2 Publishable summary

2.1 Project summary and objectives

There is little doubt in the maritime industry that the age of passenger ships capable of accommodating more than 8,000 people onboard has dawned. The very fact of a single floating platform hosting such a large number passengers and crew poses unprecedented challenges to designers, operators and regulators alike. Among them, fire safety is the most pertinent one, albeit the less catastrophic compared to collision and grounding, according to accident statistics (Figure 1). Considering that the design, production and operation of ships of this size unavoidably build on innovation, a discrepancy with the existing fire regulatory framework emerges naturally. That is, because regulations are largely built on past experience they cannot cater for ships of such complexity and size, and unnecessary constraints are imposed on novel designs, which although not inherently unsafe, may have difficulty satisfying the existing set of rules.

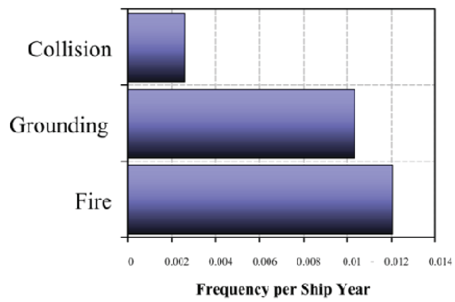


Figure 1: Frequency of collision, grounding and fire accidents in cruise ships, [1]

In response to this problem, FIREPROOF will elaborate on the development of a universally applicable regulatory framework for maritime fire safety, which in principle will be similar to the probabilistic framework for damage stability and it will address fire risk (concerning incapacitation and/or loss of life of crew and passengers) on passenger ships only. The FIREPROOF methodology is founded on a probabilistic model for ignition and generation of fire scenarios, and numerical models for fire growth and consequence assessment in terms of incapacitation and/or loss of life of crew and passengers. FIREPROOF is subdivided in four work packages (WP), only the first two of which are active in this reporting period of the project:

- WP1 - Scenario Generation
- WP2 - Consequences Assessment
- WP3 - Implementation and Benchmarking
- WP4 - Probabilistic Fire Safety Regulations

The outcome of the project will be submitted to Maritime Safety Committee at IMO for consideration and future enforcement. More details about FIREPROOF and regular updates about its progress can be found here: www.fireproof-project.eu.

2.2 A description of the work performed since the beginning of the project and the main results achieved so far

The governing idea of FIREPROOF is the rational assessment of fire risk, and in particular the assessment of the level of safety against fire hazards onboard passenger ships. In this context, risk is used as the measure of safety that needs to be minimised or reduced as far as reasonably practicable. Conventionally, the risk (R) associated to an unwanted event is defined as the product of its probability of occurrence (P) and its ensuing consequences (C): R = P × C. In this way, the notion of risk clearly differentiates from the notion of reliability, as it refers to events with catastrophic outcomes that occur only once. In the context of FIREPROOF, the outcome of a fire accident is related to the number of fatalities (societal consequences) of the exposed passengers and crew onboard a ship. Along these lines, risk can be formulated as follows, [2]:

(1)

Where:

- R_F: total fire risk;
- i: counter for the number of spaces onboard;
- ΔR_i: risk for space *i*;
- f_i: frequency of ignition in space *i*;
- j: counter for the number of escalation outcomes;
- $P(E)_{i,j}$: probability of escalation from space *i* with outcome *j*;
- $N_{i,j}$: number of fatalities in space *i* with outcome *j*.

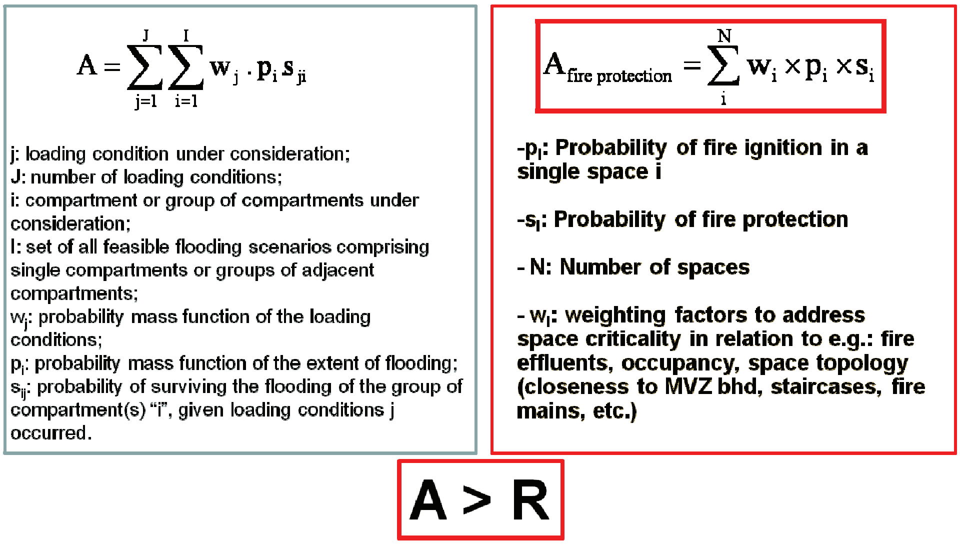


Figure 2: Flooding and fire probabilistic frameworks

The indices *i* and *j* represent the fire scenarios and their variations respectively, as it is discussed in [3]. The elements of Eq. (1) will be analysed in more detail in the following two sections, namely, the *Scenario Generation (WP1)* and the *Consequence Assessment (WP2)*. Consolidation of all the derived information will be formulated (in parallel to the flooding framework of SOLAS Ch.II-1) as presented in Figure 2. In both frameworks the attained index (A) should be larger than the required index (R). In this context, fire protection should be understood as the "contain, control and suppress" objectives described in SOLAS Ch. II-2. Moreover, the compatibility in the formulation of the two frameworks opens the way for their future unification.

The developed fire framework will be implemented to all spaces onboard, i.e. for every space of a main vertical zone and for all zones, Figure 3. In this manner, a clear picture (map) of the fire risk across the ship will be drawn during the approval process. It should be stressed that the large number of spaces on board a passenger ship can deem this exercise very cumbersome. For this reason, a product model with the required information and integration of all the necessary tools for fire risk analysis will be elaborated upon in *WP3 – Implementation and benchmarking*.

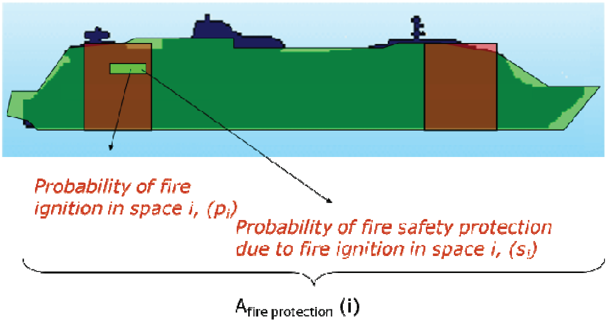


Figure 3: Application of the proposed framework for all spaces onboard a passenger ship

WP1 - Scenario Generation

A methodology for the generation of fire scenarios and the quantification of injuries and fatalities on the exposed population of passengers and crew is one of the key elements of the project. A fire scenario describes the development of fire in a space onboard by taking into consideration the fire ignition and the effectiveness of passive and active fire safety means, namely detection, containment and suppression. The fire development in an enclosure depends on various parameters, like the fire type and size, geometrical and ventilation characteristics as well on effectiveness and reliability of the fire fighting systems and crew (or passenger) intervention. In the process of scenario generation a database with fire incidents was compiled, [4].

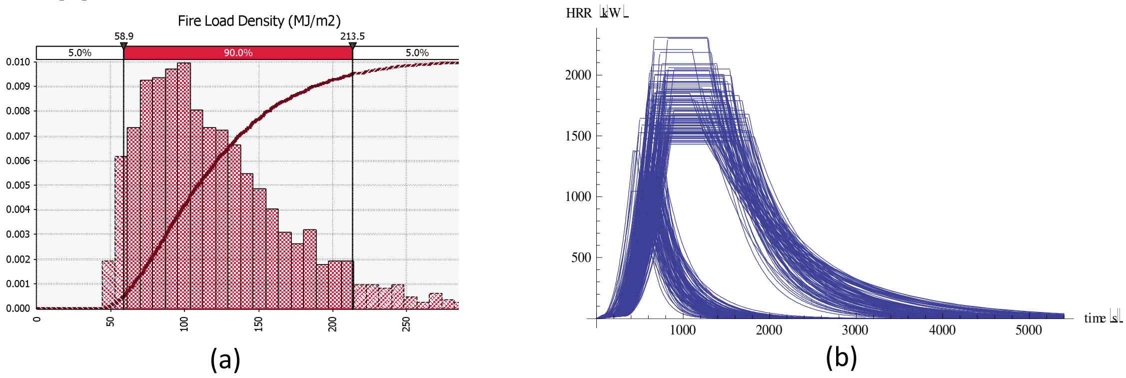


Figure 4: (a) Fire load density for a passenger cabin, and (b) Probabilistically generated HRR curves

Scenario characteristics related to the fire type, size and development in a space are represented by the Heat Release Rate (HRR) curve. An HRR curve describes the main fire stages, namely the *incipient*, the *growth*, the *fully developed* and the *decay* stage. A physically rational model that generates probabilistically HRR curves based on key parameters like fire load, incipient time, growth potential and others has been reported in [5]. Due to the uncertainty associated to these parameters (e.g. the amount and type of the combustible materials present in a space), they are represented as random variables, Figure 4(a). A number of HRR curves are produced probabilistically, Figure 4(b), and used as input in terms of fire characteristics in the scenario generation methodology, as well as in the numerical tools for fire modelling of WP2.

In addition, the reliability and effectiveness of the fire safety systems is incorporated in the methodology using generic fault trees, [6]. For the component failure rates, manufacturers' data and data available from similar equipment is used.

Scenarios and their variations are generated using the data mining technique, [7], in combination to Bayesian Networks, Figure 5, where the critical set of events are identified for various states of the automatic detection and suppression systems, the ventilation openings, etc., [8]. The initial set of scenarios was based on the information available in the project database, [4], and a project wide workshop that was held in Southampton on the 15th of December 2010 for their verification, [9].

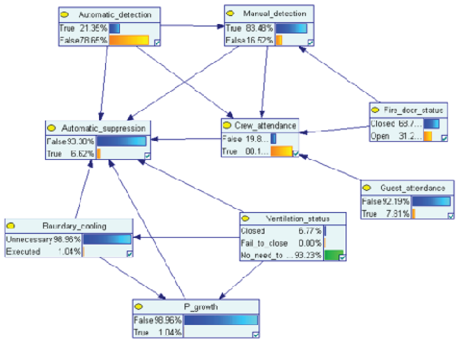
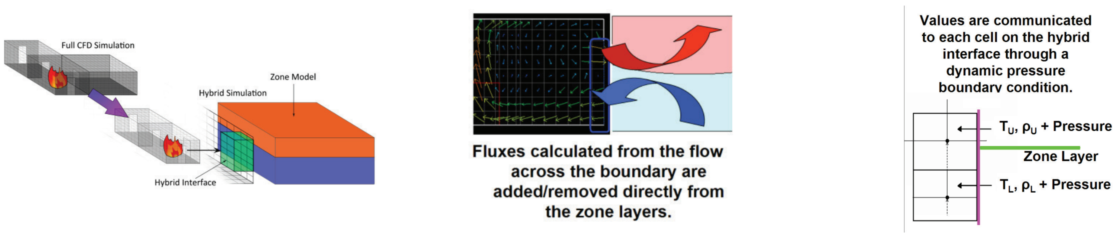


Figure 5: Scenario generation with a Bayesian Network

WP2 - Consequence Assessment

The definition of scenarios in WP1 is followed by simulations with numerical tools in order to gain deeper insight into their potential consequences. The outcomes of fire scenarios and their variations will be assessed with

(i) The formulation and development of an integrated fire model based on a hybrid (Figure 6) between Computational Fluid Dynamics (CFD) and zone models that combines the advantages of both models by reducing the computation time compared to a full CFD model and increased applicability and fidelity compared to a zone model for a wide range of fires). The newly developed model is based on the SMARTFIRE code and will use CFD modelling for complex geometries and areas beyond the reliable application of the empirical zone models. Zone modelling will be applied in areas where the empiricism can be consistently applied, [10].



(a) (b) (c)

Figure 6: (a) Conceptual view of Hybrid fire model, and data transfer from (b) CFD to zone model, and (c) zone model to the CFD code

(a) (b)

Figure 7: (a) maritimeEXODUS with smoke concentration from fire model imposed on the evacuation, and (b) VR representation of passenger mustering

(ii) The use of a societal consequence model is based on the coupling of the initial occupancy of various spaces, the fire growth simulations produced by the hybrid model, and the evacuation behaviour and passenger movement (Figure 7). The maritimeEXODUS model, [11], which is deployed in this case, can utilize physiological toxicity models (e.g. Fractional Effective Dose FED), which predict injury, incapacitation and fatality based on the exposure to toxic fire products such as carbon monoxide and hydrogen cyanide.

2.3 The expected final results and their potential impact and use (including the socio-economic impact and the wider societal implications of the project so far)

The hardly undisputed fact of strong societal demands for high standards of service and safety have motivated the work in FIREPROOF from its inception. The former issue is largely based on innovative arrangements onboard passenger ships and the latter on current regulatory framework for fire safety (in this particular case). As the passenger ships become progressively more accessible to larger proportions of society, the ship sizes increase and along with them the complexity and sophistication of the facilities offered onboard, Figure 8.

(a) (b)

Figure 8: Size and complexity increase of cruise ships

Considering that this trend is expected to be maintained in the foreseeable future, FIREPROOF will contribute and support a similar upgrade in the philosophy of the regulations in order to ensure that the much needed safety standard will reflect the complexity of passenger ship operations and will remain high.

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