SafePASS Project: A Risk Modelling Tool for Passenger Ship Evacuation and Emergency Response Decision Support

Authors

Stefanou Evangelos[a*], Stefanidis Fotios[a], Boulougouris Evangelos[a],Louvros Panagiotis[a],Komianos Alexandros[a],Michalec Romain[a],Aung Myo[a], Sotiralis Panagiotis[b], Annetis Emmanouil[b]

[a] University of Strathclyde – Maritime Safety Research Centre (MSRC), 16 Richmond Street, Glasgow G1 1XQ, United Kingdom

[b] National Technical University of Athens (NTUA), 9 Iroon Polytechniou Str., Athens, 157 80, Greece

UNIVERSITY of STRATHCLYDE
MARITIME SAFETY
RESEARCH CENTRE

1. Executive summary

One of the biggest challenges in the field of maritime safety is the integration of all the systems related to the evacuation and emergency response under one Decision Support Tool that could broadly cover all the emergency cases and assist in the co-ordination of the evacuation process. Besides, for a decision support tool to be useful we need to be able to calculate the Available time to Evacuate based on real-time data, such as the passenger distribution on board and of course based on the various sensor data that will monitor the damage and its propagation. For all the above, the risk modelling tool developed in SafePASS H2020 project is able to estimate the potential fatalities both in the design phase and in real-time, assessing the evacuation and abandonment risk dynamically, based on real-time data related to the passenger distribution, route, semantics, LSA availability, procedural changes, and damage case (fire or flooding) propagation.

2. Introduction

Maritime emergency response and ship evacuation are complex, multi-variable problems and any effort towards improving the current performance level requires an approach that will be capable of capturing the dynamic nature of the associated parameters.

Following, the European Commission (European Commission, 2018) has taken a proactive approach in addressing the challenges of Maritime Accident Response by providing funding towards research and innovation initiatives that have the potential of not only minimizing the frequency of maritime accidents, but also mitigating the consequences through novel systems and updated emergency procedures. The SafePASS project lies well within this overarching strategy of reducing the risk by tackling, simultaneously, the various points of failure during an emergency and looking into solutions that improve the performance standards during the mustering and the abandonment phase of a passenger ship. One of the most crucial solutions developed within the project is the creation of a risk model that is able to radically improve the emergency response.

*Corresponding author. Tel.: + 44(0) 7753964327

E-mail address: evangelos.stefanou@strath.ac.uk

3. Background

The purpose of an evacuation and abandonment risk model is to highlight the major influences that affect the probability of successful evacuation and abandonment. It should also provide risk estimates for the persons onboard during the various phases of the process. This will be accomplished by bringing together historical accident data gathered and analysed with a number of underlying assumptions and expert judgements.

Generally, risk models are developed based on decision sequences that specify major ramifications in the sequence between accident and consequences. Such a generic model for life-saving appliances was submitted in IMO as part of the FSA for bulk carrier LSAs in 2001 (MSC 74/5/5) (IMO, 2001).The EU research project SAFECRAFT (Safe abandoning of ships, Improvement of current Life-Saving Appliances Systems, 2004 to 2009) proposed a methodology for assessing the performance of LSAs using performance indicators, considering the whole sequence of mustering, abandonment, waiting at sea and recovery [(Prat, et al., 2008), (Mery N., 2010)].

The model created and which is described briefly herein is based on publicly available and well-established previous studies. SafePASS risk model is based on the pioneering works conducted in GOALDS (Papanikolaou, et al., 2013), EMSA III [(Zaraphonitis, et al., 2013), (Konovessis, et al., 2015)], eSAFE (Luhmann, et al., 2018) and the more recent submission in IMO SSE7/INF.3 (IMO, 2020). The model introduces a sequence of events during the evacuation and abandonment of both passengers and crew, onboard passenger ships, with emphasis being given primarily to large capacity vessels. As most of the previous models were staying at higher-level events, in the SafePASS model, a more detailed approach proposed in SSE7/INF.3 (IMO, 2020) is adopted. Its advantage is that it introduces several sub-models which address various aspects of the global risk and extends beyond the conventional risk models, including the search and rescue probability as a risk contributor.

4. Solution

In that light, the Maritime Safety Research Centre of the University of Strathclyde is developing, within its work on the SafePASS Horizon 2020 project, a Risk Modelling Tool (RMT) that will form the backbone of a Decision Support System (DSS), which will assess the emergency state from Alarm to Search and Rescue. In practice, the SafePASS RMT is dedicated in the quantification of the projected risk and the Potential Loss of Life.

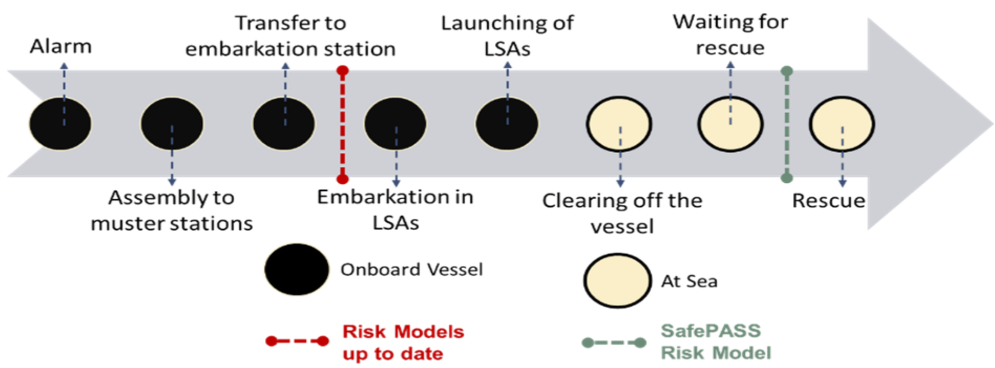

Figure 1. Alarm to Search and Rescue graph.

The SafePASS RMT is comprised by a series of influence diagrams corresponding to distinct states of the event sequence shown above. Each influence diagram describes the network of critical parameters that impact each stage of the emergency state and evacuation/abandonment process and is based on contemporary research results and an extensive analysis of serious passenger ship accidents. The structure and elements of the influence diagrams, together with input from on-board sensors and other SafePASS systems and devices, will allow for the quantification of risk in real-time.

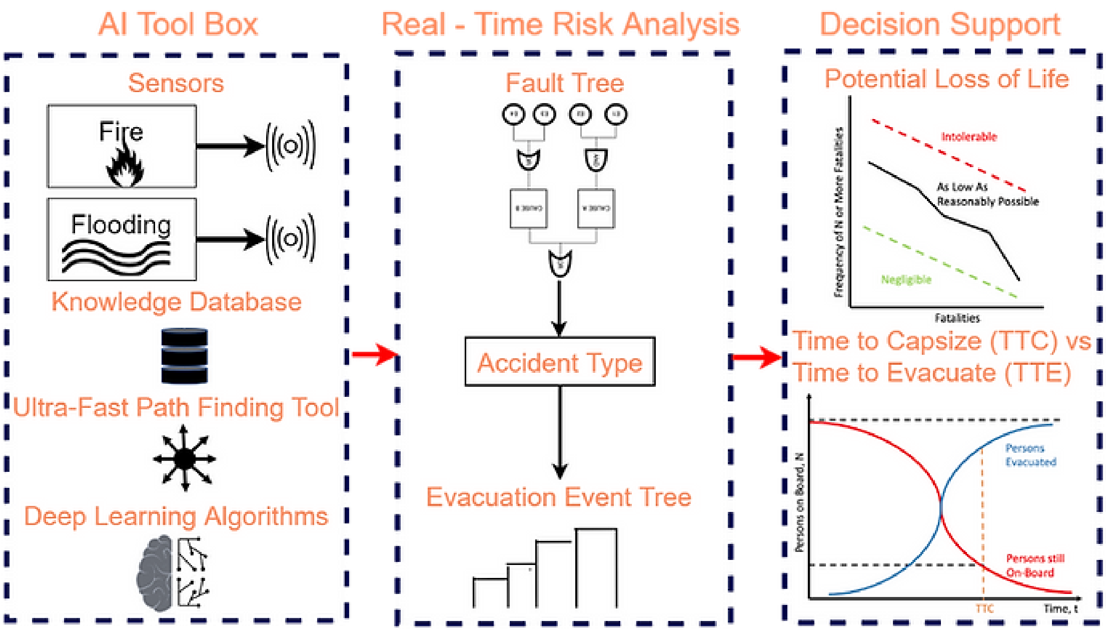

Figure 2. Flow of the Decision Support Tool

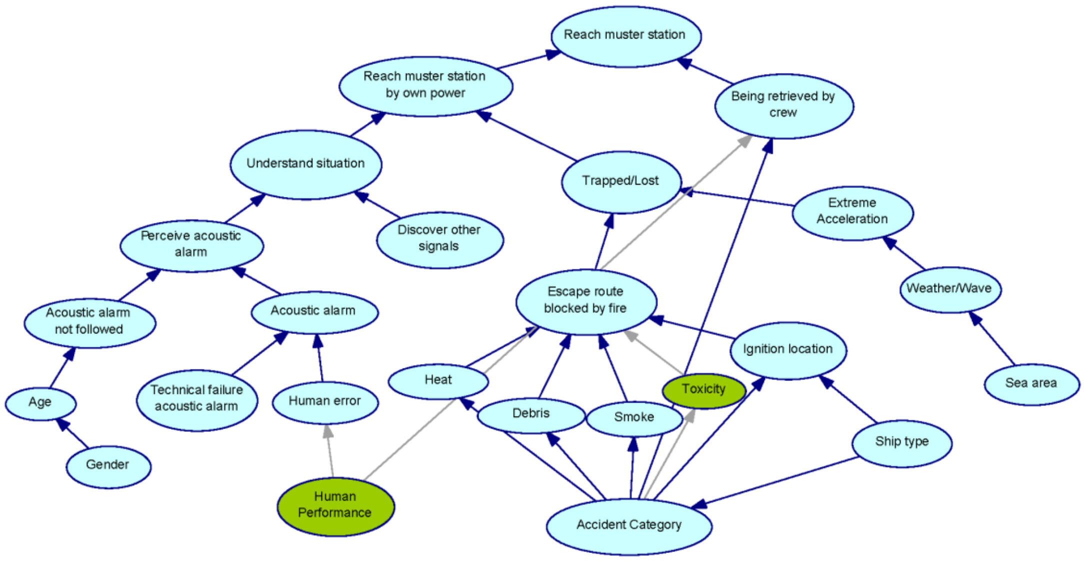

Figure 3. Bayesian network for Reaching Muster Station (fire/explosion)

One novel output of this approach is the coupling of the Available Time to Evacuate (ATE), depending on the emergency state (i.e. flooding or fire) propagation data and simulations, with the Estimated Time to Evacuate (ETE), based on real-time passenger distribution information and crowd dynamic simulations. This overarching dynamic risk modelling analysis allows for the calculation of the risk of ship loss and of the potential fatalities at each stage, hence providing the decision makers with vital insight on the potential consequences based on real-time data.

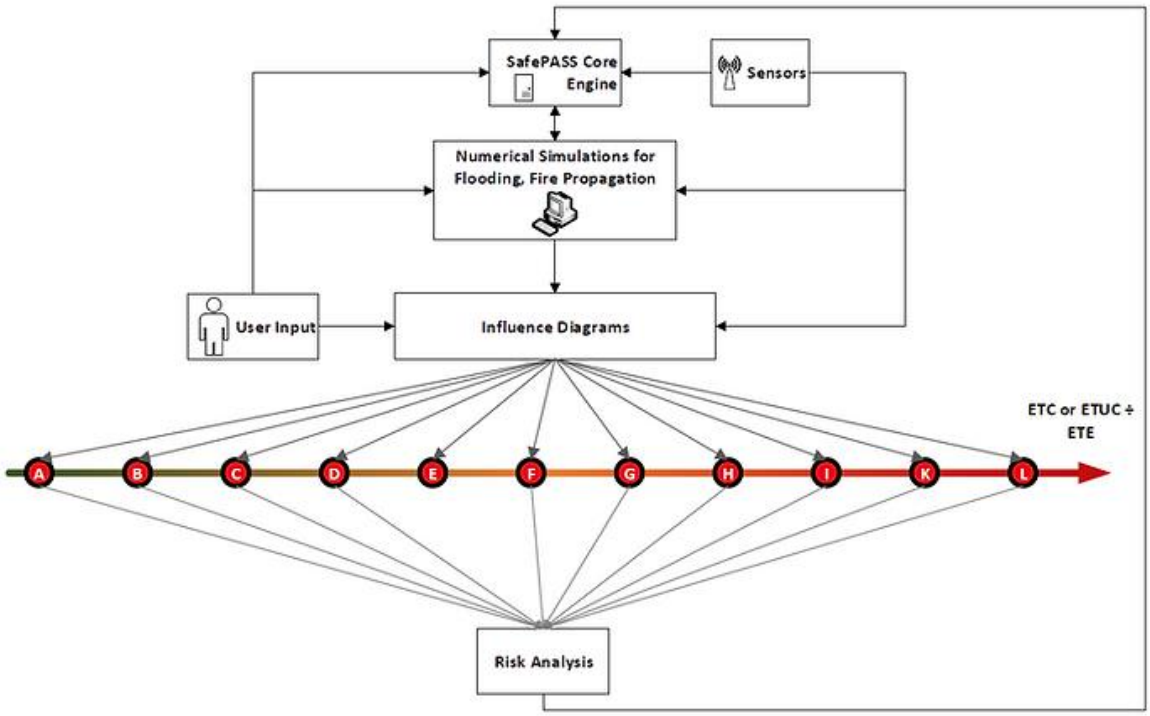

Figure 4. SafePASS Dynamic ET Information Flow

The goal of the RMT is to provide the decision makers with useful, up-to-date risk metrics, based on the unfolding emergency state, that could assist their risk mitigation efforts and emergency response performance.

Hazards considered

Based on the accident database developed, the SafePASS risk model considers the following hazards:

- collision
- grounding
- fire & explosion

To be more precise, the Risk modelling tool is consisted of the following four components which will be further explained herein:

- The Numerical simulation database
- The Case-Based Reasoning Algorithm
- The Dynamic Risk Analysis
- The Risk modelling Tool dashboard

1) Numerical simulation database

The database of the numerical simulations contains critical flooding, fire, and evacuation scenarios. In this way, the hazards already mentioned have been taken into account. Real-time information about the distribution of the passengers onboard, the location and extend of the damage, blocked routes and ship stability data will allow, through the CBR methodology, an estimation of the time available and time required for evacuation. These data will be used for prognostic purposes and will permit the dynamic assessment of the risk.

To begin with the flooding simulations, these are required to build the case base. The accuracy of those simulations is dictating the maximum possible accuracy of the prediction. The time-domain - state of the art, software PROTEUS is used to evaluate conditions across time. This method is much more accurate than static simulations in the presence of a seaway and transient phenomena. However, it is much more expensive computationally. The overall approach is to use static simulations to decide which cases require closer inspection with PROTEUS. The greater the size of the database the better the performance of the CBR methodology, but much more time will be needed to create and access the database. The output will be the expected time to capsize, or more specific information on when the vessel becomes unattainable. This is linked to the survivability of passengers and time available for effective evacuation but also to large roll angles which can severely slow or outright stop passengers and affect LSA deployment. Besides, the spaces untraversable due to flooding are also assessed. For instance, flooded corridors may slow down passengers or outright prohibit their use or watertight openings will probably be closed or unavailable.

To facilitate the fire risk aspect of the risk modelling tool, fire simulations are conducted using Pyrosim Software, a graphical user interface of the FDS software. More specifically, the results of such simulations will indicate which areas are blocked or impaired due to fire and smoke propagation or increased toxicity levels. In this way, the evacuation simulations will be also fully updated and ready to capture any given critical scenario.

Finally, the evacuation simulations were performed by the EVI software, which allows for the estimation of the evacuation time needed in each scenario. Moreover, EVI has multiple uses in the SafePASS project; It is initially being used to benchmark specific scenarios. In the meantime, a series of accident flooding simulations are being examined, the outputs of which, in terms of ship motions and flooded areas are being fed into Evi with the purpose of assessing the available time to evacuate and calculating the number of potential fatalities. Consequently, Evi is also playing a key role on the development of the dynamic risk model of the project which will serve as a real-time Decision Support System.

In the following figures you will find a few screenshots from simulations conducted for the creation of the database.

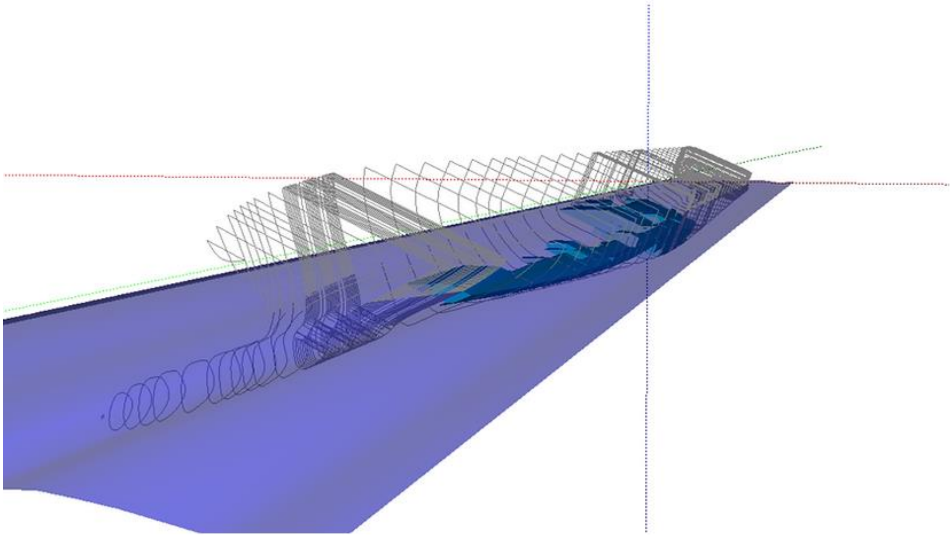

Figure 5. Flooding Simulations using PROTEUS software.

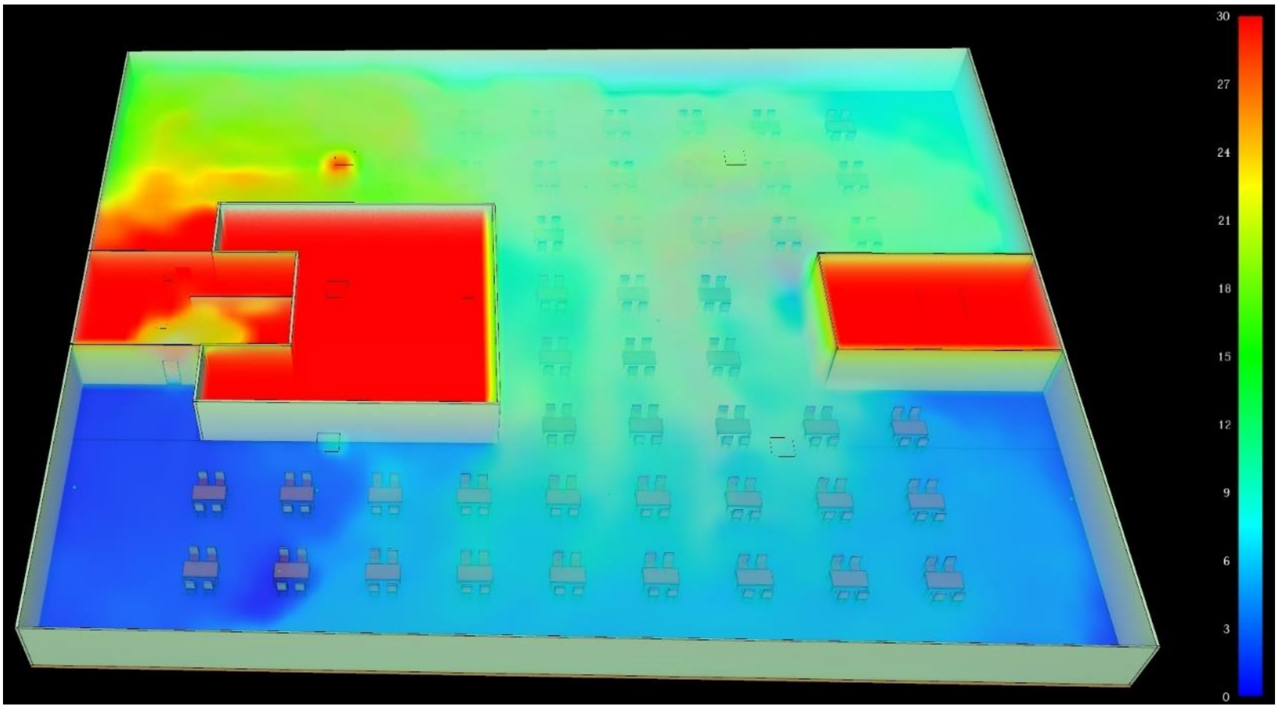

Figure 6. Fire simulations using FDS software.

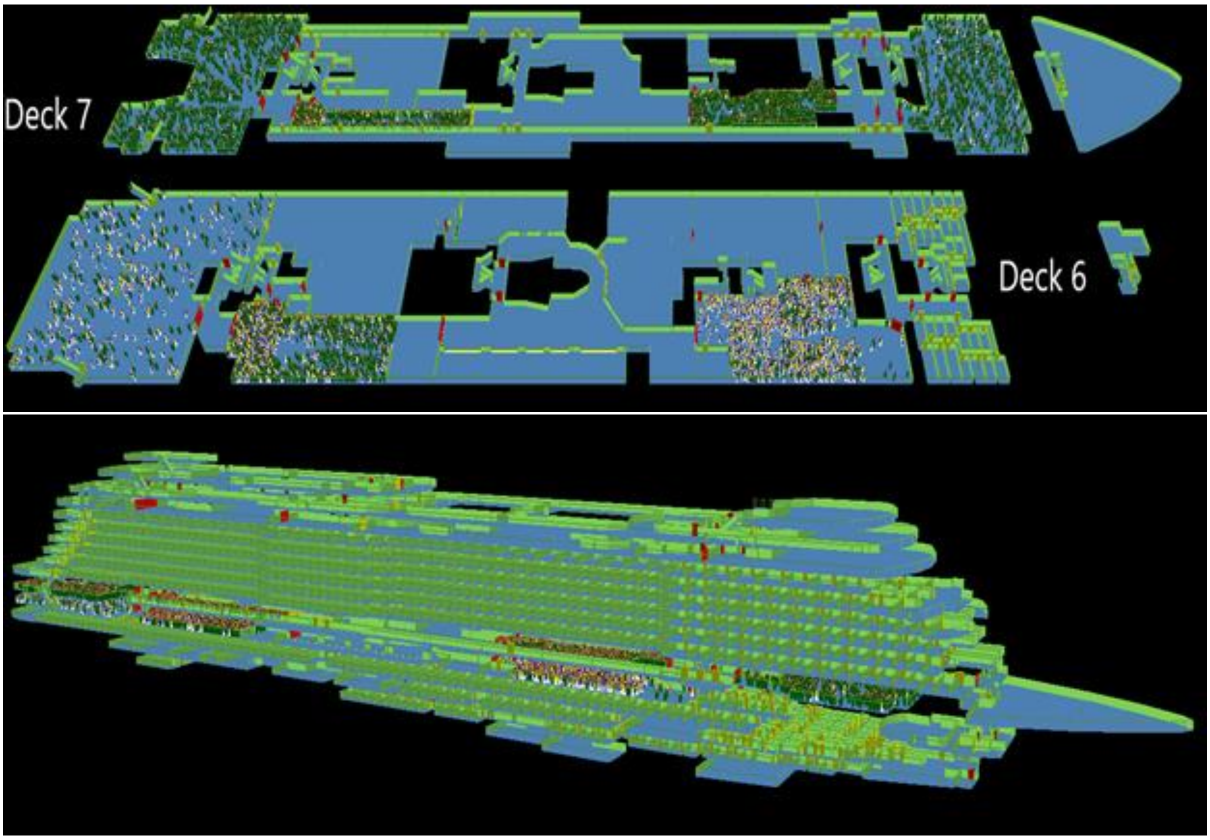

Figure 7. Evacuation software EVI

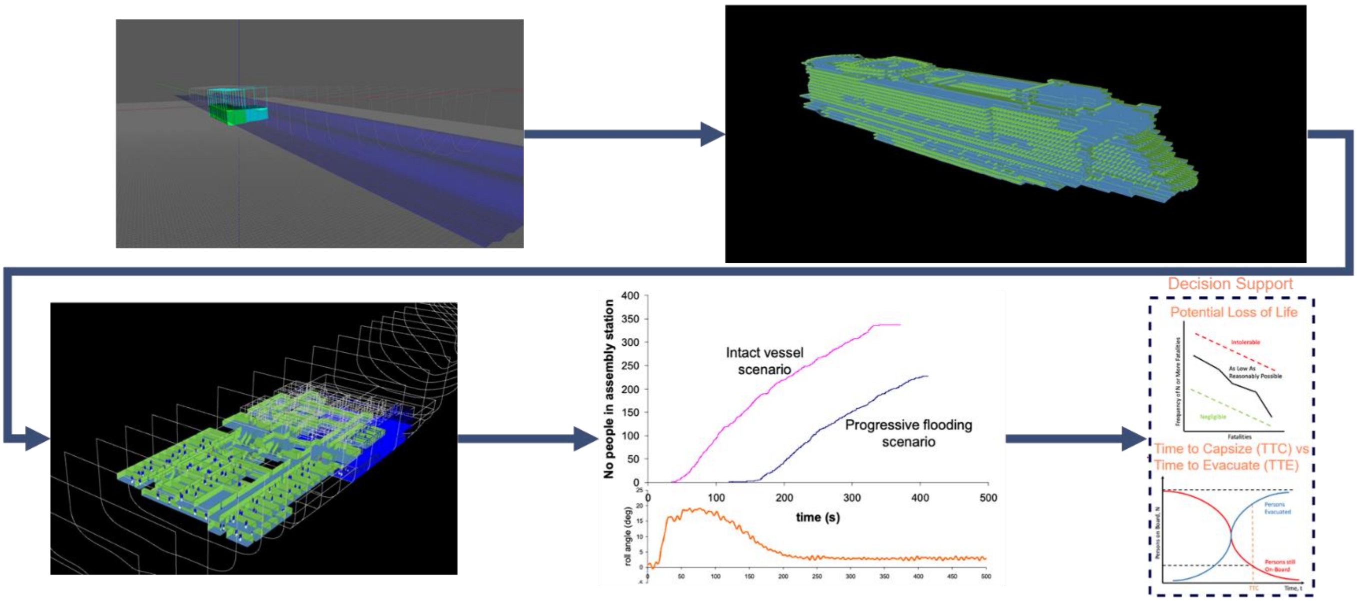

Figure 8. Correlation per the various software tools.

2) Case-Based Reasoning Algorithm

The numerical simulation tools available today are able to predict quite accurately the outcome of even the most complex flooding damage scenarios.

Case based reasoning, or CBR, is a problem-solving approach that relies on relevant past cases to find solutions to emerging situations. In this process, similar situations, which happened in the past, are searched for and the experience gained in those situations is used. The problems and their solutions are represented by cases and these cases are generally stored in a dynamic database (or case base).

From (J. L. Kolodner Artif. Intell. Rev., 1992):

- Case-based reasoning allows a reasoner to propose solutions in domains that he/she/it does not understand completely.
- Case-based reasoning gives a reasoner a means of evaluating solutions when no algorithmic method is available for evaluation.
- Cases are particularly useful for use in interpreting open-ended and ill-defined. concepts.
- Remembering previous experiences is particularly useful in warning of the potential for problems that have occurred in the past, alerting a reasoner to take actions to avoid repeating past mistakes.
- Cases help a reasoner to focus its reasoning on important parts of a problem by pointing out what features of a problem are the important ones.

Case based reasoning revolves around the idea of experience. Experience in this sense is stored in cases, hence the term “case-based”. This experience, if devolved or deconstructed is simply a combination of inputs and outputs; how a system responds to specific inputs. Using this “black box” approach many problems can be solved based on past experience. This is a function that humans frequently use and is the basis for many sciences as it is directly linked with concepts such as empiricism. For example, medicine is largely based on using the symptoms (evidence/input) to discover what condition afflicts a patient and then use an appropriate set of treatment options to cure that condition based on what has been shown to work. Doctors routinely reach a diagnosis by recollecting a past case that had similar symptoms. They can then rapidly apply what worked or avoid what did not using their experiences. Just from this example, it is obvious that case-based reasoning is an important tool, especially in highly complicated cases such as medicine. It is also easy to see how this process can lead to accurate conclusions skipping otherwise necessary steps of due diligence and investigation.

The main reason why CBR is considered in this problem is the speed of execution. The processes and tools to conduct a detailed simulation of a damaged ship in waves exist and can provide adequate answers for the task at hand. However, the time and resources needed for those to be effective is well beyond what is available for an emergency or what can practically be provided in an uncertain environment such as a nautical accident. CBR could be the answer to providing swift answers that can be constantly updated with new information to be used to predict to a large degree the behaviour of the vessel in the future. Such information is of paramount importance for decision support. Namely, evacuating or not the vessel could mean the difference between mass casualties or no casualties. The time to capsize or sink, if known can give rescuers and the ship’s crew a time window to plan operations within. For example, if sinking is imminent passengers should evacuate immediately, while if the time to sink or capsize is large then safer rescue operations could be planned such as towing the vessel to port or waiting for external assistance (using rescue boats or helicopters) to transfer the passengers to land or to another vessel. Taking such decisions has been a judgement call so far, which even though is found on human-based CBR lacks the epistemic certainty that can be provided by analysing the ship's behaviour and environment through first-principles calculations.

The approach of CBR for the case of a damaged ship will be based on pre-calculated cases similar to detail to what naval architects are accustomed to in case studies but through the process of CBR a multitude of cases will allow for extrapolation of a new, emerging case from the calculated ones. This will necessitate an able amount of precalculated cases to be run along with an appropriate organisational and procedural regime (indexing).

3) Dynamic Risk Analysis

This module contains the Bayesian networks that correspond to different stages of the evacuation, abandonment, and survival at sea phases. The dynamic analysis of the risk is made possible by coding the Bayesian network models for each stage in python and updating the 'evidence' of their basic influence parameters based on user input or 'live' data. The output of the Bayesian networks is the posterior probability distribution of the possible states of the top event of each network.

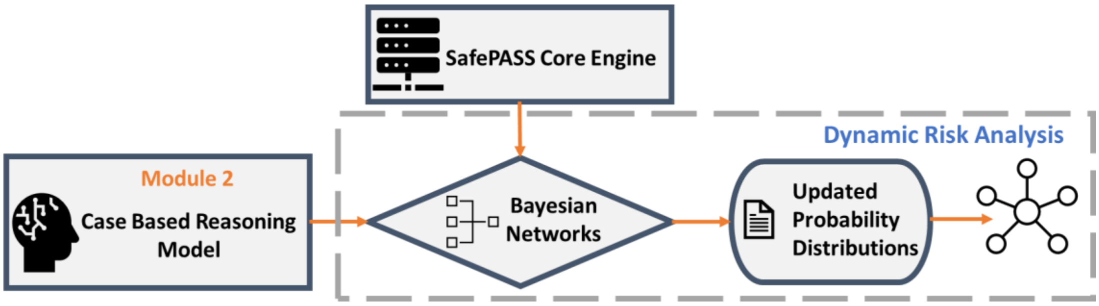

Figure 9. Module 3: Dynamic Risk Analysis

In fact, the purpose of developing the risk model is to evaluate and mitigate the risks related to the evacuation process. This is materialised through dealing with the dynamically changing risks during an evacuation, but also through the evaluation of various Risk Control Options (RCOs). The model is structured in two levels. The first one refers to an event tree, similar to the event trees developed within the Formal Safety Assessment (FSA) of Cruise Ships (IMO, 2008) and the EMSA 3 study (A. Papanikolaou et al., 2015) but by focusing on the evacuation process. Figure 10 describes the evacuation process, according to (SSE4/3., 2017), while also highlighting the focus of the SafePASS project.

The developed trees refer to the main accident categories, i.e., collisions, contacts, groundings, fire and explosions. The second level of the model refers to a series of sub-models, constructed as static Bayesian networks. Each of the sub-models corresponds to a specific event gate within the event tree and includes all the parameters related to that specific phase of the evacuation process. All the sub-models, i.e., Bayesian networks, regarding flooding accidents (collisions, contacts and groundings) are listed in the following page:

1. Capsize/Untenable Conditions
2. Reaching Muster Station
3. Lifeboat/LSA Availability
4. Transferring and Embarking on Lifeboats/LSAs
5. Lifeboat/LSA Lowering
6. Lifeboat/LSA Clearing
7. Survival in Lifeboat/LSA
8. Survival at Sea
9. Fatality in Unsafe Lowering (linked to the lowering phase)
10. Capsize and Evacuation (linked to the clearing phase)

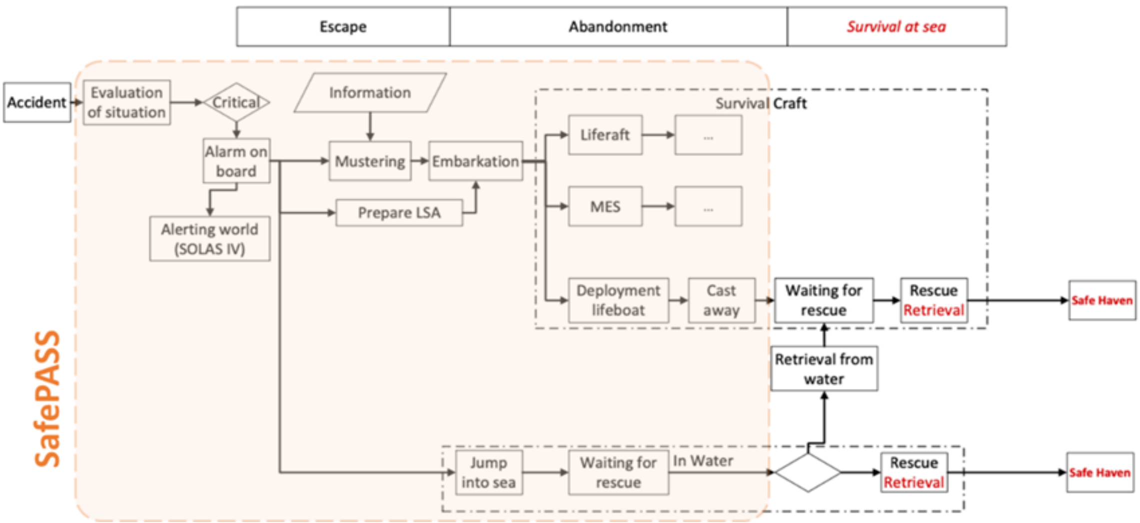

Figure 10. Event sequence in emergency case (SSE4/3., 2017)

4) Risk modelling Tool Dashboard

A selection of the emergency critical information for the decision makers is being displayed in dashboard format containing various widgets via the function of Module 4. This Module is responsible for the post-processing of the output from Module 3 to analyse and depict the various risk metrics in a user-friendly format. It is in this module where, for each stage, the potential fatalities are calculated, based on the Bayesian models' outputs and the exposed population.

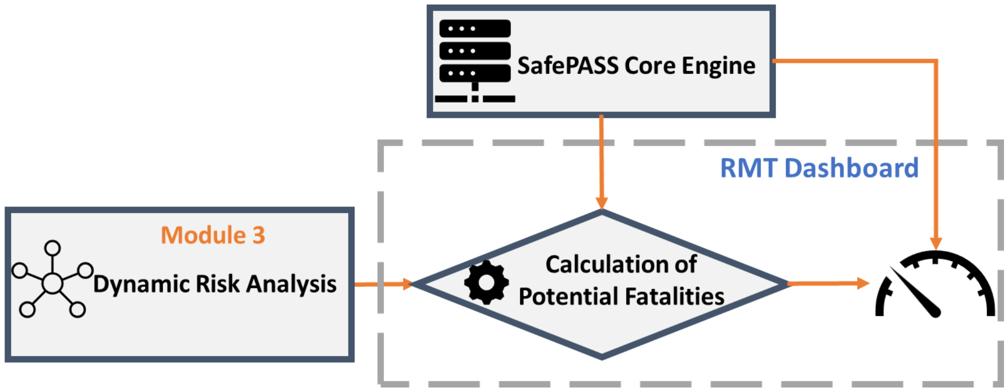

Figure 11. Module 4: RMT Dashboard

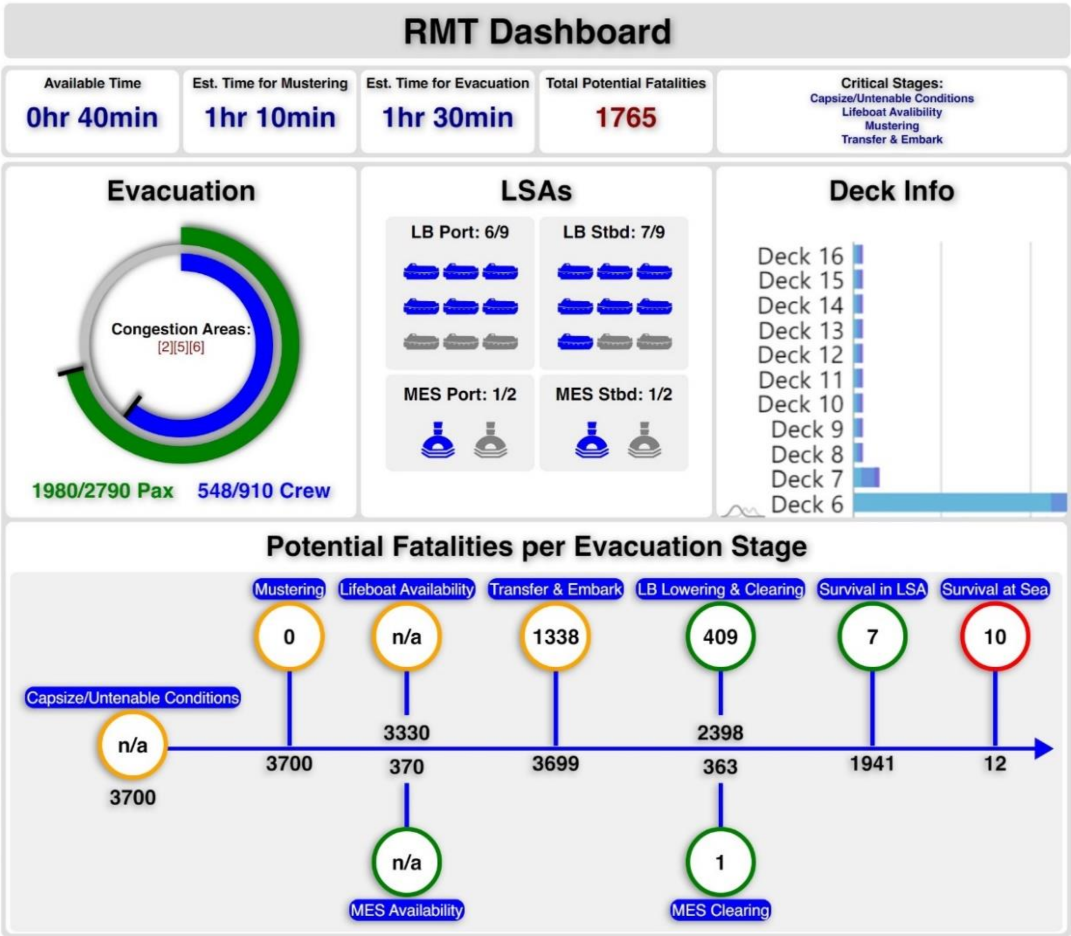

Figure 12. Results' visualisation

5. IMO Submission

At this point, it is crucial to highlight the significance of such actions and promote the outcomes of similar successful projects. In this way, the results may contribute to a safer maritime emergency response reducing risk significantly and saving life at sea.

For this reason, the European Commission has submitted to the IMO an INF paper entitled as: 'REVISION OF SOLAS CHAPTER III AND THE LSA CODE REVISION OF SOLAS CHAPTER III AND THE LSA CODE | Information on the EU research project SafePASS', with an insight to the risk model developed within the SafePASS project considering all relevant influences on the survivability of people.

Furthermore, the detailed models provide input for the development of functional requirements for SOLAS Chapters II-2 and III, by highlighting the parameters to be considered when developing expected performances. Following, this document focuses on the Risk Modelling Tool, highlighting the fact that it is able to provide estimates of the potential fatalities in various stages of the evacuation, abandonment, and survival at sea phases. This is calculated in a timely manner and based on "live" data and the exposed population on each stage.

Afterwards, it explains that all information, together with additional information on influence parameters are then being inputted in the Bayesian networks of the risk model and provide updated probability distributions for the potential outcomes of each stage of the evacuation, abandonment and survival at sea phases. Finally, this report ends up by bringing into the forefront the RMT dashboard and its ability to calculate the potential fatalities by displaying them together with other evacuation related information.

6. Conclusions

To sum up the SafePASS RMT can provide estimates of the potential fatalities in various stages of the evacuation, abandonment, and survival at sea phases. They are calculated in a timely manner and based on 'live' data and the exposed population on each stage. The four modules comprising the SafePASS RMT have been presented and their underlying assumptions and methodologies have been outlined. Their integration under the RMT framework creates this novel tool that allows the flow of info in real-time to the decision makers onboard large passenger ships.

Module 1 of the RMT contains the demonstration scenarios that were selected for fire and flooding cases as well as their matching evacuation simulations. The main task of this module is to create pairs of potential ASET and RSET values in extreme cases. Module 2 is then responsible for determining, based on 'live' data, which is the database case that should be used in order to make predictions on the future state of the damage. That information, together with additional information on influence parameters are then being inputted in the Bayesian networks of Module 3 and provide updated probability distributions for the potential outcomes of each stage of the evacuation, abandonment and survival at sea phases. Finally, the RMT dashboard Module calculates the potential fatalities and displays them together with other evacuation related relevant information.

7. Acknowledgements

The SafePASS project has received funding from the European Commission's Horizon 2020 Research and Innovation programme under the Grant Agreement No. 815146. The opinions expressed are those of the authors and the European Commission is not responsible for any use that may be made of the information it contains. This work was supported by DNV and Royal Caribbean Group, sponsors of Strathclyde University's MSRC, NTUA and other partners of the SafePASS project. The opinions expressed herein are those of the authors and do not reflect the views of the sponsors.

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