# PASSENGER RESPONSE TIME DATA-SETS FOR LARGE PASSENGER FERRIES AND CRUISE SHIPS DERIVED FROM SEA TRIALS

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## ABSTRACT

This paper describes research that was carried-out under the EU FP7 research project SAFEGUARD and presents passenger response time data generated from five full-scale semi-unannounced assembly trials at sea. The data-sets were generated from three different types of passenger ships, a RO-PAX ferry without cabins (RP1), a cruise ship (CS) and a RO-PAX ferry with cabins (RP2). In total, response times from 2366 people were collected making it the largest response time data-set ever collected – on land or sea. The analysis methodology used to extract the response time data and the resultant response time distributions (RTD) is presented. A number of key findings from the data analysis are presented along with three recommendations to modify the IMO guidelines governing ship evacuation analysis, namely; (a) it is inappropriate to use the same RTD for cruise ships and RO-PAX vessels; (b) a new Day Case RTD is suggested for RO-PAX vessels and (c) new Day and Night RTDs are suggested for cruise ships.

## NOMENCLATURE

| | |
|---|---|
| AS | Assembly Station |
| CCTV | Closed Circuit TV |
| CS | Cruise Ship |
| ER | Eurostar Roma |
| EU | European Union |
| FP | Framework Programme |
| IMO | International Maritime Organization |
| MSC | Maritime Safety Committee |
| RP1 | RO-PAX vessel number 1 |
| RP2 | RO-PAX vessel number 2 |
| RTD | Response Time Distribution |
| P | Statistical term meaning the probability of obtaining a test statistic as extreme as the one that was actually observed assuming the null hypothesis is true. |
| Z | Statistical term representing the difference between the sum of the ranked values and population mean normalised by the standard deviation of the population. |

## 1. INTRODUCTION

Understanding how people behave in emergency situations within maritime settings is vital if we are to design evacuation efficient vessels and evacuation procedures for the crew to follow. An essential component of this understanding is the collection and characterisation of data for human performance when responding to alarms and moving to assembly stations. Unfortunately, little data exists relating to passenger response time or for full-scale validation of evacuation models specific to maritime environments. As part of the EU FP7 research project SAFEGUARD, 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. The validation data-set was described in an earlier paper [1] and this paper will focus on the 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 project SAFEGUARD was to develop a series of passenger response time distributions that can be used in passenger ship evacuation analysis. Response time is defined as the time between the sounding of the alarm and when passengers start purposeful movement to an assembly station.

In one of the first International Maritime Organisation (IMO) documents to specify protocols for the use of ship evacuation models for the analysis and certification of passenger ship design, IMO MSC/Circ.1033 [2], an arbitrary uniform random distribution was set to represent the response time behaviour 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 [3]. As part of the EU FP5 research project FIRE EXIT, passenger response time data was collected for a passenger ship at sea [4]. This data was accepted by the IMO and used in the formulation of IMO MSC/Circ.1238 [5], the modified protocols for passenger ship evacuation analysis and certification. However, the response time data produced by FIRE EXIT related to only a single RO-PAX vessel (with cabins), the Eurostar Roma (ER). 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 [6] 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". Project SAFEGUARD was developed to meet this requirement by measuring passenger behaviour during planned assembly trials at sea on three different types of vessels – a ferry with cabins, a ferry without cabins and a cruise ship. This paper presents the Response Time Distributions (RTD) generated from all five trials on three different types of passenger ships, a large RO-PAX ferry (without cabins), (RP1); a large cruise ship, (CS); and a large RO-PAX ferry (with cabins), (RP2).

### 1.1 SHIP AND TRIALS DETAILS

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. 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, numerous trips to discuss trial logistics with officers and crew and understand the layout of each vessel. The precise timing for each assembly drill was unannounced but for ethical reasons, the passengers were informed that at some time on 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 along side 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

## 2. DATA COLLECTION AND ANALYSIS METHODOLOGY

In order to collect the response time for a passenger, one must observe the passenger's behaviour following the alarm and record the time that has elapsed to the point when the passenger is deemed to have started purposeful movement to the assembly station. In order to do this for as many passengers as possible in as many regions of the ships as possible, the team mounted battery-powered video cameras in strategic locations (Figure 1) or made use of the ship's own CCTV camera system (Figure 2) [7] . Before each trial, the team ensured that cameras were synchronised to a known, pre-recorded trial time standard or that they were capable of recording audio so that the audible alarm could be used as a reference point for synchronisation.

The cameras were set to record as early as possible before the trial so that passengers were not alerted to their presence and possibly influence their behaviour during the trial. On completion of the trials, the cameras were removed and the video record backed-up to redundant storage devices. The files were then processed to remove unnecessary footage at the start and end of the recording period, a time stamp was added and the resulting videos were compressed to a more manageable size. In total, 30 video cameras were installed on RP1, while on CS 106 cameras were used (94 of the ship's own CCTV cameras and 12 digital video cameras) and on RP2, 40 cameras were used.

Figure 1. Digital video cameras and mounting options (left: magnetic and right: friction clamp)


(a) micro fisheye camera


(b) dome style digital camera

Figure 2. Ship's CCTV cameras used during the CS trial (a) micro fisheye (b) dome style

A considerable amount of video data was collected during the five trials: approximately 14 GB of video data (6 hours of footage) during the first RP1 trial and 11.7 GB (5 hours of footage) on the second trial; approximately 37 GB of video data (53 hours of footage) during the CS trial; approximately 20 GB of video data (representing 9 hours of video footage) during the first RP2 trial and 16 GB (7 hours of footage) on the second trial.

Given the vast amount of video data collected and the large number of passengers to be analysed, a team of three people was trained to extract response times from the video footage. To ensure reliability and consistency in their results, the analysts had to pass an inter-rater testing process in which they each analysed the same set of passengers and compared their results. As part of this process, a dictionary of definitions was developed to describe, as precisely as possible, the nature of passenger actions to be identified and measured. If an analyst's times were outside defined levels of accuracy and/or interpreted passenger actions were inconsistent, then corrections were made to the person's methods and the group did a retest with different passengers. This process was repeated until all three analysts produced reliable, repeatable results (accuracy of 90% or greater). At this point, the team moved to the analysis of all the video footage. This process was repeated for all three vessels.

Analysis was undertaken using commercially available software - Adobe Premiere Pro. Using this software allowed the video analyst to place markers on the video time line for each individual passenger being analysed. Software was then developed to extract all the marker information from the Premiere Pro project files for each passenger analysed and export the data into a single Excel compatible spreadsheet.

In total, 533 and 470 response time data points (trial 1 and trial 2 respectively) were collected from the RP1 trials (1003 in total), 1228 data points were collected from the CS trial and 54 and 81 (trial 1 and trial 2 respectively) were collected on the RP2 trials (135 in total).

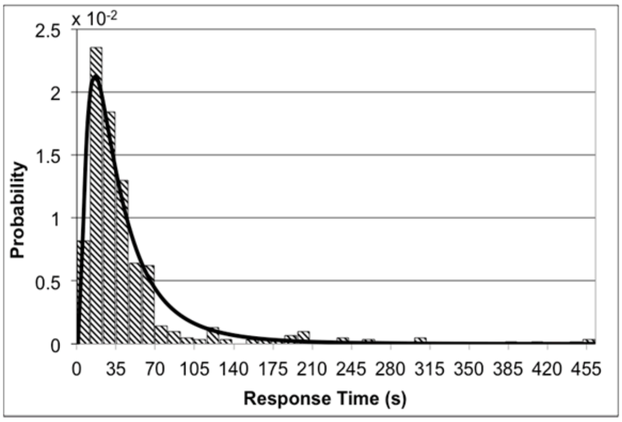
## 3. RESULTS AND DISCUSSION

The response time distributions for the two RP1 trials, the CS trial and the two RP2 trials are now presented.

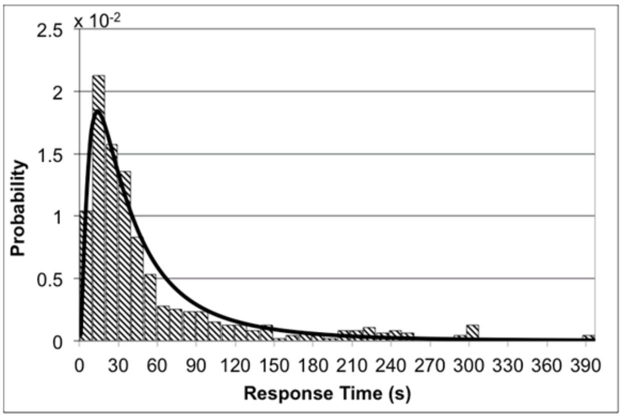
### 3.1 RP1 RTDs

Response time distributions were generated from the data for each day of the trials on RP1 (Figure 3). The data displays the typical log-normal distribution and so a log-normal curve was fitted to each of the data-sets and the curves from both trials compared in Figure 4. As can be seen the curves from both trials are remarkably similar. A Mann-Whitney non-parametric U-Test [8], [9] was performed with the null hypothesis that trial 1 and trial 2 results were independent samples from identical continuous distributions with equal medians. Results show that the null hypothesis is not rejected at the 5% significance level, with a p-value = 0.0795 and a z-value = 1.7534. This suggests that both distributions are identical. This further suggests that if the trial were to be repeated again within the same environment with a different group of people with similar demographics, it would be expected to generate the same RTD. This is a powerful result and suggests that if the response times and demographics of sufficient people are characterised for a given type of structure, then if the assembly exercise is repeated under similar notification conditions, a similar RTD will be generated. In other words, under these conditions the RTD is invariant. While the RTD for the same ship is likely to be invariant, it is not clear if the same type of RTD is likely to be generated for other similar types of passenger ships (i.e. different ships of the same type). As there were no significant differences between the two distributions, the results from both trials can be combined to form a single data-set that is representative of RO-PAX ferries without cabins (Figure 5) and the equation of the resulting log-normal distribution takes the form:

$$y = \frac{1}{\sqrt{2\pi} \times 0.901x} \exp\left[\frac{(\ln(x) - 3.516)^2}{2 \times 0.901^2}\right] \quad [1]$$




(a)




(b)

Figure 3. Response time distributions for RP1, (a) Trial 1 and (b) Trial 2

The minimum and maximum response times are 0.6 s and 470 s, while the mean of the logarithm of response times is 3.516 s and the standard deviation of the logarithm of response times is 0.901 s. The arithmetic mean response time for passengers is 53 s and 50%, 75% and 90% of the passengers have responded after 32 s, 56 s and 119 s respectively.

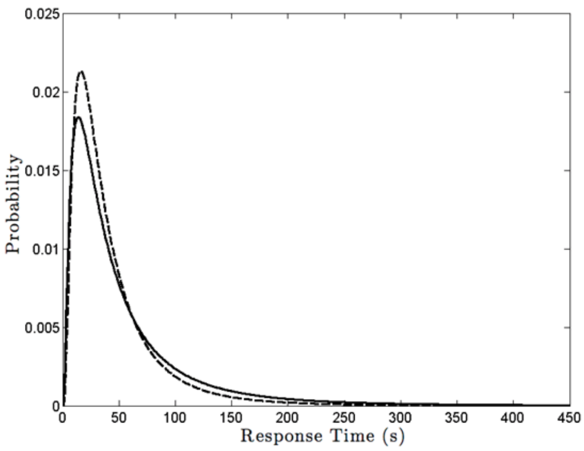



Figure 4. Comparison of response time distributions for trials 1 (dashed) and 2 (solid) on RP1

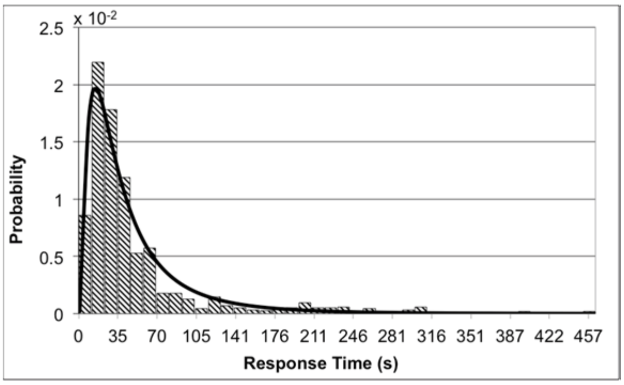



Figure 5. Overall response time distribution for RP1 (including trials 1 and 2)

### 3.1(a) Comparing RTDs in Public Spaces for RP1 and Eurostar Roma

The RTDs shown in Figure 3 are for two different assembly trials on the same vessel. As discussed, these appear to be virtually identical; however it is desirable to demonstrate that assembly trials on different vessels of the same type will produce a similar RTD. The only other detailed RTD collected on a large passenger ship at sea during a semi-unannounced trial was generated as part of the EU FP5 research project FIRE EXIT. The vessel used in this trial was the RO-PAX vessel Eurostar Roma (ER). The vessel consisted of 11 decks of which three could be utilised by passengers. The total passenger capacity of the vessel is 1400, with 208 passengers in aircraft style seating, 626 accommodated in cabins and 566 deck passengers. The vessel has two restaurants, two bars and a casino area. The ship also has a reception area, shop and outdoor pool. The vessel is of a similar type to the RP1 but with cabins. As part of the FIRE EXIT project, response time data was collected for passengers in public spaces and in cabins. Here only the data from the public spaces is considered in order to be comparable with that generated for the RP1. In total some 67 response times were collected from passengers located in public spaces and used to generate the day time RTD [4] in IMO MSC/Circ. 1238 [5]. The fitted log-normal distribution for the ER data-set along with that for the RP1 data-set is presented in Figure 6. As can be seen from the Figure, the two distributions are almost identical. A Mann-Whitney non-parametric U-Test [8], [9] was performed with the null hypothesis that the RP1 and ER results were independent samples from identical continuous distributions with equal medians. Results show that the null hypothesis is not rejected at the 5% significance level, with a p-value = 0.641 and a z-value = -0.466. Using this result, it is argued that the RTD derived for RP1 can be considered representative of this type of vessel – RO-PAX without cabins. Furthermore, the fact that the RTD derived from 1003 individual response times (RP1 data-set) is similar to that derived from 67 individual response times (ER data-set) suggests that the fitted RTD is robust.

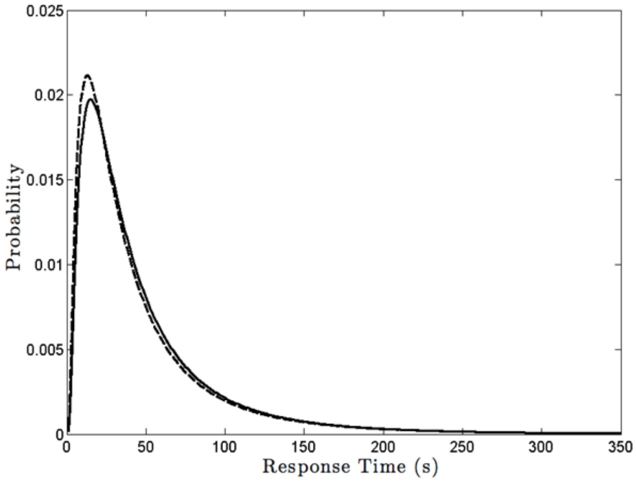



Figure 6. Comparison of RTDs for RP1 (solid) and ER (dashed)

### 3.2 CS RTDs

The overall RTD for data generated from the CS trial (1228 passengers) is presented in Figure 7. The data points display the typical log-normal distribution and so a log-normal curve was fitted to the data-set as shown. The equation for the log-normal fit takes the form:

$$y = \frac{1}{\sqrt{2\pi} \times 0.890x} \exp\left[\frac{(\ln(x) - 5.012)^2}{2 \times 0.890^2}\right] \qquad [2]$$

The minimum and maximum response times are 8.3 s and 1379 s, while the mean of the logarithm of response times is 5.012 and the standard deviation of the logarithm of response times is 0.89.

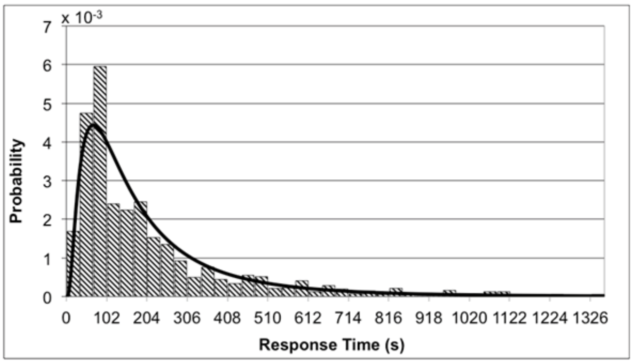



Figure 7 – Response time distribution for CS

As the assembly trial started during breakfast on the second day of the cruise, a number of passengers were still located in their cabins when the alarm was sounded. The passenger response times collected during this trial can therefore be broadly divided into two main groups – passengers who are in cabins (595 passengers) and those who are in the public areas (633 passengers) of the ship (Figure 8).

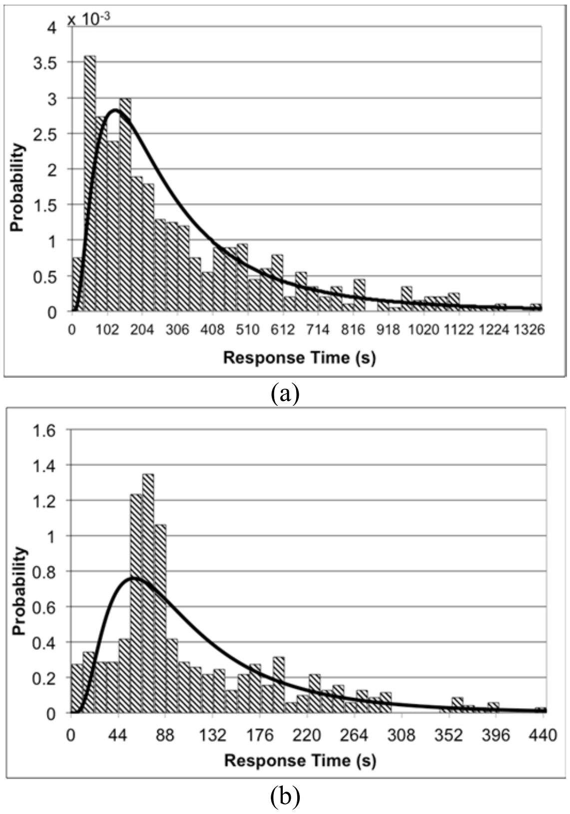



Figure 8. Response time distributions for CS in (a) cabins and (b) public spaces

Because the video data does not reveal passenger behaviour within the passenger's cabin, the response time for passengers located within cabins is determined as the point when the passenger exits the cabin and starts purposeful movement towards the assembly station.

The equations for the resulting RTDs for public spaces (equation 3) and cabins (equation 4) for CS take the form:

$$y = \frac{1}{\sqrt{2\pi} \times 0.702x} \exp\left[\frac{(\ln(x) - 4.562)^2}{2 \times 0.702^2}\right] \qquad [3]$$

$$y = \frac{1}{\sqrt{2\pi} \times 0.817x} \exp\left[\frac{(\ln(x) - 5.49)^2}{2 \times 0.817^2}\right] \qquad [4]$$

Comparing the response time distributions for passengers in cabins with passengers in public spaces shows that the two distributions are quite different (Figure 9). A Mann-Whitney non-parametric U-Test [8], [9] was performed with the null hypothesis that results for passengers responding from cabins and results for passengers responding from public areas were independent samples from identical continuous distributions with equal medians. Results show that the null hypothesis is rejected at the 5% significance level, with a p-value = 0.000 and a z-value = 18.230. Thus, passenger response times in each area are from statistically different distributions which suggests that different RTDs should be used to represent passengers in cabins and public spaces on cruise ships. This observation is consistent with that from the earlier work based on the ER [4].

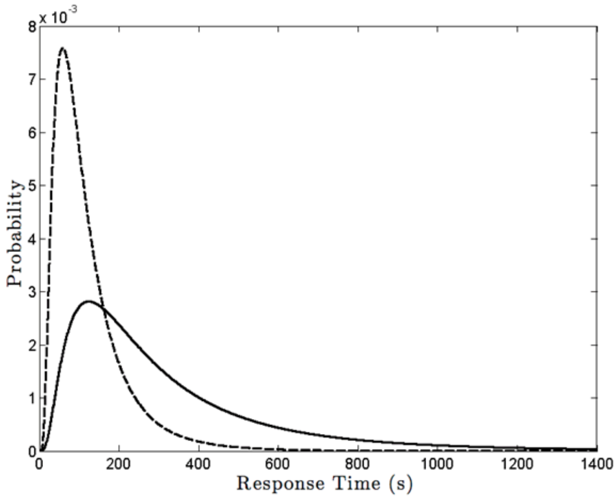



Figure 9. Comparison of RTDs for CS in cabins (solid) and in public spaces (dashed)

Clearly, passengers in cabins take considerably longer to respond than passengers in the public areas. The arithmetic mean response time for passengers in cabins is 333 s while for passengers in public spaces it is 88 s. Furthermore, for passengers in their cabins, 50%, 75% and 90% have responded after 233 s, 470 s and 704 s respectively. For passengers in public spaces, 50%, 75% and 90% have responded after 88 s, 165 s and 242 s respectively. The longer response times for passengers in cabins compared to passengers in public spaces could be due to longer notification times and a different range of action and information tasks undertaken during the response phase [10]. For example, passengers in cabins could be asleep or in the process of dressing, leading to longer notification times and a different range of action and information tasks compared to passengers in public spaces. This, in turn, results in the different RTD observed.

3.2(a) Comparing RTDs in Public Spaces for CS and RP1

As the CS is a different type of vessel (i.e. cruise ship) to the RP1 (i.e. RO-PAX without cabins) it is important to determine if the RTD generated for the RP1 is similar to that for the public spaces on CS. Presented in Figure 10 are the RTDs for passengers in public spaces for both vessels, as well as for the ER – clearly there is a difference between the RO-PAX curves and the CS. A Mann-Whitney non-parametric U-Test [8], [9] was performed with the null hypothesis that results for CS passengers in public spaces and results for RP1 were independent samples from identical continuous distributions with equal medians. Results show that the null hypothesis is rejected at the 5% significance level, with a p-value = 0.000 and a z-value = 22.456 and it is concluded that the distributions are statistically different. This is a significant result as it suggests that RTD for public spaces generated for one type of vessel cannot necessarily be applied to another type of vessel.

The difference in response behaviour between passengers on the RO-PAX vessels and cruise ships may be due to the differences in the nature of the voyage and the impact this has on passenger perceptions of their connection to the vessel. RO-PAX vessels are considered by passengers as a means of transport from one location to another, whereas voyages on cruise ships are considered an integral part of the vacation experience. Voyages on RO-PAX vessels are typically short, passengers generally have their belongings with them and they are anticipating making a speedy departure as soon as the vessel arrives. In effect, the passengers are primed to leave. In contrast, passengers on cruise ships expect to stay on the ship for several days. They effectively make the ship their home and have a greater expectation of permanency. This may have impacted passenger response times presented here, with passengers taking longer to react in public spaces on the CS compared to the RP1.

If the RTD for the RP1 (and by implication the public spaces on the ER) is compared with that derived for the CS for passengers in public spaces, significant differences are found in the manner in which people are responding to the alarm. For the RP1 and the CS (for passengers in public spaces), the arithmetic mean response time for passengers is 53 s and 88 s respectively – a difference of 66%. For the RP1/CS (public spaces only), 50%, 75% and 90% of the population responded after 32 s/88 s, 56 s/165 s and 119 s/242 s respectively. Clearly, passengers in public spaces on the cruise ship take considerably longer to respond to the alarm than passengers in public spaces on RO-PAX vessels. It is further noted that all the trials took place at approximately the same time of day and so this is not considered to be a contributory factor in the differences observed.

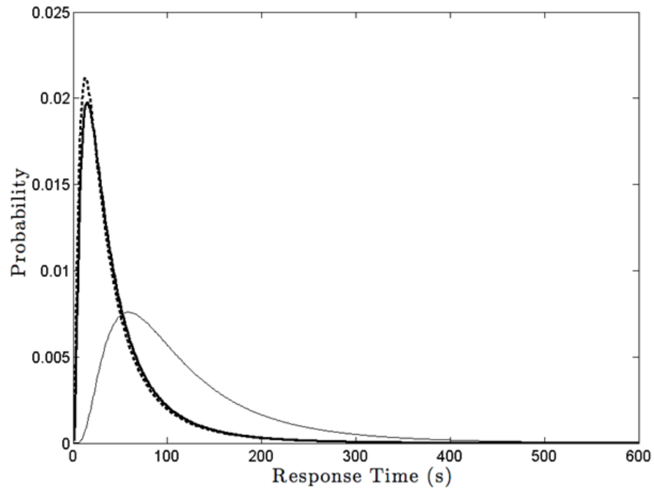



Figure 10 – Comparison of RTD for public spaces on RP1 (thick solid), CS (thin solid) and ER (dashed)

3.2(b) Comparing RTDs in Cabin Spaces for CS and ER

A comparison was also made between the response time data for cabin spaces on the CS and the ER (Figure 11). In total, some 126 response times were collected from passengers located in cabins on the ER. These were used to generate the night time RTD [4] presented in IMO MSC/Circ. 1238 [5]. It is clear from Figure 11 that the RTD for cabin spaces on the CS is significantly different to that on the ER (RO-PAX with cabins). To confirm the difference, a Mann-Whitney non-parametric U-Test [8]. [9] was performed with the null hypothesis that cabin area results for ER and CS were independent samples from identical continuous distributions with equal medians. Results show that the null hypothesis is rejected at the 5% significance level, with a p-value = 0.000 and a z-value = -12.5655.

While it may have been expected that the RTDs for people in cabins on a cruise ship would be the same as that for passengers on a RO-PAX vessel, there are several reasons that may account for the differences. The cabin spaces on the two types of vessel are significantly different and as has been already described, the nature of the voyage is different which leads to differences in how the cabin spaces are used and perceived by the passengers. The voyage on ER was a means of transport from one location to another, whereas the voyage on CS was part of the vacation experience. As such, the cabins on CS were generally more luxurious and a more desirable place to stay than on ER. CS cabins were in essence temporary homes and passengers "move in" unpacking their belongings and personal effects. In contrast, cabins on the ER were places to sleep for a few hours and so passengers were less likely to settle in. This may have impacted passenger response time, with passengers taking longer to get ready to leave the cabin in the CS compared to the ER.

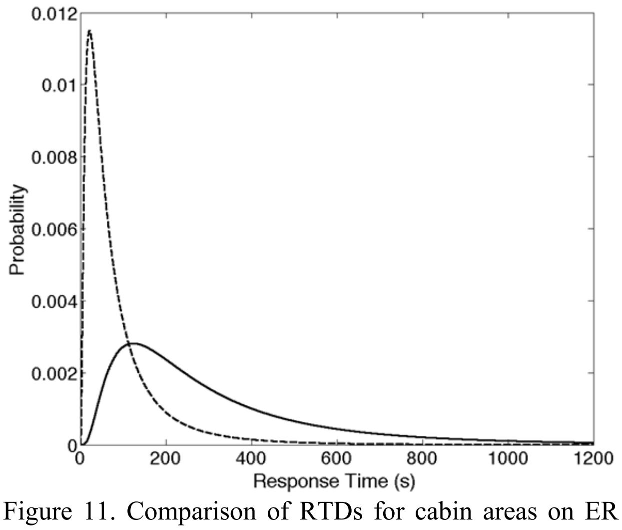


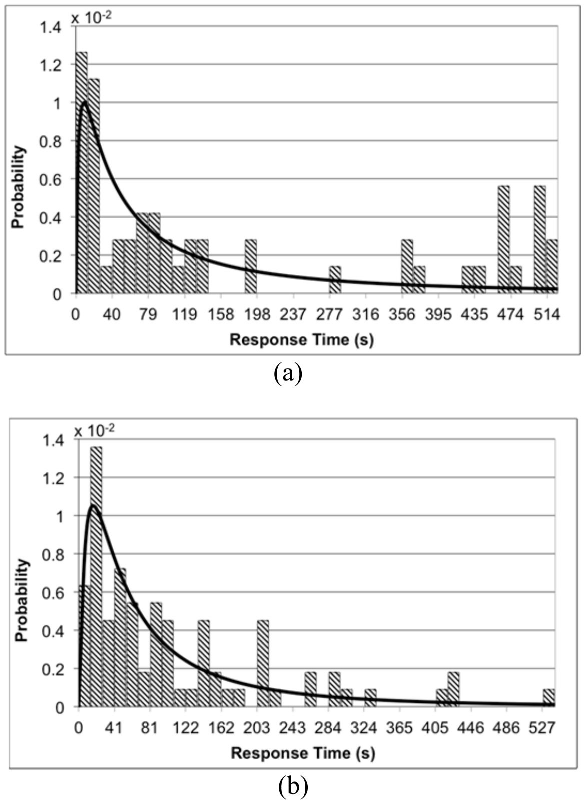

Figure 11. Comparison of RTDs for cabin areas on ER (dashed) and CS (solid).

This, together with a similar observation concerning the public space RTD for CS are significant results as they suggest that RTDs generated for one type of vessel cannot necessarily be applied to another type of vessel. Clearly, passengers in public spaces and cabins on the CS take considerably longer to respond to the alarm than passengers on the RO-PAX vessel. The implications of this finding are that the current RTDs used in IMO MSC/Circ. 1238, which are derived from the assembly trials on a RO-PAX vessel with cabins (ER) are not appropriate for all ship types and different RTDs should be used for evacuation analysis of cruise and RO-PAX vessels.

3.3 P2 RTD

When analysing the data from the RP2 trials, it should be noted that this data-set is quite small, with 54 data points from trial 1 and 81 data points from trial 2. In addition, the small number of data points is split between two types of spaces - public and cabin. Thus there is considerably less confidence in the data-sets generated from these trials compared to the other two RO-PAX trials. The data is further complicated due to the demographics of the population, which was considerably different from that of the other trials.

RTDs were generated from the data for each day of trials on RP2 (Figure 12). The data points for trial 2 display the typical log-normal shape, while data for trial 1 does not appear to have a strong log-normal shape.




(b)

Figure 12. RTDs for RP2, (a) Trial 1 and (b) Trial 2

However, given that the data-sets were quite small and with the understanding that response times are typically distributed in a log-normal fashion, a log-normal curve was fitted to each of the data-sets and the curves from both trials compared in Figure 13. As can be seen, the fitted curves from both trials are, again, very similar. A Mann-Whitney non-parametric U-Test [8], [9] was performed with the null hypothesis that trial 1 and trial 2 results were independent samples from identical continuous distributions with equal medians. Results show that the null hypothesis is not rejected at the 5% significance level, with a p-value = 0.2791 and a z-value = 1.0824. This suggests that both distributions are identical and can be combined to form a single, larger data-set for RP2 (RO-PAX ferry with cabins) (see Figure 14). The equation of the resulting log-normal distribution takes the form:

$$y = \frac{1}{\sqrt{2\pi} \times 1.308x} \exp\left[\frac{(\ln(x) - 4.259)^2}{2 \times 1.308^2}\right] \qquad [5]$$

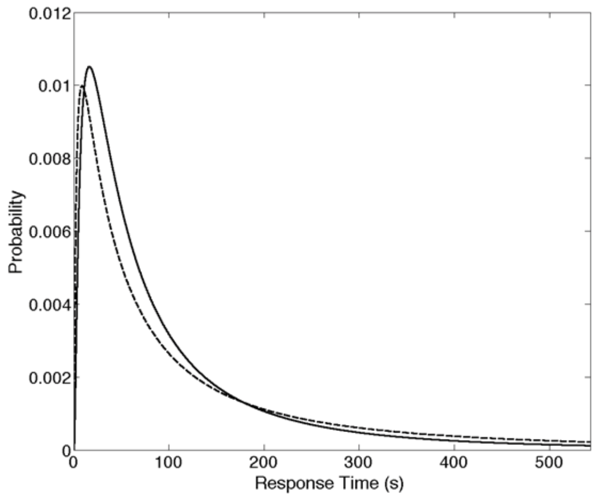



Figure 13. Comparison of RTDs for trials 1 (dashed) and 2 (solid) on RP2

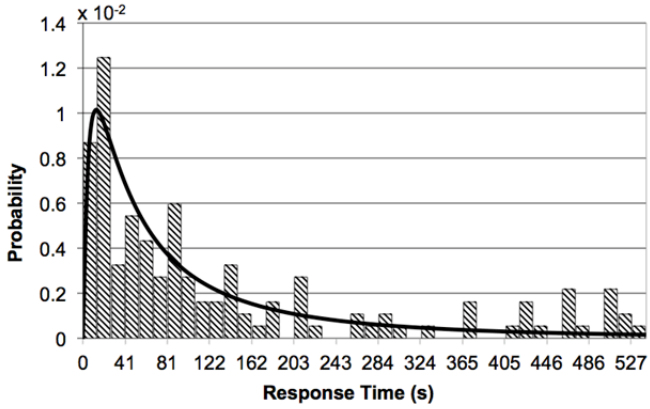



Figure 14. Overall RTD for RP2 (including trials 1 and 2)

As with the trials on RP1 and ER, this further suggests that if the trial were to be repeated again within the same environment with a different group of similar people, we would expect to generate the same RTD. This is a powerful result and suggests that if the response times and demographics of sufficient people are characterised for a given type of structure, then if an assembly exercise is repeated under similar notification conditions, a similar RTD will be generated. In other words, under these conditions the RTD is invariant. While the RTD for the same ship is likely to be invariant, it is not clear if the same type of response time distribution is likely to be generated for other similar types of passenger ships i.e. different ships of the same type.

The minimum and maximum response times are 1.6 s and 548 s, while the mean of the logarithm of response times is 4.259 and the standard deviation of the logarithm of response times is 1.308. The arithmetic mean response time for passengers is 71 s and 50%, 75% and 90% of the passengers have responded after 29 s, 60 s and 158 s respectively.

The combined data-set was then separated into public spaces (40 data points) and cabins (95 data points). The RTD generated for public spaces (Figure 15) and cabins (Figure 16) generally follow a log-normal form and so log-normal curves were fitted to the two distributions (see Equations 6 and 7 respectively). It is, however, noted that the public spaces distribution is a small data-set (approximately 40% fewer response times than the data-set derived from trials on the ER) and so there is considerably less confidence in the RP2 public space data-set compared to the other two trials on RP1.

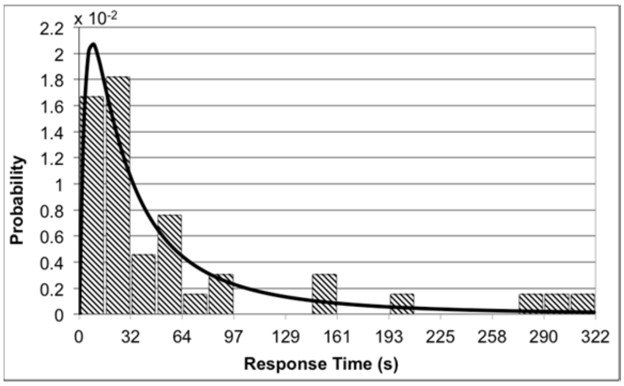



Figure 15. RTD for public spaces on RP2

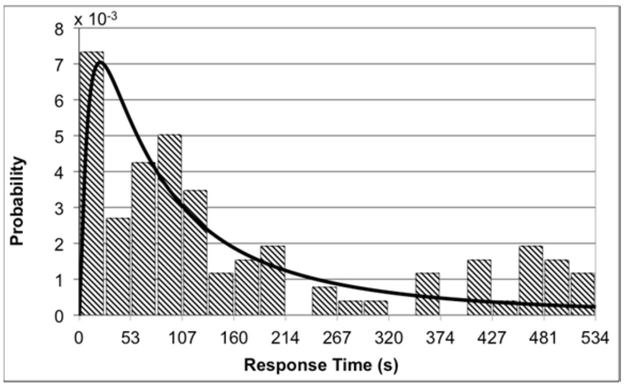



Figure 16. RTD for cabin areas on RP2

$$y = \frac{1}{\sqrt{2\pi} \times 1.18x} \exp\left[ \frac{(\ln(x) - 3.485)^2}{2 \times 1.18^2} \right] \qquad [6]$$

$$y = \frac{1}{\sqrt{2\pi} \times 1.224x} \exp\left[ \frac{(\ln(x) - 4.584)^2}{2 \times 1.224^2} \right] \qquad [7]$$

Comparing the RTDs developed for cabins and public spaces on RP2 (Figure 17), it is clear that they are not from the same distribution. A Mann-Whitney non-parametric U-Test [8], [9] was performed with the null hypothesis that cabin and public area results were independent samples from identical continuous distributions with equal medians. Results show that the null hypothesis is rejected at the 5% significance level, with a p-value = 0.000 and a z-value = -4.5874. Thus, for RP2, the RTDs for cabins areas and public spaces are different.

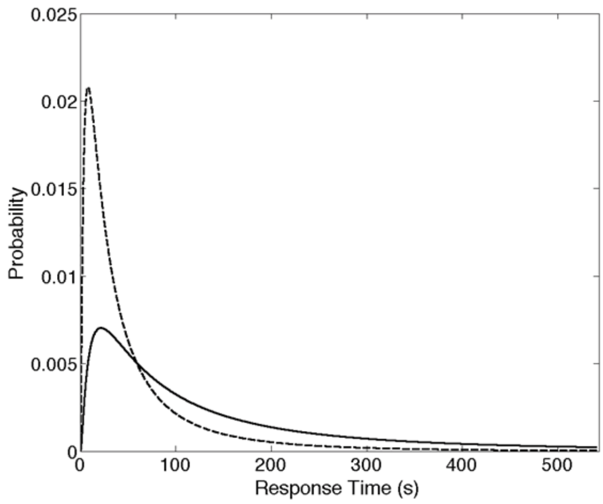



Figure 17. Comparison of response time distributions for cabin areas (solid) and public spaces (dashed) on RP2 (both trials combined).

3.3(a) Comparing RTDs in Public Spaces for RP2 and RP1

A comparison was made between the response time data for RP1 (Equation 1) and RP2 public spaces (Equation 6). Shown in Figure 18, the response time distributions for each vessel appear to be virtually the same. A Mann-Whitney non-parametric U-Test [8], [9] was performed with the null hypothesis that the RP1 data and the RP2 public space data were independent samples from identical continuous distributions with equal medians. Results show that the null hypothesis is not rejected at the 5% significance level, with a p-value = 0.8128 and a z-value = -0.2369. This suggests that both data-sets are the same. While this is a promising result and consistent with findings presented above (see section 3.1.1), the two data-sets have not been combined. This is because the data-set derived from RP2 is very small and hence may not be representative. Furthermore, there were significant differences in the population demographics on each ship during the trials (see Table 1). From Table 1, it is noted that 47.5% of the population on RP2 was less than 19 years of age compared to 6.9% of the population on RP1. Furthermore, 41.7% of the population on RP1 was over 40 years of age compared to 0% of the population on RP2. These differences in population demographics may have had a significant impact on the RTD and so the data-sets are not combined.

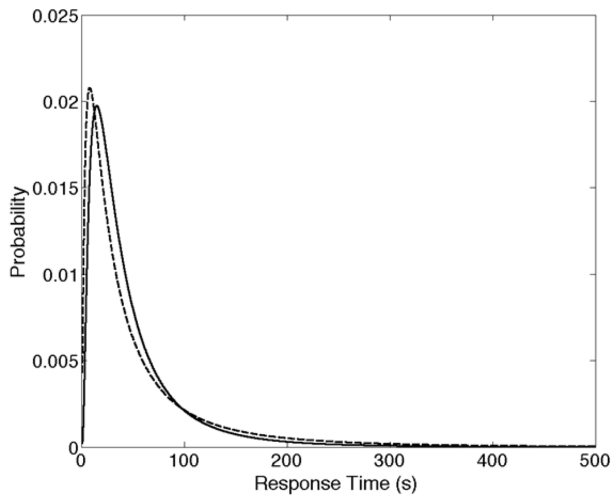



Figure 18. Comparison of RTDs for RP1 (solid) and public spaces on RP2 (dashed).

Table 1. Population demographics on RP1 compared RP2 public spaces

| Age Group | RP1 | | RP2 – Public Spaces | |
|---|---|---|---|---|
| | No. | % of total | No. | % of total |
| **11-19** | 69 | 6.9 | 19 | 47.5 |
| **20-39** | 473 | 47.2 | 20 | 50 |
| **40-64** | 410 | 40.9 | 0 | 0 |
| **65+** | 8 | 0.8 | 0 | 0 |
| **Unknown** | 43 | 4.3 | 1 | 2.5 |
| **Totals** | **1003** | **100** | **40** | **100** |

3.3(b) Comparing RTDs in Cabin Spaces for RP2 and CS

A comparison was made between the RTD for cabin spaces on both CS (Equation 4) and RP2 (Equation 7) (see Figure 19). It is clear from Figure 19 that the RTD for each vessel is different. To confirm the difference, a Mann-Whitney non-parametric U-Test [8], [9] was performed with the null hypothesis that cabin RTDs for CS and RP2 were independent samples from identical continuous distributions with equal medians. Results show that the null hypothesis is rejected at the 5% significance level, with a p-value = 0.000 and a z-value = -6.8096. This result is significant and supports the earlier result (see section 3.2.2) that different types of vessel may require different RTDs. In addition to the reasons identified earlier, suggesting why the RTDs for cabin spaces on cruise ships may be different to that for RO-PAX vessels (see section 3.2.2), the differences in population demographics of the two vessels may also have contributed to the observed differences in RTDs. As with the public spaces, there were significant differences in the population demographics in cabins on each ship during the trials (Table 2). From Table 2, it is noted that 44.2% of the population on RP2 was less than 19 years of age compared to 7.7% of the population on CS. Furthermore, 48.7% of the population on CS was over 40 years of age compared to 33.7% of the population on RP2. The differences in vessel type along with the significant differences in passenger demographics may explain the typically longer response times in the cabins areas on CS compared with RP2.

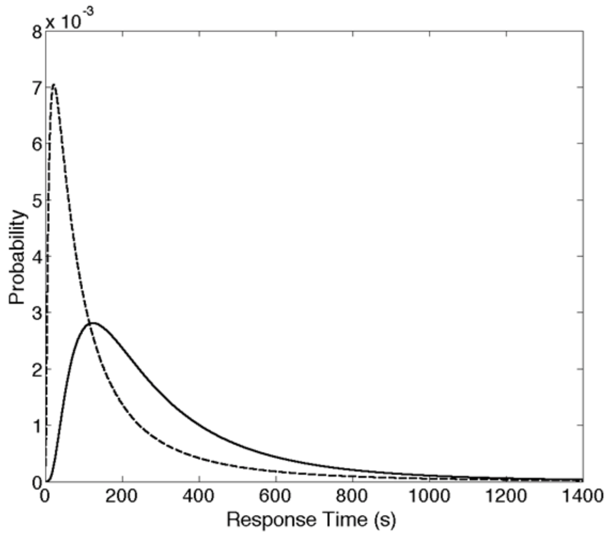



Figure 19. Comparison of RTDs for cabin areas on CS (solid) and RP2 (dashed).

Table 2. Population demographics in cabins on CS compared cabins on RP2

| Age Group | CS - Cabins | | RP2 – Cabins | |
|---|---|---|---|---|
| | No. | % of total | No. | % of total |
| **11-19** | 46 | 7.7 | 42 | 44.2 |
| **20-39** | 216 | 36.3 | 10 | 10.5 |
| **40-64** | 240 | 40.3 | 26 | 27.4 |
| **65+** | 50 | 8.4 | 6 | 6.3 |
| **Unknown** | 43 | 7.2 | 11 | 11.6 |
| **Totals** | **595** | **100** | **95** | **100** |

3.3(c) Comparing RTD in Cabin Spaces for RP2 and ER

A comparison was made between the response time data for cabin spaces on ER and RP2 (Figure 20). It is clear from the figure that the RTD for each vessel is different. To confirm the difference, a Mann-Whitney non-parametric U-Test [8], [9] was performed with the null hypothesis that cabin space results for ER and RP2 were independent samples from identical continuous distributions with equal medians. Results show that the null hypothesis is rejected at the 5% significance level, with a p-value = 0.000 and a z-value = 3.7360 supporting the observation that the two distributions are statistically different.

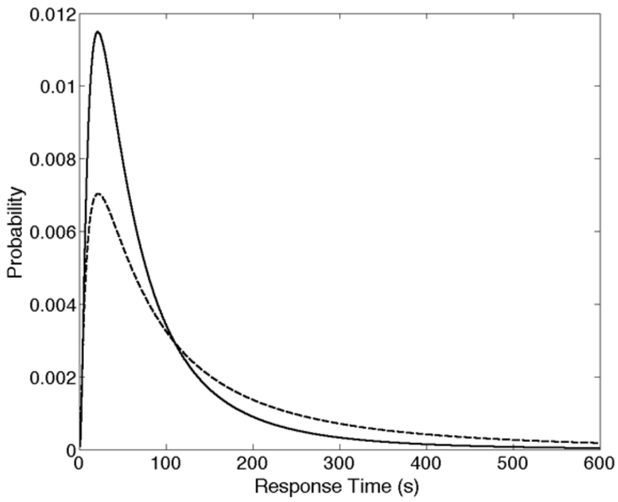



Figure 20. Comparison of RTDs for cabin areas on ER (solid) and RP2 (dashed).

As both the ER and RP2 are vessels of the same type (RO-PAX with cabins), the cabin spaces are similar and the nature of the journeys both vessels were on is similar, it may have been expected that both RTDs would also have been similar. The difference between the two RTDs is believed to be due to differences in population demographics. As already noted, the population in cabins on RP2 was predominately young (see Table 2) with almost half (44.2%) of the population being under 19 years of age. While the detailed population demographics for the ER are not available [4], the information that is available suggests that the population in cabins on the ER were primarily adults. This is based on the following analysis. Of the two ER trials, 508 passengers were involved in the first trial, "the majority of which were unaccompanied teenage school children" [4]. In the second trial, 236 passengers were involved which consisted of a "mixture of adults and unaccompanied school aged children" [4]. From the first trial, 124 questionnaires were completed and returned by the passengers, representing 25% of those on board. From the second trial, 80 questionnaires were completed and returned by the passengers, representing 34% of those on board. From the questionnaires returned, 42% from the first trial indicated that they were less than 21 years of age, while from the second trial 21% were under the age of 21. From this data it is clear that fewer of those in the second trial were young compared to the first trial. In addition, the combined RTD for the cabin spaces derived from the ER consisted of 22 data points from the first trial and 105 data points from the second trial. Thus the vast majority of data in the cabin RTD from the ER trials comes from the second trial. It follows from this that the majority of passengers in cabins were likely adults (which explains the small number in the first trial).

Thus, while not certain, it is likely that there were greater proportions of adults in cabins in the ER cabin RTD data-set than in the RP2 cabin data-set. This difference in demographics may explain the difference in the RTD for the two RO-PAX vessels and would support the premise that passenger demographics influenced the RTD.

## 4. PROPOSED MODIFICATIONS TO RTDS USED IN IMO EVACUATION ANALYSIS GUIDELINES

The RTD currently used in the IMO guidelines governing ship evacuation analysis [5] are based on two assembly trials conducted on the ER. In total 194 unique response time data points were collected on the ER from which two RTDs were generated, one for the Day Case, and one for the Night Case. Here modifications to these RTDs are proposed based on the data presented in this paper which consists of 2366 response time data points generated from five trials.

### 4.1 CRUISE SHIP AND RO-PAX RTDS

The RTDs currently used for evacuation analysis of passenger ships within IMO MSC/Circ.1238 are used for all types of passenger ships e.g. RO-PAX and cruise ships. The data and analysis presented in this paper clearly show that the RTDs for RO-PAX vessels are significantly different to that for cruise ships (see sections 3.2.1 and 3.2.2). It is thus suggested that the guidelines be modified so that different RTDs are used for RO-PAX and Cruise Ships.

### 4.2 PROPOSED RTD FOR RO-PAX VESSELS

Given that the public space RTDs derived from trials on RP1 and ER were found to be statistically the same (see section 3.1.1), they can be combined to produce a single RTD for public spaces. The combined curve consists of 1003 response time data points collected from the two SAFEGUARD trials and 67 response time data points that comprise the RTD currently used within the IMO evacuation analysis guidelines. The combined RTD is based on significantly more data (15 times more) than is currently used and is based on data from four trials from two different vessels, significantly improving the confidence in its reliability. The combined curve is truncated at 300 s, removing the tail of the distribution, as is currently done for the IMO Day Case RTD. Since truncating the distribution represents 99.2% of the overall distribution, a scale factor must be applied so that the area under the curve equals 1.0. The new Day Case RTD is presented in Figure 21 and is described using Equation 8.

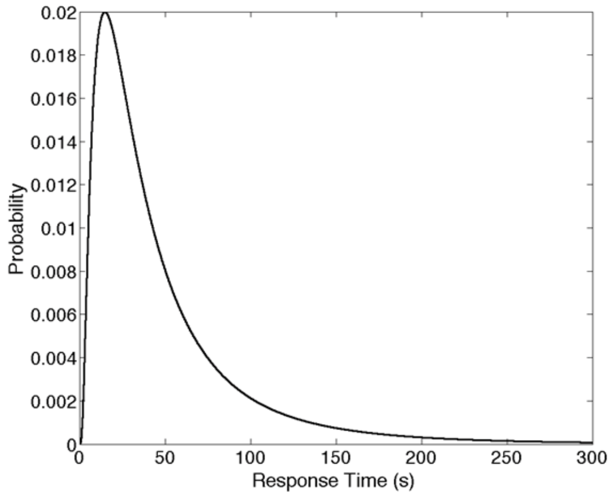



Figure 21. Suggested new IMO Day Case RTD for RO-PAX ferries

$$y = \frac{1.0076}{\sqrt{2\pi} \times 0.903x} \exp\left[\frac{(\ln(x) - 3.511)^2}{2 \times 0.903^2}\right] \quad [8]$$

Due to significant differences in population demographics, the public space response time data generated from the RP2 vessel is not included in the suggested Day Case RTD for RO-PAX vessels (see section 3.3.1). Furthermore, the cabin space response time data generated from the RP2 vessel is not considered suitable for the same reasons (see section 3.3.3) and so is not included in the RTD used to define the Night Case RTD. Thus it is suggested that the Night Case RTD currently used within the IMO evacuation guidelines remains unaltered.

### 4.3 PROPOSED RTD FOR CRUISE SHIPS

It is suggested that the RTD derived from CS for public spaces (Figure 8b) should be used to represent the new Day Case RTD for Cruise Ships. The RTD is truncated at 300 s, removing the tail of the distribution, as is currently done for the IMO Day Case RTD. Since truncating the distribution represents 94.8% of the overall distribution, a scale factor must be applied so that the area under the curve equals 1.0. The new Day Case RTD for Cruise Ships is presented in Figure 22 and is described using Equation 9. The new Day Case RTD is based on 633 data points, considerably more than the 67 data points used in the existing IMO evacuation analysis guidelines. It is suggested that the RTD derived from the trial on CS for cabin areas (Figure 8a) should be used to represent the new Night Case RTD for cruise ships. Truncating the RTD at 300 s, which is done in the current IMO evacuation guidelines, results in only 60.3% of the data-set being included.

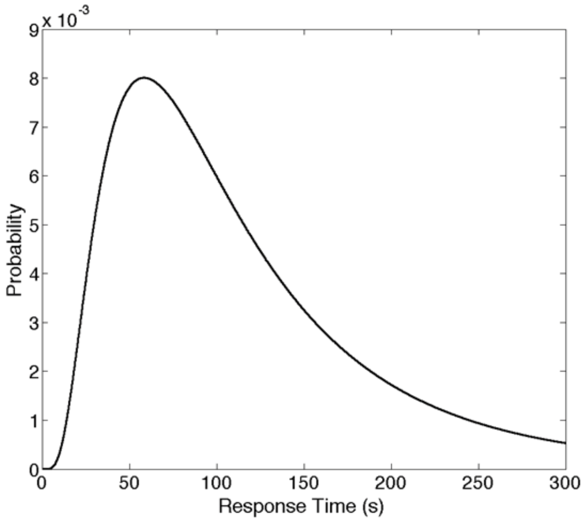



Figure 22. Suggested new IMO Day Case RTD for Cruise Ships.

$$y = \frac{1.0548}{\sqrt{2\pi} \times 0.702x} \exp\left[\frac{(\ln(x) - 4.562)^2}{2 \times 0.702^2}\right] \quad [9]$$

Clearly, as a significant proportion of the data is represented in the tail, truncating the RTD at 300 s is not appropriate. It is suggested that the truncation point be extended to 700 s, which would include 90.3% of the original data-set and require the use of a smaller scaling factor to ensure the area under the curve equals 1.0. Furthermore, in keeping with the approach IMO uses to represent the night case RTD, this curve should also be shifted by 400 s to account for the fact that passengers would be sleeping (which is typically not the case for the trials conducted). This truncated, shifted and scaled curve is presented in Figure 23 and described using Equation 10.

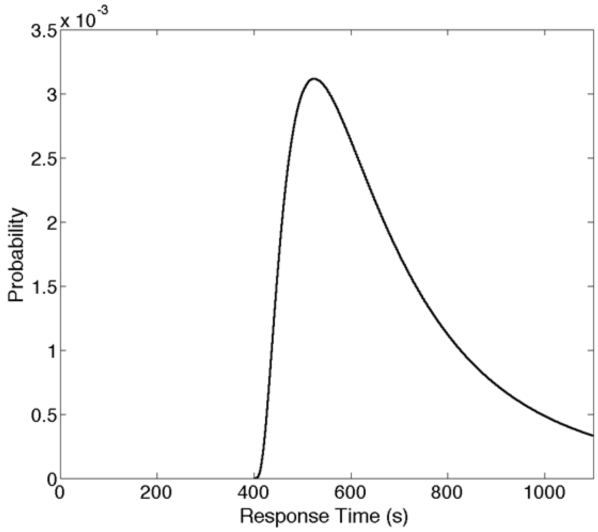



Figure 23. Suggested new IMO Night Case RTD for Cruise Ships.

$$y = \frac{1.1074}{\sqrt{2\pi} \times 0.817(x - 400)} \exp\left[\frac{(\ln(x - 400) - 5.49)^2}{2 \times 0.817^2}\right] \quad [10]$$

The new Night Case RTD is based on 598 data points, considerably more than the 127 data points used in the existing IMO evacuation analysis guidelines.

## 5. ASSESSING THE IMPACT OF THE NEW RTDS ON PASSENGER SHIP ASSEMBLY TIMES

Three new RTDs are proposed for adoption by IMO to replace the existing RTDs in IMO MSC/Circ.1238. A new Day Case RTD is suggested for RO-PAX vessels which is essentially similar to the existing RTD within IMO MSC/Circ.1238 (see Figure 6 and Figure 21 and Equation 8). As the proposed RTD is essentially the same as the existing RTD it is not expected to significantly impact predicted assembly times. To assess the impact of the new RTD on the assembly process a Day assembly scenario, as specified by IMO MSC/Circ.1238 [5], is investigated. The test geometry used in this analysis is the same RO-PAX ship geometry that was used in the original analysis of the IMO MSC/Circ.1238 RTD [4]. This was a hypothetical RO-PAX vessel consisting of three main vertical zones across 10 decks, of which five decks could be occupied by passengers. The vessel has a capacity of 1650 passengers and has 150 crew.

The model parameters, with the exception of the RTD, used in the simulations are compliant with those specified in IMO MSC/Circ.1238 [5]. As is required by IMO MSC/Circ.1238 a total of 50 repeat simulations were produced for each scenario, where the starting locations of the passengers within the various starting regions are randomised and the 95th percentile case is selected to represent the prediction of the assembly process. For a vessel of this size, the predicted assembly time must be less than 40 min (2400 s).

The Day Case requires passengers to be in public spaces at the sounding of the alarm. On responding to the call to assemble, the passengers move directly to the assembly station within their vertical zone. For each response time distribution, the case is simulated 50 times, changing the population after every 5 simulation runs, in order to build up a distribution of results. The maritimeEXODUS software [3, 4] was used to perform all the simulations.

The software was run (50 times) using the IMO MSC/Circ.1238 specified RTD and this process was repeated using the SAFEGUARD RO-PAX Day Case RTD (see Equation 1). Presented in Table 3 are the results for the Day Scenario. As can be seen, the maximum difference between the assembly times for the two cases is 3.5%, with the 95$^{th}$ percentile cases differing by 3.2%.

Table 3: Day Case Assembly Times Using Standard RTD and SAFEGUARD RO-PAX RTD

| | IMO (s) | SAFEGUARD (s) | % Difference |
|---|---|---|---|
| **Min** | 340 | 352 | 3.5 |
| **Average** | 384 | 393 | 2.3 |
| **Max** | 460 | 459 | 0.2 |
| **95th percentile** | 444 | 458 | 3.2 |

Presented in Figure 24 are the assembly curves for the 95th percentile case using the IMO Day Case RTD and the SAFEGUARD RO-PAX Day Case RTD. As can be seen, the difference between the two assembly curves is very small, consistent with the increase in the overall assembly times. It is also noted that the total assembly time using both RTDs easily satisfies the IMO requirement for overall assembly times.

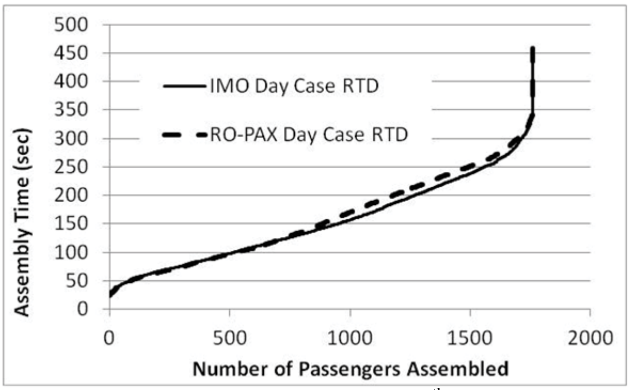



Figure 24: Assembly curves for the 95th percentile case generated using the standard IMO Day Case RTD and the SAFEGUARD RO-PAX Day Case RTD

There were also no significant differences between the two cases in terms of congestion generated during the assembly process. All the differences in values between the two models are considered insignificant (i.e. less than 10%) and as such it can be said that the two RTDs have the same impact on the simulations.

The proposed Day and Night RTDs for cruise ships (see Equations 9 and 10) are significantly different to those specified in IMO MSC/Circ.1238 [5] and so it is necessary to identify the likely impact these will have on the assembly process of a cruise ship. This is assessed by undertaking the Day and Night assembly scenarios as specified by IMO MSC/Circ.1238 [5] for a cruise ship geometry. The test geometry used in this analysis is the same cruise ship geometry used in the SAFEGUARD validation analysis [11]. The vessel consists of 12 passenger decks, of which seven decks are accommodation space consisting of passenger cabins (see Figure 25). The other five decks consist of general circulation and entertainment spaces such as; restaurants, bars, disco, swimming pools, casino, theatre, cinema, spa/health centre, business centre, leisure pursuits (such as gymnasium, climbing wall, crazy golf, cards room) and retail areas. The ship has 18 assembly stations (AS) distributed over two decks, deck 5 and 6, of which 10 are external and eight are internal. The vessel has a maximum berthing capacity of 3001 passengers, which is the size of the population during the IMO Night scenario and a 2501 capacity during the IMO Day scenario.

The model parameters, with the exception of the RTD, used in the simulations are compliant with those specified in IMO MSC/Circ.1238 [5]. As is required by IMO MSC/Circ.1238 a total of 50 repeat simulations were produced for each scenario, where the starting locations of the passengers within the various starting regions are randomised and the 95th percentile case is selected to represent the prediction of the assembly process. For a vessel of this size, the predicted assembly time must be less than 48 min (2880 s).

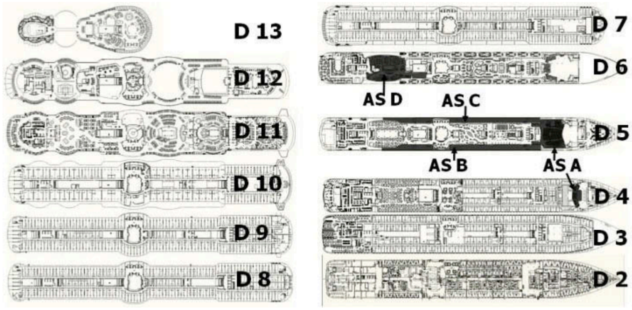



Figure 25. Layout of Cruise Ship used in Day and Night Analysis [12]

Four different scenarios were run, the standard Day and Night scenarios (which utilise the RTDs specified in IMO MSC/Circ.1238) and the Day and Night scenarios using the SAFEGUARD RTDs (Equations 9 and 10 respectively). The results for the Day Scenarios are presented in Table 4.

Table 4: Day Case Assembly Times Using Standard RTD and SAFEGUARD Cruise Ship RTD

| | IMO (s) | SAFEGUARD (s) | % Difference |
|---|---|---|---|
| **Min** | 729 | 769 | 5.5 |
| **Average** | 848 | 882 | 3.8 |
| **Max** | 1021 | 1032 | 1.1 |
| **95th percentile** | 981 | 982 | 0.1 |

As can be seen, the maximum difference between the assembly times for the two cases is 5.5%, with the 95th percentile cases differing by 0.1%.

Presented in
Figure 26 are the assembly curves for the 95th percentile case using the IMO Day Case RTD and the SAFEGUARD Cruise Ship Day Case RTD. As can be seen, the difference between the two assembly curves is quite small, consistent with the increase in the overall assembly times. It is also noted that the total assembly time using both RTDs easily satisfy the IMO requirement

for overall assembly times. There were also no significant differences between the two cases in terms of congestion generated during the assembly process.

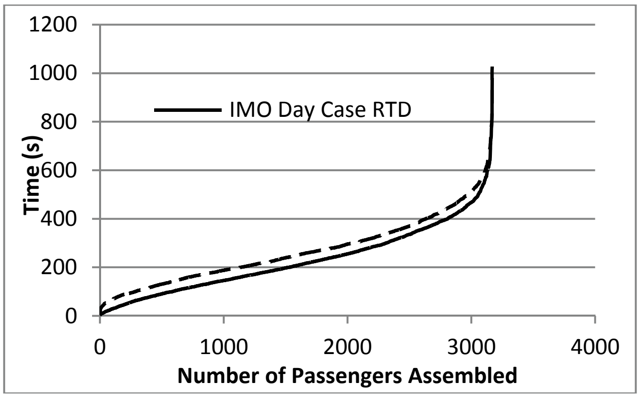



Figure 26: Assembly curves for the 95th percentile case generated using the standard IMO Day Case RTD and the SAFEGUARD Cruise ship Day Case RTD

The results for the Night Scenarios are presented in Table 5. As can be seen, the maximum difference between the assembly times for the two cases is 21.4%, with the 95th percentile cases differing by 21.2%. The significant increase in the assembly times is due to the significantly longer tail in the newly proposed cruise ship Night Case RTD which extends to 1100 s - beyond the upper limit of 700 s in the current night RTD specified in IMO MSC/Circ.1238.

Table 5: Night Case Assembly Times Using Standard RTD and SAFEGUARD Cruise Ship RTD

| | IMO (s) | SAFEGUARD (s) | % Difference |
|---|---|---|---|
| **Min** | 1126 | 1260 | 11.9 |
| **Average** | 1158 | 1335 | 15.3 |
| **Max** | 1210 | 1469 | 21.4 |
| **95th percentile** | 1187 | 1439 | 21.2 |

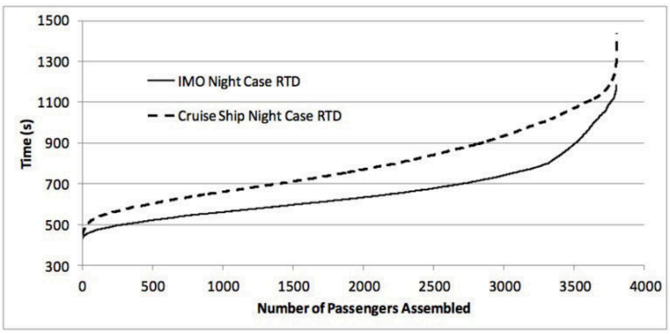



Figure 27: Assembly curves generated using the standard IMO Night Case RTD and the SAFEGUARD Cruise ship Night Case RTD

Presented in Figure 27 are the assembly curves for the 95th percentile case using the IMO Night Case RTD and the SAFEGUARD cruise ship Night Case RTD. As can be seen, the difference between the two assembly curves is quite large and increases as the number of agents to assemble increases. However, even in this case, it is noted that the total assembly time using both RTDs easily satisfies the IMO requirement for overall assembly times. There were also no significant differences between the two cases in terms of congestion generated during the assembly process.

These findings have been submitted to the IMO committee on Fire Protection to be considered for use in the framing of the next iteration of the international guidelines for ship evacuation analysis [13].

## 6. CONCLUSIONS

This paper has presented the results of research that was carried out to address the shortage of passenger response time data for large passenger ships, in particular cruise ships and RO-PAX ferries. The response time data was collected 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 presented - 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:

(i) Passenger Response Time Distributions (RTD) 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;

(ii) 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 identical.

(iii) Passenger RTDs for both public spaces and cabin spaces are dependent on the type 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

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

(v) 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 (the first RO-PAX vessel) 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.

(vi) 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 Cruise Ship 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.

(vii) 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 Cruise Ship 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.

These findings have been submitted to the IMO to be used to frame the next iteration of the international guidelines for ship evacuation analysis.

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