Safety at Speed - S@S

FORMULATION OF MODELS
CONTAINMENT OF DAMAGE AND FIRE
DELIVERABLE NO. D4.2.0

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AUTHORS:

Name	Date	Signature
Dimitris Konovessis	*2002-12-23*	

Note: The production of this report has been a joint effort of Elisabetta Noce and Mauro Pedrali of D' Appolonia, Jeppe Skobakke Huhl of FORCE Technology - DMI, Jon McGregor of University of Newcastle and Dimitris Konovessis of SSRC.

APPROVAL:

Approved for release by:

Name	Date	Signature
Dracos Vassalos	*2002-12-23*	

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CONTENTS

1. EXECUTIVE SUMMARY SUITABLE FOR PUBLICATION

Task 4.2 of the project aims at the development of models for the analysis and assessment of risks relevant to HSC damage and fire resistance. Following the work undertaken in Task 4.1 on the identification of the main means for containment of damage and fire, work in this task has primarily focused on the derivation of models suitable for application during the early stages of the design process (conceptual and early preliminary design).

Models relevant to the effect of the human factor, passive design systems and active design systems have been developed. The approach adopted involves the identification of the design parameters relevant to each of the above mentioned systems, the development of the models based on first-principles tools and applicable regulations, as well as representation of the processes involved into suitable risk analysis constructs. In this respect, event trees have been developed since the work was focusing on the identification of the outcomes (consequences) of any relevant potential incident.

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2. INTRODUCTION

Task 4.2 aims to develop models for assessing HSC damage and fire resistance related to the human factor, passive design systems and active design systems. Task 4.2 consists of three subtasks:

- Subtask 4.2.1: The human factor as the means for containment of damage and fire;
- Subtask 4.2.2: Passive design systems as the means for containment of damage and fire; and
- Subtask 4.2.3: Active design systems as the means for containment of damage and fire.

The principal objective is to develop models for the analysis and assessment of risk relevant to the containment of damage and fire during HSC operation, suitable for application at the early stages of design. Following a brief description of the work undertaken in the next section of the report, the developed risk models are detailed. Taking into account the project-wide on-going considerations on the cost models to be developed and applied, some initial information of the cost models in some of the areas concerned in this work package are also presented in this report, before drawing conclusions. The last part of the report is a series of appendices that include technical elements of the work undertaken.

In accordance with the Technical Annex (Annex I) of the CEC Contract of the project, this document represents a consolidated edition of the four deliverables of Task 4.2. The work has been performed by the partners specified in the Technical Annex, namely by DMI FORCE Technology (derivation of models relevant to the effect of the human factor), SSRC (derivation of models relevant to passive systems as means of containment of damage), DAP (derivation of models relevant to passive systems as means of containment of fire) and UNEW (derivation of models relevant to active systems).

3. DESCRIPTION OF WORK

The objective of the work related to the human factor as a mean for containment of fire is to develop and validate procedures for assessing HSC fire survivability by means of a suitable risk/cost model. The risk model is based on a general description of a fire accident scenario 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 which is generic and widely quoted in the literature, a list of performance shaping factors and a set of parameters for intervention. The cost model is based on estimations made by experts of the cost of each element in the set of parameters. The risk/cost 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.

The objective of the work related to damage resistance is to develop and validate procedures for assessing HSC damage survivability, to be assessed through advanced simulation tools, and to feed this information in appropriate formats for application in design. The development takes the form of a suitable risk/cost model with the view to offer to capability of investigating the effects on damaged survivability of varying parameters such as size, freeboard, level of subdivision, location and extent of damage etc. while accounting for the risk associated with structural integrity of HSC following collision and grounding by mainly taking input from Work Package 1.

A Fire Risk Analysis (FRA) methodology that can be used by designers in the early design phase of HSC is presented in this report. The fire development depends on active systems and passive systems on board ships and therefore the FRA methodology will be applied to both systems.

The FRA methodology developed is firstly presented focusing on passive design systems: this means that only the parameters that influence the passive systems have been analysed. At the moment, a general and qualitative approach has been followed in the definition and analysis of the parameters. The FRA methodology is focused on the definition of a preliminary and qualitative fire event tree.

Analysis of active systems is conducted in a qualitative manner. Sensitivities where then examined using the FMECA process and by the use of incident reports. This enabled the work to be focused on systems that where deemed to be safety critical. Event and fault trees where then developed to act as a framework for the risk model. From this the area of interest was further refined in accordance with budgetary constraints. In combination with the subtask leaders from 4.2.1 and 4.2.2.b a risk model was then developed which allows for the considerable interaction and uncertainty involved in the systems of interest.

4. FORMULATION OF RISK MODELS

4.1 Risk Model for the Effect of the Human Factor

A fire accident scenario on board a HSC develops over time. The development can be described in five stages:

1. Ignition
2. Detection
3. Alarm
4. Suppression
5. Evacuation

Human factor or human element

The human factor is or can be involved in all five stages, but this chapter will only focus on the human factor in relation to the stages detection, alarm and suppression.

A risk model for the effect of the human factor on detection, alarm and suppression should be based on the following elements:

1. A simplified model of human cognition and behaviour - SMoC (Hollnagel & Cacciabue, 1991)
2. Performance shaping factors (PSF)
3. Parameters for intervention

These elements will be described in detail in the following sections of this chapter. In the final section of the chapter an explanation is given on how these elements should be integrated and used together to form a risk model for the effect of the human factor.

4.1.1 The simplified model of human cognition and behaviour - SMoC

Human cognition and human behaviour is complex. Often it is not deterministic, but rather unpredictable. The human element in an accident scenario of fire can therefore not be explained or calculated in formulas. It is however possible to make relatively simple models of human cognition and human behaviour to be used in attempts to explain and predict human activity. One important scientific tradition is – when it comes to this type of models – the tradition of cognitive science and information processing theory. The model of human cognition and behaviour from this tradition 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.

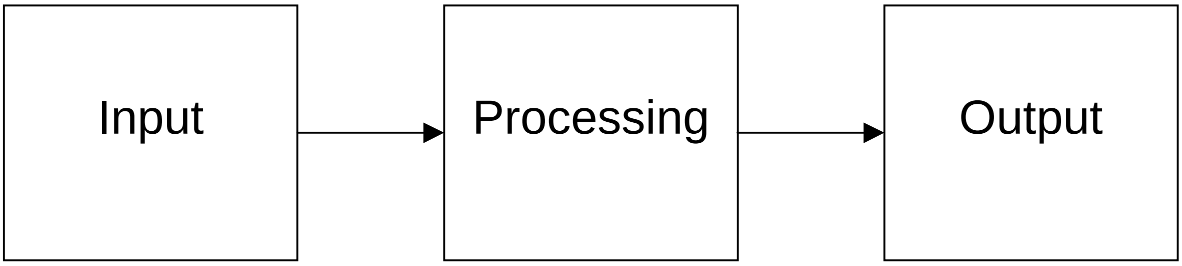

Figure 4.1.1: The simple information processing model

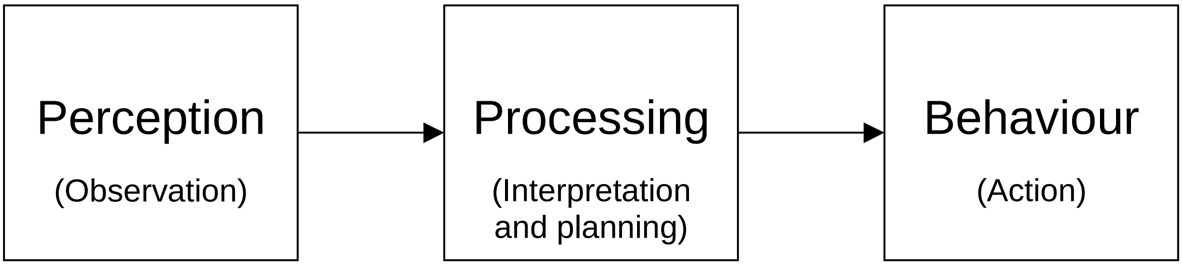

Figure 4.1.2: The simple information processing model adapted to the domain of psychology (Hollnagel & Cacciabue, 1991).

4.1.2 Performance Shaping Factors - PSF

A performance-shaping factor can be defined as a psychological condition either internal in the individual person (e.g. crewmember) or external in the inter-personal interaction between the individual person (e.g. crewmember) and other people (L-L). This condition can also be in the interaction with written material, guidelines, manuals, procedures, checklists etc. (L-S), in the interaction with the vessels and its equipment (L-H), or in the interaction with the surrounding environment (L-E) affecting the human performance (Figure 4.1.3).

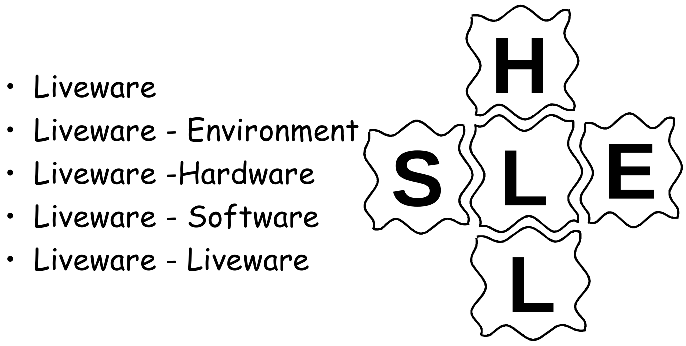

Figure 4.1.3: SHEL model. Edwards (1972), Hawkins (1987).

The condition can be permanent or temporary, and the way it affects the human performance rely on individual differences. The human performance is relatively 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.

A performance-shaping factor is very often an aggregated construct of several quantifiable sub-factors. A complete list of performance shaping factors and sub-factors is found in Appendix A. 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 (Hollnagel & Cacciabue, 1991) is illustrated in Figure 4.1.4. Performance shaping factors has – according to this model – impact on observation, interpretation, planning and action. The result is inadequate performance, human error etc.

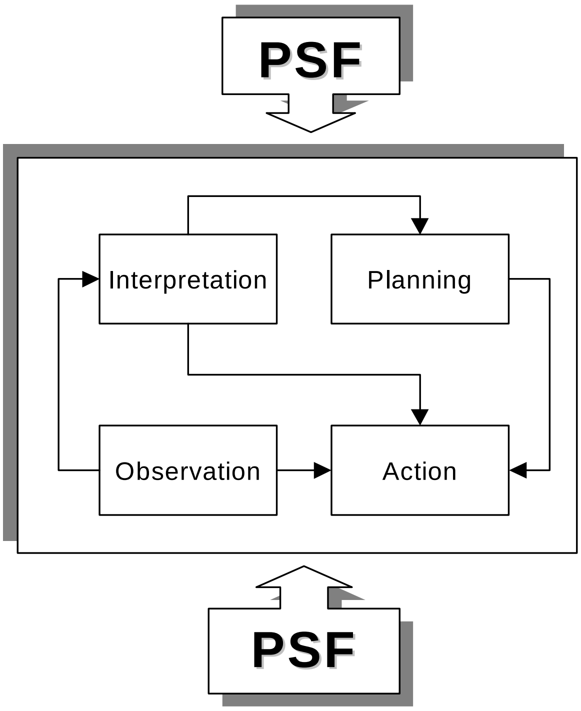

Figure 4.1.4: The relationship between PSF's and the simplified model of human cognition and behaviour.

4.1.3 Parameters for intervention

Parameters for intervention can be organized 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.

Examples of design and operational parameters related to the human factors are given in the table below. It is possible to divide a parameter into sub-parameters to ensure proper level of detail for future attempts of quantification.

Parameter	**Sub-parameters**	**Nominal value**	**Ordinal value**
Training and education of Crew	Amount of training and education	None	0
		Little	1
		Medium	2
		High	3
		Very high	4

Parameter	Sub-parameters	Nominal value	Ordinal value
	Overall quality of training and education	Very low Low Medium High Very high	0 1 2 3 4
Selection of crew – qualifications	Number of well spoken working languages on board	Only one Two or more	4 0
	Amount of experience	None Little Medium High Very high	0 1 2 3 4
	Amount of training and education	None Little Medium High Very high	0 1 2 3 4
	Overall quality of training and education	Very low Low Medium High Very high	0 1 2 3 4
Selection of crew – personality and attitudes	Amount of bridge discipline	Very low Low Medium High Very high	0 1 2 3 4
	Ability to cope with operational pressures	Very low Low Medium High Very high	0 1 2 3 4
	Ability to cope with boredom (e.g. due to routine work)	Very low Low Medium High Very high	0 1 2 3 4
	Amount of concern about safety	Very low Low Medium High Very high	0 1 2 3 4
	Amount of risk taking attitude	Very low Low Medium High Very high	4 3 2 1 0
	Level of confidence (in self, others, automation/technology)	Very low Low Medium High Very high	0 2 4 2 0
	Level of exposure to domestic issues	Very low Low Medium High Very high	4 3 2 1 0

Parameter	Sub-parameters	Nominal value	Ordinal value
Selection of crew – medical and physical condition	Level of overall medical and physical condition	Very poor	0
		Poor	1
		Medium	2
		Good	3
		Very good	4
Operation and procedures	Amount of daily time and/or scheduling pressure	Very low	2
		Low	3
		Medium	4
		High	2
		Very high	0
	Amount of commercial and/or organizational pressure	Very low	2
		Low	3
		Medium	4
		High	2
		Very high	0
	Amount of individual workload in the daily routine work	Very low	2
		Low	3
		Medium	4
		High	2
		Very high	0
	Amount of especially demanding planned situations (e.g. fire drills)	Less than 1/month	0
		1-3/month	2
		1-2/week	4
		3-6/week	2
		1 or more/day	0
	Amount of resources for maintenance, repair, retrofit, new equipment etc.	Very low	0
		Low	1
		Medium	2
		High	3
		Very high	4
Safety culture	Level of overall safety culture on board	Very low	0
		Low	1
		Medium	2
		High	3
		Very high	4
	Level of overall safety culture in company/land organization	Very low	0
		Low	1
		Medium	2
		High	3
		Very high	4
Company practice	Overall quality of working terms and conditions – long term (vacation, salary, promotion possibilities etc.)	Very low	0
		Low	1
		Medium	2
		High	3
		Very high	4
	Overall quality of working terms and conditions – daily basis (working hours, rest periods, working environment, accommodation etc.)	Very low	0
		Low	1
		Medium	2
		High	3
		Very high	4
Bridge discipline	Level to which extend bridge discipline is regulated by procedures and/or practice	Very low	0
		Low	2
		Medium	4
		High	4
		Very high	2

Parameter	**Sub-parameters**	**Nominal value**	**Ordinal value**
Design of equipment and means for navigation	Level of automation	Very low Low Medium High Very high	0 2 4 4 2
	Level of transparency	Very low Low Medium High Very high	0 1 2 3 4
HMI principles	Overall quality of interaction design and ergonomics	Very low Low Medium High Very high	0 1 2 3 4
User's manual	Availability of user manuals	None Little Medium High Very high	0 1 2 3 4
	Overall quality of user manuals	Very poor Poor Medium Good Very good	0 1 2 3 4
Means for communication	Availability of means for communication	None Little Medium High Very high	0 1 2 3 4
	Overall quality of means for communication	Very poor Poor Medium Good Very good	0 1 2 3 4
Procedures for communication	Level to which extend onboard communication is regulated by procedures and/or practice	Very low Low Medium High Very high	0 2 4 4 2

4.1.4 Risk model for the effect of the human factor on detection, alarm and suppression

The single elements in the model for the effect of the human factor on detection, alarm and suppression are now outlined: The simple model of human cognition and behaviour, performance shaping factors and parameters for intervention.

Any change in the parameters will induce variation in the configuration of performance shaping factors, which again will result in variation in the human cognition and behaviour. These behavioural variations will have an effect on the detection, alarm and suppression stage of a fire in the extend these stages rely on human observation, interpretation, planning and action (see Figure 4.1.5). 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. 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.

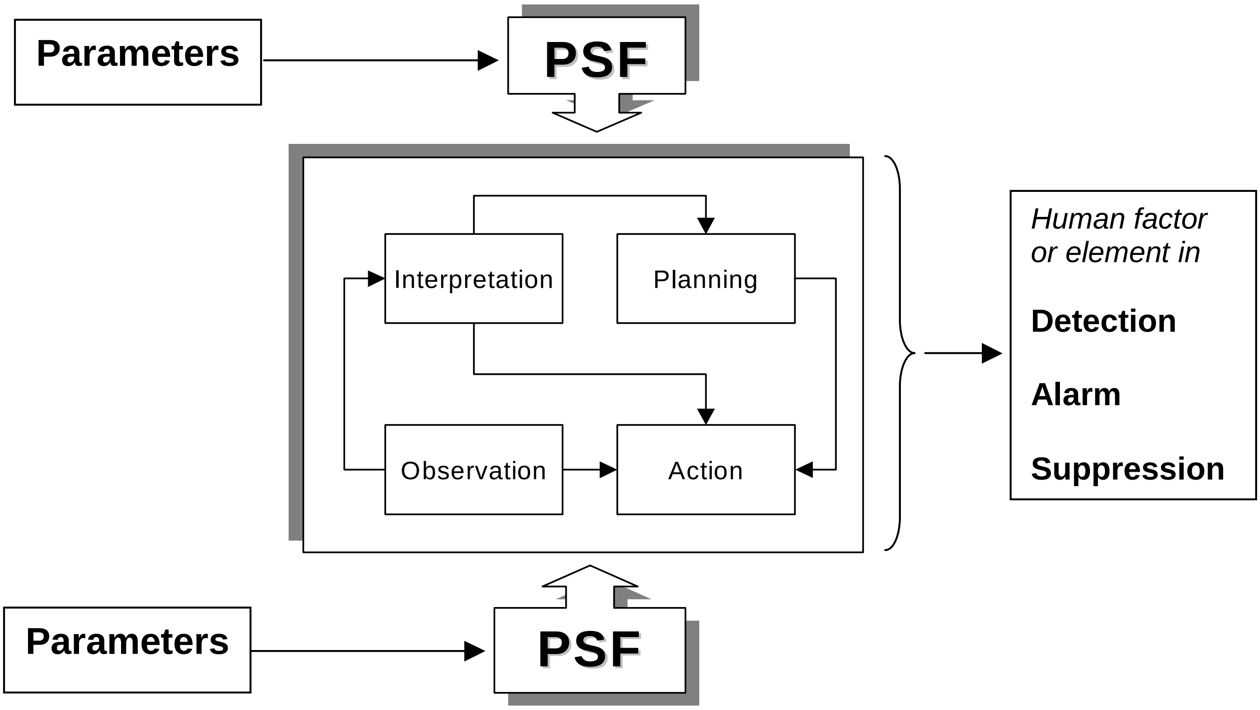

Figure 4.1.5: The model for the effect of the human factor on detection, alarm and suppression

However, it is possible – by means of expert judgements – to make qualitative estimations on the effect of the human factor on detection, alarm and suppression given some variations in parameters and performance shaping factors. 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.

4.2 Risk Model for the Containment of Damage

The various elements, and their interrelations, of a risk model appropriate for containment of damage during high-speed craft operation are described in this part of the report. The focus is on the applicability of the model during the design process. Models and methods for the utilisation of the model are given, as well as required input for the full implementation of the model is identified.

The model comprise of the following elements:

1. Models and methods for the estimation of the frequency of incidents, which have flooding after damage as their potential outcome;
2. Models and methods for the 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;
6. Cost-effectiveness analysis of the effects of possible means.

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 to be presented in this section of the report mainly deals with incidents relating to collision, grounding and impacts. The effect of the human factors has been dealt with in the previous section (4.1), whilst analysis for the remaining two foreseeable initiating events requires further elaboration based on the outcome of relevant work being carried out in Work Packages 2 and 3 of the project, and will be reported as part of the Task 4.3 work.

4.2.1 Models for the estimation of frequency

The catastrophic scenario under consideration is large-scale flooding following damage. Since the first-principles design tools to be used refer to damage to the side shell and predict the survivability resistance of a vessel according to the external and internal characteristics and the extent of the damage in a given environment, it is reasonably accurate to consider collision and grounding incidents as the sole initiating events of such a catastrophic scenario. For reasons of completeness of the model, impacts are also being taken into account.

In this respect, estimation of the frequency and detailed breakdown of the resulting chain of events is required for collision, grounding and impact incidents. Estimation of the overall frequency of collision incidents is to be provided by work to be carried out in Work Package 2 (Collision and Grounding), or alternatively Fujii’s model can be used. The model is simple to implement, and is based on information on the route characteristics, crossing traffic data and basic characteristics of the vessel under consideration. A formulation of this model is contained in [DNV Technica (1996)]. In the same report, the following generic consequential scenarios have been considered as possible outcomes of collisions (Table 4.2.1), grounding (Table 4.2.2) and impact (Table 4.2.3).

Table 4.2.1: Possible Collision Outcomes

CODE	SCENARIO
C1	Collision under way, minor damage
C2.1	Collision under way, serious casualty, struck ship, impact only, non-fatal impact
C2.2	Collision under way, serious casualty, struck ship, impact only, fatal impact
C2.3	Collision under way, serious casualty, striking ship, impact only
C3.1.1	Collision under way, serious casualty, struck ship, flooding, remains afloat
C3.1.2	Collision under way, serious casualty, struck ship, flooding, sinking, slow sinking
C3.1.3	Collision under way, serious casualty, struck ship, flooding, sinking, rapid capsize
C3.2.1	Collision under way, serious casualty, striking ship, flooding, remains afloat
C3.2.2	Collision under way, serious casualty, striking ship, flooding, slow sinking
C4.1	Collision under way, serious casualty, struck ship, fire, minor damage
C4.2	Collision under way, serious casualty, struck ship, fire, major damage
C4.3	Collision under way, serious casualty, striking ship, fire, minor damage
C4.4	Collision under way, serious casualty, striking ship, fire, major damage
C4.5	Collision under way, serious casualty, striking ship, fire, total loss
C5/C6	Striking at berth

Table 4.2.2: Possible Grounding Outcomes

CODE	SCENARIO
G1	Minor grounding incident
G1	Serious grounding casualty, no flooding
G2	Serious grounding casualty, flooding double bottom only
G3.1	Serious grounding casualty, flooding above double bottom, hard aground
G3.2.1	Serious grounding casualty, flooding above double bottom, floats free, remains afloat
G3.2.2	Serious grounding casualty, flooding above double bottom, floats free, slow sinking
G3.2.3	Serious grounding casualty, flooding above double bottom, floats free, rapid capsize

Table 4.2.3: Possible Impact Outcomes

CODE	SCENARIO
M1	Minor impact incident
M2	Serious impact casualty, no flooding
M3.1	Serious impact casualty, flooding, remains afloat
M3.2	Serious impact casualty, flooding, aground upright
M3.3	Serious impact casualty, flooding, slow sinking
M3.4	Serious impact casualty, flooding, rapid capsize

These outcomes have been used to form the corresponding generic event trees, Figures 4.2.1 to 4.2.3. The branch probabilities of these event trees have been derived using statistical data and judgement, referring to operation of conventional passenger Ro-Ro vessels. For the purposes of Safety @ Speed project these probabilities are subject to review, in order high-speed craft operational patterns to be reflected.

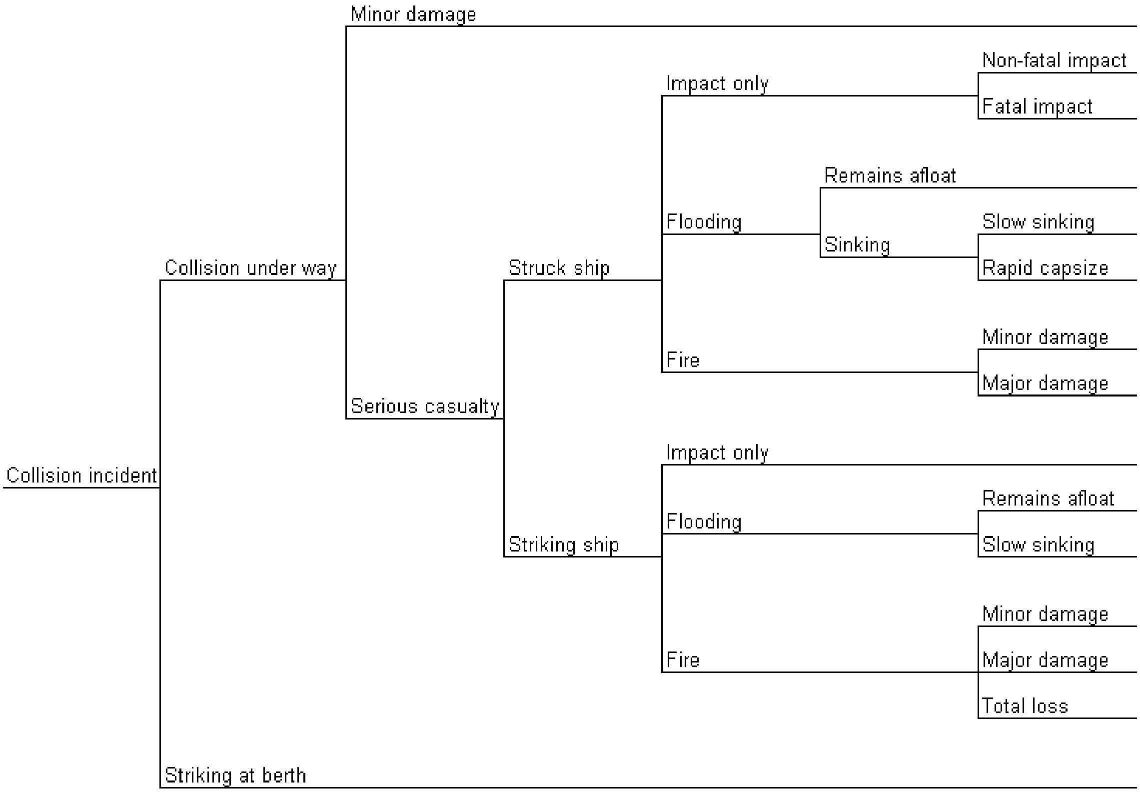

Figure 4.2.1: Generic Event Tree for Collision Outcomes [DNV Technica (1996)]

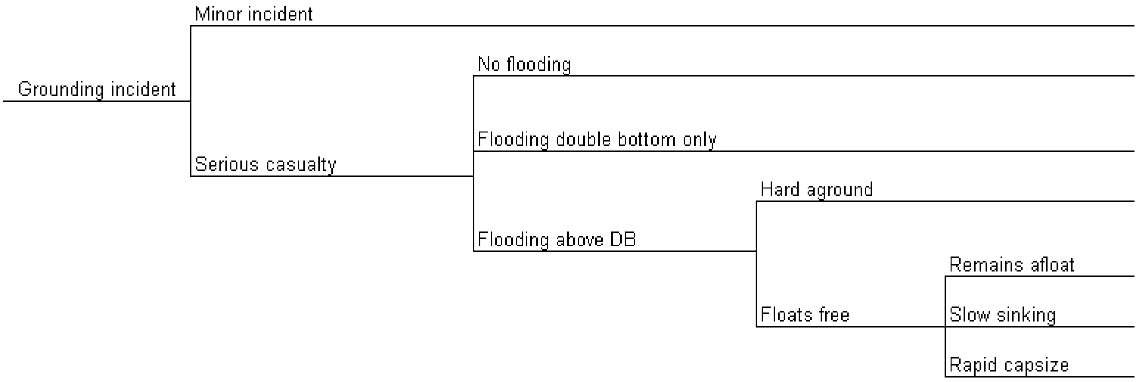

Figure 4.2.2: Generic Event Tree for Grounding Outcomes [DNV Technica (1996)]

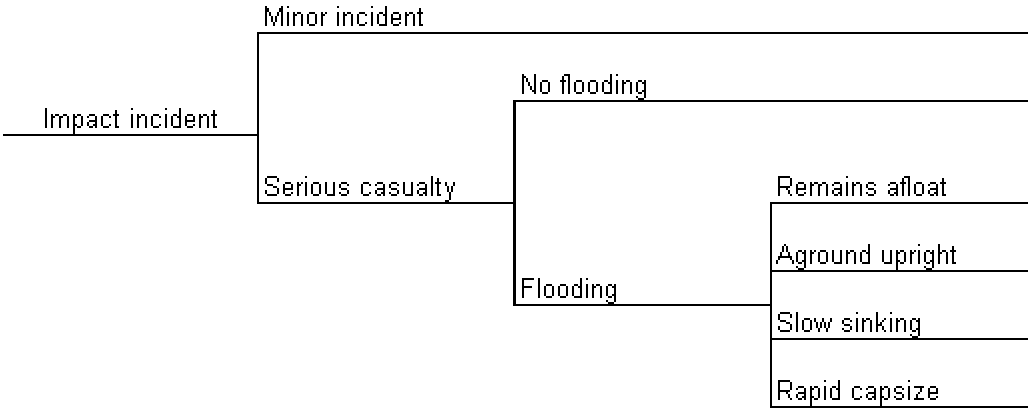

Figure 4.2.3: Generic Event Tree for Impact Outcomes [DNV Technica (1996)]

4.2.2 Models for the estimation of consequences

In general, the consequences of an accident may be classified as follows:

- Fatalities and/or injuries. For a global approach, as the one advocated here, consideration of fatalities only should suffice. Further, according to the severity, accidents that reflect only individual risk or societal risk (danger to a larger group of people) can be distinguished. The frequencies for these consequences of an accident can be measured using well-established ratios, such as the Fatal Accident Rate (FAR) for individual risk, and the F-N curve for societal risk.

- Environmental effect. There are certain measures to predict pollution, such as frequency and volume and effect of substances.

- Property loss. This can be expressed in monetary units, and includes potential damage repair costs, insurance costs or cost incurred by business interruption, rescue, salvage, inquiry cost.

Of the list of potential outcomes (Tables 4.2.1 to 4.2.3), the following have been considered to be fatal:

Collision Outcomes

- Struck ship, fatal impact (C2.2)
- All flooding incidents that lead to slow sinking (C3.1.2 and C3.2.2)
- Flooding incident C3.1.3 that leads to rapid capsize
- Fire incidents that lead to major damage (C4.2 and C4.4) and to total loss (C4.5)

Grounding Outcomes

- Flooding above double bottom, float free, slow sinking (G3.2.2)

- Flooding above double bottom, float free, rapid capsize (G3.2.3)

Impact Outcomes

- Flooding, slow sinking (M3.3)
- Flooding, rapid capsize (M3.4)

Based on experience with accidents occurred a generic figure on the percentage of fatalities that each of these outcomes could result to, can be derived.

4.2.2.1 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 (usually calculated excluding the top 10% of the available data, for example, as defined in the Stockholm Agreement for the North Western part of Europe), 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:

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

Monte Carlo methods have been used extensively for the quantification of the uncertainty levels of various systems in fields as divert as accounting, economics, engineering, finance, logistics, marketing, operations management and strategy development. The methods develop through the building of a probabilistic model of the system under investigation and recording of the performance of predetermined entities, during successive runs of a simulator. The latter are achieved utilising random generators of the uncertain characteristics of the system, which are either discrete or follow known statistical distributions. The outcome of the simulations is usually presented as averages and as risk levels in histograms and cumulative graphs of the predetermined entities.

Adopting the formulation of the Static Equivalent Method (SEM) 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 or survival. Further details of the SEM can be found in [Vassalos et al., 1997].

Distributions of the operational profiles of intact draught and associated vertical and longitudinal centre of gravity form the necessary input to this model. Table 4.2.4 contains particulars of the loading conditions of a monohull high speed craft, which can be used to derive initial conclusions regarding the nature of the input distribution. From these figures, it can be concluded that the deviations in the values are not significant (mean values and deviations from the mean; intact draught: 2.278 m, +8% /

-10%; trim: 0.383 m, ±57% - which is not significant, given that the mean trim is only 0.3% of the overall length; VCG: 7.556 m, +3% / -2%; displacement: 1,648.1 tonnes, +12% / -15%). During the project, further studies and investigations will be carried out, to verify this and eventually establish appropriate distributions for these parameters.

Table 4.2.4: Draught distribution for a monohull HSC
(125 metres overall length, 1250 passengers and 238 cars, 40 knots maximum speed)

Loading Conditions	Displacement [tonnes]	Mean Draft [m]	Trim [m]	VCG [m]
Light Ship	1,380.3	2.025	0.639	7.381
1	1,846.4	2.454	0.273	7.567
2	1,846.3	2.464	0.165	7.557
3	1,576.2	2.224	0.353	7.509
4	1,471.0	2.126	0.434	7.148
5	1,772.6	2.379	0.418	7.771
6	1,772.5	2.390	0.310	7.760
7	1,502.4	2.144	0.511	7.747
8	1,397.2	2.044	0.601	7.385

Figure 4.2.4 shows an example of a cumulative survivability curve, from where the probability of survival for a given damage case can be calculated provided the significant wave height that characterises the area of operation.

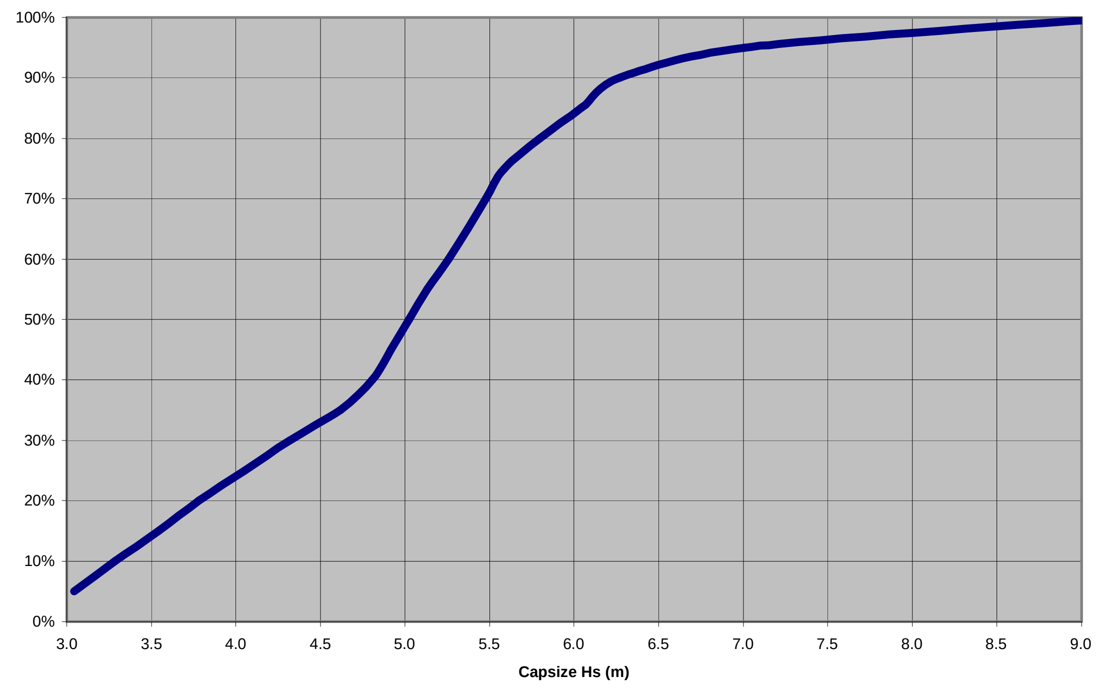

Figure 4.2.4: Distribution of Capsize H_s – Cumulative Curve

The outcomes where reference is made are concerned with the struck ship, when flooding occurs. Figure 4.2.5 focuses on these outcomes. 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 as affected by various effects that could in the main be assessed using residual stability curves, as described above, 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 utilized 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 formulation of SOLAS chapter B-1 is used, since this contains a formulation for horizontal subdivision, as opposed to A.265. Alternatively, the work presented in [Pedersen and Zhang, 2000] on damage distributions can be used. This probability can be generally represented by the factor p_i, as shown in Figure 4.2.5.

- 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 (Appendices B and C).

- The assumption that factor s_w takes unity value in case the vessel remains afloat is reflected by the formulation proposed in Figure 4.2.5. The overall formulation can be considered in a cumulative sense, i.e. including every possible damage case.

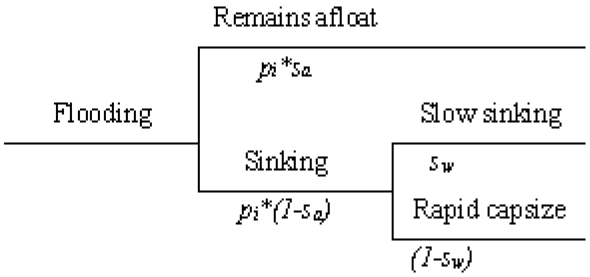

Figure 4.2.5: Event Tree for Struck Ship, Flooding Occurring

4.2.2.2 Formulation of the Static Equivalent Method

Original Formulation

The Static Equivalent Method (SEM) was initially developed from the observations of model tests and numeric simulations of damaged RoRo ships. The primary observation of the model test was that the capsize mechanism was almost always appeared to be quasi-static in nature and depenedent upon the volume of water pumped up onto the vehicle deck due to wave action. The basis of the method is the the derivation of two components; (1) the critical volume of water to cause the ship to capsize, and (2) the relationship between dynamic water head on the vehicle deck and the seastate which causes the head.

The critical volume of water is calculated statically for any specific damage case, and is defined to be the volume of water required to reduce the damage GZ curve to neutral stability, see Figure 4.2.6. This volume of water is then related static waterline ot measure the dynamic head (h) at the critical heel angle, See Figure 4.2.7.

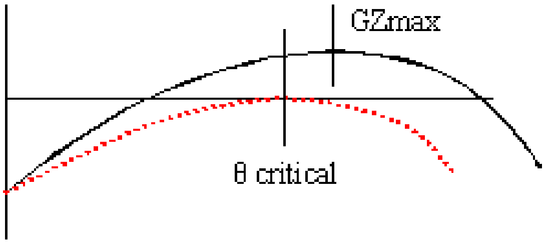

Figure 4.2.6:
Reduction of GZ Cruve

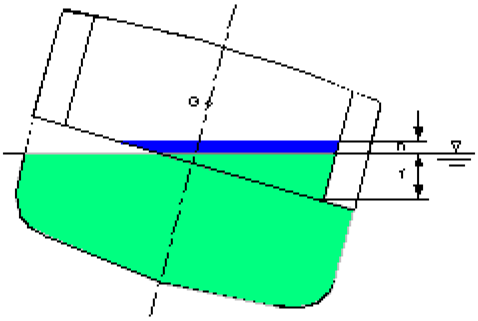

Figure 4.2.7:
Definition of Dynamic Head (h)

The second component, the relationship between the dynamic head and seastate is derived from purely a stistical correlation of measured dynamic water heads and seatates for damaged model and sumulations at the critical heel angle or the the heel angle after which the ship proceed rapidly to a full capsize. The resulting SEM formulations was simply the stastical relationship between "h" and the survival seastate "H_S" represented by the formula:

$$H_S = (h/0.085)^{1/1.3}$$

This SEM methodology was generally considered to be the most accurate and reliable method, short of a full model test programme, to determine the survival characteristics of a damaged RoRo ship.

Recent Developments

An estimate of the volume and height of water accumulated on deck for RoRo ships can be made using the SEM procedure. In principle, the method statically develops the volume of water that will reduce the damage GZ curve to exactly zero, see Figure 4.2.6. From this neutral stability position, any less water volume will be survivable and any more water will cause a capsize. For the re-analysis of the SEM method, at this critical heel angle two parameters h – the dynamic water head, and f – the freeboard at the θ critical angle are calculated, see Figure 4.2.8.

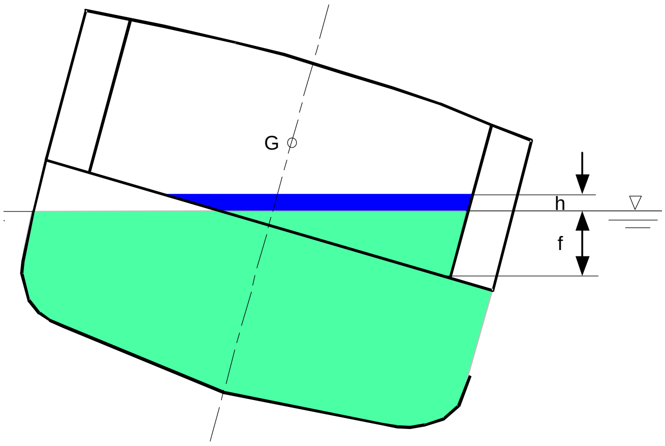

Figure 4.2.8: SEM Parameters "h" and "f"

These values of h and f are then statistically correlated with the survival seastate boundary from damage stability model tests.

Three items should be noted about the static calculation required to determine the SEM parameters. First, the damaged compartments above the vehicle deck (vehicle space and any damaged wing spaces) are considered free flooding as in a standard damage stability calculation, with buoyancy being contributed to by intact wings or casings. Second, the development of the reduced GZ lever curves should be-based on constant volume of added water, not a constant dynamic head (h). Three, it should be noted that the critical angle (θ critical) is generally solved for iteratively, and is typically less then the GZmax angle when calculating the lever curves without the dynamic water.

Model Test Results and Statistical Correlation

In a manner similar to the original formulation of the SEM, the statistical relationship between dynamic water head (h), the freeboard at the θ critical (f), and the mean significant survival wave height (H_S) was re-examined. A three dimensional regression was carried out to fit a 3D function through the data. There is some statistical scatter in the data however it was found that a simple plane fit the data as well as other more complicated surface functions. The resulting best-fit plane surface is shown in Figure 4.2.9. In comparison, the original SEM formulation, based only on "h" is indicated in Figure 4.2.10, where it can be observed that the two surfaces are not fundamentally different. The best-fit planar regression is:

$$H_S = 6.7245h - 0.8437f - 9.333$$

The statistical data for the fit is as follows:

Residual Sum of Squares = 4.411
Standard Error of the Estimate = 0.448
Coefficient of Multiple Determination (R^2) = 0.9423

Proportion of Variance = 94.23%
Highest Overestimate = 0.636m
Lowest Underestimate = -0.787m
Mean Error = 0.35m

However the equation can be simplified to:

$$H_S = 6.7h - 0.8f - 0.9$$

without any appreciable loss of accuracy.

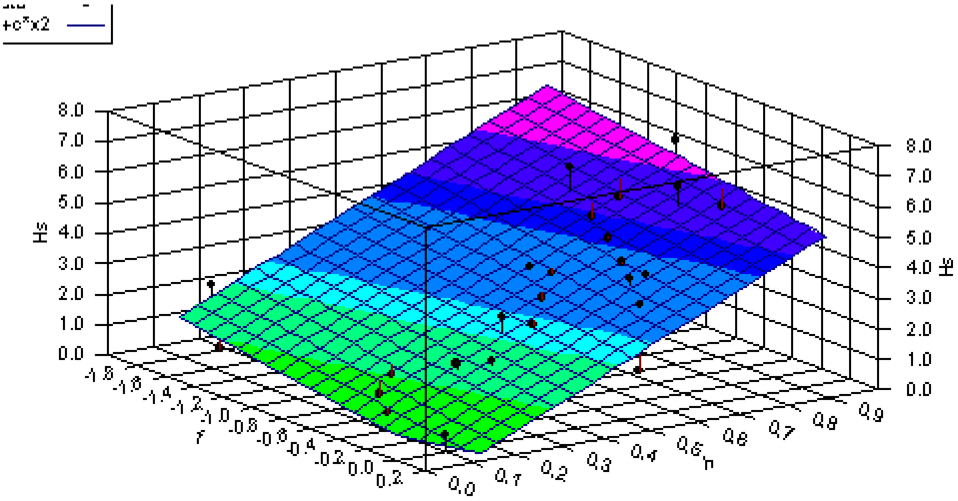

Figure 4.2.9: New Regression for H_S as a function of "h" and "f"

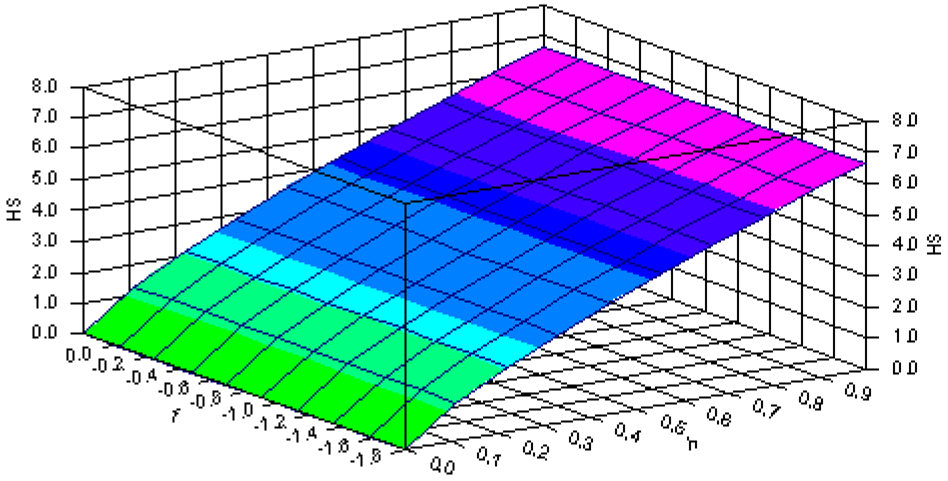

Figure 4.2.10: Previous Regression for HS as a function of h

Previous international and national damage stability criteria have traditionally used other common stability characteristics to measure the survival characteristics for damaged ships. Damage GM and damaged Freeboard were used as the measure of stability in A. 265 and most traditional damage stability criteria employ the use of properties of the GZ lever curves, such as GZmax, GZ Range, or GZ Area. The SEM methodology was developed in recognition that these traditional measures could not adequately be used to predict the survivability of damaged RoRo ships. In order to illustrate this point the following plots, Figures 4.2.11 to 4.2.13, show the correlation of these three parameters with the observed survival seastate from the model tests and possible trend lines.

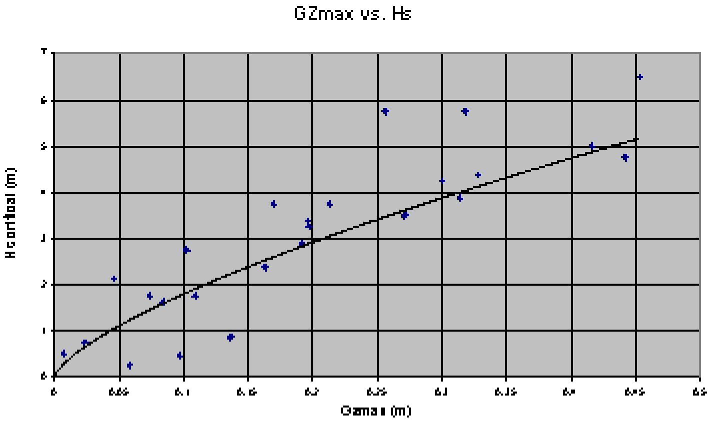

Figure 4.2.11

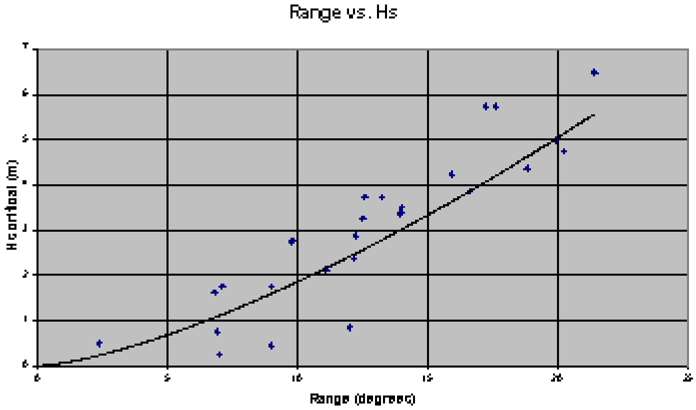

Figure 4.2.12

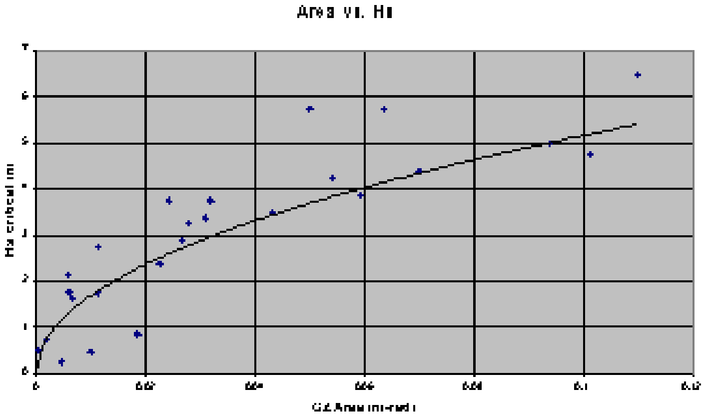

Figure 4.2.13

It can be observed that there is a considerable spread, typically about a 1m band, around the mean regression values. Range alone has the best correlation, with a Mean Error of about 0.6m, but the sum of the squared of the errors is 15.07, with the Maximum Overestimate of 1.59m and the Minimum Underestimate of –1.16m. So it is concluded that these traditional measures are far less accurate as indicators of the survival characteristics of RoRo ships compared to the SEM methodology.

4.2.3 Acceptable risk level

Risk is the product of the frequency of an incident occurring and of the consequences of the accident. For the current application there are at least three types of risks to be evaluated:

- Individual risk – to be expressed by individual risk per year and the Fatal Accident Rate (FAR)
- Societal risk – to be expressed by the F-N curve and the Potential Loss of Life (PLL)
- Property loss – to be expressed as a monetary value

The first two can be compared against established risk acceptance criteria. The latter will be evaluated on a comparative basis through the iterations to be performed during the application of the proposed procedure.

<u>Individual</u> risk is the risk experienced by a single individual in a given time period. It reflects the severity of the hazards and the amount of time the individual is in proximity to them. This form of risk is not significantly affected by the number of people on board.

Individual risks are presented in the following ways (risk of death of an individual per year is defined as the product of the frequency of an incident per year multiplied by the percentage of fatalities expected from this incident occurring):

- Maximum individual risk of death for crew members or passengers; and
- Fatal Accident Rates (FAR), which is defined as FAR = fatalities x 1.00E-08 / person hours exposed. For a ship, the number of person hours exposure is the number of hours at sea multiplied by the number of people on-board. Statistical fatalities in this respect, are calculated as the product of the expected fatalities of an incident multiplied by the overall frequency of the accident (same as the Potential Loss of Life calculations).

As it is detailed in the IMO document MSC 72/16 "Formal Safety Assessment: Decision Parameters including risk acceptance criteria" submitted by Norway on 14 February 2000, individual risk criteria may be proposed for ships as follows, based on those published by the UK Health and Safety Executive:

Maximum tolerable risk for crew members	1.00E-03 annually
Maximum tolerable risk for passengers	1.00E-04 annually
Negligible risk	1.00E-06 annually

Risks below the tolerable risk but above the negligible level should be made ALARP by adopting cost-effective risk reduction measures.

The maximum tolerable criteria specified above are not particularly strict, and it may be required that all ships should meet them. Furthermore, it may be appropriate to have a more demanding target to meet in some cases (for example, when carrying out a comprehensive FSA for new ships). These may be indicated as follows:

Target individual risk for crew members	1.00E-04 annually
Target individual risk for passengers	1.00E-05 annually

It is also mentioned that although it is not necessarily essential to have risks below these targets, failure to meet them would suggest that cost-effective risk reduction measures might be available. In any case, demonstration that risks are ALARP should be provided.

<u>Societal</u> risk is the total risk experienced by the whole group of people travelling on or working onboard a ship, even if they only travel once or twice a year. Societal risks are presented in the following ways:

- F-N curves, showing explicitly the relationship between the cumulative frequency (F) and number of fatalities (N); and
- Potential Loss of Life (PLL, also known as annual fatality rates), which consists of the product of the frequency and number of fatalities in each event. This is a convenient and concise measure of risk.

High societal risks are usually indicated by vessels where PLL exceeds 0.1 fatalities per ship year. In this respect, criteria for FAR can also be established, based on the hours a person is exposed to a risk.

The concept of "equivalent fatalities" could also be used in the risk calculations, which integrate injury and fatality risks. For example, Railtrack uses the following equivalency:

1 equivalent fatality = 1 fatality = 10 major injuries = 200 minor injuries

4.2.4 Available means for containment

Typical measures pertaining to passive design systems for damage survivability problems, applicable throughout the life cycle of the vessel, are the following (the list is not exhaustive):

a. <u>External</u>
    - High stability hull forms
    - Lifting surfaces

b. <u>Internal</u>
    - Side casings, including watertight arrangements of existing, if any.
    - Longitudinal bulkheads inside B/5
    - Transverse retractable bulkheads and doors
    - Buoyancy spaces and devices, incl. modification of tank arrangements

- Cross-flooding devices
- Watertight arrangements (closing of openings, water/weather tightness of doors and man-holes, raising of air pipes, passages etc.).

c. Operational Measures

- Reduction of operational draft (reduction of payload)
- Change of route to less severe operational sea states
- Combination of the above, along with possible change on payload arrangements, if significant effect on KG (lowering of CoG)

4.2.5 Design parameters

The range of the different internal arrangements, above and below the main car deck, when combined, form possible alternative layouts, the survivability and overall effectiveness of which (with respect to other design criteria and constraints) are to be determined. This should be achieved in a manner that accounts for their nature, number, characteristics and range of variation. The following is a list of the different internal arrangements.

BELOW MAIN CAR DECK	ABOVE MAIN CAR DECK
Pure Transverse Subdivision	Open Car Deck
Transverse and Longitudinal Subdivision	Centre Casing
Transverse Subdivision and Lower Hold	Side Casings
Horizontal Subdivision	Centre and Side Casings
Various Combinations	Fully Watertight Vehicle Deck
	Various Combinations

The focus in defining design parameters is on the characteristics of the internal layouts, i.e. it is considered that relevant hull form parameters are taken care of other parameter forms. In this respect, the design parameters to be considered include:

- The number and position of transverse or longitudinal watertight bulkheads;
- The length, width and height of the lower hold (if any);
- The longitudinal and transverse extent of the side casings on the car deck;
- The height to the main vehicle deck.

These parameters can be of discrete or continuous nature, as further explained in the following:

For the arrangement below the main vehicle deck

- Transverse subdivision: The number i and longitudinal position x_i of the transverse bulkheads. These parameters are of discrete nature, subject to constraints related to their longitudinal positioning.

- Longitudinal subdivision: The length l_L and transverse position w_L of longitudinal bulkheads, if such an arrangement is present. These parameters are of proportional nature, depending on the size of the cargo units and the carriage arrangements as these are prescribed by the relevant rules. Figure 4.2.14 shows a relevant arrangement that can be considered.

- Vertical subdivision: The number j and height h_j of any immediate decks below the main deck. These parameters are subject to constraints relevant to the provision of adequate deck heights for cargo carriage and manufacturing.

For the arrangement above the main vehicle deck

The presence of side casings (length l_S and width w_S) should be considered during optimisation. The nature and constraints to these parameters are similar to those for longitudinal subdivision below the main vehicle deck.

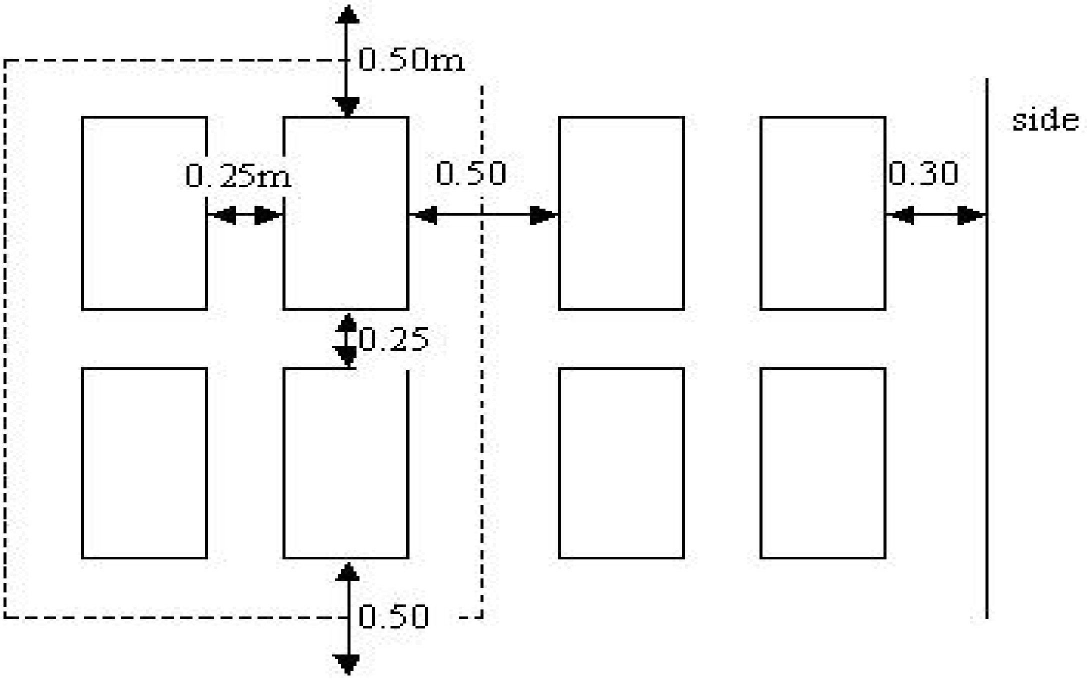

Figure 4.2.14: Cargo Unit Carriage Arrangement

An issue of particular importance in determining subdivision is the choice of the propulsion unit, which has a direct implication on the space utilisation below the main car deck. For each of these subdivision alternatives a space is to be set up. The range of variation of these parameters cannot be globally foreseen, it is more related to parametric studies to be carried out on the specific design under consideration.

4.3 Risk Model for the Containment of Fire

Fire is one of the most dangerous scenario which structures (building, ships , etc.) and people might experience. Therefore, the main goal of everybody involved in fire-fighting is to avoid the loss of both the structure and human life.

Fire safety has wide applications in the design of fire protection measures for buildings (civil field).

The fire outbreak and its development affect the tenability of structures and the ability of occupants to escape.

Figure 4.3.1 illustrates the relationship between the development of a fire, the progressive reduction of tenability, and ability of occupants to escape.

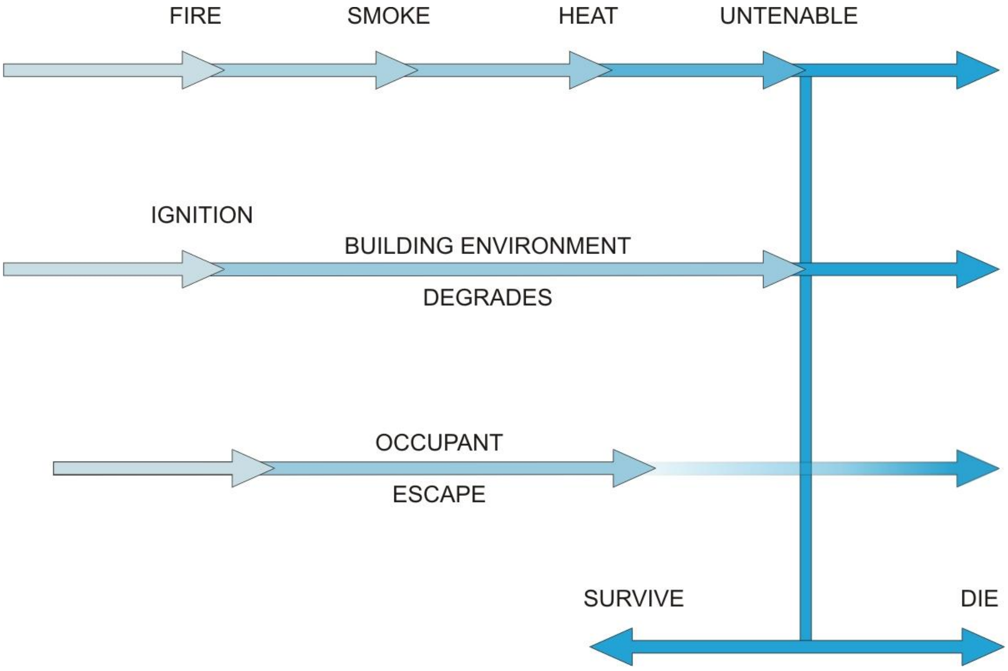

Figure 4.3.1: Relationship between the Development of Fire, the Reduction of Tenability and Ability to Escape (Source: http:www.safetyline.wa.gov.au)

Figure 4.3.1 shows that the ability of people to escape depends on the development of fire and the tenability of structures.

The development of fire and the tenability of structures are in relationship with the fire protection measures.

The fire protection measures within a building can be broken down into passive and active systems. The same approach can be followed concerning ships and HSC, in particular.

Figure 4.3.2 illustrates the sequence of events and the relationship between fire, passive systems, active systems and the evacuation of occupants.

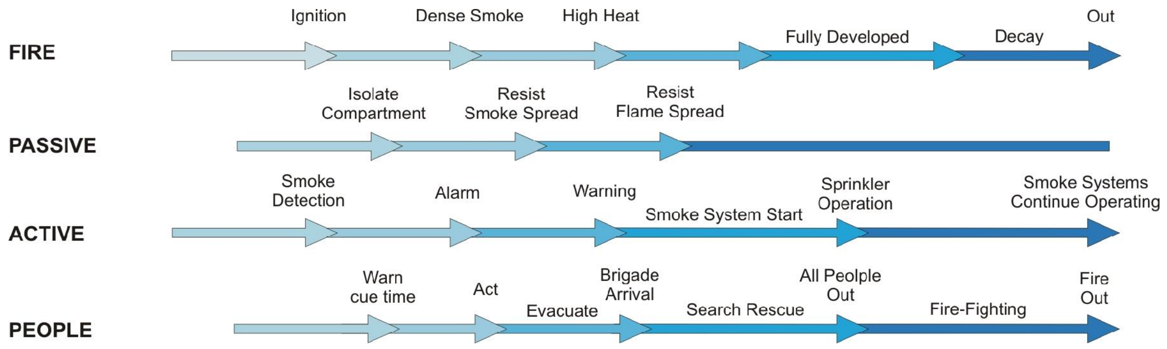

Figure 4.3.2: Relationship between Fire, Passive Systems, Active Systems and People (Source: http:www.safetyline.wa.gov.au)

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.

Fire Risk Analysis (**FRA**) is focusing on passive fire protection systems therefore on the characteristics of fire resistance of constructions and reaction to fire of products. The scope of FRA is to recognise paramete rs and variables influencing the development of a fire event in order to develop a fire event tree.

The analysis of requirements specified in the HSC Code related to passive systems allows to identify the parameters and variables that influence fire resistance of construction and the reaction to the fire of products. Products used on board ships and related to fire resistance have to comply with minimum requirements in the HSC Code and in the FTP Code.

The minimum fire safety level can be reached applying minimum fire safety requirements according to IMO regulations through applicable codes (SOLAS, HSC Code and FTP Code).

Appendix D contains a brief description of applicable codes (SOLAS, HSC Code and FTP Code) to which this report refers.

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;

The development of steps listed above is presented in Sections 4.3.1, 4.3.2, 4.3.3 and 4.3.4 respectively.

4.3.1 Analysis of Requirements (Step 1)

The fire safety requirements for HSC are specified in Chapter 7 of the HSC Code.

The HSC Code indicate requirements for the following items:
Fire Resisting Divisions, that influence the fire resistance of constructions;
Restricted use of combustible materials, that influence the reaction to fire of materials and products and is related to the use of:

- Non-combustible materials;
- Fire-restricting materials.

The definitions of Fire Resisting Divisions, Non-Combustible Materials and Fire-Restricting Materials are reported in Sections 4.3.1.1 and 4.3.1.2, respectively. Appendix E contains a further description of related HSC Code requirements.

4.3.1.1 Fire-Resisting Divisions

"Fire-resisting divisions are those divisions formed by bulkheads and decks which comply with the following:

- *they shall be constructed of non-combustible or fire-restricting materials which by insulation or inherent fire-resisting properties satisfy the requirements listed below;*
- *they shall be suitably stiffened;*
- *they shall be so constructed as to be capable of preventing the passage of smoke and flame up to the end of the appropriate fire protection time;*
- *a test of a prototype bulkhead or deck in accordance with the Fire Test Procedures Code shall be required to ensure that it meets the above requirements."*

(HSC Code, Paragraph 7.2.1).

The identification of parameters and variables influencing characteristics and qualities of fire-resisting divisions, is presented in Section 4.3.2 and the analysis of the parameters and variables is presented in Section 4.3.3.1.

4.3.1.2 Restricted use of combustible materials

The HSC Code specifies that the use of combustible materials on board HSC must be restricted. The restriction of the use of combustible materials can be performed through the use of:

- Non-Combustible Materials
- Fire-Restricting Materials.

This section reports the definition of Non-Combustible Materials and Fire-Restricting Materials give in HSC Code. Further details about HSC requirements are presented in Appendix D.

The identification of parameters and variables influencing the restricted use of combustible materials is presented in Section 4.3.2 and the analysis of parameters and variables is presented in Section 4.3.3.2.

4.3.1.2.1 Non-Combustible Materials

"Non-combustible material is a material which neither burns nor gives off flammable vapours in sufficient quantity for self-ignition when heated to approximately 750°C, this being determined in accordance with the Fire Test Procedures Code" (HSC Code, Paragraph 7.2.3)".

4.3.1.2.2 Fire-Restricting Materials

"*Fire-restricting materials are those materials which have properties complying with the Fire Test Procedures Code (HSC Code, Paragraph 7.2.2)".*

4.3.2 Definition of Parameters and Variables (Step 2)

This paragraph presents the identification and the definition of parameters and variables that influence materials and products behaviour in case of fire.

Fire-resisting divisions influences the fire resistance of constructions and the type of material used (non-combustible or fire-restricting) influences the reaction to fire of materials and products, therefore the characteristics of ignitability, flame spread, heat release and production of smoke and toxic gas species.

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 (1st order variables) that, in their turn, can be further detailed through a second set of variables (2nd order variables).

The identified parameters represent the gates of the fire event tree (Section 4.3.4). The state of the parameters/gates (P_1 or P_2/Y or N) is determined by relationships with the states of 1st or 2nd order variables.

The relationships between parameters and variables (of 1st and 2nd order) depends on the area of application of materials and product evaluated. (Materials and products have to be evaluated and tested in different ways on the basis of their use on board ship. Further details are in Appendix D.

Table 4.3.1 reports the relationships between each parameter and 1st order variables and between 1st and 2nd order variables.

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

Table 4.3.1: Parameters and Variables related to Passive Systems

PARAMETERS/GATES	VARIABLES	
	1st Order	2nd 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)

The methodology applied in this analysis match with that used in WP1 for modelling human errors, automation & mechanical failures and manoeuvring errors. For further information concerning the WP1 methodology, refer to D1.2.0 "Formulation of Models" [Pedrali et. al, 2002].

4.3.2.1 Parameters and Gates

As showed in Section 4.3.2, parameters/gates can be defined through variables of 1st or 2nd order; it means that it exist a relationship between parameters/gates and variables.

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 an 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 (defined in section 4.3.4), 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 1st 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 1st 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 1st order variables and between 1st and 2nd order variables are deterministic. This means that the state of a parameter or of a 1st order variable is determined respectively by "yes-or-no" (i.e., Boolean) relationships with the states of 1st or 2nd order variables.
- The relationships have been formulated through matrices.

Table 4.3.2 reports the minimum number of combinations (i.e.,2) that can be set in the models; in this case there is one gate G with two possible range values (G_1 and G_2), each depending on one Parameter only that has two possible states.

Table 4.3.1: Minimum No. of combinations (4) between a BE and one Parameter

Parameter (P)	P_1	P_2
Gate (G)	G_1	G_2

Table 4.3.3 reports the maximum number of combination (81), that can be set in the models; in this case there are three Parameters with three possible states, each depending on three Variables with three possible states each.

Table 4.3.2: Maximum No of combinations (81) between a Parameter and three Variables

Variables (V)	**V1**	$V1_1$									$V1_2$									$V1_3$								
	V2	$V2_1$			$V2_2$			$V2_3$																				
	V3	$V3_1$	$V3_2$	$V3_3$																								
Parameter	**P_1**																											
	P_2																											
	P_3																											

Next step (Step 3) consists of the definition of the relationships between parameters and 1st order variables and between 1st and 2nd order variables.

4.3.3 Analysis of Parameters (Step 3)

This Section presents the analysis of the parameters and variables introduced in Table 4.3.1. The scope of the analysis to identify the set of variables (1st and 2nd order) that are in relationship with the parameters and that determine the states of identified parameters

In Step 2 (Section 4.3.2), the following parameters have been identified:
- "Fire-Resisting Divisions" (FRD);
- "Fire-Restricting Material" (FRM);
- "Non-Combustible Material" (NCM).

Section 4.3.3.1 contains the analysis of the "Fire-Resisting Divisions" (FRD) parameter and Section 4.3.3.2 contains that of "Fire-Restricting Material" (FRM) and "Non-Combustible Material" (NCM). Last two parameters (FRM and NCM) have been analysed together because they are complementary.

4.3.3.1 "Fire-Resisting Divisions (FRD)" parameter

"Fire-Resisting Divisions" (FRD) parameter 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;
- minimize potential damage to adjacent properties.

The word *sufficient* in the first objective is emphasized to indicate that the required level of performance (degree of fire resistance) will vary according to design circumstances.

The degrees of fire resistance for products such as decks, bulkheads, doors, ceiling, linings are specified in the HSC Code. These products are required to be a "A" class divisions and shall comply with FTP Code Part 3.

The states of the FRD parameter (FRD_1 or FRD_2) are determined by the states of the following 1st 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).

Variables listed above have been determined applying the classification of fire resisting of building structures [Quintiere, 1993].

In this case, 2nd order variables are not needed.

It has to be noted that also the production of smoke and toxic products from bulkheads and decks can play an important role during the development of fire therefore the production of smoke can be considered as another variables influencing the FRD parameter.

The minimum level of safety corresponds to the minimum fire resistance period required for fire resisting divisions according to Table 4.4.1. The designer can increase the level of safety increasing the degree of fire resistance, i.e. from 15 min to 30 min or from 30 min to 60 min.

Table 4.3.4 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 4.3.3: States of FRD parameter and related 1st order variables

PARAMETER	VARIABLES	STATES	RANGE VALUES
Fire-Resisting Divisions (FRD)	Stability (R)	R_1	As for requirements
		R_2	As for requirements+ 15 min
		R_3	As for requirements+ 30 min
	Integrity (E)	E_1	Low
		E_2	High
	Insulation (I)	I_1	Low
		I_2	High
	Production of Smoke (PS)	PS_1	Low
		PS_2	High

Table 4.3.4: Relationships between FRD parameter and 1st order variables

		R_1				**R_2**				**R_3**			
		E_1		**E_2**		**E_1**		**E_2**		**E_1**		**E_2**	
		I_1	**I_2**	**I_1**	**I_2**	**I_1**	**I_2**	**I_1**	**I_2**	**I_1**	**I_2**	**I_1**	**I_2**
FRD	**FRD_1**												
	FRD_2												

4.3.3.2 "Fire-Restricting Material (FRM)" and "Non-Combustible Material (NCM)" parameters

"Fire-Restricting Material (FRM)" and "Non-Combustible Material (NCM)" parameters represent the characteristics of reaction to fire of materials and products.

According to HSC Code, the following products have to be of non-combustible or fire-restricting materials:

- All separating divisions, ceilings and lining, if not a fire-resisting divisions;

- Draught stops;
- All case furniture in public spaces and crew accommodation;
- All other furniture (chairs, sofas and tables) in public spaces and crew accommodation.

These parameters are analysed together because they are complementary: a material has to be a fire-restricting material or a non-combustible material.

The higher level of safety is reached if the 100% of all the products listed above are of non-combustible materials. The lower level of safety is reached if the 100% of all the products are of fire-restricting materials. Intermediate level of safety can be reached varying the percentage of fire-restricting materials and non-combustible materials.

FRM and NCM parameters depend on the following 1st order variables:

- "Quantity of Fire-Restricting Material" (QFRM) or "Quantity of Non-Combustible Materials" (QNCM);
- "Resistance to the Propagation of Flame" (RPF);
- "Resistance to the Ignition and Propagation of Flame" (RIPF);
- "Quantity of Smoke and Toxic Products" (QSTP).

Table 4.3.6 reports the relationships between FRM and NCM parameters and 1st order variables.

Table 4.3.5: Relationships between FRM/NCM parameters and 1st order variables

		$QFRM_1/QNCM_1$																$QFRM_2/QNCM_2$															
		RPF_1								$RPF_{2/}$								RPF_1								$RPF_{2/}$							
		$RIPF_1$				$RIPF_{2/}$				$RIPF_1$				$RIPF_{2/}$				$RIPF_1$				$RIPF_{2/}$				$RIPF_1$				$RIPF_{2/}$			
		FSC_1		FSC_2		FSC_1		FSC_2		FSC_1		FSC_2		FSC_1		FSC_2		FSC_1		FSC_2		FSC_1		FSC_2		FSC_1		FSC_2		FSC_1		FSC_2	
		$QSTP_1$	$QSTP_2$	$QSTP_1$	$QSTP_2$	$QSTP_1$	$QSTP_2$	$QSTP_1$	$QSTP_2$	$QSTP_1$	$QSTP_2$	$QSTP_1$	$QSTP_2$	$QSTP_1$	$QSTP_2$	$QSTP_1$	$QSTP_2$	$QSTP_1$	$QSTP_2$	$QSTP_1$	$QSTP_2$	$QSTP_1$	$QSTP_2$	$QSTP_1$	$QSTP_2$	$QSTP_1$	$QSTP_2$	$QSTP_1$	$QSTP_2$	$QSTP_1$	$QSTP_2$	$QSTP_1$	$QSTP_2$
FRM/NCM	FRM_1/NCM_1																																
	FRM_2/NCM_2																																

Each 1st order variables listed above can be defined through a set of 2nd order of variables. The set of variables of 2nd order and the relationships between 1st and 2nd order variables are presented in the following sections.

4.3.3.2.1 "Quantity of Fire-Restricting Materials" (QFRM) and "Quantity of Non-Combustible Materials" (QNCM) 1st order variables

The "Quantity of Fire-Restricting Materials" (QFRM) and the "Quantity of Non-Combustible Materials" (QNCM) is determined by the quantity of fire-restricting materials and non-combustible materials used for furniture and furnishings in public spaces and crew accommodation.

Table 4.3.7 shows 2nd order variables identified and the states that each variable can assume. The state of QFRM variables determines the level of safety reflected by the variable itself.

Table 4.3.6: States of QFRM 1st order variable and related 2nd order variables

1st ORDER VARIABLE	2nd ORDER VARIABLES	STATES	RANGE VALUES
Quantity of Fire-Restricting Materials (QFRM)	Separating Divisions, Ceiling, Lining and draught stops (QDCL)	$QDCL_1$	100% ÷ 70%
		$QDCL_2$	70% ÷ 35%
		$QDCL_3$	35% ÷ 0%
	All case furniture and all other furniture (chairs, sofas and tables) (QF)	QCF_1	100% ÷ 70%
		QCF_2	70% ÷ 35%
		QCF_3	35% ÷ 0%
	Any thermal and acoustic insulation (QTAI)	$QTAI_1$	100% ÷ 70%
		$QTAI_2$	70% ÷ 35%
		$QTAI_3$	35% ÷ 0%

The same approach can be followed considering the QNCM variable. The only difference is in the definition of the percentage of quantity in the different states because the two variables are complementary (if QNCM increases in percentage, QFRM decreases).

Table 4.3.8 shows 2nd order variables identified and the states that each variable can assume.

Table 4.3.7: States of QNCM 1st order variable and related 2nd order variables

1st ORDER VARIABLE	2nd ORDER VARIABLES	STATES	RANGE VALUES
Quantity of Non-Combustible Materials (QNCM)	Separating Divisions, Ceiling, Lining and draught stops (QDCL)	$QDCL_1$	0 %÷ 30%
		$QDCL_2$	30% ÷65%
		$QDCL_3$	65% ÷ 100%
	All case furniture and all other furniture (chairs, sofas and tables) (QF)	QF_1	0 %÷ 30%
		QF_2	30% ÷65%
		QF_3	65% ÷ 100%
	Any thermal and acoustic insulation (QTAI)	$QTAI_1$	0 %÷ 30%
		$QTAI_2$	30% ÷65%
		$QTAI_3$	65% ÷ 100%

Table 4.3.9 shows relationships between 1st order variables QFRM/QNCM and 2nd order variables.

Table 4.3.8: Relationships between QFRM/QNCM 1st order variables and 2nd order variables

		$QDCL_1$						$QDCL_2$						$QDCL_3$					
		QCF_1		QCF_2		QCF_3		QCF_1		QCF_2		QCF_3		QCF_1		QCF_2		QCF_3	
		$QTAI_1$	$QTAI_2$	$QTAI_1$	$QTAI_2$	$QTAI_1$	$QTAI_2$	$QTAI_1$	$QTAI_2$	$QTAI_1$	$QTAI_2$	$QTAI_1$	$QTAI_2$	$QTAI_1$	$QTAI_2$	$QTAI_1$	$QTAI_2$	$QTAI_1$	$QTAI_2$
QFRM// QNCM	$QFRM_1$/ $QNCM_1$																		
	$QFRM_2$/ $QNCM_2$																		

4.3.3.2.2 "Resistance to the Propagation of Flame (RPF)" 1st order variable

Draperies, curtains and other suspended textile materials have to be evaluated on the basis of characteristics of "Resistance to the Propagation of Flame (RPF)".

These materials have to comply with the requirements specified in FTP Code Part 7 and have to be tested in accordance with the fire test procedure specified in resolution A.471(XII) as amended by resolution A.563(14). This resolution describes a method of assessment of resistance to propagation of flames for the materials specified above.

The "Resistance to Propagation of Flame" (RPF) variable can be defined through the following set of 2nd order variables:

- Flame time (FT);
- Burn (B);
- Ignition of cotton wool (IG).

Variables listed above have been identified analysing the requirements specified in FTP Code Part 7.

The state of the 1st order variable (RPF_1 or RPF_2) is determined by the states of the 2nd order variables that are characterised by the range values. Table 4.3.10 shows 2nd order variables, the states of each variable and an example of range values that each 2nd order variable can assume.

Table 4.3.9: States of RPF 1st order variable and related 2nd order variables

1st ORDER VARIABLE	2nd ORDER VARIABLES	STATES	RANGE VALUES
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)	FT_1	2.5÷5.0 sec
		FT_2	0÷2.5 sec
	Number of specimen tested with surface application of the pilot flame in which burn through to any edge (B)	B_1	50÷100% of specimens
		B_2	(0÷50%) of specimens
	Number of specimen in which there is ignition of cotton wool below the specimen	IG_1	50÷100% of specimens

	(IG)	IG_2	(0÷50%) of specimens

Table 4.3.11 shows relationships between RPF 1st order variable and related 2nd order variables.

Table 4.3.10: Relationships between RPF 1st order variable and 2nd order variables

		FT_1				**FT_2**			
		B_1		**B_2**		**B_1**		**B_2**	
		IG_1	**IG_2**	**IG_1**	**IG_2**	**IG_1**	**IG_2**	**IG_1**	**IG_2**
RPF	**RPF_1**								
	RPF_2								

4.3.3.2.3 “Resistance to the Ignition and Propagation of Flame (RIPF)” 1st order variable

All upholstered furniture and bedding components in public spaces and crew accommodation have to be evaluated on the basis of the qualities of “Resistance to the Ignition and Propagation of Flame (RIPF)”**.**

The resistance to the ignition and propagation of flame (RIPF) is determined in different ways for upholstered furniture and bedding components.

The upholstered furniture has to comply with the FTP Code Part 8 while bedding components have to comply with the FTP Code Part 9. This means that the same fire characteristics, represented by the “Resistance to the Ignition and Propagation of Flame” (RIPF) variable, has to be evaluated in two different ways:

– upholstered furniture have to be tested and evaluated with the fire test procedure specified in IMO resolution A.652 (16);
– bedding components have to be tested in accordance with the fire test procedure specified in resolution A.688 (17).

The RIPF variable can be defined through the following set of 2nd order variables:

- “Time after Cigarette in Position” (TCP) that indicate the period of time during which the tested object not show any signs of development of smouldering fire or flames after the smouldering cigarette has been places in position. This period must be greater than one hour;
- “Time after Ignition Flame Removed” (TIFR) that indicate the period during which the tested object not show any signs of development of smouldering fire or flames more after the ignition flame has been removed from the object. The period must be greater than 120 seconds.

Table 4.3.12 presents TSFF and TIFR 2nd order variables, the states of each variable and an example of range values that each 2nd order variable can assume.

Table 4.3.11: States of RIPF 1st order variable and related 2nd order variables

1st ORDER VARIABLE	2nd ORDER VARIABLES	STATES	RANGE VALUES
Resistance to the Ignition and Propagation of Flame (RIPF)	Time to develop Smouldering Fire or Flames" (TSFF)	TSFF$_1$	60 min. ÷ 90 min. after
		TSFF$_2$	90 min. ÷ 120 min. after
	Time after Ignition Flame Removed" (TIFR)	TIFR$_1$	120÷150 seconds
		TIFR$_2$	150÷200 seconds

Table 4.3.13 presents relationships between RIFP 1st order variable and the related 2nd order variables, TSFF and TIFR.

Table 4.3.12: Relationships between RIPF 1st order variable and 2nd order variables

		TSFF$_1$		**TSFF$_2$**	
		TIFR$_1$	**TIFR$_2$**	**TIFR$_1$**	**TIFR$_2$**
RIPF	**RIPF$_1$**				
	RIPF$_2$				

4.3.3.2.4 "Quantity of Smoke and Toxic Product (QSTP)" 1st order variable

Exposed surfaces in corridors and stairway enclosures, and of bulkheads (including windows), wall and ceiling lining, in all public spaces, crew accommodation, service spaces, control stations and internal assembly and evacuation stations have to be constructed of materials which, when exposed to fire, are not capable of producing excessive quantities of smoke or toxic products *(HSC Code, Section 7.4.36).*

The "Quantity of Smoke and Toxic Products" (QSTP) is a 1st order variable that influence the FRM/NCM parameters.

The QSTP variable can be defined through the following set of 2nd order variables:
- "Optical Density of Smoke" (ODS), that represents the quantity of smoke produced and recorded during the test period. The ODS must not exceed the limits specified in FTP Code;
- "Concentration of Toxic Products" (CTP), that represents the concentration of CO, HCl, HF, Nox, HBr, HCN, SO_2. The gas concentration must not exceed the limits specified in FTP Code.

Maximum values acceptable are specified in FTP Code for ODS and CTP.

Limits for ODS values change with the use of the material tested (materials used as surface of bulkheads, lining or ceiling, materials used as primary deck covering). For instance, materials used as surface bulkheads, linings or ceilings must have an ODS value lower than 200 in any test condition.

FTP Code specifies maximum values of gas concentration for each toxic gas that can be produced during a fire event.

In Table 4.3.14, range values corresponding to each states of CTP have been specified in terms of the total concentration of toxic products. Range values can be also defined in term of concentration of each toxic products. In any case, gas concentration must be lower than maximum values specified in FTP Code.

Table 4.3.14 shows 2nd order variables, the states that each variable can assume and the range values associated to each state.

Table 4.3.13: States of QSTP 1st order variable and related 2nd order variables

1st ORDER VARIABLE	2nd ORDER VARIABLES	STATUS	RANGE
Quantity of Smoke and Toxic Products (QSTP)	Optical Density of Smoke (ODS)	ODS_1	200÷ 100
		ODS_2	100÷ 0
	Concentration of Toxic Products (CTP)	CTP_1	100÷ 50% of ppm total
		CTP_2	100÷ 50% of ppm total

Table 4.3.15 presents relationships between QSTP and related 2nd order variables.

Table 4.3.14: Relationships between QSTP 1st order variable and 2nd order variables

		ODS_1		**ODS_2**	
		CTP_1	**CTP_2**	**CTP_1**	**CTP_2**
QSTP	**$QSTP_1$**				
	$QSTP_2$				

4.3.4 Fire Event Tree (Step 4)

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.

Step 2 and Step 3 (Section 4.3.2 and 4.3.3 respectively) have led to the identification of the following parameters have:

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

Each parameter can have only two states (i.e.FRD_1 or FRD_2) and each gate of the event tree has who 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 1st and 2nd variables.

A generic and qualitative fire event tree focused on passive design systems is presented Figure 4.3.3.

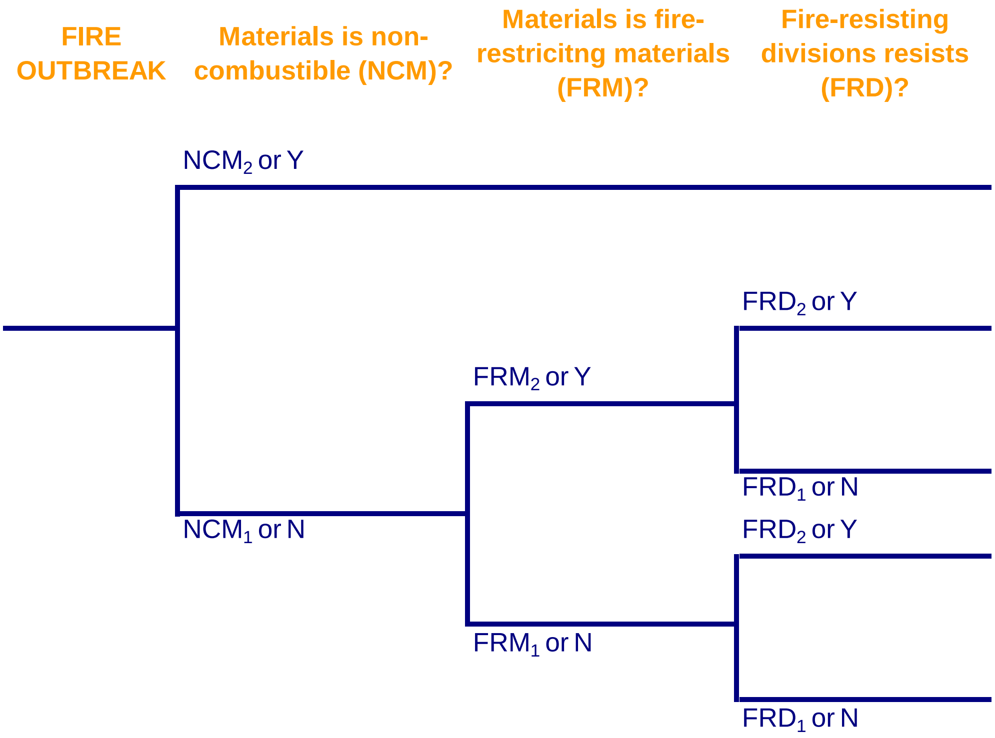

Figure 4.3.3: Qualitative Event tree- Passive Systems

4.4 Risk Model for the Effect of Active Systems

Through the use of a systems analysis and a FMECA exercise we were able to identify the Life Saving Appliances for the vessel and the active systems involved with fire detection and extinguishing as the greatest areas of interest.

4.4.1 Life Saving Appliances

From deliverable 410 we were able to determine the main LSA available to the designers of HSC are:

- Lifeboats
- Life rafts (MES)
- Man Overboard Boat
- Personal Floatation Devices

As well as this the following also have an impact on the effectiveness of LSA's:

- Other vessels
- Helicopters
- Shore based lifeboats

We then constructed event trees and Fault trees for abandoning the vessel. The LSA event and fault trees were tailored for use in HSC from existing trees that were publish in "Formal Safety Assessment of Life Saving Appliances for Bulk Carriers". These can be found in Appendix G.

It was then decided that the work on LSA's could not be taken any further at this point due to the financial constraints of the project and a higher perceived need to concentrate on fire related active systems.

4.4.2 Fire Risk Analysis

The Fire Risk Analysis in this section was focused on Active systems. 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 containment of fire.

As for passive systems the process followed 4 steps. These are:

Step 1: Analysis of Requirements
Step 2: Definition of Parameters
Step 3: Analysis of Parameters
Step 4: Fire Event Trees

The fire safety requirements for HSC are specified in Chapter 7 of HSC Code.

The requirements are detailed in Appendix I. From this we were able to move on to step two "Definition of Parameters and Variables".

This process involved taking the parameters, for example smoke detectors, and identifying the variables associated with them, in this case distance from bulkheads, floor area per detector, distance centre to centre for detectors, and time to operate versus smoke density. These parameters were then entered into the standardised S@S forms issued by WP 5. The forms can be found in Appendix J.

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

For this example we will examine the impact of altering the variables associated

Table 4.4.1: Smoke Detectors and Associated Variables

PARAMETER	VARIABLES	STATES	RANGE VALUES
Smoke detectors (SD)	Installation Requirements: distance from bulkhead	DB_1	0.5m – 2.5m
		DB_2	2.5m – 3.5m
		DB_3	3.5m – 5.5m
	Floor area per detector	FA_1	0 – 30m^2
		FA_2	30m^2 – 50m^2
		FA_3	50m^2 – 74m^2
	Distance apart between centres	DA_1	3m – 7m
		DA_2	7m – 11m
	Time to operate versus smoke density	T_1	2 – 7.25%
		T_2	7.25 – 12.5%

This allows us now to relate the parameters as gates. In other words we can arrange the related variables in a matrix that will lead to every out come being explored. This in turn will allow the designer to alter the “sliders” for the variables on the design tool. In so doing he will pick new paths through the matrix and give the appropriate values for that particular gate. In this example it means he will be able to vary the distance from the bulkheads, floor area per detector, distances apart between centres, and time to operate versus smoke density. As he changes the values he will change his path through the matrix to give new values for “Smoke detectors work, Yes or No”. The matrix can be seen below in Table 4.4.2.

As yet the table is unpopulated as this work will come in the implementation of the model.

Table 4.4.2: Smoke Detector Matrix that will give risks for every combination of associated variables

		DB$_1$																DB$_2$																DB$_3$															
		FA$_1$				FA$_2$				FA$_3$				FA$_1$				FA$_2$				FA$_3$				FA$_1$				FA$_2$				FA$_3$				FA$_1$				FA$_2$				FA$_3$			
		DA$_1$		DA$_2$		DA$_1$		DA$_2$		DA$_1$		DA$_2$		DA$_1$		DA$_2$		DA$_1$		DA$_2$		DA$_1$		DA$_2$		DA$_1$		DA$_2$		DA$_1$		DA$_2$		DA$_1$		DA$_2$		DA$_1$		DA$_2$		DA$_1$		DA$_2$		DA$_1$		DA$_2$	
		T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$	T$_1$	T$_2$
SD	SD$_1$																																																
	SD$_2$																																																

The next stage was to analysis the parameters in order to extract any rules that apply to them. These rules are outlined below.

- If neither heat detectors nor smoke detectors activate then the automatic alarm can not function.
- If human detection has not occurred then the manual alarm can not be sounded.
- If the ventilation fails to shut down then the CO_2 system cannot be used.
- If the CO_2 system is used the crew can not enter to use either fixed hoses or portable extinguishers.
- The alarm needs to sound (manual or automatic) before the automatic fire fighting systems work.

It was also realised that the 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 previously stated in this report that feed into the event tree to help resolve some of the gates.

The event tree associated with fire can be found in Appendix K.

5. FORMULATION OF COST MODELS

5.1 Cost Model for the Effect of the Human Factor

The cost model for the effect of the human factor is based on the list of parameters for intervention and the degrees of freedom built into that. The cost model is expected to take the cost of any change in parameters into consideration, but it is not expected to take into account the derived cost related to the change in risk e.g. costs related to accidents and incidents, changes in insurance premium index etc.

Adjustments of some parameters are very cheap while adjustments of other parameters are more expensive. Costs related to the change of any given parameter can be subject to local or regional variations; variations in labour expenses and variations in organisational costs related to the change of e.g. procedures, plans, checklists, manning etc.

Estimations for each parameter and sub-parameter can be made by experts from the maritime domain (e.g. ship owners, labour organisations, naval academies and training institutions and suppliers of equipment and automation) and entered in a table as the one below. This table will then – together with the risk model for the effect of the human factor on detection, alarm and suppression – act as cost model for the effect of the human factor.

Parameter	**Sub-parameters**	**Nominal value**	**Ordinal value**	**Estimated cost per vessel**
Training and education of Crew	Amount of training and education	None Little Medium High Very high	0 1 2 3 4	… … … … …
	Overall quality of training and education	Very low Low Medium High Very high	0 1 2 3 4	
Selection of crew – qualifications	Number of well spoken working languages on board	Only one Two or more	4 0	
	Amount of experience	None Little Medium High Very high	0 1 2 3 4	
	Amount of training and education	None Little Medium High Very high	0 1 2 3 4	
	Overall quality of training and education	Very low Low Medium High Very high	0 1 2 3 4	

Parameter	**Sub-parameters**	**Nominal value**	**Ordinal value**	**Estimated cost per vessel**
Selection of crew – personality and attitudes	Amount of bridge discipline	Very low	0	
		Low	1	
		Medium	2	
		High	3	
		Very high	4	
	Ability to cope with operational pressures	Very low	0	
		Low	1	
		Medium	2	
		High	3	
		Very high	4	
	Ability to cope with boredom (e.g. due to routine work)	Very low	0	
		Low	1	
		Medium	2	
		High	3	
		Very high	4	
	Amount of concern about safety	Very low	0	
		Low	1	
		Medium	2	
		High	3	
		Very high	4	
	Amount of risk taking attitude	Very low	4	
		Low	3	
		Medium	2	
		High	1	
		Very high	0	
	Level of confidence (in self, others, automation/technology)	Very low	0	
		Low	2	
		Medium	4	
		High	2	
		Very high	0	
	Level of exposure to domestic issues	Very low	4	
		Low	3	
		Medium	2	
		High	1	
		Very high	0	
Selection of crew – medical and physical condition	Level of overall medical and physical condition	Very poor	0	
		Poor	1	
		Medium	2	
		Good	3	
		Very good	4	
Operation and procedures	Amount of daily time and/or scheduling pressure	Very low	2	
		Low	3	
		Medium	4	
		High	2	
		Very high	0	
	Amount of commercial and/or organizational pressure	Very low	2	
		Low	3	
		Medium	4	
		High	2	
		Very high	0	
	Amount of individual workload in the daily routine work	Very low	2	
		Low	3	
		Medium	4	
		High	2	
		Very high	0	

Parameter	**Sub-parameters**	**Nominal value**	**Ordinal value**	**Estimated cost per vessel**
	Amount of especially demanding planned situations (e.g. fire drills)	Less than 1/month	0	
		1-3/month	2	
		1-2/week	4	
		3-6/week	2	
		1 or more/day	0	
	Amount of resources for maintenance, repair, retrofit, new equipment etc.	Very low	0	
		Low	1	
		Medium	2	
		High	3	
		Very high	4	
Safety culture	Level of overall safety culture on board	Very low	0	
		Low	1	
		Medium	2	
		High	3	
		Very high	4	
	Level of overall safety culture in company/land organization	Very low	0	
		Low	1	
		Medium	2	
		High	3	
		Very high	4	
Company practice	Overall quality of working terms and conditions – long term (vacation, salary, promotion possibilities etc.)	Very low	0	
		Low	1	
		Medium	2	
		High	3	
		Very high	4	
	Overall quality of working terms and conditions – daily basis (working hours, rest periods, working environment, accommodation etc.)	Very low	0	
		Low	1	
		Medium	2	
		High	3	
		Very high	4	
Bridge discipline	Level to which extend bridge discipline is regulated by procedures and/or practice	Very low	0	
		Low	2	
		Medium	4	
		High	4	
		Very high	2	
Design of equipment and means for navigation	Level of automation	Very low	0	
		Low	2	
		Medium	4	
		High	4	
		Very high	2	
	Level of transparency	Very low	0	
		Low	1	
		Medium	2	
		High	3	
		Very high	4	
HMI principles	Overall quality of interaction design and ergonomics	Very low	0	
		Low	1	
		Medium	2	
		High	3	
		Very high	4	
User's manual	Availability of user manuals	None	0	
		Little	1	
		Medium	2	
		High	3	
		Very high	4	

Parameter	**Sub-parameters**	**Nominal value**	**Ordinal value**	**Estimated cost per vessel**
	Overall quality of user manuals	Very poor	0	
		Poor	1	
		Medium	2	
		Good	3	
		Very good	4	
Means for communication	Availability of means for communication	None	0	
		Little	1	
		Medium	2	
		High	3	
		Very high	4	
	Overall quality of means for communication	Very poor	0	
		Poor	1	
		Medium	2	
		Good	3	
		Very good	4	
Procedures for communication	Level to which extend onboard communication is regulated by procedures and/or practice	Very low	0	
		Low	2	
		Medium	4	
		High	4	
		Very high	2	

5.2 Cost Model for the Containment of Damage

A common measure for the evaluation of the effectiveness of a risk control option (as the ones described in section 4.2.4 of this report) is the calculation of the ICAF value (Implied Cost of Averting a Fatality). The ICAF is calculated as:

$$\text{ICAF} = \frac{\text{Net Annual Cost of Measure}}{\text{Reduction in Annual Fatality Rate}}$$

In general, measures whose cost is less than £2m per fatality averted are considered to be cost-effective and should in general be adopted. Measures whose cost is in the range of £2-50m per fatality averted should be considered for adoption and may be appropriate if the individual or societal risks are high in the ALARP region. Measures whose cost exceed £50m are not considered cost-effective and would not normally be adopted unless the individual or societal risks were considered to be intolerable.

Costs of risk control options such as investment, training, operating, maintenance, repair, could be sought and the effects on commercial performance of these options quantified.

Benefits of risk control option such as:

- Safety (life, health, injury) improvement,
- Environmental protection
- Commercial benefit

can be calculated using risk free rate of return to discount to present values.

One way to present the results can be as "Risk Profiles" i.e. in the form of "F-N" like diagrams and integrated results could be generated in the following schematic form:

Risk control option I: Costs		
Consequence mode	**Without risk control options**	**Using control option I**
Total loss of the ship	Present value €	
Repair of structural damage	Expected value €	Monetary units €
Environmental pollution	Expected value €	
Loss of human life	Expected value (number)	(Number)
Loss of reputation	Expected value €	
Additional building cost		
Loss of cargo	Expected value €	
Loss of revenue	Expected value €	
Total	€	

In this respect, when quantifying the effectiveness of risk control options relevant to containment of damage followed by flooding, trade-offs between the available carrying capacity (as this can be expressed through well-established techno-economic criteria) and the weight of the structure ought to be performed in order to calculate the marginal costs of the corresponding risk control options. Models for structural weight, building cost, and required freight rate calculations will be presented in the following.

5.2.1 Structural Weight and Building Cost

As briefly discussed in the foregoing, is it more appropriate to have an indicator of the difference on the structural weight among the various subdivision alternatives considered. A formulation for the weight of decks and bulkheads is appropriate for this scope is as follows:

$$\Delta WEIGHT_{decks} = \rho_{material} . e_{decks} \cdot \left(\sum_{decks} S - \sum_{decks} S_{ini} \right)$$

$$\Delta WEIGHT_{bulkheads} = \rho_{material} . e_{bulkheads} \cdot \left(\sum_{bulkheads} S - \sum_{bulkheads} S_{ini} \right)$$

$$\Delta WEIGHT = \Delta WEIGHT_{decks} + \Delta WEIGHT_{bulkheads}$$

The formulation should also account for the stiffeners of the decks and bulkheads, which can be considered as 30% of the plating weight.

Material and labour costs for additional material weight can be calculated from formulae available in the literature, which are producing reasonable results in general, or based on the experience of members of the project consortium.

5.2.2 Required Freight Rate (RFR) Model

A model appropriate for the calculation of the Required Freight Rate has been developed. An initial estimate of the design development and building cost is required for the techno-economic calculations. Having defined this, the variation of the steel weight cost related to exploration of alternatives configurations can be considered in the following manner:

[Initial Cost] = [Design Development and Building Cost] ± [Δ(Material Weight Cost)]

The input information to the model is the following:

- Single trip length;
- Carrying capacities (passenger and lane metres);
- Crew size and number of crews;
- Service speed and installed horsepower;
- Number of trips per day in peak and off-peak season;
- Percentage of capacity utilisation;
- Ratio of passenger to lane metre fare.

The economic assumptions made are (deriving from experience with conventional ferries – the figures are expected to be slightly different when referring to HSC operations):

- Maintenance and Insurance (M&I) cost equal to 6.5% of initial cost;
- Sales and Administration (S&A) cost equal to 40% of running cost;
- Port and Miscellaneous (P&M) cost equal to 70 % of M&I cost.

The utilisation parameters are calculated from the following formulae:

$$[\text{Transit Hours per year}] = \frac{\text{Single Trip Length}}{\text{Service Speed}} \times$$
$$[(\text{Peak Period}) \times (\text{Trips per day}) + (\text{Off-Peak Period}) \times (\text{Trips per day})]$$

$$[\text{Passenger Miles per year}] = [\%\ \text{Utilisation}] \times [\text{Passenger Carrying Capacity}] \times [\text{Single Trip Length}] \times [\text{Number of Trips per year}]$$

$$[\text{Lane Metre Miles per year}] = [\%\ \text{Utilisation}] \times [\text{Lane Metre Carrying Capacity}] \times [\text{Single Trip Length}] \times [\text{Number of Trips per year}]$$

The average annual costs (A.A.C.) are calculated as:

$$[\text{Fuel Cost}] = [\text{Transit Hours per year}] \times [\text{Installed Power}] \times [\text{Consumption}] \times [\text{Fuel Price}]$$

$$[\text{Crew Cost}] = [\text{Crew Size}] \times [\text{Number of Crews}] \times [\text{Average Crew Salary}]$$

$$[\text{Running Cost}] = [\text{Fuel Cost}] + [\text{Crew Cost}] + [\text{M\&I}] + [\text{P\&M}]$$

$$[\text{Annual Return on Initial Cost}] = [\text{Initial Cost}] \times (\text{CR} - \text{i}\% - \text{N})$$

The Capital Recovery Factor (CR – i% – N), is given by (i% is the compound interest and N is the duration of the investment):

$$(\text{CR} - \text{i}\% - \text{N}) = \frac{\text{i} \times (1+\text{i})^{\text{N}}}{(1+\text{i})^{\text{N}} - 1}$$

$$\text{A.A.C.} = [\text{Running Cost}] + [\text{S\&A}] + [\text{Annual Return on Initial Cost}]$$

The required fares per mile are now calculated as:

$$\text{Required Passenger Fare} = \frac{\text{A.A.C.}}{[\text{Passenger Miles}] + [\text{Fare Ratio}] \times [\text{Lane Metres Miles}]}$$

$$\mathrm{Required\ Lane\ Metre\ Fare} = \frac{\mathrm{Required\ Passenger\ Fare}}{\mathrm{Fare\ Ratio}}$$

The figures calculated from these formulae are considered to be 75% of the gross required fares, due to discounts and commissioning.

5.3 Cost Model for the Containment of Fire

Fire risk analysis focused on passive fire protection systems has been developed in Section 4.3 in order to recognise parameters and variables influencing the development of fire events. The appliance of fire risk analysis during the early design phase leads to the fulfilment of the "fire risk reduction" through the application of technological measures to reduce fire risk to a tolerable level. Reduced fire risk means fewer fire losses, less production downtime, better employee morale, better public relations and greater profit potential; however risk reduction can not be obtained without cost.

The cost model related to passive systems will be applied by calculating the change on costs attributable to the change of parameters' characteristics in terms of behaviour in case of fire.

According to the cost estimation methodology prepared by UNEW, the total cost associated to a parameter, can be splitted in:

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

Generally, Through Life Costs have to be taken as a whole for the "Containment of Damage and Fire". The only Through Life Costs that can be calculated for each system separately are the maintenance costs.

5.3.1 Costs Associated with Passive Systems

Costs related to passive systems depend on the parameter costs, in terms of material costs, direct labour costs and overheads.
Parameters and variables concerning to passive systems differ hugely through the whole HSC. For this reason, three different scenarios have been identified:

- Public spaces (bars, refreshment kiosks, main seating areas, lounges, dining rooms, etc);
- Vehicle decks;
- Engine Spaces.

Parameters identified during fire risk analysis concern the behaviour of the different types of materials typically used on board HSC for furnishing, ceiling/lining and resisting divisions.
In order to perform the cost estimation, the following activities are needed, for each parameter identified

- definition of "default values" for each parameter (x'_{basis}) where the default values are values usually associated to parameters in the design phase;
- definition of the range of variability ($x'_{min}<x'_{basis}<x'_{max}$) of each parameter (x) for each material type (') and for each identified scenario;
- identification of various materials for each type and for each scenario, in which parameters' value is equal to minimum value acceptable (x'_{min}), maximum value acceptable (x'_{max}), default value (x'_{basis}) and two values comprise in the range of variability (x'_1 and x'_2);
- calculation of the change in Total Cost of each selected material for each state of the selected parameters (δ'_{min}, δ'_{basis}, $\delta'_{max,}$ δ'_1 and $\delta'_{2.}$

As each parameter can change, it is needed to calculate the impact on Total Cost of the change in terms of changes in the following cost elements:

- Material Cost ;
- Labour Cost;
- Overhead Cost;
- Maintenance Cost;
- Crew Cost (not applicable in this case)

The change of cost elements for each parameter can be represented through parameter matrix as the following.

Table 5.3.1: Example of Parameter matrix

PARAMETER	COST ELEMENTS				
	Material Cost (€)	Labour Cost (€)	Overhead Cost (€)	Maintenance Cost (€)	Crew Cost (€)
x_{max}	1+δ	1+δ	1+δ	1+δ	1+δ
x_1	1+δ	1+δ	1+δ	1+δ	1+δ
x_{basis}	1	1	1	1	1
x_2	1+δ	1+δ	1+δ	1+δ	1+δ
x_{min}	1+δ	1+δ	1+δ	1+δ	1+δ

The parameter matrix presents costs element in term of variation (δ) on costs attributable to the change on the parameter value respect of the default value associated to the same parameter in the basic vessel (1+δ).

5.4 Cost Model for the Effect of Active Systems

In order to evaluate the quality of a design it is also important to evaluate the cost of the risk control options. As with all areas of S@S we can differentiate between two different types of cost. These are:

1. Build Costs
2. Through Life Costs

These costs can be further broken down. How we do this is outlined below.

5.4.1 Build Costs Associated with Active Systems

With build costs we can break it down into two "dimensions". The first dimension is called the Work Breakdown Structure (WBS). The WBS is a method of splitting up the ship into logical sections and systems so that the design of the ship can be taken in manageable pieces. The need for this is especially true for HSC where the added complexity of many systems increases the required knowledge and skill levels of the designers.

Traditionally the WBS is split up into four levels the first two being separated by systems and levels 3 and 4 being separated spatially along the fire zones and sub fire zones. The work in this section is aimed at levels 2 and 3.

The systems we are investigating are essentially this first dimension. They are stated below:

- Smoke detectors
- Heat Detectors
- Automatic Alarms
- Manual Alarms
- Sprinklers
- Carbon Dioxide Systems
- Fixed Fire Fighting Systems
- Portable Fire Fighting Systems

The second dimension is the Cost Breakdown Structure (CBS). The CBS consists all the different types of cost associated with a system these are outlined below:

- Materials
- Outsourced services (studies, system design, etc)
- Subcontracts (basic design through to production)
- Direct costs (Travel, EU projects, tests, rent, etc)
- Internal Costs (Man/Hours, Administration, Services)
- Contingencies
- Bank charges/ Proceeds

With these two dimensions the designers are now able to start calculating the values of these costs. Clearly some of these are outside the scope of this project and it will be up to the designers to estimate the costs associated with them using their own tailored process.

S@S is capable of providing estimates of the following information:

- Type of Materials
- Grade of Materials
- Quantity of Materials (Mass)
- Type of Components
- Grade of Components
- Quantity of the Components
- Complexity of Design (For all relevant structures and systems)

From these areas this section of the cost model is interested in :

- Type of Components
- Grade of Components
- Quantity of the Components
- Complexity of Design (For all relevant structures and systems)

We are now able to construct the matrix that cost model is contained in. This is given below:

Table 5.4.1: Cost Matrix for Containment of Fire Active Systems

	Type of Components	Grade of Components	Quantity of the Components	Complexity of Design or Installation
Smoke Detectors				
Heat Detectors				
Automatic Alarms				
Manual Alarms				
Sprinklers				
Carbon Dioxide Systems				
Fixed Fire Fighting Systems				
Portable Fire Fighting Systems				

We now have to fill these boxes with values. To do this we have to refer back to the risk model and extract the values and translate this into numbers of components for the parameters in each row of this matrix.

For an example we have taken the smoke detectors situated in an area 10m by 10m. The variable ranges are:

Installation Requirements: distance from bulkhead:	0.5m – 2.5m
Floor area per detector:	0- 30m^2
Distance apart between centres:	3m – 7m
Time to operate versus smoke density:	2 – 7.25%

This means there are at least 4 detectors in this area and at most there are 8.

So the line in the matrix may look like:

Table 5.4.2: Example Entry in the Cost Matrix

	Type of Components	Grade of Components	Quantity of the Components	Complexity of Design or Installation
Smoke Detectors	Acme Ltd Smoke detector	A*	4 - 8	Level 2

The designer now inputs the cost per unit and multiplies by 4 and 8 to give the range of cost for this section. E.g. €20 * 4 = €80 and €20 * 8 = €160

He then looks at the complexity level and sees that that means it takes 1 man hour to fit a unit. This allows him to calculate up how many man hours the area will take and therefore how much the overhead costs of fitting them are.

This is a very simplified example but it is valid for the entire vessel.

5.4.2 Through Life Costs

Through life costs for "Containment of Damage and Fire" have to be taken as a whole. The only real through life costs that can be calculated with out taking the whole system into account are the maintenance costs, which are simply taken from the manufacturer's guidelines or from historical data for that type of active system.

Having said this, the potential impact of active systems in the containment and extinguishing of fire will have a huge impact on cost. We can estimate through the use of fire outbreak statistics how likely a fire is and then through our risk model we can see the probability of that fire not being put out.

A distribution for the severity of the fire is then fitted. This will allow us to calculate the potential capital costs and human costs associated with that fire. If we then run the simulation many times we will build up a distribution for the costs associated with the out break of fire in any given vessel.

This is incorporated into our cost model in two ways the first is to give a purely monetary value to all the costs including the cost of human life. This will allow us to enter the cost as though it were an overhead.

The alternative is to compare the design to a basis vessel and divided the cost of the risk control options by the human savings achieved. This process is known as the "Implied cost of Averting a Fatality" [Spouge, 1996]. It is proposed that both methods are available in the tool as both have advantages and disadvantages.

5.4.3 Relative versus Absolute

At the Helsinki PMC in September 2002 it was proposed that S@S use the absolute method of calculating the build cost. This means that estimates of the total cost of the vessel would be made. This means that for different designs we are calculating all the costs. This is the type of estimation demonstrated in the Smoke Detector Example.

During the discussion that followed it was argued by a significant part of the project that perhaps we should be looking at what are termed “Relative Costs” By this we mean the difference in cost when compared with a basis vessel.

This argument is especially strong when making improvements to a sister ship. As you all ready know how much it cost to build and run the first vessel it would be easier and perhaps more useful to be able to say:

“Ship B will be 15% cheaper than Ship A to build but will require 5% more maintenance on its hull every year (a particularly expensive overhead for HSC).”

There is merit in this discussion and it has been agreed that it should continue with WP5 leading a workshop on the topic in Nice in November 2002.

6. CONCLUSIONS

In this report, the work undertaken by all the partners responsible for the activities of Task 4.2 has been presented. Risk models for the containment of damage and fire in the respect of the effect of the human factors and of relevant passive and active systems have been detailed. Initial considerations on the cost models have also been presented, which will be further elaborated upon in the work to be carried out in Task 4.3, as well as within the activities of Work Package 5.

Task 4.3 will deal with the synthesis of a systematic method, which contrasts risks and associated costs pertaining to HSC damage and fire resistance, suitable for integration into Work Package 5. The input will consist of the developments in the work presented in this report. A link between the incidents considered in the project and potential societal and economic consequences (losses/gains of human life, cargo, money, environment etc.) will be established, through the development of an appropriate formalised framework. Example applications will be undertaken to assist in the refinement of the work.

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APPENDICES

Appendix A	List of Performance Shaping Factors (PSF's)
Appendix B	2000 HSC Code: Chapter 2 – Buoyancy, Stability and Subdivision
Appendix C	2000 HSC Code: Annex 8 – Stability of Monohull Craft
Appendix D	IMO Regulations relevant to Fire Safety of HSC
Appendix E	Description of Fire Safety Requirements (HSC Code – Chapter 7)
Appendix F	Fire Tests
Appendix G	Event Trees and Fault Trees associated with LSAs
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Appendix I	Regulatory Requirements for Active Systems associated with Fire Safety
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Appendix K	Fire Event Tree