Final Report Summary - SAFEGUARD (Ship evacuation data and scenarios)

Executive summary:

The collection of human performance data in full-scale ship trials is vital for the calibration and validation of ship based evacuation models. The IMO Fire Protection (FP) Sub-Committee in their modification of MSC Circ 1033 at the FP51 meeting in February 2007 invited member governments to provide, '...further information on additional scenarios for evacuation analysis and full scale data to be used for validation and calibration purposes of the draft revised interim guideline.' The purpose of the SAFEGUARD project was to address this requirement by (a) providing full-scale data for calibration and validation of ship based evacuation models and (b) proposing and investigating additional benchmark scenarios to be used in certification analysis. The results of both of these tasks have been reported to the IMO in the form of information papers for possible incorporation into future modifications of MSC Circ 1238.

Project Context and Objectives:
How long does it take to evacuate a ship?

In particular, how do people behave in a maritime emergency, and how long do they take to reach their mustering stations?

To anyone concerned with the safety of passengers and crew, these questions are of vital importance. However, to this date little real-life data on human behaviour in a maritime emergency is available. Hence in an attempt to answer the above questions, naval architects, ship operators and regulators routinely utilise evacuation simulation software. While these tools produce plausible results, the lack of real-life data means that it is very difficult to assess their accuracy and reliability.

To improve this situation, the Framework Programme 5 project FIRE EXIT collected full-scale passenger response time data on a ship at sea [3]. This work prompted the International Maritime Organization (IMO) to revise the protocols for passenger ship analysis and certification [4].

Starting in April 2009 and finishing in November 2012, the SAFEGUARD project has successfully completed its objectives. A total of five full-scale passenger trials were performed in 2010/11 on three different vessels:
- A ROPAX ferry operated by Color Line;
- A cruise ship operated by Royal Caribbean;
- A ROPAX ferry with cabins operated by Minoan Lines.

Based on this work, the SAFEGUARD project has produced the following results:

- Five response time data-sets, consisting of 2,366 data points;
- Two validation data sets with more than 3,000 data points in total;
- A validation protocol and acceptance criteria for the evaluation of maritime evaluation simulation tools;
- A set of enhanced certification scenarios, including the effects of fire as well as trim and heel.

These results are presented to the IMO in the form of three information papers, including recommendations for future revisions of the regulations on evacuation analysis.

Project Results:

3.1 Sea Trials

Understanding how people behave in emergency situations within maritime settings is vital if we are to design and develop evacuation efficient vessels and crew evacuation procedures, train crew in the management of evacuation situations, develop reliable ship evacuation models and regulate the design and operation of vessels. An essential component of this understanding is the collection and characterisation of human performance data. Unfortunately, little data relating to passenger response time or full-scale validation data in maritime environments exists. In the first International Maritime Organization (IMO) document to specify protocols for the use of ship evacuation models for the analysis and certification of passenger ship design, IMO MSC Circ. 1033 [1], an arbitrary uniform random distribution was set to represent the response time behavior of passengers. This has been shown to be
was set to represent the response time behavior of passengers. This has been shown to be unrepresentative of actual passenger response time and liable to produce incorrect or misleading conclusions concerning the suitability of ship design for evacuation [2]. As part of the EU framework 5 project FIRE EXIT, passenger response time data was collected for a passenger ship at sea [3]. This data was accepted by IMO and used in the formulation of IMO MSC Circ. 1238 [4], the modified protocols for passenger ship evacuation analysis and certification. However, the response time data produced by FIRE EXIT related to only a single passenger vessel. As such the data cannot be considered representative of passenger ships as a whole. The IMO Fire Protection (FP) Sub-Committee in their modification of MSC Circ. 1033 at the FP51 meeting in February 2007 [5] invited member governments to provide, '...further information on additional scenarios for evacuation analysis and full scale data to be used for validation and calibration purposes of the draft revised interim guideline.'

The EU Framework Programme 7 project SAFEGUARD addressed this requirement by providing (a) full-scale data for validation of ship based evacuation models, (b) response time data sets for RO-PAX ferries and cruise ships and (c) propose and investigate additional benchmark scenarios to be used in certification analysis. As part of project SAFEGUARD, five response time data sets and two full-scale validation data sets from three different types of passenger vessels were collected, a RO-PAX ferry, a RO-PAX ferry with a significant number of cabins and a cruise ship.

To collect this data, five full-scale semi-unannounced assembly exercises were carried out on three different types of passenger vessel; RO-PAX ferry, a cruise ship, and a RO-PAX ferry with cabins. The first vessel (RP1) is operated by Color Line and can carry approximately 2000 passengers and crew and over 700 vehicles. The route taken by the vessel during the data collection trials was from Kristiansand in Norway to Hirtshals in Denmark, a trip of 3 hours and 15 minutes. The ship contains a mixture of public passenger spaces spread over three decks including business and traveller class seating areas (airline style seating), large retail and restaurant/catering areas, bar areas, indoor and outdoor general seating areas and general circulation spaces. The second vessel (CS) is operated by Royal Caribbean Cruise Lines International and has a capacity of 2500 passengers and 842 crew members. The route taken by the vessel during the data collection trial was from Harwich (UK) to St Petersburg (Russia) via Copenhagen (Denmark), a total voyage of about 7 days. The trial was conducted on the leg of the voyage to Copenhagen. The ship contains a variety of spaces spread over 12 passenger decks including staterooms (cabins), restaurant areas, bar areas, large retail areas, theatre, cinema, gym, sports facilities, casino, indoor and outdoor general seating areas and general circulation spaces. The third vessel (RP2) is operated by Minoan Lines and can carry approximately 2200 passengers and crew and approximately 600 vehicles. The route taken by the vessel during the data collection trials was from Patras in Greece to Venice in Italy, a trip of about 21 hours. The ship contains a mixture of cabins and public passenger spaces spread over four decks including business and traveller class seating areas (airline style seating), large retail and restaurant/catering areas, bar areas, indoor and outdoor general seating areas and general circulation spaces.

Prior to undertaking any data collection, approval was sought and received from the research ethics committee at the University of Greenwich. Planning and preparations for the sea trials was a lengthy process which took several months and involved a number of visits to the vessels in order to understand the layout of each vessel and to discuss the trial logistics with the ships' officers and crew. The precise timing for each assembly drill was unannounced but for ethical reasons, the passengers were informed.
Timing for each assembly drill was unannounced but for ethical reasons, the passengers were informed that at some time during their voyage an assembly drill would take place. It is worth noting that these assembly trials were conducted while the vessels were at sea. This is unusual as almost all ship assembly drills are conducted while the vessel is alongside in port. It was important to undertake the drills while at sea as this added to the realism of the exercise and hence the collected data.

Two assembly drills were conducted on RP1. The first took place on 4 September 2009 at 08:20 and the second on 5 September 2009 at 08:19 approximately 30 minutes after the vessel departed from Kristiansand en route to Hirtshals. It is important to note that the trials took place on the same leg of the ship’s regular route and that different passengers were onboard each day. A total of 1431 and 1349 passengers were onboard for the first and second trials, respectively. One assembly drill was conducted on the CS on 31 July 2010 at 09:01 on the morning after departure from the UK. A total of 2292 passengers were on board. Two assembly drills were conducted on RP2. The first took place on 12 March 2011 at 00:40, approximately 40 minutes after the vessel had departed from Patras en route to Venice. The second trial took place on 14 March 2011 at 19:12 about 72 minutes after the vessel had departed from Venice en route to Patras. A total of 240 and 270 passengers were onboard for the first and second trials respectively.

Each of the trials was planned and designed by staff from the University of Greenwich Fire Safety Engineering Group (FSEG). The trial teams needed to setup the equipment and run each of the trials consisted of 25 staff (9 FSEG staff, 12 SAFEGUARD and 4 crew) for RP1, 25 staff (5 FSEG staff, 6 SAFEGUARD and 14 crew) for the CS and 22 staff (5 FSEG, 4 SAFEGUARD and 13 crew) for RP2. Three types of data sets were collected in each trial, Passenger Response Times, Passenger Assembly data and Passenger Behavioural data.

Passenger Response Time data.

The passenger response time was collected using video cameras positioned throughout the vessel. The cameras were placed at strategic locations throughout the vessel to record not only the time at which passengers responded, but also the nature of the activities that they were involved in at the time. In the case of the cruise ship, the on board CCTV system was also used to capture passenger response time data and response phase behavior. For RP1 and RP2 some 30 specially positioned battery powered mini digital video cameras were used while for the CS a combination of 12 video cameras and 94 ship CCTV cameras were used. Some 2366 passenger response times were collected from the five trials; 1003 from RO-PAX1, 135 from RO-PAX2 and 1228 from the cruise ship. This passenger response time data was used to develop response time distributions for RO-PAX and cruise ships for both cabin spaces and public spaces.

Passenger Assembly data.

The second type of data collected comprised validation data for ship based evacuation models. This consisted of start and end locations of passengers and the arrival time at the designated assembly areas. This data was collected using a novel data acquisition system consisting of a number of Infra-Red (IR) beacons, each emitting unique IR signals and data logging tags that were worn by each passenger. The data was generated using 30 IR beacons and 5034 IR tags. In total 3680 assembly times were generated.
Data was generated using 30 IR beacons and 3004 IR tags. In total 3680 assembly times were generated, 902 for trial 1, 764 for trial 2 (RP1), 1779 for trial 3 (CS) and 116 for trial 4 and 119 for trial 5 (RP2). The assembly data was used to develop two validation data-sets, one for RP1 (trial 2) and one for the CS (trial 3).

Passenger Behavioural data.

The third type of data consisted of a questionnaire that was completed by passengers after the assembly trial was over. The purpose of the questionnaire was to capture information from the passengers that cannot be obtained from the video footage or the IR tracking devices. The questionnaire provides essential additional information for reinforcing, correlating or verifying the data collected by the video camera and IR systems. The questionnaires allowed participants to describe what they did and why they did it. The questionnaire was compiled by FSEG and tailored for each vessel. For RP1 the questionnaire consisted of 21 questions while the questionnaires for RP2 and the CS consisted of 24 questions. In total, 3648 questionnaires were completed by the passengers in the five trials, 1534 for RP1, 1862 for the cruise ship and 252 for RP2. The questionnaire provided additional information for reinforcing, correlating or verifying the data collected by the video camera and IR systems.

3.2 Response Time Data Sets

On board a passenger ship, the general emergency alarm is sounded (seven short blasts and one long blast of the ship's horn) to call passengers to assemble and is often the first cue an individual receives that an incident has occurred which may require evacuation. The individual's behaviour during this early stage of an evacuation can have a major impact on how the evacuation progresses. Thus, when modelling the evacuation process, it is important that this stage is properly understood and quantified. One of the objectives of the SAFEGUARD project was to develop a series of passenger Response Time Distributions (RTD) that can be used in passenger ship evacuation analysis. A passenger's response time is defined as the time between the sounding of the alarm and the moment at which the passenger starts purposeful movement to an assembly station.

The SAFEGUARD project generated response time data from semi-unannounced assembly trials, using real passengers while at sea, making the generated results relevant, credible and realistic. Furthermore, the response time data-set, consisting of 2366 response time data points, represents the largest response time data-sets ever collected - on land or sea. Five new response time data-sets were generated - two from a RO-PAX ferry without cabins, one from a cruise ship and two from a RO-PAX ferry with cabins. The key findings from this work include:

- Passenger RTDs generated for RO-PAX vessels and cruise ships, in public spaces and in cabin spaces, were generally found to fit the log-normal model, consistent with response time data generated for the built environment, thus passengers are responding to evacuation alarms on passenger ships in a similar manner to that in the built environment;

- If assembly trials involving a large number of different people with a given population demographic are repeated with a different population from the same broad population demographic, in the same physical environment and exposed to the same notification conditions, the RTD generated is likely to be statistically
environment and exposed to the same notification conditions, the RTD generated is likely to be statistically identical.

- Passenger RTDs for both public spaces and cabin spaces are dependent on the class of vessel.

RTDs for cruise ships generally have longer and more significant tails compared to RTDs for RO-PAX vessels.

It is inappropriate to use the same RTD when assessing assembly performance for cruise ships and RO-PAX vessels.

- Data from these trials suggests that passenger demographics may have a significant impact on passenger RTD.

A new Day Case RTD is proposed for the IMO guidelines governing ship evacuation analysis to replace the existing RTD for RO-PAX vessels.

This is based on the 1003 response time data points collected from the two SAFEGUARD RP1 trials and 67 response time data points that comprise the RTD currently used within the IMO evacuation analysis guidelines.

The new RTD is statistically similar to the existing RTD in the IMO evacuation analysis guidelines. The new RTD is unlikely to significantly impact evacuation analysis for RO-PAX vessels but is considered to be a more representative, robust and reliable RTD.

- A new Day Case RTD is proposed for the IMO guidelines governing ship evacuation analysis for Cruise Ships to replace the existing RTD.

This is based on the 595 response time data points collected from the SAFEGUARD CS trial.

The new RTD is statistically significantly different to the existing RTD in the IMO evacuation analysis guidelines.

In a demonstration evacuation analysis for a cruise ship geometry which adhered to the IMO guidelines, the new RTD was found to increase the predicted total assembly time for the 95th percentile case by a small (0.1%) amount compared to the existing analysis.

- A new Night Case RTD is proposed for the IMO guidelines governing ship evacuation analysis for Cruise Ships to replace the existing RTD.

This is based on the 633 response time data points collected from the SAFEGUARD CS trial. The new RTD is statistically significantly different to the existing RTD in the IMO evacuation analysis guidelines.

In a demonstration evacuation analysis for a cruise ship geometry which adhered to the IMO guidelines, the new RTD was found to increase the predicted assembly time for the 95th percentile case by a moderate (21.2%) amount compared to the existing analysis.
While the response time data collected in this work has been comprehensive, additional data is required to:

- Quantify the RTD for passengers in cabins on RO-PAX vessels. Sufficient high quality, reliable response time data is required to characterise the response times for passengers in cabins.

- Better quantify the impact of sleeping passengers on the night time RTD. Currently, the cabin space RTD is arbitrarily shifted by 400 s to represent sleeping passengers. A more reliable data set based on actual experimental data is required to characterise how long sleeping passengers will require to respond to the call to assemble.

- Explore the dependence of population demographics on the RTD. Passenger vessels may have very different populations based on the nature of the voyage. This may vary from significant numbers of young people to significant numbers of elderly people. The impact that this will have on passenger response times should be characterised.

3.3 Validation Data Sets

In 2002 the International Maritime Organization (IMO) introduced guidelines for undertaking full-scale evacuation analysis of large passenger ships using ship evacuation models [1]. These guidelines, known as IMO MSC Circular 1033, were to be used to certify that passenger ship design was appropriate for full-scale evacuation. As part of these guidelines it was identified that appropriate full-scale ship based evacuation validation data was not available to assess the suitability of ship evacuation models. As suitable validation data was not available, a series of test cases were developed which verified the capability of proposed ship evacuation software tools in undertaking simple simulations. However, these verification cases were not based on experimental data. Furthermore, successfully undertaking these verification cases does not imply that the evacuation model is validated or capable of predicting real evacuation performance. In 2007, IMO MSC Circular 1238 (MSC1238) [4], a modified set of protocols for passenger ship evacuation analysis and certification were released however, the issue of validation of passenger ship evacuation models was not addressed. The IMO Fire Protection (FP) Sub-Committee in their modification of MSC Circ. 1033 at the FP51 meeting in February 2007 [5] invited member governments to provide, '...further information on additional scenarios for evacuation analysis and full scale data to be used for validation and calibration purposes of the draft revised interim guideline.' The EU Seventh Framework Programme (FP7) project SAFEGUARD aims to address this requirement by providing full-scale data for calibration and validation of ship based evacuation models.

As part of the SAFEGUARD project, a series of five semi-unannounced full-scale assemblies were conducted at sea on three different types of passenger vessel. From these trials five passenger response time data-sets and two full-scale validation data-sets were collected. Here we summarise the two SAFEGUARD Validation Data-Sets (SGVDS) and the proposed validation protocol. The validation data-sets were generated from assembly trials conducted on a large RO-PAX ferry operated by Color Line (RP1) and a Cruise Ship (CS) operated by Royal Caribbean - SGVDS1 and SGVDS2 respectively.
Data from two semi-unannounced assembly trials at sea for a RO-PAX passenger ferry and a cruise ship have been collected consisting of passenger response time data, starting locations and arrival time at the designated assembly stations. The response time data was collected using digital video cameras while the start and end locations and the arrival time for the passengers was collected using a novel Infra-Red (IR) data acquisition system consisting of ship-mounted IR beacons and IR data logging tags worn by each passenger. The collected data is used to define two unique validation data-sets for ship evacuation models. The data-sets are considered unique for a number of reasons, primarily because unlike most validation data-sets, they contain information defining occupant response times, starting locations, end locations and final arrival times. Most evacuation validation data-sets lack these essential details allowing modellers the opportunity to tune their predictions in order to obtain the best fit to the experimental results. Furthermore, the trials were conducted on real ships, at sea and were semi-unannounced making the results relevant, credible and realistic.

The ERD is used to assess the average difference between the experimental data (Ei) and the model data (mi). This equation should return a value of 0 if the two curves are identical in magnitude. The smaller the value for the ERD, the better the overall agreement. An ERD of 0.2 suggests that the average difference between the model and experimental data points, taken over all the data points is 20%. The EPC calculates a factor which when multiplied by each model data point (mi) reduces the distance between the model (m) and experimental (E) vectors to its minimum. Thus the EPC provides a measure of the best possible level of agreement between the model (m) and experimental (E) curves. An EPC of 1.0 suggests that the difference between the model (m) and experimental (E) vectors are as small as possible. The SC, unlike the other two measures, it provides a measure of how well the shape of the model data curve matches that of the experimental data curve. It makes use of the secants (which approximate to tangents) through both curves. An SC of 1.0 suggests that the shape of the model (m) curve is identical to that of the experimental (E) curve.

Based on the analysis undertaken as part of project SAFEGUARD, the suggested validation protocol is as follows:

- Perform 50 simulations of the validation scenario.
- Rank each simulation according to the ERD (see equation 1) determined for the total assembly.
- Select the simulation producing the smallest ERD which will be the basis of the validation comparison.
- For the selected simulation case go through the two phase assessment process which consists of the following phases:

  Phase 1: For the predicted total assembly curve, determine ERD, EPC, SC (see equations 1, 2 and 3) and % TAT (Total Assembly Time). Determine if all four predicted parameters satisfy the acceptance criteria. If so, go to Phase 2. If not, the software has failed the assessment.

  Phase 2: For the predicted assembly curve for each of the four assembly stations, determine ERD, EPC and SC. Determine which of the 12 predicted parameters (three for each assembly station) satisfy the acceptance criteria. At least 9 out of 12 criteria must be met for SGVDS1 and 10 out of 12 criteria must be met for SGVDS2 to satisfy the criteria and it is not acceptable to have two or more failed criteria in any one assembly station.

- The process must be repeated for SGVDS1 and SGVDS2.

In blind applications of the validation protocol to three commonly used ship evacuation software tools.
In blind applications of the validation protocol to three commonly used ship evacuation software tools (maritimeEXODUS, EVI and ODIGO), each software tool was found to satisfy the acceptance criteria for each data-set, suggesting that it is capable of predicting the outcome of the assembly process for these two vessels to the specified level of accuracy as defined by the acceptance criteria.

The two validation data-sets represent the first comprehensive ship evacuation model validation data-sets collected. It is proposed that the two validation data-sets, validation protocol and the acceptance criteria could be used by IMO as part of a validation suite to determine acceptability of maritime evacuation models in a future enhancement to MSC1238. As part of the validation protocol, all information required to setup the evacuation analysis are provided on a website [9]. This includes: CAD layout of vessel, starting location of passengers, end location of passengers, passenger response time distribution and the assembly curves for each assembly station and the overall assembly process. All other parameters required to perform the simulations will be extracted from IMO MSC Circ 1238.

These findings and recommendations have been submitted to the IMO/FP sub-committee in the form of an IMO Information paper, to be used to assist in the framing of the next iteration of the international guidelines for ship evacuation analysis [10]. In this way we hope to improve the reliability of the assessment of ship evacuation capabilities based on computer simulation and hence the safety of all those who travel and work on passenger ships.

3.4 Fire Scenarios

In the current IMO guidelines for ship evacuation analysis, IMO MSC Circ 1238 [4], fire is not considered to explicitly impact passenger performance. While evacuation scenarios 3 and 4 in MSC Circ 1238 are intended to represent a damage situation - including a potential fire situation - these scenarios do not represent the impact of the fire on the evacuating population. In these scenarios, the ‘fire’ is only considered to force the passengers in the affected vertical fire zone to move into the neighboring fire zones. However, it is possible that the passengers within the affected zone will be impacted by spreading fire hazards and as a result their movement rates are likely to be affected. A safety factor of 1.25 was introduced to the predicted total assembly time to account for this and other omissions and simplifying assumptions.

One of the aims of the EU FP7 project SAFEGUARD is to include a representation of the impact of the fire on the passengers in the affected zone. Fire effluent consists of smoke, irritant and toxic gases and heat. The impact of fire effluent on an exposed evacuating population is complex and varied. Smoke tends to obscure vision and as a result slows movement speeds of exposed individuals. Toxic gases such as Carbon Monoxide (CO) and Hydrogen Cyanide (HCN) can cause intoxication, resulting in staggered movement, slowed down movement and eventually incapacitation and death. Irritant gases such as Hydrogen Chloride (HCl) can affect the eyes making it difficult to see and the respiratory track and lungs making it difficult to breathe, both of which can impede the exposed passengers’ evacuation progress, resulting in incapacitation and in extreme cases, death. Heat, both convective and radiative, can cause pain to exposed skin, resulting in burns and may damage the respiratory track and lungs, making it difficult to breathe. Excessive exposure to heat can result in a reduction in travel speeds, and can cause incapacitation and death [11].
The most straightforward and accurate way to include the impact of fire on passengers would be to undertake a fire simulation (using advanced computational fluid dynamics (CFD) fire simulation tools) for a prescribed fire scenario and couple the results to an evacuation simulation. However, this approach has the disadvantage of being prohibitively expensive in terms of time, resources and computational power. Furthermore, not all ship evacuation simulation software tools have the ability to incorporate the impact of fire hazards on individuals. An alternative approach is to define a generic data-set specifying both the temporal and spatial spread of fire hazards (smoke, temperatures, toxic gases) for a generic predetermined fire. Hazard conditions on each deck would then be determined as a function of distance from the seat of the fire on the deck of fire origin. This approach was considered impractical as it is not possible to deduce scaling rules that could be reliably applied to any arbitrary geometry, and so it is not possible to define a generic fire hazard data-set that could be applied to any arbitrary ship geometry.

The approach which was finally adopted simply takes into consideration the reduction in passenger travel speeds that would result from exposure to fire hazards. Using this approach a representative set of reduced passenger travel speeds must be determined. As such, the resulting evacuation analysis will not require the fire hazard data to be input into the evacuation simulation. The specification of a travel speed reduction is also consistent with the specification of the current MSC Circ 1238.

This approach is the simplest solution and eliminates the need to calculate the effects of heat and toxic gases and trying to determine the spread of the fire atmosphere via CFD fire simulation or applying scaling methods to an arbitrary geometry. In addition, the proposed approach could also be used within the simplified evacuation analysis. It is however noted that the approach would not produce a prediction of expected fatalities or injury levels, nor would it provide an assessment of the fire safety provision afforded by the design. Finally, the only additional requirement imposed on the evacuation model by the suggested analysis process is that it has an ability to prescribe a passenger travel speed reduction factor within specified regions of the vessel. This approach is referred to as the Fire Degraded Speed Model (FDSM).

The analysis undertaken involved detailed Computational Fluid Dynamics (CFD) fire modelling analysis of fire scenarios (using the SMARTFIRE fire simulation software [12-16]), analysis of experimental data relating to fires in passenger ships and extensive evacuation simulation using two established ship-based evacuation modelling tools (maritimeEXODUS and EVi).

An attempt has been made to develop a benchmark fire scenario that could be included in a modified form of the IMO evacuation analysis guidelines. The aim of the benchmark scenario was to include the impact of a severe fire on the evacuating passengers without introducing the need to undertake a full fire simulation. The primary impact of the generation and spread of fire hazards considered in the benchmark analysis is the reduction in travel speeds of passengers due to smoke obscuration and a change in the evacuation procedures associated with the fire zone containing the severe fire. The reduction in agent travel speeds was not found to have a significant impact on the time to assemble; even when the travel speeds of the affected agents was reduced to 0.3 m/s. Thus it is suggested that there is no need to include a speed reduction in the proposed fire benchmark scenario. However, the modified evacuation procedures were found to have a significant impact on the time to assemble. Furthermore, two fire scenarios were considered, one in which all the decks within the affected MVZ are considered to be impaired by fire hazards and a scenario in which only a single deck within the affected MVZ is impaired. In the former
hazards and a scenario in which only a single deck within the affected MVZ is impaired. In the former, there is only a single case that must be examined, while in the latter each deck within the affected MVZ must be examined in turn, resulting in a case for each deck in the affected MVZ. Analysis suggests that both scenarios produce essentially identical results and as the former requires less effort to implement, but represents the most challenging hazard, it is selected as the fire scenario. The fire scenario is intended to represent a severe fire requiring the evacuation of the affected MVZ with all vertical access considered to be non-tenable.

The modified assembly procedure for the fire case is as follows:
- Identify the MVZ that has the longest assembly time as in the current requirements. This zone is considered to contain the fire.
- Any assembly stations within the affected MVZ are considered viable and agents may pass through the affected MVZ only on the decks containing the assembly stations.
- All stairs within the affected MVZ (i.e. primary and secondary) are considered non-viable.
- Agents within the affected MVZ exit the zone horizontally moving to their nearest neighboring MVZ. If the affected MVZ is an end zone then all agents move horizontally to the nearest neighbouring MVZ.
- Crew involved in searching tasks are assumed to start their search based on the lowest response time associated with the scenario.
- Crew and passengers may only use stairs in the unaffected zones.
- The process is repeated for both the day and night cases.

The impact of the suggested fire benchmark scenarios was assessed for a large cruise ship configuration consisting of seven MVZs and 2502 passengers and 801 crew members in the day case and 3001 passengers and 801 crew members in the night case. The assembly time for the 95th percentile case in the fire benchmark day case was found to increase by 34% (310 s) compared to the standard day case. For the fire benchmark night case, the assembly time for the 95th percentile case is increased by 30% (470 s). For this vessel, the total assembly time for the fire benchmark day and night cases are 20.3 min and 33.5 min respectively, both well within the maximum allowed.

3.5 Heel Scenarios

Heel and trim scenarios have been investigated as part of the possible additional scenarios to be proposed for a modification of the IMO guidelines on the evacuation analysis.

As limited data is available as to the effect of heel and trim on the evacuating people only scenario 1 (static angles) was retained to be implemented in the two evacuation software: EVi and maritimeExodus.

Also due to a lack of data and although several effects of heel and trim were identified, only the impact on walking speeds has been implemented in the software by means of lookup tables for speed variation factors (SVF). An example of the lookup table is given below:

A standard IMO Night case and a SAFEGUARD Day case (similar to the standard IMO Day case but with the population also assigned to outer decks) were tested. For each case 50 simulation runs were performed.
As anticipated the heel and trim conditions increased the total mustering time.

The results showed that for a Night case with 3001 passengers and 801 crew members onboard the cruise vessel, the average mustering time in heel conditions was found to be 10% longer than the average mustering time for the night case. For the 95th percentile run the mustering time was 5.4% longer than the 95th percentile of the night case.

In trim conditions the increase in the average mustering time was found to be 6.42% longer than the average mustering time for the night case and 5.2% longer for the 95th percentile.

For the SAFEGUARD Day case onboard the cruise vessel, there were 2502 passengers and 735 modelled crew members. Passengers were randomly located in public spaces (including outer decks) throughout the ship and were assigned a specific muster station.

The average mustering time in the 20° heel condition was found to be 23% longer than the average mustering time of the SG day case. The 95th percentile of the 20° heel scenario was also found to be longer than the one for the SG day case by 24%.

In trim conditions, results showed an increase of 10% in the average mustering time and 13% increase for the 95th percentile mustering time.

For the Ro-Pax vessel only a standard IMO Day case was assessed as the ferry did not have passenger’s cabins. A total of 1781 passengers and 66 crew members were modelled.

The average mustering time in heel conditions was found to increase by 10% and for the 95th percentile the mustering time was 11% longer when compared to the day case. In trim conditions the average was found to increase by 6% and the 95th percentile was 7% longer than the day case.

It should be noted that in the work completed there were several important simplifications with the approach adopted for including the impact of heel and trim:

- The reductions in travel speed should only be considered approximate as they are based on a small number of trials; in particular the data associated with trim and were collected in a small test facility, unrepresentative of ship dimensions.
- The impact of handrails is not considered. The presence and use of handrails by persons would create a different behavior, as persons would need to walk in a single file and their speed would be further reduced, as they would not be able to walk faster than the persons before them in the line. Although this aspect has not been investigated in the SAFEGUARD project, it is anticipated that this would have a significant impact on the total mustering time.
- Other behavioral factors which may be significantly impacted by heel and trim are ignored. For example, the presence of family groups or passengers with movement disabilities may be disproportionally impacted by conditions of heel and trim. Rather than simply reducing travel speeds, movement in a particular direction may become impossible.
3.6 Enhanced Scenarios

The current regulation, IMO MSC/Circ. 1238 Annex 2, has many areas where improvement is possible. The potential enhancement of scenarios used in the approval process is addressed in this sub-section.

The work presented here involves a detailed look at all available historical data from databases and accident reports. This is a fairly typical process, however the work differs in that the partners also took an in-depth look at the procedures on-board the vessels, including large cruise ships, and interviewed crews who have been involved in evacuation incidents. Getting feedback from professional mariners is very important because it brings realism and credibility to the scenarios being enhanced.

3.6.1 Safety Assessment

As its part in the project, Bureau Veritas has been analysing past accidents. The research included the quantitative study of accident databases and the qualitative assessment of accident reports and professional mariners' feedback. This was done in 2009. For the quantitative study, 135 relevant accidents on passenger ships from 1999 to 2009 were studied.

Factors to emerge included that 20% of evacuations happened in listing conditions and 12% with smoke having spread in the ship super-structure.

It was also noted that 45% of abandonments were at sea, the other 55% took place in port (of origin, destination or transit). One third of these disembarkations at berth probably happened in hazardous conditions.

It was also shown that the majority of stranding and wrecking accidents lead to an abandonment of the ship at sea, whereas the majority of collisions and contacts are followed by disembarkation at berth, as would be expected. Finally this table shows that 50% of fires lead to evacuation of passengers at berth and 50% at sea. In many cases the casualty leads to a serious situation but the SAR manage to tow the ship to a port or the ship itself manages to reach a port.

3.6.2 Scenarios

Accident reports and testimonies also provided excellent details on past incidents. They revealed, for example, that in addition to accidents, passenger assembly occurs for 'man overboard' or security alerts as well.

From a procedural point of view it was highlighted that the evacuation process on Ro-pax and cruise ships differs and the impact was shown on the different phases of an evacuation process. Another factor to emerge was that the evacuation procedures on cruise ships can vary considerably from one ship to another.

All this information was gathered to identify areas for improvement and then expert judgement was applied to recommend enhancements to test. Recommendations were also made for other risk assessment.
to recommend enhancements to test. Recommendations were also made for other risk assessment methods. We discussed whether our proposals should take into account that IMO MSC/Circ. 1238 is used for purposes other than standard evacuation, such as alternative design for fire safety and alternative design for life saving appliances.

We have listed current evacuation scenarios but added other possible alternatives to be considered. Our initial study looked at the enhancement of existing cases, which are recommended to the next IMO MSC/FP56:

- Adding congestion as a performance criterion, and applying this as a fixed criterion value, i.e. fixed threshold of density of persons (4p/m²) not to be exceeded longer than 10% of the maximum allowed assembly time;
- Realigning existing secondary cases 3 and 4 so that they take into account smoke effects in the scenario and also aim to be consistent with the Safe Return to Port concept where the casualty threshold is exceeded in some critical main vertical zones (MVZ). These critical zones would be the longest to evacuate and the most populated. Our view is that only these worst case degradations should be evaluated. These would be evacuated using first horizontal secondary routes, then main routes to the assembly stations.

As a first attempt in SAFEGUARD, the original idea was to block the access back in the degraded MVZ, therefore potentially to assembly station(s) in it, but many re-allocation issues were encountered by the developers. Indeed, there is a problem with the software (how to define the arriving passengers being redirected to a new AS?), but also (and mainly) with the operations: how are people assigned a new AS? Finally, the unavailability of the assembly stations in the degraded zone has been left aside.

Examples of results are given below:

- When the alternative assembly stations are chosen in remaining public spaces over the ship, the evacuation dynamics totally changes from the original and effects on the evacuation are very dependent on the assumptions made.
- When the alternative assembly stations are the existing ones, with an increase of the capacity thereof, the assembly time (on a specific ship) increases by 10-15%.
- When access is still admitted to assembly stations in the degraded zone, the increase of assembly time is of the magnitude of 30%-35%.

What is noteworthy is that the dynamics of the evacuation is totally different because of the change in the procedure. This was reflected by the congestion criteria analysis with different congestion spots and durations. This also highlighted the role of the procedure and questioned what is addressed by the IMO MSC/Circ.1238 guideline: is it the design or the procedures? Both are legitimate.

3.6.3 Other scenarios relevant to the purpose of the operation of the ship

Within the project we also tested interesting additional cases which are relevant mostly to the operation of the ship:

- Locating some passengers on public open decks for day cases - this had an effect only when loading the sun deck with a significant amount of people. This was concluded to be recommended and done with a maximum load. Additionally this gave rise to the idea to investigate the day case with specific public.
maximum load. Additionally this gave rise to the idea to investigate the day case with specific public spaces filled at 100%, according to the actual commercial attraction of the public spaces of the ship.

- Setting up a hybrid of night and day cases where 50% of the passengers are in cabins and 50% in public areas. This has been tested to see how it compares to the current day and night case. We identified different congestion spots and longer evacuation times compared to the day case but not longer than the night case. However, in our test the night response time (delayed by 400s) has been applied to people starting in cabins, whereas the response time for cabin day ought to be closer to the one measured on the cruise ship. As the two sets of populations would start at the same time, more cross flow would then be observed.

Finally, four areas have been identified which need further research as data is not yet available to make recommendations to modify the Circular.

These are:

- Establishing a disembarkation to shore case where people start from the assembly station and evacuate through gangways/footbridge. But no sufficient data to model flows on gangways or footbridges are available.

- Simulating life vest recovery in the day case for cruise ships. Models for life vest recovery procedures are presented below:
  Procedure A: Passenger go to assembly stations and are given their life vests in the vicinity.
  Procedure B: Passengers collect life vests from their cabins and then proceed to the assembly station with their life vest
  Procedure C: Crew members collect life vests from passenger cabins and bring them to the assembly station. The life vests are then distributed to the passengers at the assembly stations.

While they cover all the known procedures on board, not enough information is available about the time taken to find and put on lifejackets, their effect on the speed of people during evacuation and the way people behave carrying or wearing lifejackets.

- Establishing a complete evacuation performance standard including abandonment. This case has been developed in SAFEGUARD. Our proposals would keep the methodology for analysing only the assembly phase within a timescale of 30 minutes, as set out in the current circular, abandonment overlapping on the assembly phase or not depending on the case. Additional features have been identified for designers when calculating abandonment times. This includes grouping at the assembly station, the time taken for passengers to travel from the assembly station to the embarkation points, and the embarkation time in the life-crafts. This will require defining new time variables for individuals (grouping, travelling to embarkation, embarking and launching) so that the whole procedure on board can be modelled. The methodology needs several 'allocation' tables to map where people or groups of people ought to go during the different phases of evacuation. The global performance standard for the current circular is 60 or 80 minutes (assembly plus abandonment). However, more data is necessary to model the group behaviour over all phases of evacuation and to model the flow of persons at the LSA entrances.

3.6.4 Recommendations to IMO/EP sub-committee
3.6.4 Recommendations to IMO/FP sub-committee

Most of these enhanced scenarios and additional scenarios have been developed and tested in an implementation work phase of SAFEGUARD. Final recommendations are currently made in the IMO information paper.

3.7 Modelling

The SAFEGUARD project made heavy use of maritime evacuation software to test the suggested enhanced scenarios and the effects of the newly compiled response time distributions. Three tools are implemented in the project: EVI (Safety at Sea), maritimeExodus (FSEG) and ODIGO (Principia).

Three ships have been studied: a high speed ROPAX ferry operated by Color Line AS, a cruise ship owned by Royal Caribbean Cruise Line, and a high speed ROPAX ferry operated by Minoan Lines.

The former two were modelled and simulated according to the scenarios setup after the analysis of the data collected during the trials at sea. The other high speed ROPAX ferry was eventually not modelled, as it was found that the data collected during the trials was not significant enough to allow defining scenarios for simulations because of a low number of participants to the trials.

The SAFEGUARD project included building evacuation models of the ships with each of the three tools used, defining the evacuation scenarios and running the simulations.

3.7.1 Modelling tools

3.7.1.1 EVI

EVI is developed by Safety At Sea, in partnership with the University of Strathclyde. It can be used to simulate pedestrian movement in any environment. It has been used extensively to model circulation and evacuation of persons from ships, offshore structures and buildings. The program works with a 3D interactive interface, which allows the user to represent realistic scenarios and make changes in real-time. People are modelled as individual entities (agents), which interact with each other and with the environment. There are no limits as to the number of agents and the size of the environment which can be modelled. All demographic variables such as age and gender which impact on the agents’ walking speed are user-defined and can be described probabilistically.

3.7.1.2 maritimeEXODUS

MaritimeEXODUS is developed by the Fire Safety Engineering Group at the University of Greenwich. It is an egress model designed to simulate the evacuation of large numbers of individuals from ships and offshore installations. The model tracks the trajectory of each individual as they make their way to a muster/assembly station and then proceed to abandon the ship. The software is also capable of simulating the interaction of individuals with fire products such as heat, smoke and toxic gases. The software is rule-based, the progressive motion and behaviour of each individual being determined by a set of heuristics or rules.
3.7.1.3 ODIGO

ODIGO is developed by PRINCIPIA. Its initial development took place between 2000 and 2005. It is used to simulate crowd movement aboard ships. It includes a pre-processor, a simulation engine, and a post-processor. The model describes areas representing public spaces created on decks and related staircases. The simulation engine uses a multi-agent method of a cognitive/reactive hybrid type. It also uses an exact geometry: agents may move anywhere in areas provided that they respect margin distances between themselves and walls. The agents' features and starting positions are defined randomly before the simulation is started. The agents act upon objectives (join cabin, move to craft) and they may chain several objectives.

3.7.2 Geometry Modelling

All three simulation tools have been designed to take raw DXF files as primary input. From there, each use a different strategy but the starting point is the same.

The ship models represent free spaces (zones, corridors) linked together, and allow taking into account obstacles that can influence the occupants' motions (doors, furniture, etc.). Stairwells are a key element in evacuation analysis, and are necessarily represented. The implementation of the scenarios specified by the IMO regulation implies that the zones are distinguished by their type: public spaces, restaurants, theatre, etc. Passenger zones and crew zones are also to be distinguished. The geometry of the model must be defined as close to reality as possible, as it can be of a great impact on the flow rates of moving occupants, and on the initiation of congestion.

3.7.3 Definition of the simulation scenarios

Several simulation scenarios were defined for each of the ships being modelled. In the case of the Color Line ROPAX ferry, three scenarios were studied, while one scenario was used in the case of the RCCL cruise ship. All the scenarios followed the same overall procedure.

For all the scenarios, the population was set up based on the IMO MSC.1/Circ 1238 document. The initial repartition of passengers to be used in the simulations was defined according to the answers to the questionnaires the participants had to fill in after the trials.

Each area of the ship had a given number of initial passengers, and a given number of passengers were assigned to each assembly station, following the numbers that were observed during the sea trials.

The response time distribution was a log-normal distribution with given parameters for each scenario. These parameters were determined using the data collected during the sea trials. Two types of approaches were analysed concerning the response time. A global response time repartition was defined, as defined by the IMO MSC.1/Circ 1238, but local distributions were also analysed in two scenarios on the ROPAX ferry. These local response time distributions were defined based on a zone-by-zone analysis of the response times observed during the trial. This analysis produced different response time distributions for restaurants, shops, seat areas, etc. Consequently, in these simulations the response time of each
for restaurants, shops, seat areas, etc. Consequently, in these simulations the response time of each agent depends on its starting location.

The three scenarios used to study the Color Line ROPAX ferry were defined as follows:

- Scenario A: send passengers to their assigned assembly stations using regional response time distributions
- Scenario B: repeat Scenario A using the global response time distribution
- Scenario C: send passengers to the nearest assembly stations using regional response time distributions

One scenario was defined for the RCCL cruise ship, using a global response time distribution for the whole population.

### 3.7.4 Simulations

According to the MSC circular, 50 simulations were run for each of the four scenarios.

For each scenario, each of the 50 runs provides the position of each agent at each moment of the simulation, the number of agents in each area, the rate of flows through doors, etc. This large amount of data is then processed in order to provide one set of results by scenario, corresponding to the 95th percentile case.

The results of these simulations were then compared to the data collected during the trials. The models of the RCCL cruise ship were also implemented to evaluate the enhanced evacuation scenarios.

### 3.7.5 Views of the models

### 3.8 REFERENCES

5. IMO, 'FP 51/WP.3' Fire Protection Sub-Committee, 51st session, Work Package 3, 8 Feb 2007

10. IMO FP56/INF.13 14 Nov 2012, Review of the Recommendations on Evacuation Analysis for new and existing passenger ships. The SAFEGUARD validation data set and recommendations for updating MSC.1/Circ.1238


17. IMO FP56/INF.11 14 Nov 2012, Review of the Recommendations on Evacuation Analysis for new and existing passenger ships. The SAFEGUARD Enhanced scenarios and recommendations for updating MSC.1/Circ.1238

Potential Impact:
Section A (public)

This section includes two templates

-Template A1: List of all scientific (peer reviewed) publications relating to the foreground of the project.


These tables are cumulative, which means that they should always show all publications and activities from the beginning until after the end of the project. Updates are possible at any time.

TEMPLATE A1: LIST OF SCIENTIFIC (PEER REVIEWED) PUBLICATIONS, STARTING WITH THE MOST IMPORTANT ONES

NO. Title Main author Title of the periodical or the series Number, date or frequency Publisher Place of publication Year of publication Relevant pages Permanent identifiers

(if available) Is/Will open access provided to this publication?

1. An Evacuation Validation Data Set for Large Passenger Ships Galea, E.R. Pedestrian and Evacuation Dynamics 2012 To Appear Springer, New York, NY To appear in 2013 To Appear No
The SAFEGUARD project has produced five response time data-sets, consisting of 2366 response time data points, representing the largest response time data-sets ever collected - on land or sea. In addition, two validation data sets have been compiled and a validation protocol and acceptance criteria have been developed. These findings have been presented to the IMO Fire Protection Subcommittee in the form of information papers. The data sets could be adopted by the IMO as part of a validation suite to determine acceptability of maritime evacuation models in a future enhancement to IMO MSC Circ 1238.

The data sets and all information required for the validation of maritime evacuation software is available.
The data sets and all information required for the validation of maritime evacuation software is available online (see http://fseg.gre.ac.uk/validation/ship_evacuation/ online). A link to this page is also given on the SAFEGUARD website. Software developers are encouraged to use the data for the testing and validation of their evacuation models.

Project website: http://www.safeguardproject.info/

Related documents

140803021-8_en.zip

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