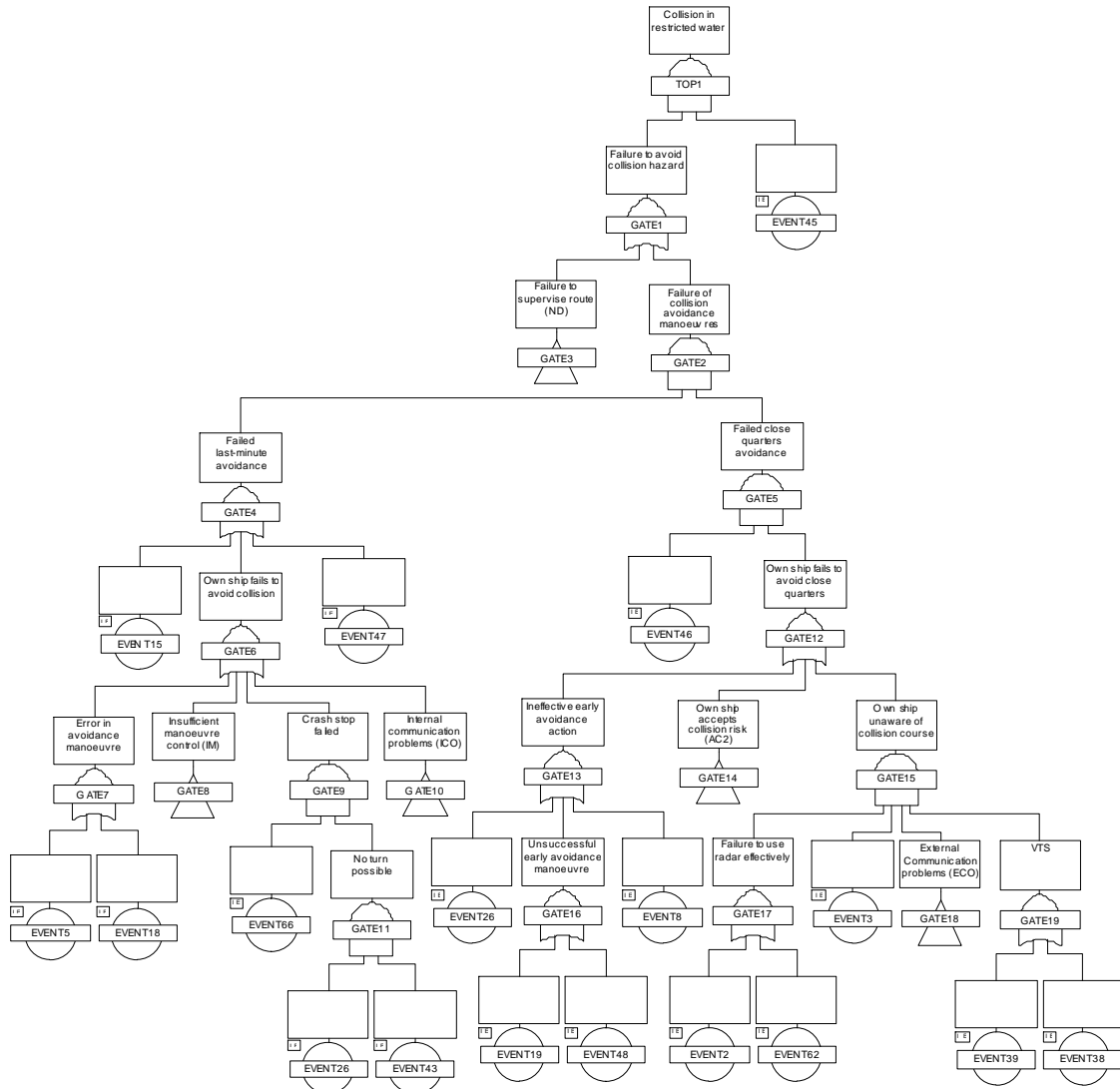
### 8.1 Appendix 1: Fault Trees

For the identification of the basic events refer to § 9.

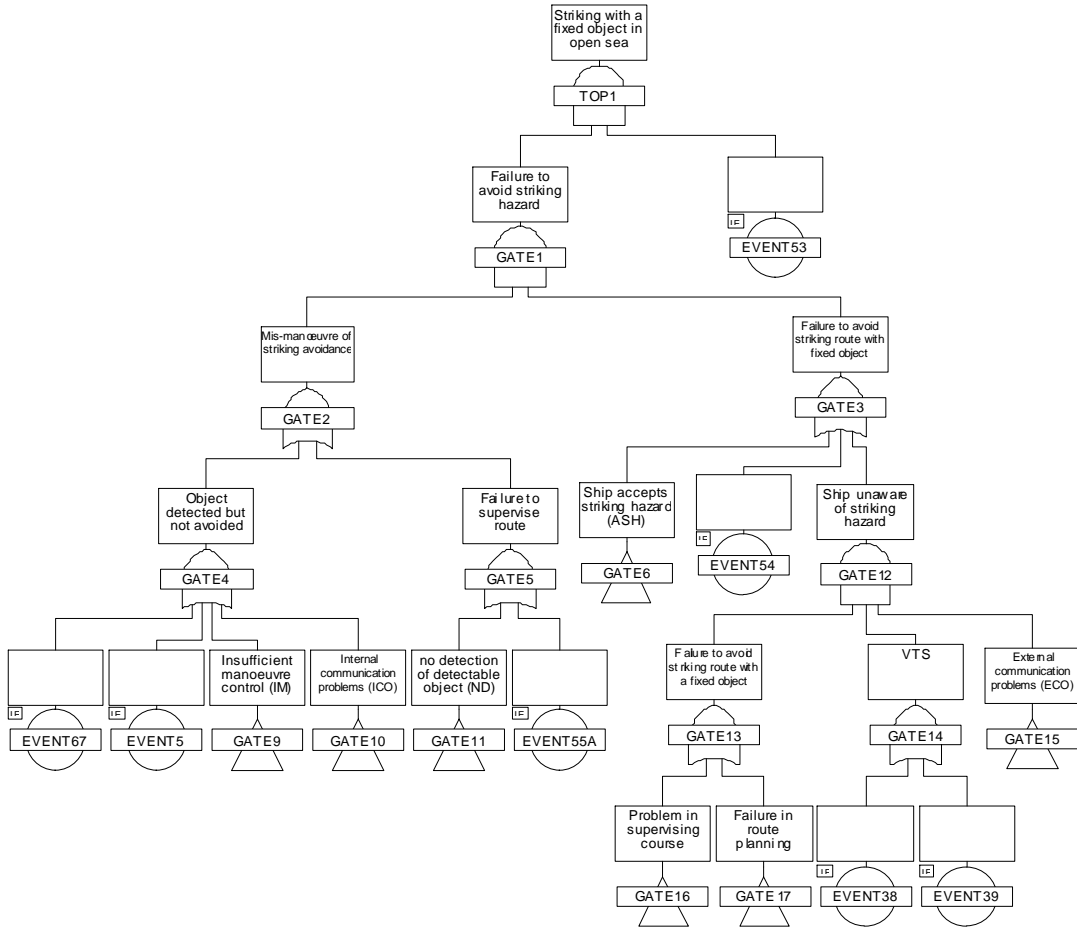
#### 8.1.1 Collision in Open Sea



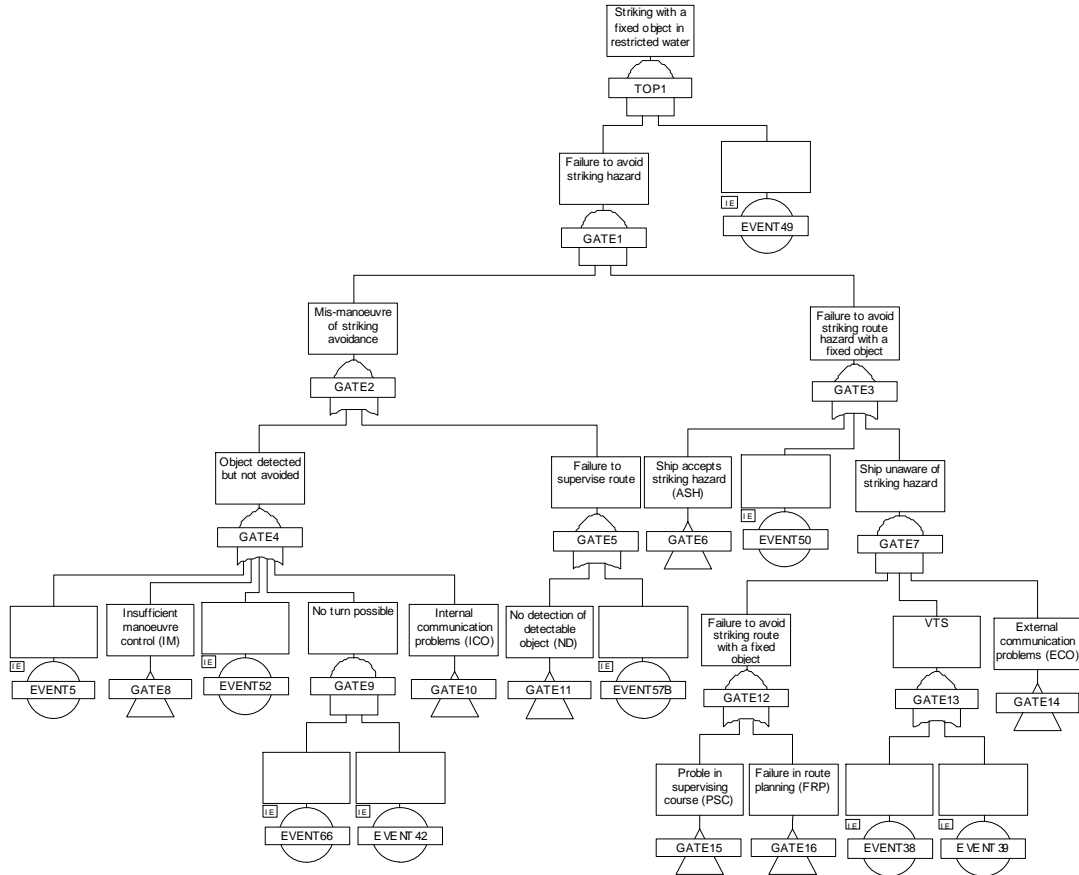
### 8.1.2 Collision in Restricted Waters



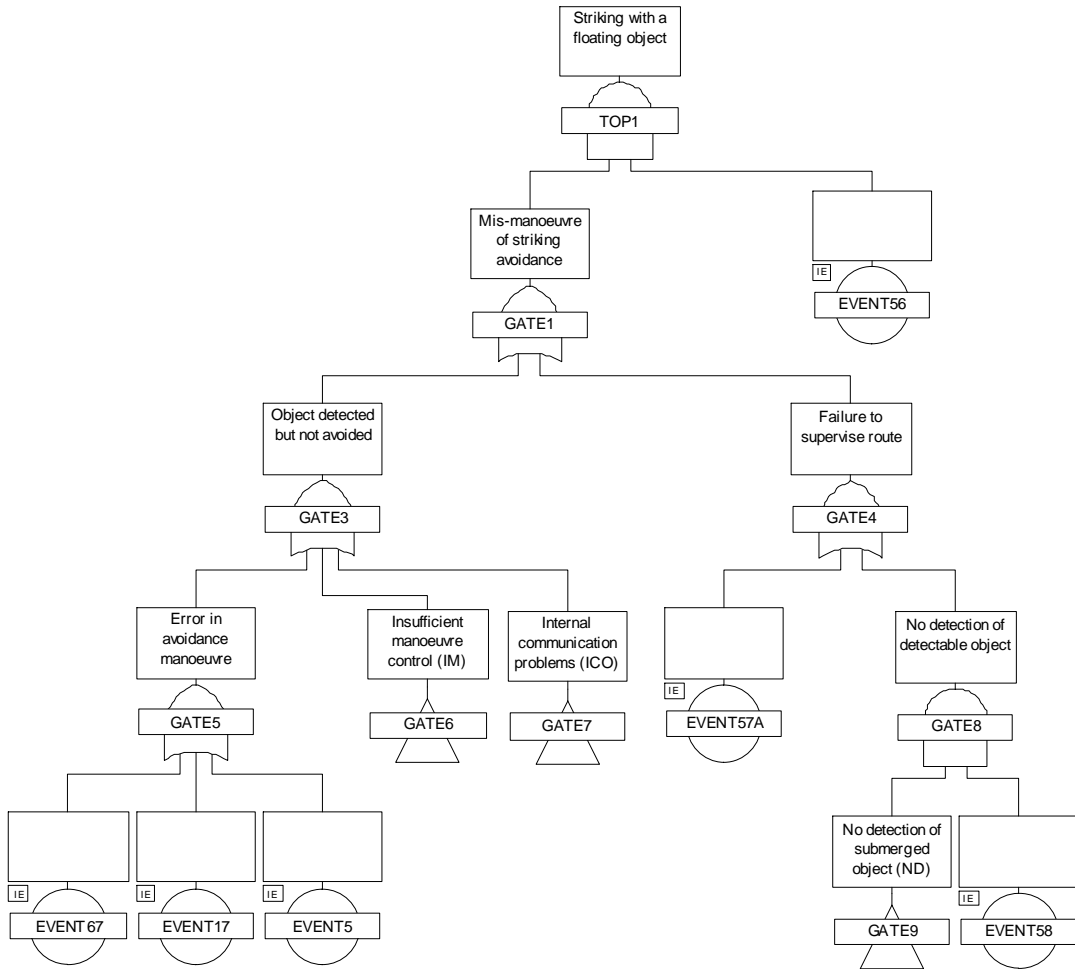
### 8.1.3 Striking with a Fixed Object in Open Sea



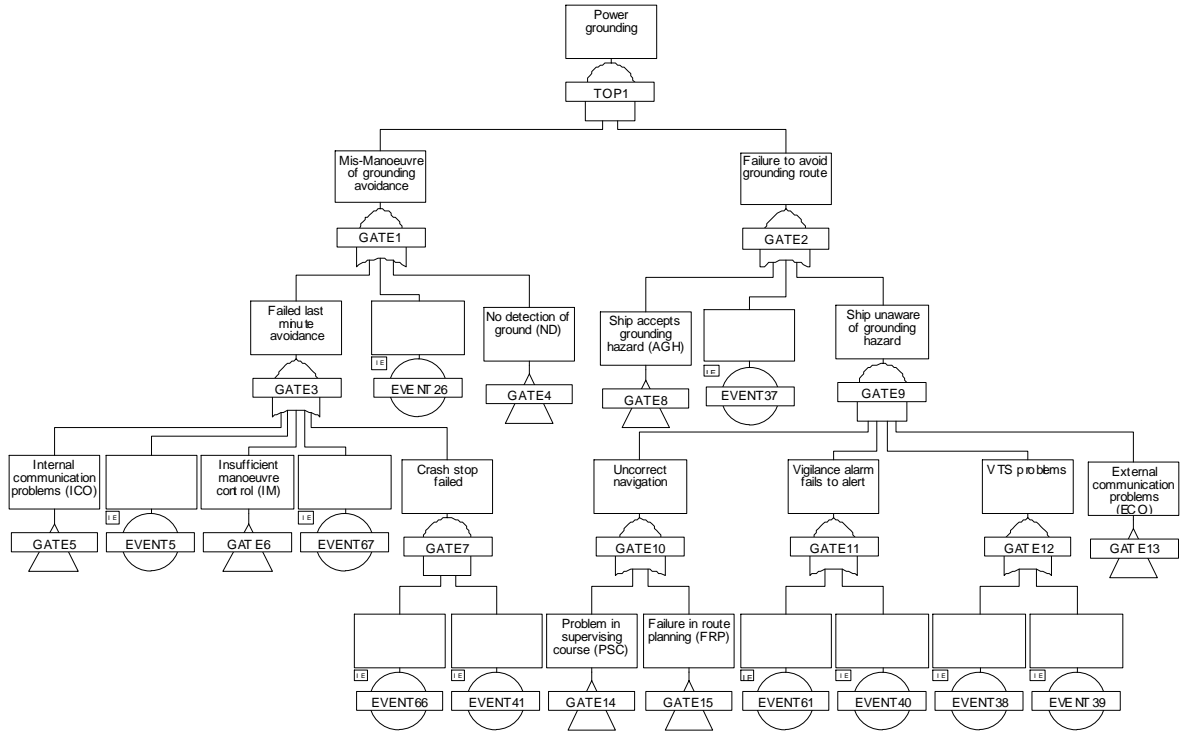
### 8.1.4 Striking with a Fixed Object in Restricted Water



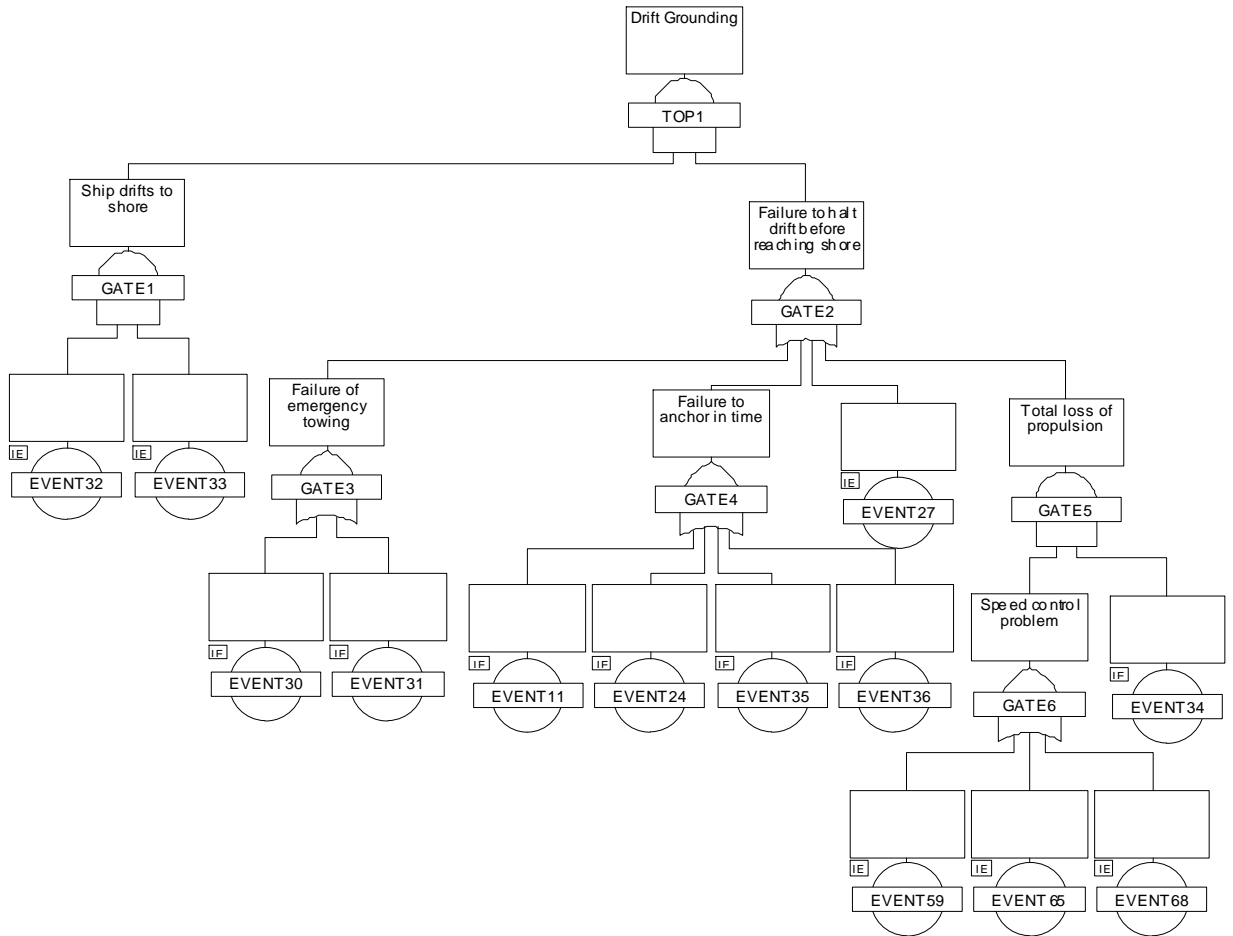
### 8.1.5 Striking with a Floating Object



### 8.1.6 Powered Grounding

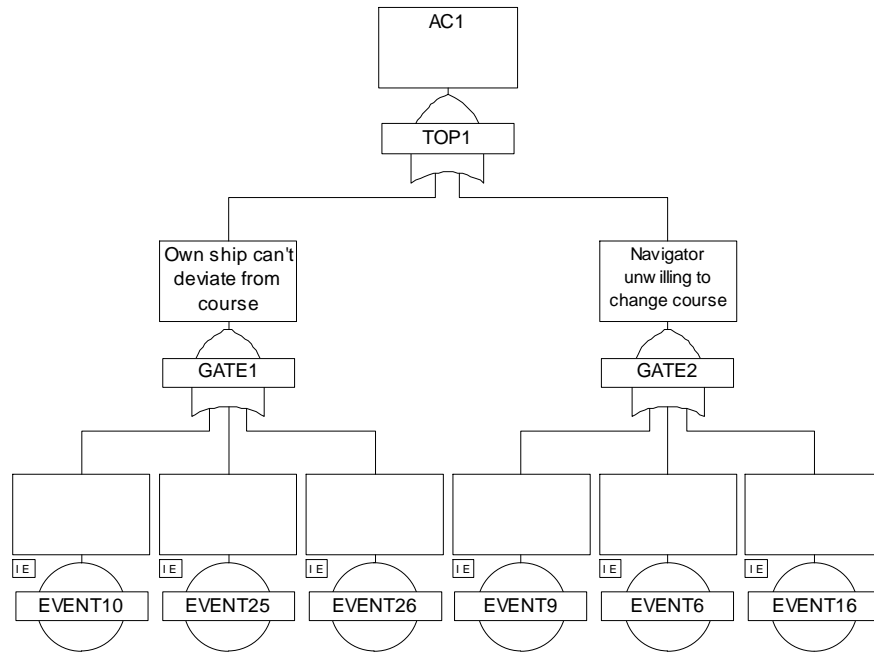


### 8.1.7 Drift Grounding

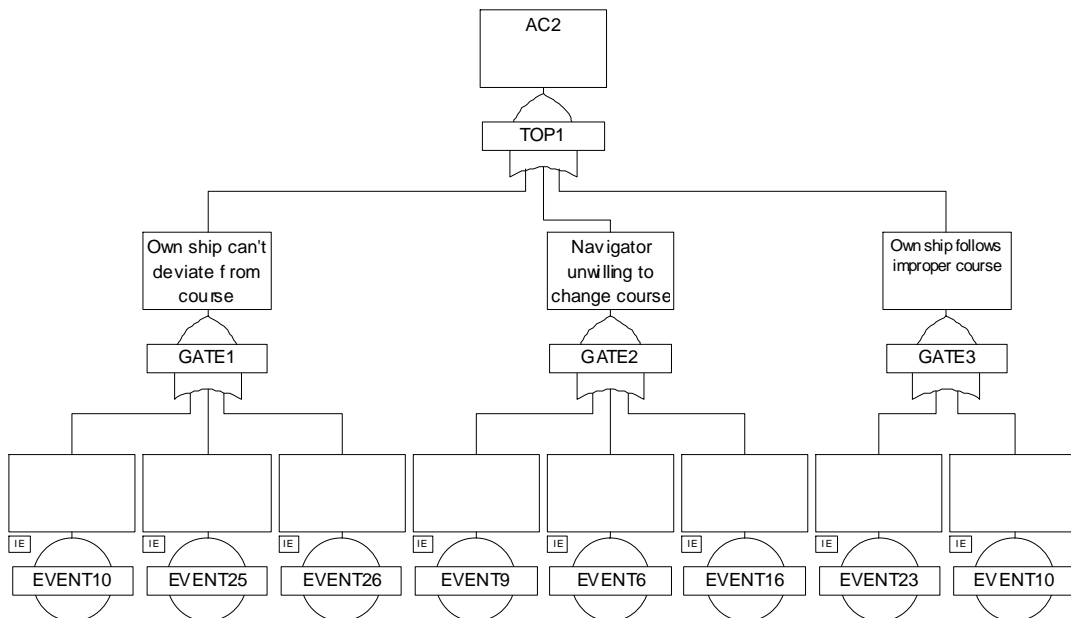


### 8.1.8 Sub-Fault Trees

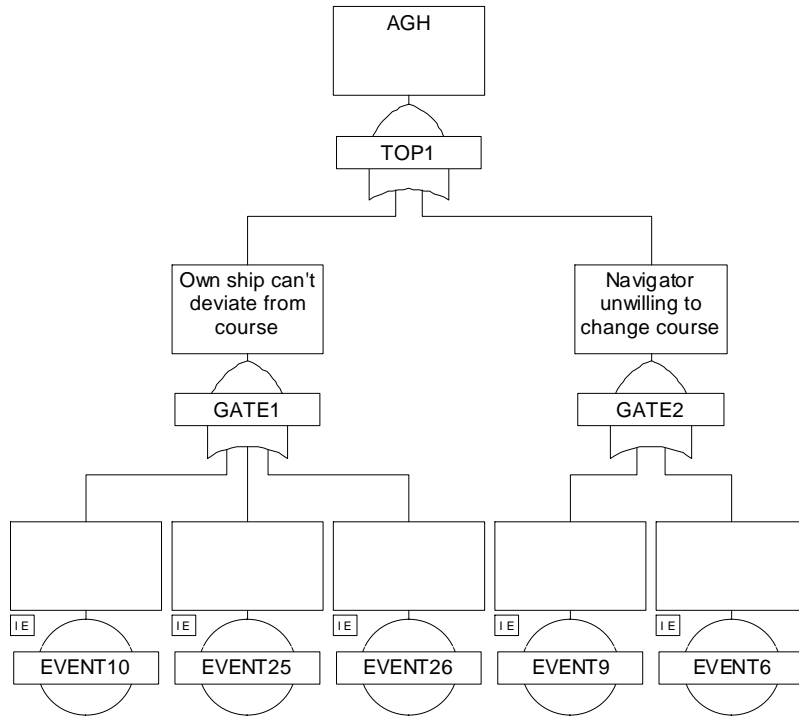
#### 8.1.8.1 AC1



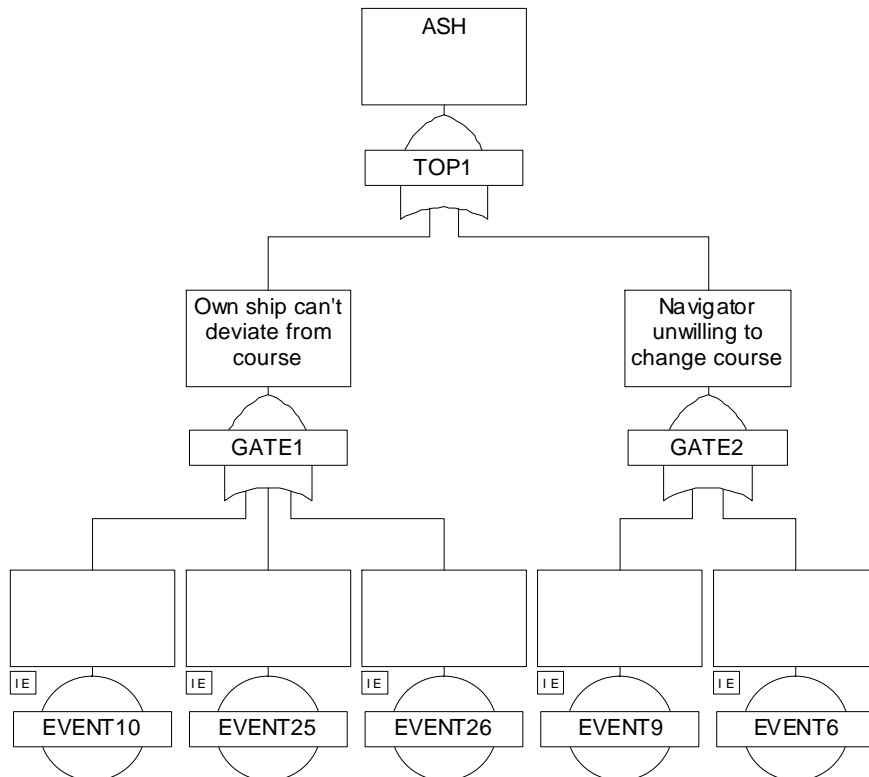
#### 8.1.8.2 AC2



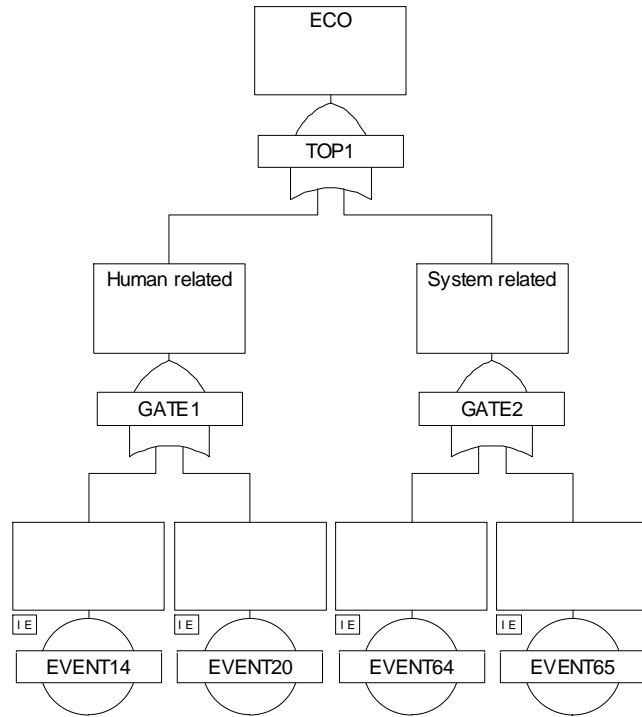
8.1.8.3 AGH



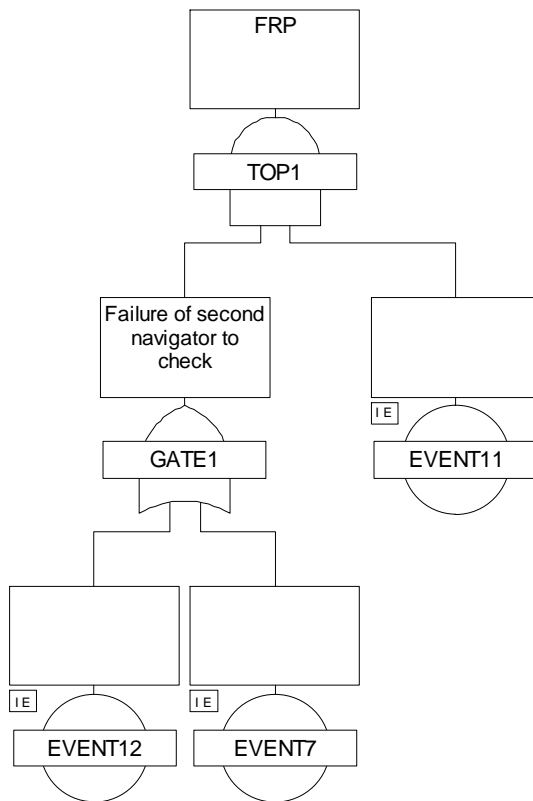
8.1.8.4 ASH



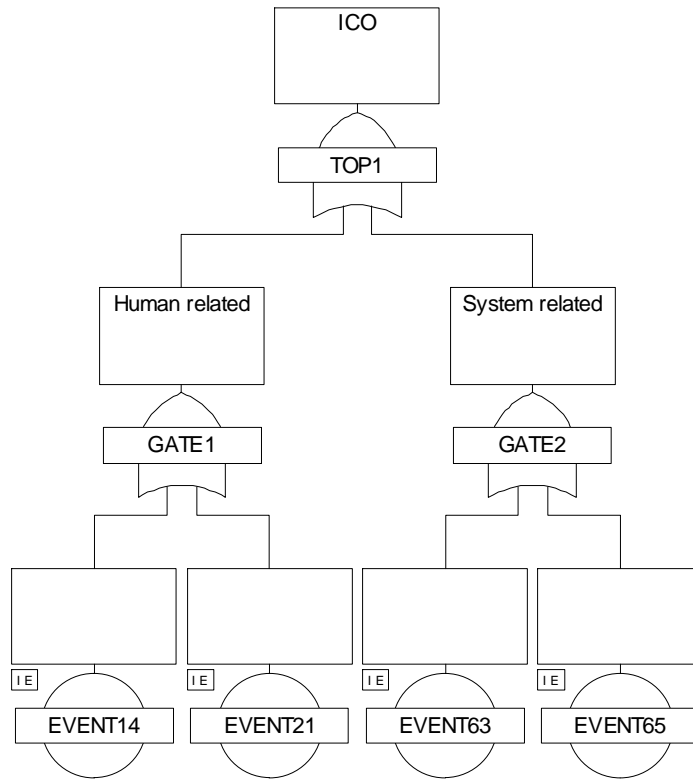
8.1.8.5 ECO



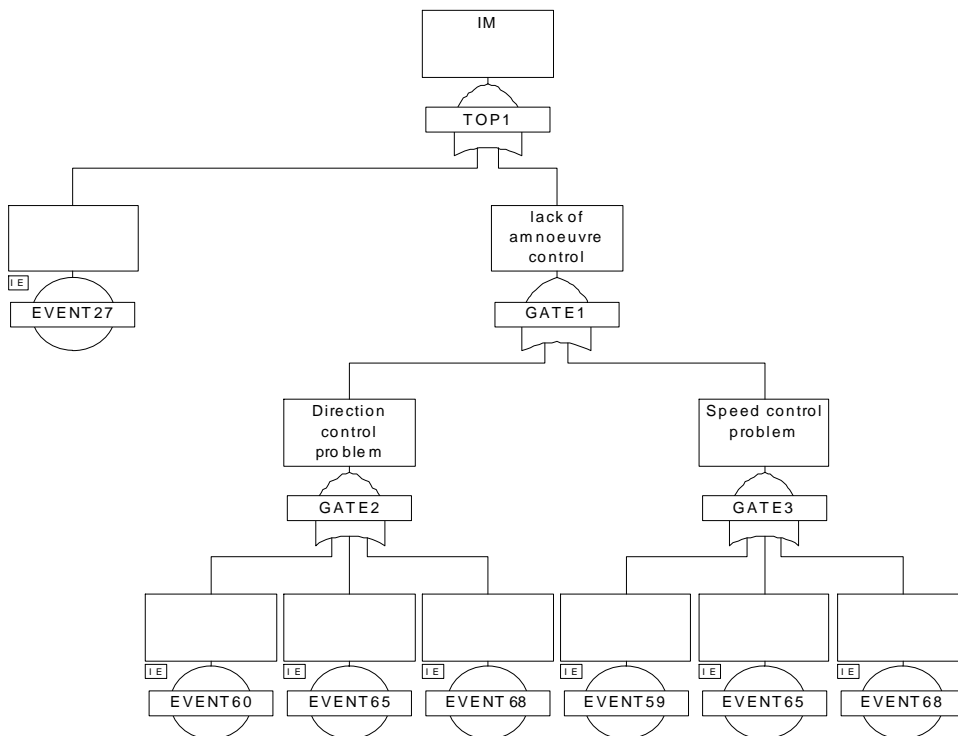
8.1.8.6 FRP



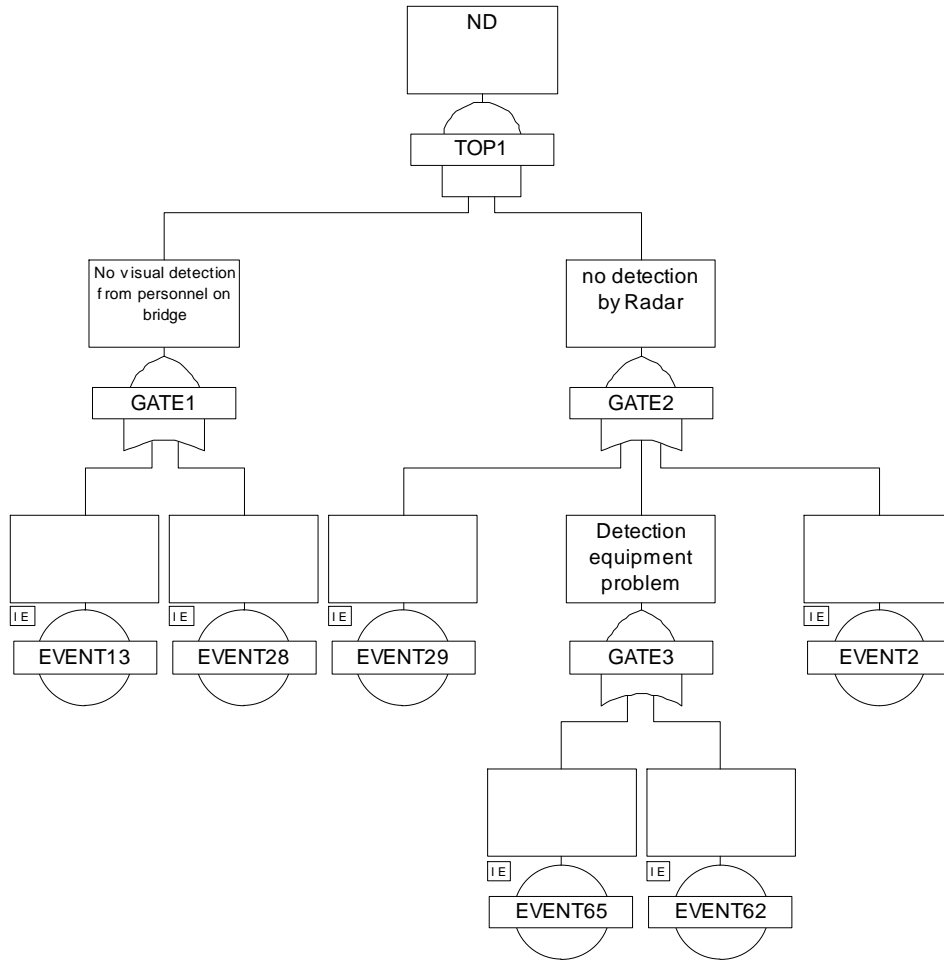
8.1.8.7 ICO



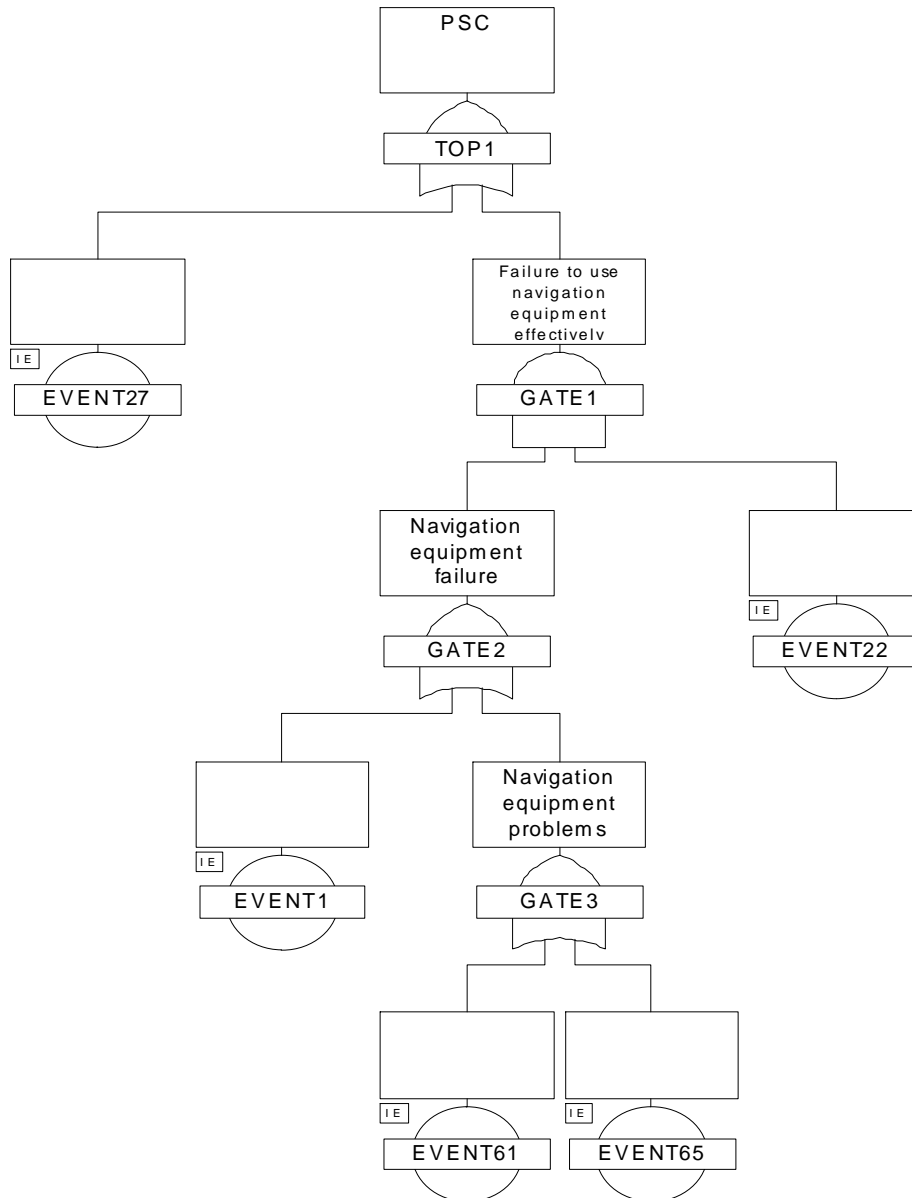
8.1.8.8 IM



8.1.8.9 ND



8.1.8.10 PSC



## 9. APPENDIX 2: BASIC EVENTS

It is important to highlight that the numeration associated to each basic event is assigned in compliance with the structure of the fault trees.

### 9.1.1 Human Factors (HFs)

The BEs related to Human Error have been numbered and are reported below:

- 1 Fail to make use of navigation equipment
- 2 Fail to make use of radar
- 3 Fail to observe relative courses
- 4 Fail to plot relative courses
- 5 Helmsman error
- 6 Navigator overconfident
- 7 Only one navigator present on bridge
- 8 Misinterpretation of collision rules
- 9 Navigator intentionally does not change course
- 10 Passing too close to the other ship
- 11 Significant error made by OOW
- 12 Second navigational officer on the bridge fails to notice error
- 13 Watch-keeping failure
- 14 Involved in wrong communication
- 15 Assume that the other ship would fulfil its obligation to give way and change its course
- 16 Assume that the other ship would change its course though it is not supposed to give way
- 17 Bad evaluation of the drift speed and course of floating object
- 18 Bad evaluation of speed and course of other ship
- 19 Confused by other ship's movement
- 20 Failure in the use of external communication
- 21 Failure in the use of internal communication
- 22 Fail to perform cross-check of equipment
- 23 Failure to keep starboard side of the channel
- 24 Anchoring system Failure(...caused by "malfunction or brake down of equipment such as anchor equipment or fuel system due to insufficient maintenance")

The same BE may be present in more than one FT but with a different meaning depending on the context specified by the Top Event.

### 9.1.2 Mechanical and Automation (M&A) Failures

The following BEs were identified and numbered for Automation and Mechanical failures:

- 59 Propulsion System failure
- 60 Steering System failure
- 61 Navigation Equipment failure
- 62 Radar failure
- 63 Int. Communication failure
- 64 Ext. Communication failure
- 65 Electric System failure
- 68 Fire

Unlike BEs related to the Human Factor, those related to the Mechanical and Automation have the same effect in a different Fault Tree (i.e., Top Event).

### 9.1.3 Manoeuvrability Errors (MEs)

These BEs are exclusively related to the manoeuvring capabilities of the vessel in normal operating condition; no human error or mechanical failure is responsible for these errors. The BEs relevant to the Manoeuvrability error cases are:

- 66 Last minute avoidance too late: failed to turn in time to avoid collision, for encountered ship sea state, with actual ship speed, and accounting for manoeuvrability performance in open sea;
- 67 Remaining distance too short for crash stop for encountered environment condition.

The same BE can have different implications depending on the type of FT (i.e., Top Event) where it is located. Thus, the position of these BEs in the various FTs is coupled with a specific scenario description that allows the characterisation of the associated design parameters and the collision avoidance trajectories.

### 9.1.4 Other Basic Events

A list of BEs that could not be grouped in any of the previous categorisation was made, these BEs are:

- 25 Contravening traffic separation scheme
- 26 Impeded by other ship
- 27 Encountered environment condition
- 28 Too bad environment conditions for eye detection
- 28A Color of the object is visible for eye detection
- 28B Visibility is sufficient for eye detection
- 28C Light conditions are sufficient for eye detection
- 28D Object size versus wave height ratio is sufficient for eye detection
- 29 Too bad environment conditions for radar detection
- 29A Shape of the object is visible for radar detection
- 29B Object size versus wave height ratio is sufficient for radar detection
- 30 Tug or towing vessel unavailable in time
- 31 Failure to connect tug in time
- 32 Wind and/or current towards shore
- 33 Shore within max drift range
- 34 Failure to self repair in time
- 35 Poor seabed conditions
- 36 Length of anchor chain (too short)
- 37 Not mapped: ground or shallow water
- 38 VTS not present
- 39 VTS fails to alert
- 39A VTS has not detected the grounding route
- 39B VTS fails to contact due to radio communication failure (VTS)
- 39C VTS does not get a reply on their call
- 39D VTS does not succeed to explain the problem due to language
- 40 Alarm not active

- 
- 41 No space to deviate from grounding route (only relevant for displacement vessels)
  - 42 No space to deviate from striking route (only relevant for displacement vessels)
  - 43 No space to deviate from collision route (only relevant for displacement vessels)
  - 44 Other ship encountered in open sea
  - 45 Other ship encountered in restricted water
  - 46 Other ship fails to avoid close quarters
  - 47 Other ship fails to avoid collision
  - 48 Failure to make VHF contact
  - 49 Fixed object encountered in restricted water
  - 50 Not mapped fixed object in restricted water
  - 51 Dangerous fixed object submerged in restricted water
  - 51A Object is submerged
  - 51B Object is dangerous (within the limit of the draught)
    - 52 Deliberate action of collision avoidance
    - 53 Fixed object encountered in open water
    - 54 Not mapped fixed object in open water
    - 55 Dangerous fixed object submerged in open water
  - 55A Object is submerged
  - 55B Object is dangerous (within the limit of the draught)
    - 56 Floating object encountered
    - 57 Dangerous floating object submerged
  - 57A Object is submerged
  - 57B Object is dangerous (within the limit of the draught)
  - 58 Object detectable

## 9.2 Appendix 3: Design Parameters

The following sub-chapters report the parameters that have been identified as the key elements upon which the designer can play to minimise the contribution of human errors, mechanical and automation failures, and manoeuvring errors to collision, grounding and striking events. These parameters are embedded in the 3 models.

### 9.2.1 Human Factors (HFs)

As it is detailed reported in D131, the human factors parameters concur, jointly, to the calculation of the HFQ whose value determine to the probability of occurrence of the BE human factors related.

PARAMETER	SUB-parameters
Training and education of Crew	Amount of training and education
	Overall quality of training and education
Selection of crew – qualifications	Number of well spoken working languages on board
	Amount of experience
	Overall quality of training and education
Selection of crew – personality and attitudes	Amount of bridge discipline
	Ability to cope with operational pressures
	Ability to cope with boredom (e.g. due to routine work)
	Amount of concern about safety
	Amount of risk taking attitude
	Level of confidence (in self, others, automation/ technology)
Selection of crew – medical and physical condition	Level of exposure to domestic issues
	Level of overall medical and physical condition
Operation and procedures	Amount of daily time and/or scheduling pressure
	Amount of commercial and/or organizational pressure
	Amount of individual workload in the daily routine work
	Amount of especially demanding planned situations (e.g. fire drills)
	Amount of resources for maintenance, repair, retrofit, new equipment etc.
Safety culture	Level of overall safety culture on board
	Level of overall safety culture in company/land organization
Company practice	Overall quality of working terms and conditions – long term (vacation, salary, promotion possibilities etc.)
	Overall quality of working terms and conditions – daily basis (working hours, rest periods, working environment, accommodation etc.)
Bridge discipline	Level to which extend bridge discipline is regulated by procedures and/or practice
Design of equipment and means for navigation	Level of automation
	Level of transparency

PARAMETER	SUB-parameters
HMI principles	Overall quality of interaction design and ergonomics
User's manual	Availability of user manuals
	Overall quality of user manuals
Means for communication	Availability of means for communication
	Overall quality of means for communication
Procedures for communication	Level to which extend onboard communication is regulated by procedures and/or practice
Comfort on board	Level of comfort directly related to WP2

**Table 7: Human Factors parameters**

### 9.2.2 Mechanical and Automation (M&A) Failures

As explained in D132, a set of parameters have been identified and put in relation with the BE Mechanical and Automation Failures related; these are reported in the following table.

Basic Event	Parameters
Propulsion System failure	No of Main Engines
	No of Diesel Engines
	No of Gas Turbines
Steering System failure	No of Steering Waterjet
	No of Dedicated Engines
Navigation Equipment failure	N° of Vessel Traffic System (VTS)
	N° of DGPS (Differential GPS)
	N° of Electronic Chart Display and Information System (ECDIS)
Radar failure	Presence of a Radar unit - 3Ghz
	Automatic Tracking Aid (ATA)
	Automatic Radar Plotting Aid (ARPA)
Internal Communication System failure	Presence of emergency system for General alarm and PA
	Presence of the Talk back systems
	Presence of the Paging systems
External Communication System failure	Redundancy of Safety Information (e.g. INMARSAT, NAVTEX)
	Presence of emergency system for the VHF Radio
	Presence of Identification Systems (e.g. AIS)
Electric System failure	No of Diesel Engines
	No of Emergency Diesel Engines

**Table 8: 8.3.2 Mechanical and Automation parameters**

### 9.2.3 Manoeuvrability Errors (MEs)

This model allows determining the conventional IMO manoeuvrability criteria for a given combination of **design parameters** (Length, Breadth, Draft, Displacement) in a **sailing configuration** (Depth, Speed). The following table presents the scenarios and associated parameters for every basic event.

SCENARIOS		BASIC EVENT	
		Last minute avoidance too late	Remaining distance too short for crash stop
Generic	Specific		
Striking with a floating object	head-on encounter	X	
	crossing encounter		
Striking with a fixed object in open sea		X	
Striking with a fixed object in restricted water			X
Collision in open sea	head-on encounter	X	
	crossing encounter	X	
	overtaking	X	
Collision in restricted water	crossing		X
	overtaking		X
Powered Grounding		X	

**Table 9: Scenarios and BE for the manoeuvring error model**