

Safety at Speed - S@S

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

This deliverable reviews WP1 to 4 procedure/scheme – models in order to prepare the integration of WP1 to 4 risk and cost models in the so called “Project tool”. This report is based on WP1 to 4 deliverables entitled “Formulation of Models”.

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## 2. INTRODUCTION

The objective of task 5.1 is to verify and validate the techniques during their development in Work Package 1 to 4 against typical, real-life designs, current rules and regulations and techniques made available from other industrial sectors to assure the applicability and quality of results.

This deliverable reviews WP1 to 4 procedure/scheme – models in order to prepare the integration phase of the achievement of WP1 to 4. These models constitute the theory on which will be built the different risk models.

This report is based on WP1 to 4 deliverables called “Formulation of Models”. It is organised according to the same project organisation by Work package & goes successively through the different models by summarising the objectives, giving a short description and finally by validating the models which will constitute the basis of the risk models.

The general validation process takes into account the cross review and validation of each individual deliverables previously performed by appointed members of the consortium as per Project Handbook. These reviews performed by experts have validated the various models theories.

The final verification and validation has been carried out for compliance with IMO SOLAS and HSC Code as well as Classification Societies Rules (ABS, BV ,GL, RINA). for the level of detail corresponding to a preliminary design.

## 3. WORK PACKAGE 1: COLLISION & GROUNDING

### 3.1 Objectives

Develop models for the comparison of costs and risks associated with:

- different Ship Control Centre (SCC) design alternatives for high-speed crafts;
- different design alternatives for the technological systems of high-speed crafts;
- the manoeuvrability of high speed crafts in restricted waters and those of conventional vessels.

### 3.2 Methodology

The activity of WP1 was articulated in the following steps:

- A Fault Tree analysis of Collision, Grounding and Striking with the purpose of identifying the basic events leading to these three hazards.
- Identification of those design parameters (available at the preliminary design phase) which will enable the effect of these basic events on Collision, Grounding and Striking to be counteracted.
- Design of a methodological approach for building a Risk Model that establishes relationships between the design parameters and these basic events and, ultimately, with one of the three hazards.
- Examples of applications of the approach for Human Errors, Automation and Technical failures were sketched.
- Development of an approach based on a Response Surface Methodology, exploiting data generated by simulation runs, for analysing manoeuvre problems in different environmental conditions.
- Development of a tool showing how a small number of design parameters changes can predict production and operational costs.

### 3.3 Formulation of the Risk Model

#### 3.3.1 Fault Tree Analysis

A fault tree analysis with a Collision/Grounding/Striking as top event has been developed. The final structure is a combination of semantic networks (i.e. classification) in its upper part, and FTs in its lower part ([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.

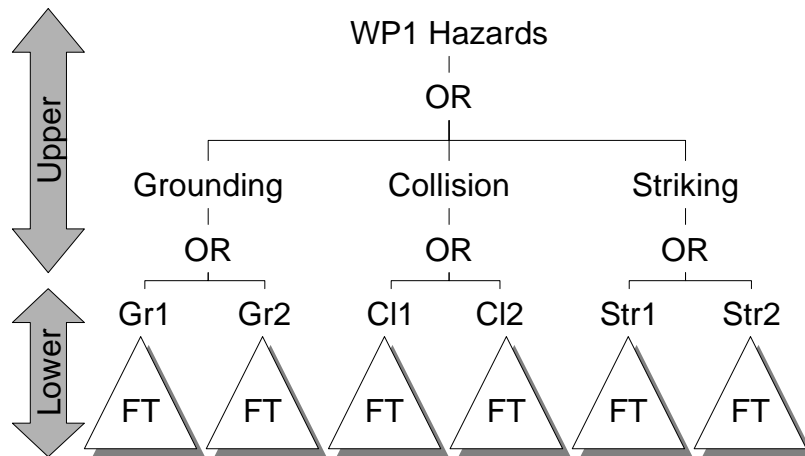


Figure 1 Overall view of WP1 hazards structure

The upper part of the structure can be schematised as in the following hierarchical list:

1. Grounding
  - 1.1. Powered grounding (separate FT)
  - 1.2. Powered grounding on landfall (separate FT)
    - 1.2.1.
  - 1.3. Drift grounding (separate FT)
2. Collision
  - 2.1. In open sea (separate FT)
  - 2.2. In restricted waters (separate FT)
3. Striking
  - 3.1. With a floating object (separate FT)
  - 3.2. With a fixed object/infrastructure
    - 3.2.1. In open sea (separate FT)
    - 3.2.2. In restricted waters (separate FT)

See Deliverable D1.2.0 for the final structure.

WP1 formulated models that would enable designer to evaluate the probability of occurrence of those basic events (BEs) which are related to different areas:

- Human error,
- Automation/Mechanical failures,
- Manoeuvring errors.

### 3.3.2 Methodological approach

The proposed approach for modelling Human Errors, Automation & Mechanical Failures, and Manoeuvring Errors hinges on the deterministic and probabilistic relationships between BEs and Parameters.

Through these dependencies it is possible to link what a designer can control in the design stage, i.e., parameters, to the outcome of an unfavourable combination of events, i.e., the hazard (e.g., collision, grounding, etc.).

These dependencies between design parameters and BEs are based on the following assumptions:

- Each BE can be related to a limited number of parameters (3 at most).
- Each Parameter also has a limited number of possible states (3 at most). This means, for instance, that the Parameter “*Speed*” can assume the values of 30, 40 or 50 knots; another example can be “*Crew Training required*” that can be either ‘high’ or ‘low’.
- Whenever a Parameter needs to be defined through a set of sub-parameters they can only have 3 states at most. Therefore, like Parameters, sub-parameters can only have 3 states at most, and if necessary each one can be related to other 3 sub-parameters at most, with 3 possible states only, and so on.
- Relationships between BE and Parameters are probabilistic. This means that the probability related to a BE depends on the combination of possible states for specific parameter(s).
- Relationships between Parameters and sub-parameter are deterministic, that it to say that the state of a Parameter or of a sub-parameter is determined respectively by ‘yes-or-no’ (i.e., Boolean) relationships.
- These relationships have been formulated through matrices.

[Table 1](#) reports the minimum number of combinations (i.e., 2) that can be set in the models; in this case there is one BE with two possible range values, depending on one Parameter only that has two possible states.

[Table 2](#) reports the maximum number of combination (i.e., 81) that can be set in the models; in this case there are three Parameters with three possible states, each depending on three sub-parameters with three possible states each.

However, 81 must be considered as a general limit of the approach; for example, a BE related to a parameter with 81 possible states originating 81 value ranges for the BE is also acceptable.

Parameter (P)	P <sup>1</sup>	P <sup>2</sup>
Basic Event		

**Table 1: Minimum No. of combinations (2) between a BE and one Parameter.**



robust, and will only suffer minor decrease from a single performance shaping factor, and a combination (configuration) of different performance shaping factors is more likely to have an impairing effect on the human performance than just a single factor.

Some examples are: Fatigue, stress, physical illness, lack of bridge resource management skills and risk taking attitude. These factors can in solitaire or together in different configurations and with different weight create the necessary lack of human performance which eventually and evaluated against a certain performance standard can be observed as a human error.

The relationship between PSF's and the simplified model of human cognition and behaviour is illustrated in figure 3. Performance shaping factors has - according to this model - impact on observation, interpretation, planning and action. The result is inadequate performance, human error etc.

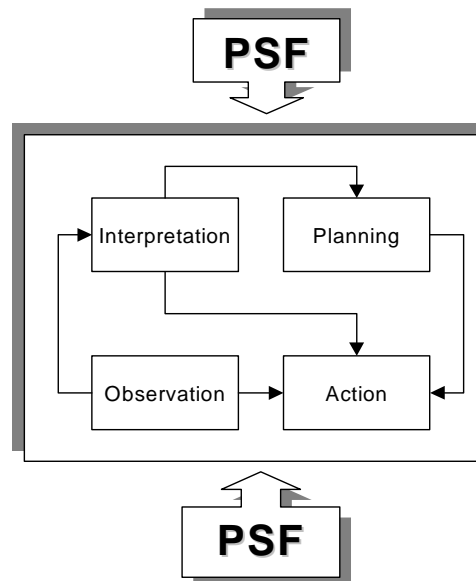


Figure 3: The relationship between PSF's and the simplified model of human cognition & behaviour

### 3.3.4 Application of the approach to Human Error

The introduction of these concepts (relationship between BE's, Human Error FT's, PSFs, sub-factors and Parameters) is instrumental in building a system, which is:

1. Able to explain the relationship between parameters and fault trees;
2. In conformity with traditional cognitive science;
3. In conformity with the general approach in the construction of the risk model;
4. Ready for implementation.

The error is based on:

1. A propagation of error through a human cognitive system involving levels of observation, interpretation, planning and action. This system is described by means of a fault tree like model: The Human Error Fault Tree.
2. Underlying causal conditions and precursors denominated performance-shaping factors (PSF).

PSFs should be understood as quantifiable concepts. Each PSF can be given a value by means of a calculation based on a system of sub-factors on different levels. The PSF act as a mediator between sub-factors and a human error.

The quantitative value of each sub-factor in the system of sub-factors can be adjusted and controlled by means of parameters. The sub-factor acts as a mediator between parameter and PSF (Figure 4).

This relationship cannot be established directly. A set of mediators must be used to secure conformity with traditional cognitive science and the general approach in the construction of the risk model.

Table 3, Table 4 and Table 5 show how the generic has been applied to an example.

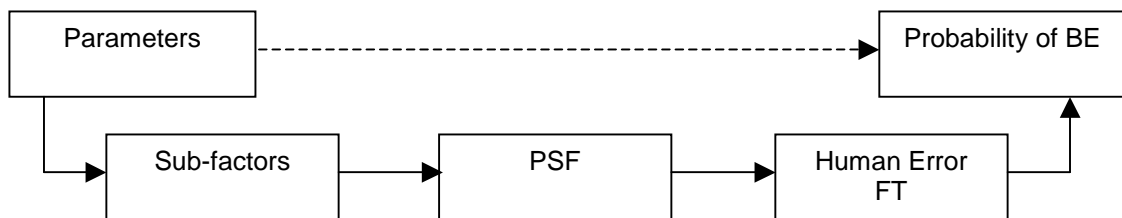


Figure 4 Relationships between Parameters and BEs.

Performance Shaping Factors	Physiological problems (PSF1)	Low			Average			High		
	Psychological problems (PSF2)	Low	Aver.	High	Low	Aver.	High	Low	Aver.	High
BE	Watch keeping failure in open sea and in good visibility									

Table 3 Example of link between BE and PSF (Fault tree: Collision in open sea).

1 <sup>st</sup> order sub-factors	Mental/emotional state (sub-factor 1)	Average		Poor	
	Cognitive problems (sub-factor 2)	No	Yes	No	Yes
Level of psychological problems	Low	1	1	1	0
	Average	0	1	1	1
	High	0	0	0	1

**Table 4 Example of link between PSF and 1st order sub-factors.**

Parameters	Selection of crew - personality and attitudes	Low level		High level	
	Company practice	Low level	High level	Low level	High level
Mental/emotional state	Average	0	1	1	1
	Poor	1	1	1	0

**Table 5 Example of link between 1st order sub-factors and Parameters.**

### 3.3.5 Application of the approach to Automation/Mechanical Failure

The approach was applied to an example regarding Automation/Mechanical failure. From the list of parameters on 'Communication System'

1. **HSC internal communication level (Parameter):** The global internal communication level of HSC.

- a) Reliability of single communication device (1<sup>st</sup> order sub-parameter 1): The quality and the reliability of the single device-equipment or unit of the internal communication system such as walkie-talkies, public address, system to implement in the HSC.
- b) HSC internal communication quality (1<sup>st</sup> order sub-parameter 2): The global quality of the HSC internal communication system.
- c) HSC internal communication coverage (1<sup>st</sup> order sub-parameter 3): % of crew on board always in contact.

The approach was also applied on "direction stability systems. The parameter was considered and formulated as follows:

- a) Reliability of single units (1<sup>st</sup> order sub-parameter 1) The quality and the reliability of the single device-equipment or unit of the directional control system to implement in the HSC
- b) Number of redundant units (1<sup>st</sup> order sub-parameter 2): the number of reserve units
- c) Maintainability of single units (1<sup>st</sup> order sub-parameters 3): the degree of labour and other logistic support to perform maintenance on the single device-equipment or unit of the directional control system to implement in the HSC

### 3.3.6 Application to Manoeuvring Errors

The development of fault trees concerning collision, striking and grounding showed that basic events related to ship manoeuvrability can be summarised as:

- Lack of manoeuvrability while manoeuvring in restricted water at low speed,
- Impossibility to avoid an object on collision route, at low and high speed, in unrestricted water,
- Impossibility to stop the ship at low and high speed in restricted water.

The models to be developed concern the following criteria:

1. The advance and technical diameter for turning circles; this gives information on the ship manoeuvrability and seems relevant in restricted waters, at moderate speed.
2. Distance travelled along the initial direction and transversely to the initial direction for initial turning ability test: this corresponds to a collision avoidance situation and should be obtained in low/high speed and open/restricted waters.
3. Crash stop distance: this seems to be relevant mainly in restricted water conditions, when no avoidance by changing direction is possible.

The approach consists in exploiting available data by means of a Response Surface Methodology (RSM).

The following parameters have been defined: ship length, breadth, draft, block coefficient, Froude number and depth Froude number.

The final output of the analyses will be, for each of the 4 identified criteria, a piece of software code which will calculate the response surface, using the database, to produce, for given input parameters values, the value of the criteria.

### 3.4 Conclusion and Validation

Work package 1 has developed fault trees leading to the top events Collision, Grounding & Striking. The basic events and the related design parameters were identified, and their relationships modelled by a matrix approach and by using the Response Surface Methodology. These models have been reviewed and validated in the perspective of the integration process.

## 4. WORK PACKAGE 2: SHIP MOTIONS

### 4.1 Objectives

The objective was the development of risk model for the identified hazard factors:

- The human factor,
- The hull design,
- The operational practice.

These models will allow comparison of risks associated with these factors of High Speed Crafts.

### 4.2 Methodology

Since the various models of risks related to ship motions hazards simultaneously involve both hull design & operational practice parameters, the models were performed in common. Two basic models related to the ship seakeeping and dynamic stability (in broaching situation) have been formulated and will be used to derive the risk models.

The influence of excessive ship motions and acceleration on human is dealt in a separate model, which uses as main input the seakeeping model. The characteristic values calculated using these methods would be compared with acceptable limit values already in the preliminary design phase of a ship. The acceptable values have been stated on the basis of existing material including the latest international standard.

### 4.3 Formulation of the Risk Model

#### 4.3.1 Seakeeping model

A rational procedure able to predict the wave-induced motions and accelerations with sufficient engineering accuracy is formulated as described in D2.2.2. The procedure takes into account all pertinent parameters: length, breadth, draught, block coefficient, forward speed and operational profile. The formulas derived are semi-analytical such that the calculations can be easily implemented in a decision support system.

The simplified ship seakeeping model will be developed and validated using reference data produced by a parametric seakeeping numerical analysis. In a first step, the numerical seakeeping tool used is selected through a benchmark of the different codes available in WP2. Then, further validation of the tool will be performed by comparison with data from model tests and sea trials specifically performed in WP2.

Model tests data will also deliver additional information concerning whipping and local hydrodynamic loads for WP3.

Sea trials will also deliver data concerning noise, vibration, indoor climate and their effects, together with ship motions, on humans, for exploitation in the human factor model.

#### 4.3.2 Dynamic stability model

The primary scope of this model is to describe the phenomenon of ship capsize by broaching. Broaching is known as a highly non-linear phenomenon.

Broaching describes the phenomenon of loss of directional stability of a ship in a wave environment and is related to both manoeuvring and stability properties of the vessel. During a broach the ship veers off course and in spite of the opposite rudder action finds itself broadside to the wave. This behaviour is encountered in following to quartering seas and is characterised by the large yaw deviations the vessel undertakes. The large rotational acceleration in yaw, allied by the unbalanced roll moments, forces the ship to large roll angles and eventually to capsize. The phenomenon is more severe when the vessel obtains a considerable forward velocity and is trapped in the front slope of a wave.

Broaching itself however is neither a necessary nor a sufficient condition for a vessel to capsize. Because of this fact broaching is normally studied by means of planar motion models while the phenomenon of actual ship capsize following a broach is usually ignored.

Ship capsize by broaching is principally described by two motions. An extreme yaw action that will set the vessel off course and extreme heeling action induced by the turning motion that will capsize the vessel. These two motions are described in their simplest representation by a roll-yaw model, which is adopted here in order to investigate the phenomenon. It is believed that the capsizal resistance of a ship during a broach could be adequately assessed by considering only a roll-yaw mathematical model. The restoring capability of the vessel should be accurately described including the influence from heave and pitch. Indeed for vessels operating in following seas the change of the underwater volume of the ship as the wave passes, alters significantly its transverse restoring moment. Contrary, surge motion can be excluded from the model provided that a critical value for the phasing between the vessel and the wave is used.

$$I_z \dot{r} + mx_G rU - mx_G z_G \dot{p} = N_r \dot{r} + N_r rU + N_{r|r} r |r| + N_R + N_W$$

$$I_x \dot{p} - mz_G rU - mx_G z_G \dot{r} = K_p \ddot{\phi} - z_Y (Y_r \dot{r} + Y_r rU + Y_{r|r} r |r|) + K_R + K_W$$

$I_x, I_z$  are the moment of inertia of the vessel with respect to the body system in the x and z directions respectively, m is the mass of the vessel,  $x_G, z_G$  are the longitudinal and vertical distance of the centre of gravity from the origin O on the vessel, U is the forward speed of vessel, p and r are the angular velocities of the vessel: roll and yaw,  $\phi$  is the roll angular rotation of the vessel,  $N_r, K_p$  are the yaw-yaw and roll-roll added mass respectively,  $N_r, Y_r$  are the yaw-yaw and sway-yaw damping coefficients respectively,  $Y_r$  is the sway-yaw added mass coefficient,  $N_{r|r} r |r|, Y_{r|r} r |r|$  are the yaw-yaw and sway-yaw manoeuvring coefficients respectively,  $N_R, K_R$  are the waterjet coefficients for the yaw and roll respectively,  $N_W, K_W$  are the wave exciting forces for yaw and roll respectively. In the above formulation it is assumed that hydrodynamic and manoeuvring coefficients will be provided externally.

It is assumed that:

- the ship tries to proceed along a prescribed heading angle while external causes result in heading deviations and heeling action,
- the effect of surge motion is neglected, (the speed of advance is assumed constant)
- variation of the underwater volume with the lateral motion of the ship is neglected,
- the coupling effect of sway with roll motion is not considered.

The accurate prediction of broaching behaviour is served through the correct modelling of the yaw wave moment and its counteracting yaw rudder moment. These are the most influencing parameters and their calculation is performed in a precise manner for the instantaneous position of the ship. The capsizal resistance of the ship can be largely defined by the roll restoring moment, which can be modelled in a precise manner for the instantaneous position of the vessel.

### 4.3.3 Models for human factor

#### 4.3.3.1 Motion sickness model

The motion sickness model is based solely on methods already presented in international standards. However, the application of even the standards is not straightforward as they present no simple criteria for assessing the ship qualities with regard to motion sickness. Neither of the standards provides any quantitative criteria, e.g. for acceptable percentage of seasick persons.

Research on the subject suggests only the calculation the Motion Sickness Dose Value (MSDV) which is linearly proportional to the incidence of motion sickness. Using the calculated MSDV value it is possible to estimate the percentage of vomiting people (Motion Sickness Incidence, MSI). These values are determined using the frequency weighted vertical accelerations measured or calculated at given location of the ship (See D2.2.1).

$$MSI = \frac{1}{3} MSDV_z$$

There are no limits given in ISO 2631-1:1997 or BS 6841:1987 for acceptable percentage of seasick (vomiting) people. However, a tentative criterion for motion sickness could be set:

MSI value in passenger spaces should not exceed 10 % for exposure period of 2 hours

The time limit of two hours has been adopted because the motion sickness incidence increases with exposure time up to about two hours. The MSI criterion of 10 % is compatible with the criterion given by ABS. The COMF+ level for maximum MSDV value in ABS Guide for passenger comfort on ships is 30 m/s<sup>1.5</sup> which corresponds to MSI value of 10 % if the constant  $K_m$  is taken as 1/3.

The MSI criterion should be fulfilled in all passenger spaces. If it is clear where the highest vertical accelerations are expected to occur, the MSI value can be determined just in one location.

If the location is not obvious all potential points should be checked.

Exposure time [h]	Motion Sickness Incidence MSI [%]
0.5	5
1.0	7
1.5	8.5
2.0	10

Table 6 MSI criteria for different exposure times.

#### 4.3.3.2 Safety of footing model

The conditions on board may be assessed with regard to the safety of footing by predicting the number of loss-of-balance events per unit of time, or motion-induced interruptions (MIIs). A MII is considered to occur when the motion-induced forces on a standing (or walking) person are large enough to cause one foot to lift off the ground (See D2.2.1).

The MIIs can be calculated in the frequency domain and takes into account the effect of vertical acceleration on the loss-of-balance .

Effects of wind, ship longitudinal acceleration, moment of inertia of the person, and arbitrary facing of the person in the ship-fixed co-ordinate are not taken into account in the present relatively simple safety of footing model.

For passenger vessels the lowest level 0.1 MII/minute or one MII in ten minutes would be adequate. As there seems not to be any more justified criterion for safety of footing the following criterion can be used:

MII value in passenger spaces should not exceed 0.1 / minute
--

#### 4.3.3.3 Noise level prediction

The conventional methods used in the prediction of the noise levels in a space of a ship follow the so-called 'Source-Path-Receiver' approach. This method can be split into the following three steps:

- a. Identification of the noise sources and determination of the corresponding Sound Power Level (PWL). The PWL values for machinery depend on its specific characteristic (like machine type, power, rotational speed, no of blades for a turbine or meshing frequency for a gear box etc.). It is preferable to use measured data if available, but in the absence of them, empirical formulae combining the main characteristics of the noise source and estimating a baseline PWL or Acceleration Level  $L_A$ , may be found in the literature. However, the estimated accuracy of these formulae may vary in a range from  $\pm 3$  db to  $\pm 10$  db, depending on the machine type considered. After this point, the PWL and  $L_A$  are subjected to a conversion, in order to obtain the octave band spectral distributions.
- b. Estimation of the attenuation caused by the path (or paths) from the source to the receiver. Two different types of paths can be distinguished here: the airborne path and the structureborne one.
- c. The final step consists of estimating the Sound Pressure Level (SPL) in the receiver space. This is done by computing the total PWL in the receiver space, considering all the noise sources and all the paths (both airborne and structureborne), and then, by applying the Room constant (R) correction to the computed total PWL in order to obtain the Sound Pressure level in the receiver space.

It must be noted that the method described above suffers from the uncertainties inherent in the prediction of the source PWL, the inaccuracies in the calculations of the airborne and structureborne paths through the complicated metallic structure of the vessel, and finally the inaccuracies in the prediction of the room constant corrections.

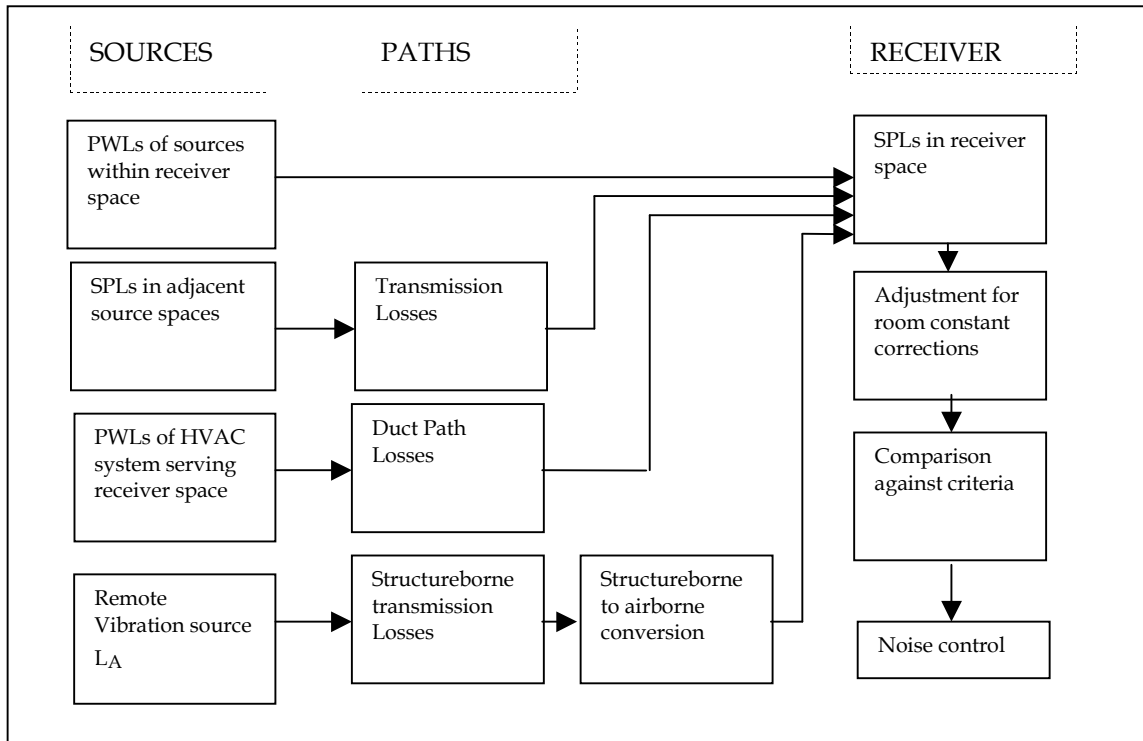


Figure 5 Noise prediction following the Source-Path-Receiver method.

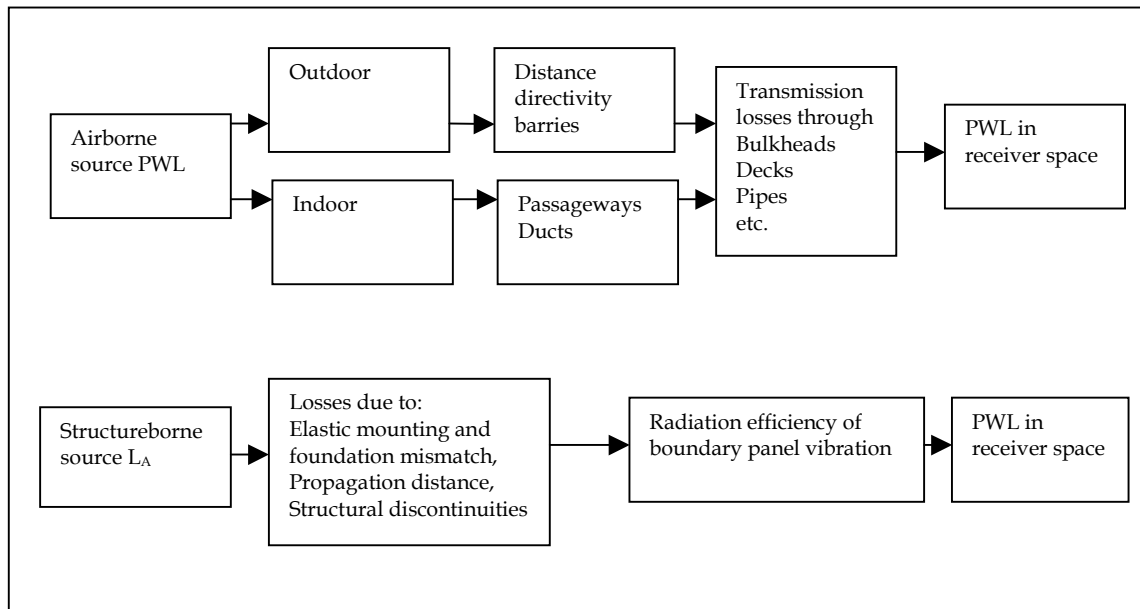


Figure 6 Attenuation factors in airborne to airborne and structureborne to airborne paths.

#### 4.3.3.4 Vibration models

The assessment of the effects of vibration on humans contains the following steps:

- parameters and criteria used in vibration analysis
- measuring and evaluating the whole-body vibration
- vibration limits recommended by the Ship Classification Societies

These are given in D2.2.1.

The prediction of vibrations and vibration excitations are dealt below in three categories:

- prediction of hull girder free vibrations
- prediction of superstructure and local vibrations
- determination of vibration excitations

#### 4.3.3.4.1 Prediction of hull girder free vibrations

The prediction of the vibration levels starts from the analysis of the low frequency free hull girder vibration. The method assumes the hull girder to behave like a floating free-free beam and solves the corresponding equation of dynamic equilibrium for natural frequencies and mode shapes, through the application of the so-called dynamic transfer matrix method.

Since the parameters entering in the dynamic equation of equilibrium equation are not constant along the length of the vessel, and, in addition some of them are not even smooth, presenting strong variations and, even more, discontinuities (like the mass distribution along the ship), a numerical procedure is necessary for the solution. The procedure starts with the division of the hull girder into segments and solves the discrete equivalent of the differential equation of equilibrium using the dynamic transfer matrix method and taking into account the boundary conditions that hold at the ends of the hull girder (free ends).

A similar to the above method of solution consists of assigning the properties of each hull girder segment to a beam finite element, and then, using the standard numerical procedures for extracting the natural frequencies and mode shapes. The hull girder is modelled as a 1D-Timoshenko beam (i.e. the influence of the shear distortions and the rotary inertia of each segment of the hull girder is accounted for). The bending strength of each segment is taken into consideration via the bending modulus, as well as the shear strength, the translational and rotational inertial of each segment and the effect of the surrounded water. The later is computed using the added mass coefficients available from the hydrodynamic analysis of each section through the application of the strip theory.

The calculated frequencies of the free vibrations can then be compared against the running speed of the major excitation sources, or the harmonics of them, and conclusions regarding the risk of resonance and of excessive vibration levels can be drawn.

Both the vertical and the horizontal vibration modes of the hull girder can be calculated by the above method, depending on the data given, which may correspond either to the vertical bending modulus, vertical added mass etc, or to the horizontal counterparts of them.

Due to its simplicity, the procedure can be used during the early stages of the ship design. The one dimensional beam method has been implemented in a software code.

Using the aforementioned beam model, the response of the hull girder in whipping vibrations can be determined, provided that the distribution of the wave loads along the ship are available.

#### 4.3.3.4.2 Prediction of superstructure and local vibrations

More elaborate techniques must be used such as the Finite Element Analysis method, to predict the vibration levels in large parts of the metallic structure of the ship, as well as the prediction of the local panel vibrations.

Numerical simulation analyses are used for both static and dynamics. These analyses are often performed using the same large size model (about 250 000 degrees of freedom for a big passenger vessel). The tools used for such an analysis are not, in most cases, ready to handle in a reasonable resolution time large models in dynamic analysis.

A ship has a slender and long structure with very high modal density in the frequency range of interest (0 - 100 Hz). In fact, ship structures are 3D assemblies of stiffened panels providing a lot of local modes with very close frequency values. Some of those modes are unrealistic due to the local approximations made in modelling for both stiffness and mass distribution and then have to be eliminated. In fact, a ship constitutes a very complex elastic/mass system characterised by strong couplings between the particular sub-systems. In addition, when the dynamic analysis is done the outfitting positions are not well known and the results must be available as soon as possible in order to allow an update of the design to make the vibration levels suitable. Due to the above reasons the FE analysis of the ship structure requires the designer to have a great experience both in modelling and in conducting the analysis.

The number of modes needed to cover the second harmonic of blade frequency is very large if direct analysis is performed (several thousands). This accuracy cannot be obtained at the project stage. For these reasons it is necessary to reduce the number of d.o.f. to be kept to compute a suitable modal spectrum for the structure. The reduction of problem size is possible using condensation methods, but the corresponding computer and modelling time is still often too long regarding ship design.

#### 4.3.3.4.3 Determination of vibration excitations

For a successful prediction of the shipboard vibrations an accurate knowledge of the excitation forces is required. These forces can be split into the following categories:

- propeller induced forces
- main engine excitation
- auxiliary machinery excitation
- wave induced dynamic forces and moments.

The wave induced dynamic forces and moments can be obtained by the models developed into the other WPs (i.e. seakeeping models). These forces may influence only the lower modes of vibration of the hull girder and, from the vibration point of view can be significant only if a relatively flexible hull girder, having its lower frequencies in the range of the wave excitation, is considered.

For the prediction of the main engine and auxiliary machinery excitation, data supplied by the manufacturers, normally obtained through specific vibration measurements, must be used. Since the frequency range of these excitations are relatively high, the prediction of the response of the ship structure can be made only by the elaborate methods previously defined.

For the prediction of the propeller-induced forces, apart from some empirical formulae, there are not any simple methods available. In contrast, very complicated procedures are used for the definition of the propeller excitation, which are based on modern boundary-integral equation formulation of the coupled propeller-hull-rudder unsteady

flow problem including cavitation. There are also available codes for the analytic prediction of the pressure pulses induced by a propeller on hull, rudder and struts; however they present the same range of complexity.

The only alternative possibility for the development of a simple code is to use the empirical formulae and the associated graphs used for rough. However these methods are suitable only for conventional propellers and can't be used for modern propulsion systems like those incorporating waterjets or surface piercing propellers.

#### 4.3.4 Indoor climate model

Apart from personal factors like clothing or individual activity, the main parameters that influence the thermal comfort (as "that condition in mind which expresses satisfaction with the thermal environment", ISO standard 7730:1994) are:

- air temperature,
- radiant temperature,
- air humidity, and
- air velocity.

The Heating, Ventilation and Air Conditioning system of the vessel should control the variations of the aforementioned parameters, in order to ensure the thermal comfort for the crewmembers and the passengers.

The ABS requirements for the Class notation pertinent to the Indoor Climate parameters are listed in the following tables:

<b>Indoor Climate requirements for COMF and COMF+ Class notation</b>	
<b>Parameter</b>	<b>Requirement</b>
Air Temperature	Adjustable range from 18 °C to 26.5°C
Relative Humidity	Min. 30%, Max. 70%
Vertical Gradient	0 to 3°C
Air Velocity	Below 0.5m/sec at the center of the space
Horizontal Gradient (Berthing)	Less than 10°C in cabins

<b>Indoor Climate requirements for HAB and HAB+ Class notation</b>	
<b>Parameter</b>	<b>Requirement</b>
Air Temperature	For HAB notation: Non-adjustable air temperature of 22°C ±1°C For HAB+ notation: Adjustable range from 18 °C to 26.5°C
Relative Humidity	Min. 30%, Max. 70%
Vertical Gradient	0 to 3°C
Air Velocity	Below 0.5m/sec at the center of the space
Horizontal Gradient (Berthing)	Less that 10°C in cabins

#### 4.4 Conclusion and Validation

Work package 2 has formulated basic models concerning hazards related to ship motions with hull design, operational practice parameters and with human factor.

Models related to the ship seakeeping and the dynamic stability (in broaching situation) have been formulated and will be used to derive the risk models. Some of the seakeeping model results will also be used as inputs in WP3 and in the motion sickness and safety of footing models. The acceptable limit values for these two models have been stated on the basis of existing materials including the latest standard.

The hazards related to excessive noise and vibrations, as well as the effect of the parameter of the indoor climate to the comfort of the passengers and the crew have been analysed. Suitable criteria and pertinent limits are presented as a basis for simplified models for the evaluation of the effect of noise, vibration and indoor climate on passenger comfort and crew workability. Several methods for the prediction of noise and vibration levels have also been presented.

These models have been reviewed and validated in the perspective of the integration process. Models like the noise prediction and indoor climate models need further development in co-operation with Fincantieri experts as it was agreed at Genoa meeting. These models have not been validated yet as they were not available to the project consortium at the time of this validation was performed. These models would be described and validated latter in the global risk model.

## 5. WORK PACKAGE 3: FOUNDERING

### 5.1 Objectives

The principal objective is to develop suitable risk/cost model addressing factors relevant to foundering. The hazards that may lead to foundering were initially identified as loading situations that may lead to structural failure, and subsequently to loss of watertight integrity:

- Global structural failure
- Local structural failure
- Structural failure due to fatigue or corrosion.

### 5.2 Methodology

WP3 performed the following thought process in order to develop its model:

- A review of the previous work was carried out. Information available to the risk model consists of the midship section and the loading information consist of the long-term vertical bending moment distribution, corrected to account for non-linear effects such as slamming and whipping.
- The fault tree established in D310 was investigated. It became apparent that reliable estimates could not be obtained for all the basic events. It was proposed that a reliability approach would be able to implicitly include all the basic events identified although their individual probabilities may not be explicitly stated. A new fault tree was then constructed.
- The structural failure is divided into 2 groups. First order where the structural failure is the first event in the failure chain and the second order where an event such as fire, collision or grounding happens first. The probability of 1<sup>st</sup> order failures will be calculated by the reliability approach, and an approximation will be made for the 2<sup>nd</sup> order failure based on consultation with the other WPs.
- The model formulated will calculate the following probabilities based on the information in the midship section and WP2's Weibull load distribution:
  - Global collapse,
  - Collapse of decks, bulkheads and shell plating,
  - Fatigue failure,
  - Local failure.

### 5.3 Formulation of the risk model

WP2 had constructed a global vertical bending moment model, which accounts for slamming & non-linear effects in determining the long-term bending moment distribution at midship. Unfortunately, simplified methods do not yet exist to determine the local pressure loading along the hull of HSC with sufficient accuracy. So the only loading and therefore structural response that could be examined are longitudinal loads & structures.

Regarding to the ultimate strength of the hull girder of a HSC under vertical bending, it is assumed to correspond to the stress at which the compression flange fails, while treating the rest of the hull girder as elastic. This gives the project a method to predict the overall strength of the vessel, which, when combined with the vertical bending

moment prediction tool, gives a fast and simple method to analyse the global strength of the vessel.

The method for determining the compression flange strength is equally applicable to other panels in the hull girder, & this was selected for the local ultimate strength model.

Reliability based fatigue calculator using the hot spot S-N approach had been produced. This model could predict the fatigue reliability of any given structural detail in the vessel.

The local ultimate strength and fatigue models were selected to model local structural damage.

All these individual parts were linked together by focusing on modelling the midship section of the vessel as it is typically the structure that is determined as part of the preliminary design. The basic approach is summarised below:

1. The midship section is discretized into a series of stiffened panels, which are entered into the calculation methodology along with the long-term loading from Workpackage Two. Fatigue detail stress concentration factors are entered for the end connection on each panel, and additional fatigue-prone locations such as expansion joints or hatch cut-outs are specified in terms of their location and stress-concentration factor.
2. The area, moment of inertia, and strength of each panel in the midship section are calculated.
3. The overall moment of inertia of the hull girder is calculated from the individual panels.
4. The safety of each panel in fatigue and ultimate strength are calculated from the section modulus at each panel or detail and the long-term loading.
5. The safety of the overall hull girder is calculated from the strength of the deck in compression, as the loading predictions have shown that the sagging load is the larger of the loads, and the deck panels are lighter than the bottom panels.

So the structural risk is measured by predicting the probability of suffering compressive collapse of individual panels, collapse of the overall hull girder and fatigue cracking of structural details. These simplified methods of determining the local and global compressive strength were developed in a reliability-based approach, which was then coupled with the fatigue reliability approach from Deliverable 3.2.4 to yield a reliability analysis of the midship section. The complete overview of the reliability approach is given in D3.3.0.

These reliability formulations were programmed using first-order reliability principles, to provide a fast method of determining the proposed design's reliability.

Links were then made from the reliability formulations to the new fault tree basic event probabilities and supplemented where required with historical data and expert judgement. Two different methods were used to determine the basic event probabilities. For events that were connected to the reliability, a method was required to go from the safety indexes to basic event probabilities. This approach was taken for the global collapse, local panel collapse, and fatigue failures. For the other events, including local and global collapse from accidental causes, uncontrolled corrosion, local defects, lack of maintenance, and risk-increasing features, probabilities were estimated from previous experience and expert judgement.

For the first group of events it is proposed to use the probability associated with the safety index as the basic event probability. It is recognised that the safety index probability is only an estimate of the actual probability, because of the first-order simplifications in calculating the reliability. However, this estimate is the best estimate currently available. For the local collapse, there are many safety indexes for each proposed design - one for each panel in the proposed midship section. For the purposes of estimating a basic event probability, a first failure approach was taken, in which the probability of the weakest panel in the midship section failing was taken as the probability of local collapse. As for the fatigue failure probability, it is defined as the summation of all of the individual probabilities of fatigue failure at all details locations.

## 5.4 Conclusion and Validation

The structural foundering approach analyses the midship section of a proposed design using reliability-based risk indices. Parameters and calculation methodologies used in the approach are compatible with the preliminary design focus of the project. First order reliability calculations, historical data, and expert judgement were used to link the risk indices to basic event probabilities in the structural foundering fault tree. These models have been reviewed and validated in the perspective of the integration process.

## 6. WORK PACKAGE 4: CONTAINMENT OF DAMAGE

### 6.1 Objectives

The principal objective of WP4 is to develop models for the analysis and assessment of risk relevant to the containment of damage and fire during HSC operation, suitable for the application at the early stages of the design. For damage resistance, emphasis will be made on flooding aspects. The effects of the human factor, passive design systems and active design systems will be developed inside the different models.

### 6.2 Methodology

The derivation of models suitable for the application during the early stages of the design process involved the following steps:

- identification of the design parameters relevant to each of the above mentioned systems,
- development of models based on first principle tools and applicable regulations,
- representation of the process involved into suitable risk analysis constructs. In this respect, event trees have been developed since the work is focused in the identification of the outcomes of any relevant potential incident.

### 6.3 Formulation of the risk model

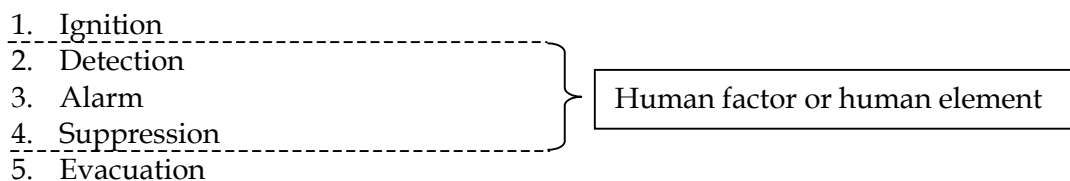
Two main models were formulated:

- risk model for the containment of damage,
- risk model for the containment of fire.

Nevertheless we also detailed here the model related to the human factor, as it is a different way of thinking and as it is part of the other models.

#### 6.3.1 Risk model for the effect of the human factor

The risk model is based on a general description of a fire accident scenario (in five stages) from which the stages of detection, alarm and suppression are taken into consideration in relation to human factors.



The model is further based on a simplified model of human cognition and behaviour, a list of performance shaping factors and a set of parameters for intervention. The risk model described above is equivalent to the model in WP1, and it shares the same simplified model of human cognition and behaviour, the same list of performance shaping factors and the same set of parameters for intervention. See 3.3.3

##### 6.3.1.1 Simplified Model of human cognition & behaviour

The model of human cognition and behaviour relies on the underlying assumption, that the human being acts as an information processing unit – a black box – which is working in interaction with a surrounding environment from which it receives

information (input) and to which it deliver information back (output) after internal processing of the information. This assumption is inspired by early computer science.

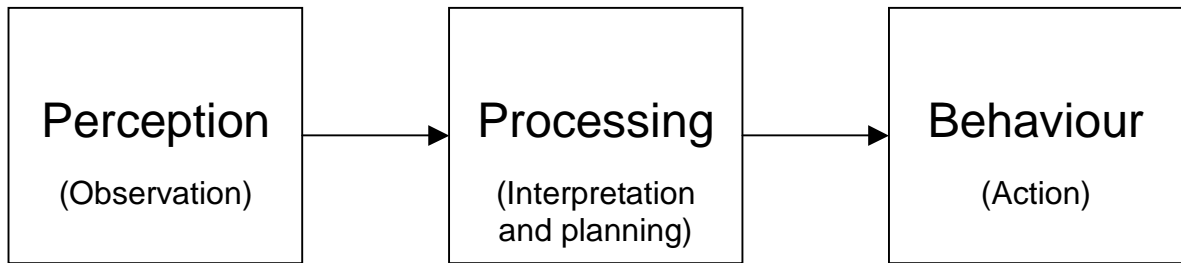


Figure 2: The simple information processing model adapted to the domain of psychology (Hollnagel & Cacciabue, 1991).

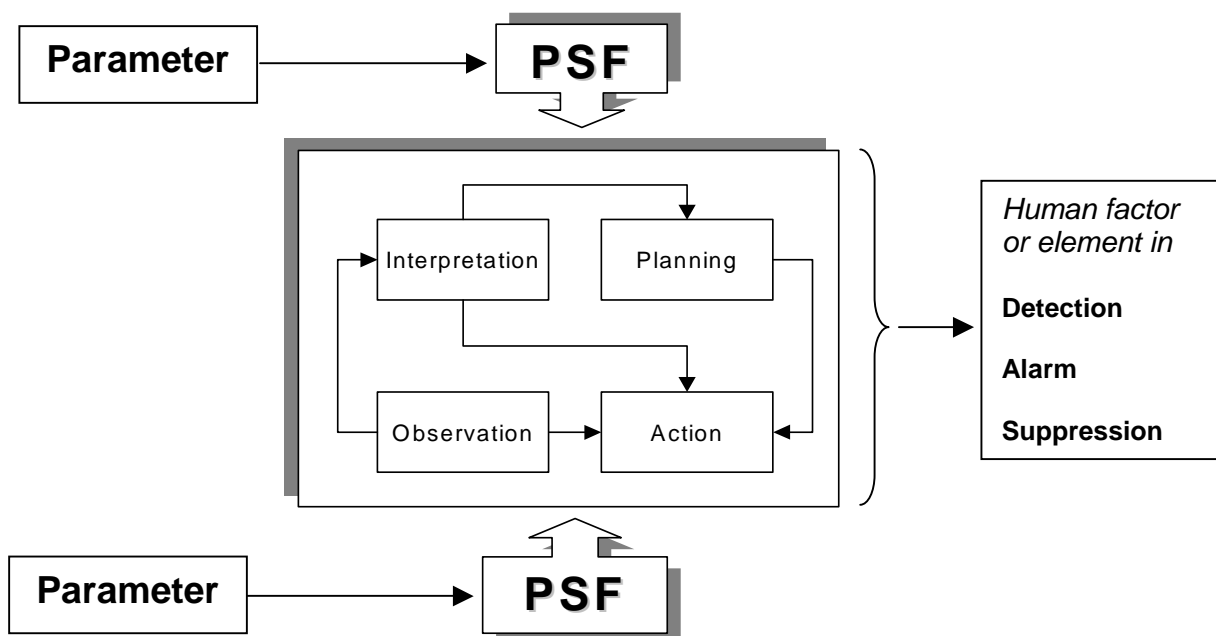
### 6.3.1.2 Parameters

Parameters can be organised in two groups: Design parameters and operational parameters. Design parameters are related to the design of the vessel and the equipment including means for communication, alarm panels etc. Operational parameters are related to the way the vessel is run and managed including procedures, plans, checklists, crew training and experience etc.

Any change in parameters will therefore – through the performance shaping factors and the human observation, interpretation, planning and action – have an effect on the level of risk related to the human contribution to the stages of detection, alarm and suppression in a fire outbreak (see [Figure 3](#)). This effect – the change in level of risk – might be very small and impossible to measure or it might be significant and easy to measure.

The causality in this model is extremely complex, it relies on significant interpersonal and intra-personal variations, and the number of possible combinations of parameters and performance shaping factors is huge. It is clearly not a deterministic system, and application of deterministic models and calculations are therefore totally meaningless.

Figure 3: The model for the effect of the human factor on detection



However, it is possible – by means of expert judgements – to make qualitative estimations. These estimations should – according to the complexity of the system – be limited to the detail of positive or negative outcome, and perhaps – if the empirical material is able to support it some graduation ranging from for example slightly positive/negative through moderately positive/negative to very positive/negative.

### 6.3.2 Risk model for the containment of damage

The formulation of this model involved the following elements:

1. Estimation of the frequency of incidents, which have flooding after damage as their potential outcome;
2. Estimation of the consequences following flooding;
3. Estimation of the resulting risk level;
4. Assessment of the effect of possible means for containment of damage, using the tools above;
5. Identification of the design parameters relevant to subdivision;

As primary initiating events for incidents with potential to lead to large scale flooding the following are considered: collision; grounding; impact; structural failure of bow or stern door; mechanical failure of watertight barriers; and operational safety management systems failure / human error.

The model mainly deals with incidents relating to collision, grounding and impacts. The effect of the human factors has been dealt with in the previous section.

For the remaining two foreseeable initiating events, a fault tree and event tree are proposed for the former (see D4.3.0), while for the latter there is no historical data available. Developments in these areas are still on-going and in this respect, results based on first principles are not available.

#### 6.3.2.1 Evaluation of the frequencies

Estimation of the frequency and detailed breakdown of the resulting chain of events is required for collision, grounding and impact incidents. Other WP will provide estimation of the overall frequency of incidents. Generic event trees have been performed to represent the possible outcomes (See D4.20).

#### 6.3.2.2 Evaluation of consequences

The consequences of the accident will be expressed as a number of fatalities. Of the list of potential outcomes, some have been considered to be fatal. Based on experience with accidents occurred a generic figure on the percentage of fatalities that each outcomes could result to, can be derived.

#### 6.3.2.3 First principles tools for damage survivability

The probability of survival can be defined as the probability of the significant wave height  $H_s$ , calculated for a given damage condition, not exceeding a predetermined significant wave height  $H_{s90}$  that characterises the area of operation of the vessel, i.e.

$$P_{survival} = P [H_s < H_{s90}]$$

Accordingly, the probability of capsize, which includes every accident that may occur (for example, slow sinking or rapid capsize), is determined as:

$$P_{\text{capsize}} = P [H_s \geq H_{s90}] = 1 - P_{\text{survival}}$$

Adopting the formulation of the Static Equivalent Method (See D4.2.0) as the means for the calculation, it should be noted that since the calculated height of water on deck for a given damage condition depends on every design parameter and their interrelations (principal dimensions and ratios, subdivision, car deck arrangement etc.), any uncertainty that is determined as influential can be examined through this very calculation, which in turn leads to the determination of the probability of survival.

For the calculation of the branch probabilities, the following approach is proposed:

- The probability of survival  $s_i$  of any given damage case is considered to be the product of factor  $s_a$ , which reflects the survival probability, with factor  $s_w$ , which reflects the survival probability in the event of large scale flooding on the main vehicle deck due to wave action.
- The factor  $s_a$  can be used as the branch probability for the scenario where the struck vessel remains afloat after flooding, whilst its complementary probability  $(1-s_a)$  can be used for the binary event of this scenario (struck vessel sinks after flooding).
- The Static Equivalent Method, as proposed to be used within a Monte Carlo simulations framework, can be utilised to calculate the branch probabilities for the final outcomes of a vessel sinking after flooding has occurred. The resulting factor  $s_w$  can be used as the branch probability for the scenario where slow sinking following flooding occurs, whilst its complementary probability  $(1-s_w)$  is assigned to its binary event (rapid capsize following flooding).
- In order to take into account the probability of extent and location of damage the the factor  $p_i$  is used, as shown in [Figure 4](#).
- In the case of HSC, these distributions are not applicable, mainly due to the much greater extent of damage that is expected. In this respect, the extents of damage defined in the relevant parts of the HSC Code will be applied in this project.
- The assumption that factor  $s_w$  takes unity value in case the vessel remains afloat is reflected by the formulation proposed in [Figure 4](#). The overall formulation can be considered in a cumulative sense, i.e. including every possible damage case.

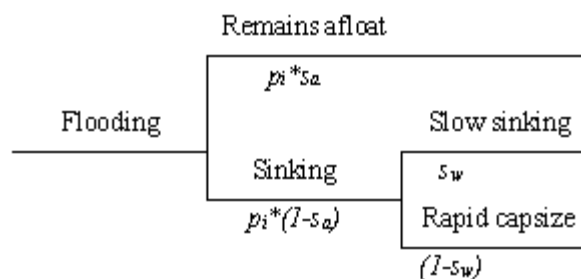


Figure 4 Event Tree for Struck Ship, Flooding Occurring

### 6.3.3 Risk Model for the containment of fire

The fire protection measures within a building or a ship can be broken down into passive and active systems. Figure 5 illustrates the sequence of events and the relationship between fire, passive systems, active systems and the evacuation of occupants.

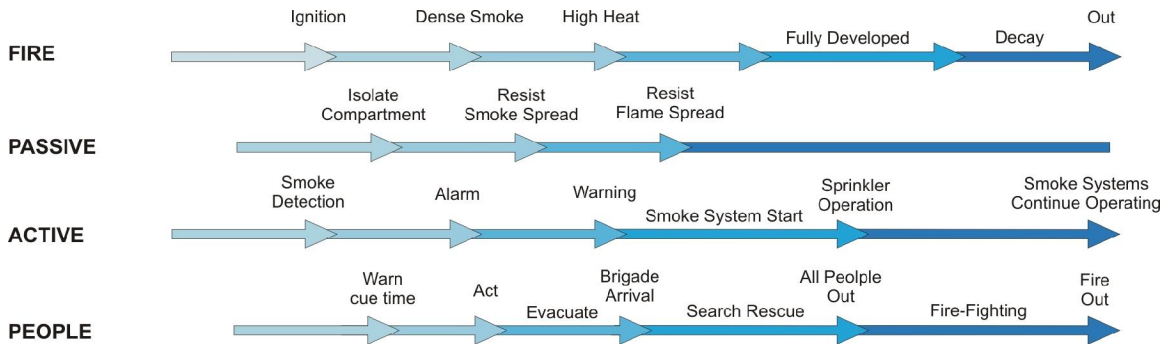


Figure 5 Relationship between Fire, Passive Systems, Active Systems and People

Passive systems are the permanent fixtures such as fire rated floors, ceiling, walls, fire isolated exits.

Active systems are services and equipment such as exit signs, emergency lighting, hydrants, hose-reels, smoke control, sprinklers, smoke and heat detectors, voice alarms and fire indicator panels.

During the design of a ship, the efforts have to be led in two different directions:

- to reduce the risk of fire outbreak;
- to reduce its propagation if it does break out.

Both active design systems and passive design systems contribute in achieving it.

#### 6.3.3.1 Effect of passive system

Fire Risk Analysis methodology consists of the following four steps:

- **Step 1:** Analysis of Requirements;
- **Step 2:** Definition of Parameters and Variables;
- **Step 3:** Analysis of Parameters;
- **Step 4:** Fire Event Trees.

##### 6.3.3.1.1 Definition of parameters and variables

The analysis of HSC Code requirements has led to the identification of following parameters:

- “Fire-Resisting Division” (FRD);
- “Non-Combustible Materials” (NCM);
- “Fire-Restricting Materials” (FRM).

Each parameter can be defined through a set of variables (1<sup>st</sup> order variables) that, in their turn, can be further detailed through a second set of variables (2<sup>nd</sup> order variables).

The identified parameters represent the gates of the fire event tree. The state of the parameters/gates (P<sub>1</sub> or P<sub>2</sub>/Y or N) is determined by relationships with the states of 1<sup>st</sup> or 2<sup>nd</sup> order variables.

Table 7 reports the relationships between each parameter and 1<sup>st</sup> order variables and between 1<sup>st</sup> and 2<sup>nd</sup> order variables.

Parameters and variables are related either to fire-resisting divisions or to restricted use of non-combustible materials.

**Table 7 Parameters and Variables related to Passive Systems**

PARAMETERS/GATES	VARIABLES	
	1 <sup>st</sup> Order	2 <sup>nd</sup> Order
Fire-Resisting Divisions (FRD)	Stability (R)	-
	Integrity (E)	-
	Insulation (I)	-
	Production of Smoke (PS)	-
Non-Combustible Materials (NCM) / Fire-Restricting Materials (FRM)	Quantity of Fire-Restricting Materials (QFRM) / Quantity of Non-Combustible Materials (QNCM)	Separating Divisions, Ceiling, Lining and draught stops (QDCL)
		All case furniture and all other furniture (chairs, sofas and tables) (QF)
		Any thermal and acoustic insulation (QTAI)
	Resistance to the Propagation of Flame (RPF)	After flame time for any of the ten or more specimens tested with surface application of the pilot flame (FT)
		Number of specimen tested with surface application of the pilot flame in which burn through to any edge (B)
		Number of specimen in which there is ignition of cotton wool below the specimen (IG)
	Resistance to the Ignition and Propagation of Flame (RIPF)	Time to develop Smouldering Fire or Flames (TSFF)
		Time after Ignition Flame Removed" (TIFR)
	Quantity of Smoke and Toxic Product (QSTP)	Optical Density of Smoke (ODS)
		Concentration of Toxic Products (CTP)

Through the dependencies between parameters/gates and variables, it is possible to link what the designer can control during the design stage, i.e. parameters, to the outcome of unfavourable combinations of events, i.e. the outbreak of a fire event.

These dependencies are expressed as a combination of deterministic and probabilistic relationships between design parameters and the gates, whose formulation is based on the following assumptions:

- Each parameter has a limited number of possible range values (2 at most).
- Each parameter can be related to a limited number 1<sup>st</sup> order variables (3 at most);
- Each variable also has a limited number of possible states (3 at most). This means, for instance, that the sub-parameter "Quantity of Furniture (QF)" can vary between the 0% and 50%; another example can be "Flame Time (FT)" that can be from 2.5 seconds to 5.0 seconds;

- Whenever a 1<sup>st</sup> order variable needs to be defined through a second set of variables, this variable can only have 3 states at most and be related to 3 variables at most. Alike parameters, these variables can only have 3 states at most and each one can be related to other 3 variables at most, with 3 possible states only, and so on.
- Relationships between parameters and 1<sup>st</sup> order variables and between 1<sup>st</sup> and 2<sup>nd</sup> order variables are deterministic. This means that the state of a parameter or of a 1<sup>st</sup> order variable is determined respectively by “yes-or-no” (i.e., Boolean) relationships with the states of 1<sup>st</sup> or 2<sup>nd</sup> order variables.
- The relationships have been formulated through matrices.

#### 6.3.3.1.2 Analysis of parameters

The scope of this analysis is to identify the set of variables that are in relationship with the parameters and that determine the states of identified parameters.

“Fire-Resisting Divisions” (FRD) parameter for instance represents the characteristics of fire resistance of construction and therefore the ability of bulkheads and decks to perform their structural fire protection function for a certain period of time.

The role of structural fire protection can be expressed by one or more of the following fire safety objectives:

- provide *sufficient* time for occupants to reach an area of safety or to escape;
- support the fire separations necessary to control the size of the fire and prevent conflagration;
- minimise potential damage to adjacent properties.

The states of the FRD parameter (FRD<sub>1</sub> or FRD<sub>2</sub>) are determined by the states of the following 1<sup>st</sup> order variables:

- “Stability or load bearing” (R) (avoidance of structural collapse or unacceptable deformation);
- “Integrity” (E) (avoidance of cracks and fissures);
- “Insulation” (I) (restriction on temperature of unexposed face).

In this case, 2<sup>nd</sup> order variables are not needed.

The minimum level of safety corresponds to the minimum fire resistance period required for fire resisting divisions according to [Table 8Table 8](#).

[Table 9Table 9](#) presents an example of the possible states of the variables that determine the states of the FRD parameter and the range values of each variable.

**Table 8 States of FRD parameter and related 1st order variables**

PARAMETER	VARIABLES	STATES	RANGE VALUES
Fire-Resisting Divisions (FRD)	Stability (R)	R <sub>1</sub>	As for requirements
		R <sub>2</sub>	As for requirements+ 15 min
		R <sub>3</sub>	As for requirements+ 30 min
	Integrity (E)	E <sub>1</sub>	Low
		E <sub>2</sub>	High
	Insulation (I)	I <sub>1</sub>	Low
		I <sub>2</sub>	High
	Production of Smoke (PS)	PS <sub>1</sub>	Low
PS <sub>2</sub>		High	

Table 9 Relationships between FRD parameter and 1st order variables

		R <sub>1</sub>				R <sub>2</sub>				R <sub>3</sub>			
		E <sub>1</sub>		E <sub>2</sub>		E <sub>1</sub>		E <sub>2</sub>		E <sub>1</sub>		E <sub>2</sub>	
		I <sub>1</sub>	I <sub>2</sub>	I <sub>1</sub>	I <sub>2</sub>	I <sub>1</sub>	I <sub>2</sub>	I <sub>1</sub>	I <sub>2</sub>	I <sub>1</sub>	I <sub>2</sub>	I <sub>1</sub>	I <sub>2</sub>
FRD	FRD <sub>1</sub>												
	FRD <sub>2</sub>												

6.3.3.1.3 Fire event Tree

Step 4 consists of the identification of gates of the event tree related to the passive systems. The identifications of gates has been achieved through the identification and the analysis of parameters and variables.

It can be assumed that the gates of the event tree coincide with parameters.

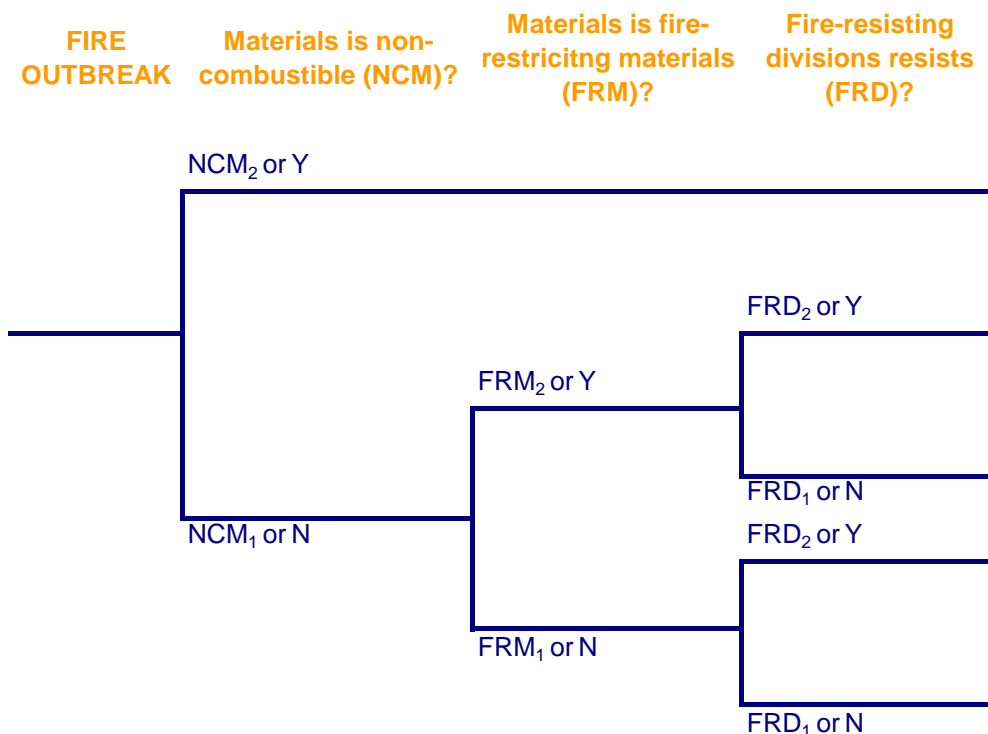
The following parameters have been identified:

- "Fire-Resisting Divisions" (FRD);
- "Fire-Restricting Materials" (FRM);
- "Non-Combustible Materials" (NCM).

Each parameter can have only two states (i.e.FRD<sub>1</sub> or FRD<sub>2</sub>) and each gate of the event tree has two branches; this means that each state correspond to one branch of the gates (Y or N). The state of the parameter and therefore the branch of the gate, is determined by the state of 1<sup>st</sup> and 2<sup>nd</sup> variables.

A generic and qualitative fire event tree focused on passive design systems is presented [Figure 6](#).

Figure 6 Qualitative Event tree- Passive Systems



### 6.3.3.2 Effect of active system

The main aim of this exercise was to identify the parameters and variables associated with active systems that are used in the detection and fighting of fires with the aim of developing a generic event tree fire.

The methodology used to construct the risk model for active systems associated with fire is identical to that previously stated. An example of parameter and associated variables for active systems is presented below:

**Table 10 Smoke Detectors and Associated Variables**

PARAMETER	VARIABLES	STATES	RANGE VALUES
Smoke detectors (SD)	Installation Requirements: distance from bulkhead	DB <sub>1</sub>	0.5m - 2.5m
		DB <sub>2</sub>	2.5m - 3.5m
		DB <sub>3</sub>	3.5m - 5.5m
	Floor area per detector	FA <sub>1</sub>	0 - 30m <sup>2</sup>
		FA <sub>2</sub>	30m <sup>2</sup> - 50m <sup>2</sup>
		FA <sub>3</sub>	50m <sup>2</sup> - 74m <sup>2</sup>
	Distance apart between centres	DA <sub>1</sub>	3m - 7m
		DA <sub>2</sub>	7m - 11m
	Time to operate versus smoke density	T <sub>1</sub>	2 - 7.25%
		T <sub>2</sub>	7.25 - 12.5%

Passive systems as well as human factors were automatically embedded in the event tree that was developed. By this we mean that the tree given is the global event tree for the outbreak of fire anywhere in the ship. It takes into account all systems whether they are active, human or passive. However, there are sub-trees and models associated with human factors and passive systems that feed into the event tree to help resolve some of the gates.

## 6.4 Conclusion and Validation

Risk models for the containment of damage and fire in the respect of human factors and of relevant passive and active systems have been developed. The chains of events following fire and incidental events have been modelled through event trees. The fire event tree embeds both the effects of human factor, passive and active systems. These models have been reviewed and validated in the perspective of the integration process.

## 7. CONCLUSION OF THE TASK

Models, which didn't fit the preliminary design stage requirement, were discarded by the work packages. Models that still need some work to be completed would be directly refined in the next WPs' task "Implementation of model". Nevertheless for the time being, all the work packages have formulated suitable risk model for high-speed craft in order to be implemented in the risk-based design methodology.

As these models have been well developed separately. The next important step of the project will be the integration of these individual models in order to develop the global risk model into the project tool. We may therefore assume that the integration process will require some refinement or modification of the Work packages' models.

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## 8. REFERENCES

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