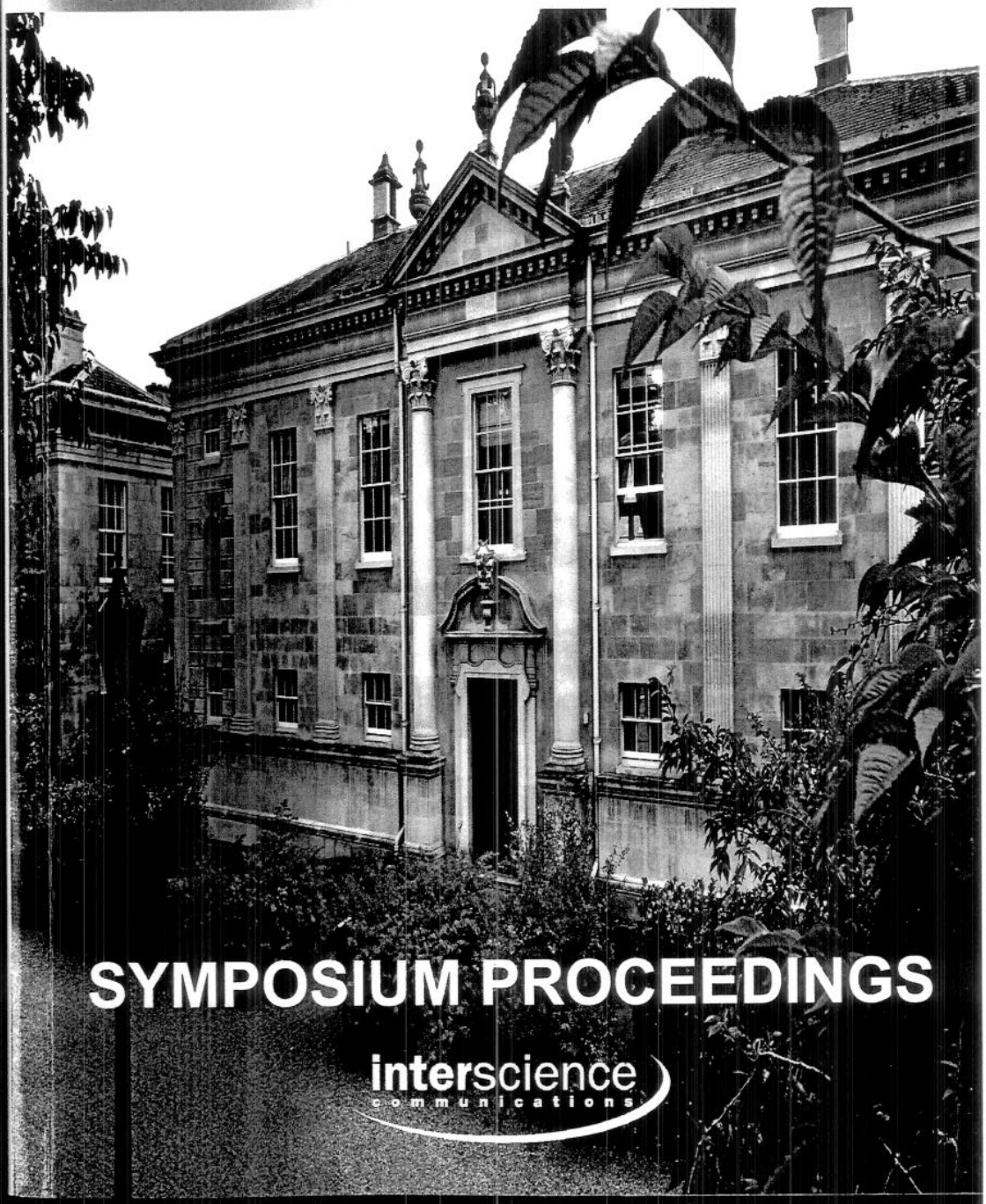
5th international Symposium

Human Behaviour in Fire 2012

Downing College, Cambridge, UK

19th - 21st September 2012



SYMPOSIUM PROCEEDINGS

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INTRODUCTION

It gives me very great pleasure to welcome you all to this the 5th international symposium on Human Behaviour in Fire. Since the symposia's inception in 1998 we have directly influenced many changes and been prominent in the development of fire safety engineering. We see colleagues make career changes and sadly some are taken from us. All the more reason then to make the most of our time here together, to network and catch up with old friends and colleagues. Remember at this symposium there are no strangers here only friends waiting to be introduced.

The Programme Committee have selected a cross section of papers to stimulate the mind and hopefully the organisers will include some moments in the social programme to stimulate the senses! Some 43 technical papers and 14 poster papers are included along with Panel Discussions and Workshops on:-

- Life Safety Options for People with Disabilities - How far have we come? - Implications of Our Aging Society on Design and Management of Buildings
- Fundamentals of Egress Calculations for Life Safety Assessment
- Workshop on the Ethics of Behavioural Studies

As we approach the 5th symposium there many big issues to be addressed. For example, where exactly are we, in human behaviour terms, with respect to fire safety engineering and performance based design? Given our well established foundations what should be our focussing on for the next decade? These issues will be addressed at the symposium and your active partition in discussions surrounding them is eagerly anticipated.

I hope you will enjoy the next 3-4 days and like me, make the most of your time here in the fine surroundings of Downing College, Cambridge.

Prof. T Jim Shields

Symposium Chair

RESPONSE TIME DATA FOR LARGE PASSENGER FERRIES AND CRUISE SHIPS

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ABSTRACT

This paper outlines research that was carried-out under the EU FP7 7 project SAFEGUARD and presents three sets of passenger response time data generated from full-scale semi-unannounced assembly trials at sea. The data sets were generated from two different types of passenger ships, a RO-PAX ferry, SuperSpeed 1 (SS1) and a cruise ship, Jewel of the Seas (JoS). In total response times from over 2200 people were collected making it the largest response time data set ever collected – on land or sea. The paper presents the analysis methodology used to extract the response time data and the resultant response time distributions (RTD). A number of key findings from the data analysis will also be presented, which includes: (a) all generated RTDs are log-normal, (b) RTDs from the two SS1 trials using two different populations are very similar, (c) The combined RTD for the SS1 is almost identical to the RTD generated from the earlier published data for the same type of vessel, (d) The RTD derived for the public spaces on the JoS is significantly different to that of the SS1, (e) The RTD for public spaces and cabins are significantly different. These findings are discussed in this paper and form the basis of a recommendation to be submitted to the International Maritime Organisation to be used to frame the next iteration of the international guidelines for ship evacuation analysis.

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 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 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 were collected and two full-scale validation data sets. 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, an audible alarm is sounded (seven short blasts and one long blast of the ships horn) and is 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 could

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 the first International Maritime Organisation (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 [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 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 class of passenger vessel and only a single example of that class. 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. In this paper we present the Response Time Distributions (RTD) generated from the first three trials on two different classes of passenger ship, a large RO-PAX ferry (without cabins), Superspeed 1; and a large cruise ship, Jewel of the Seas.

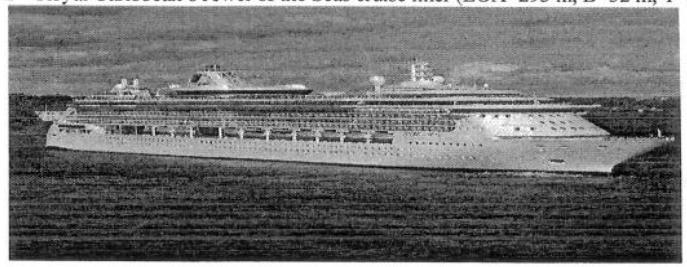
SHIP AND TRIALS DETAILS

The first vessel, SuperSpeed 1 (SS1) is operated by ColorLine AS and can carry approximately 2000 passengers and crew and over 700 vehicles (Figure 1). The route taken by the vessel during the data collection trials was from Kristiansands 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.

Figure 1. Color Line's SuperSpeed 1 ferry (LOA=213 m, B=26 m, T=6.7 m)

The second vessel, Jewel of the Seas (JoS), is operated by Royal Caribbean Cruise Lines International and has a capacity of 2500 passengers and 842 crew (Figure 2). 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.

Figure 2 – Royal Caribbean's Jewel of the Seas cruise liner (LOA=293 m, B=32 m, T=8.1 m)



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 SS1. 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 Kristiansands enroute 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 JoS on 31 July 2010 at 09:01 on the morning after departure from the UK. A total of 2292 passengers were on board.

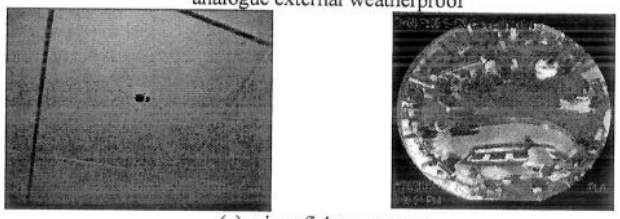
DATA COLLECTION AND ANALYSIS METHODOLOGY

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 3) or made use of the ship's own CCTV camera system (Figure 4)[6]. 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 alarm could be used as a reference point for synchronisation.

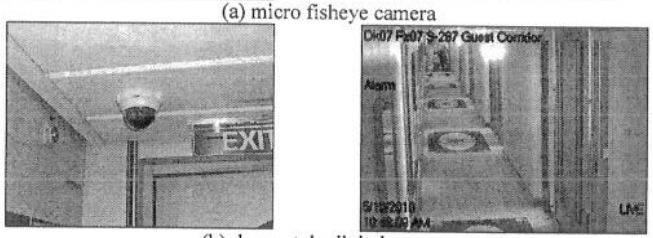
The cameras were set to record as early as possible before the trial so that passengers were not alerted to their presence and possibly influence their behaviour during the trial. On completion of the trials, the cameras were removed and the video record backed-up to redundant storage devices. The files 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 SS1, while on JOS 106 cameras were used (94 ship's own CCTV cameras and 12 digital video cameras).

Figure 3. Digital video cameras and mounting options (left: magnetic and right: friction clamp)

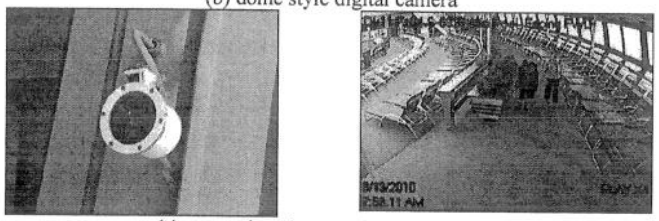
Figure 4. Ship's CCTV cameras used during the JoS trial (a) micro fisheye (b) dome style (c) analogue external weatherproof



(a) micro fisheye camera



(b) dome style digital camera



(c) external analog weatherproof camera

Approximately 14 GB of video data (representing 6 hours of video footage) was collected during the first trial on SS1 and 11.7 GB (representing 5 hours of video footage) on the second trial. Approximately 37 GB of video data (representing approximately 53 hours of video footage) was collected during the trial onboard JoS.

Given the vast amount of video 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 analysis of all the video footage. This process was repeated for both vessels.

Analysis was undertaken using commercially available software - Adobe Premiere Pro (Figure 5). Using this software allows video analyst to place markers on the video time line for each individual passenger being analysed (Figure 6). Software was then developed to extract all the marker information from the Premiere Pro project files for each passenger analysed and export the data corresponding into a single Excel compatible spreadsheet.

In total, 533 and 470 response time data points (day 1 and day 2 respectively) were collected from the SS1 trials (1003 in total) and 1228 data points were collected from the JoS trial.

Figure 5. Example screen capture of Adobe Premiere Pro work environment showing person being analysed in the red circle and timeline markers highlighted in green for the various times being recorded

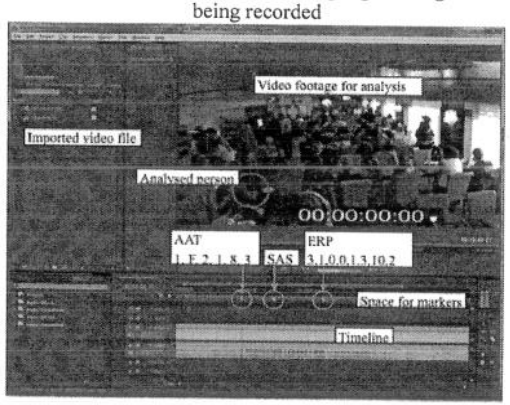


Figure 6. Example of a passenger identity key for one camera view in a shop on the JoS (showing all passengers whose response time was captured)

RESULTS AND DISCUSSION

The response time distributions for the two SS1 trials and the JoS trial are now presented.

SuperSpeed 1 Response Time Distributions

Response time distributions were generated from the data for each day of trials on SS1 (Figure 7). The data points display the typical log-normal distribution and so a log-normal curve was fitted to each of the data sets and the curves from both days compared in Figure 8. As can be seen the curves from both days are remarkably similar. A Mann-Whitney non-parametric U-Test [9, 10] was performed with the null hypothesis that Day 1 and Day 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 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 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 response time distribution is likely to be generated for other similar types of passenger ship i.e. different ships of the same class.

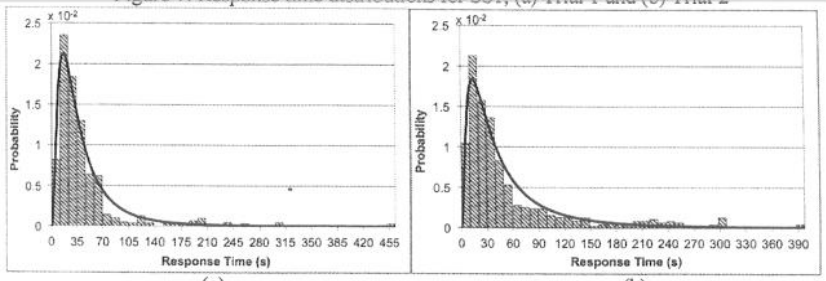
As there were no significant differences between the two distributions, the results from both days can be combined to form a single data set that is representative of RO-PAX ferries without cabins (Figure 9) and the equation of the resulting log-normal distribution takes the form:

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

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

0.901s. 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 7. Response time distributions for SS1, (a) Trial 1 and (b) Trial 2



(a) (b)

Figure 8. Comparison of response time distributions for trials 1 (dashed) and 2 (solid) on SS1

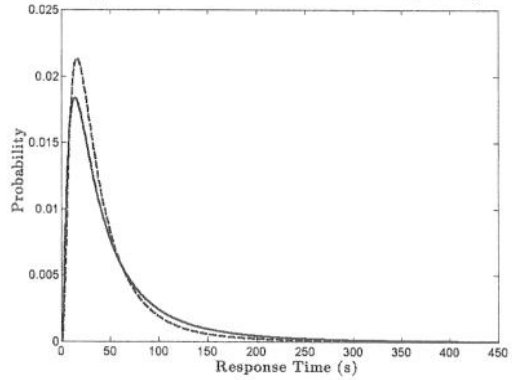
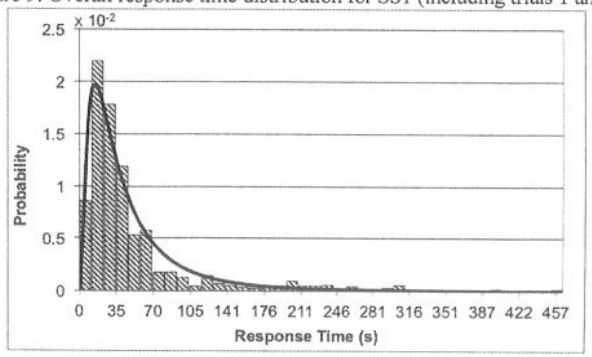


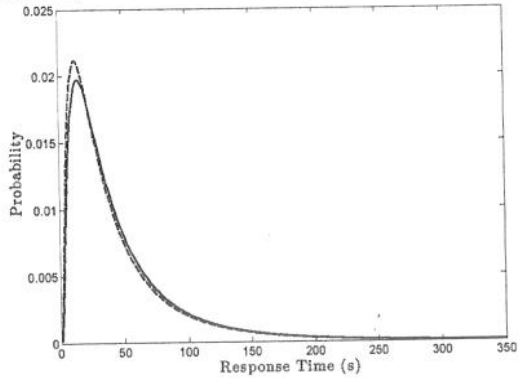
Figure 9. Overall response time distribution for SS1 (including trials 1 and 2)



Comparing Response Time Results for SuperSpeed 1 with FIRE EXIT

The RTD shown in Figure 8 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 class will produce a similar RTD. The only other detailed RTD for a large passenger ship collected at sea during a semi-unannounced trial was generated as part of the EU FP5 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 class to the SS1 but with cabins. As part of the Fire Exit project, response time data was collected for passengers in public spaces and in cabins. Here we consider only the data from the public spaces in order to be comparable with that generated for the SS1. 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 SS1 data set is presented in Figure 10. As can be seen from Figure 10 the two distributions are almost identical. A Mann-Whitney non-parametric U-Test [9, 10] was performed with the null hypothesis that SS1 and FIRE EXIT project 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 SS1 can be considered representative of this class of vessel – RO-PAX without cabins. Furthermore, the fact that the RTD derived from 1003 individual response times (SS1 data set) is similar to that derived from 67 individual response times (ER data set) suggests that the fitted RTD is robust.

Figure 10. Comparison of RTDs for SS1 (solid) and FIRE EXIT (dashed)



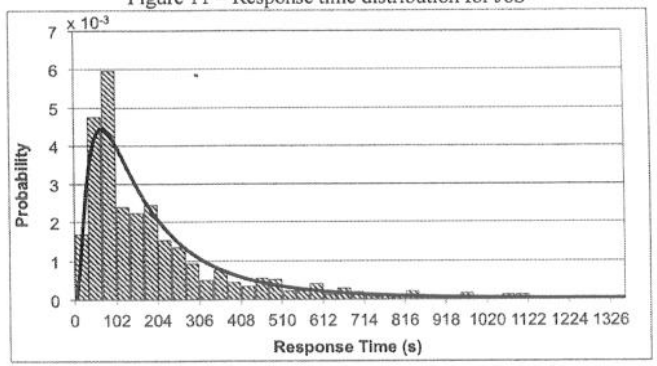
Jewel of the Seas Response Time Distribution

The overall RTD for the data generated from the JoS trial (1228 passengers) is presented in Figure 11. The data points display the typical log-normal distribution and so a log-normal curve was fitted to the data set as shown in Figure 11. The equation for the log-normal fit takes the form:

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

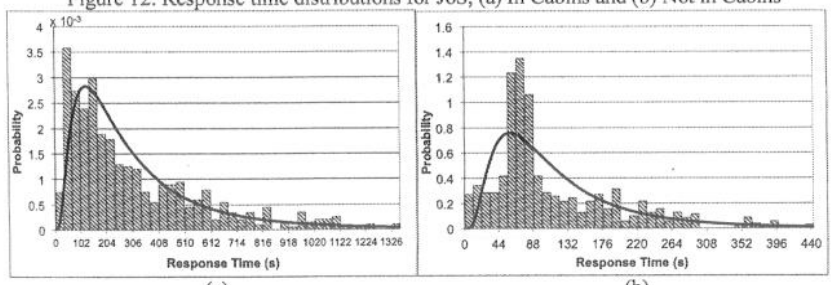
The minimum and maximum response times are 8.3 s and 1379 s, while the mean of the logarithm of response times is 5.012 s and the standard deviation of the logarithm of response times is 0.89 s.

Figure 11 – Response time distribution for JoS



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 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 12). 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.

Figure 12. Response time distributions for JoS, (a) In Cabins and (b) Not in Cabins

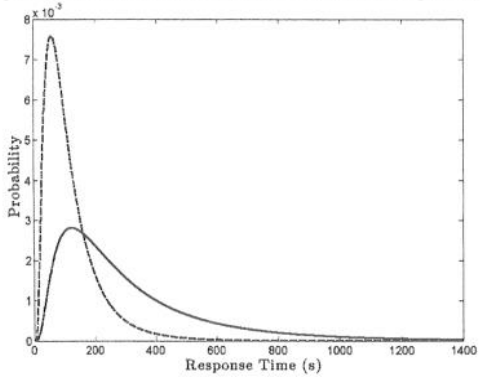


(a) (b)

Comparing the response time distributions for passengers in cabins with passengers in public spaces shows that the two distributions are quite different (Figure 13). A Mann-Whitney non-

parametric U-Test [9,10] 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 and 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 ER[4]. 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 [11]. 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.

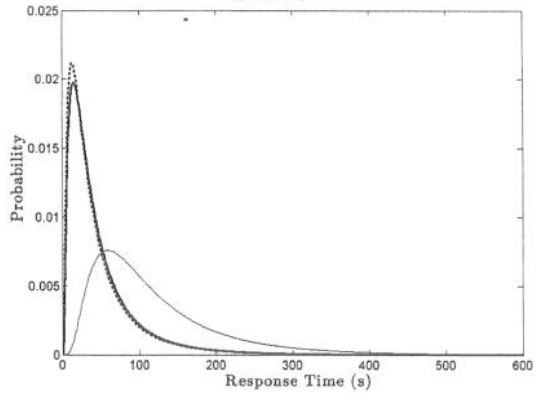
Figure 13. Comparison of RTDs for JoS in cabins (solid) and in public spaces (dashed)



As the JoS is a different class of vessel (i.e. cruise ship) to the SS1 (i.e. RO-PAX without cabins) it is important to determine if the RTD generated for the SS1 is similar to that for the JoS. Presented in Figure 14 are the RTD for passengers in public spaces for both vessels – clearly there is a difference between the two curves. A Mann-Whitney non-parametric U-Test [9,10] was performed with the null hypothesis that results for JoS passengers in public spaces and results for SS1 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 we conclude that the distributions are statistically different. This is a significant result as it suggests that RTD generated for one class of vessel cannot necessarily be applied to another type of vessel.

If we compare the RTD for the SS1 with that derived for the JoS for passengers in public spaces, we find significant differences in the manner in which people are responding to the alarm. For the SS1 and the JoS (for passengers in public spaces), the arithmetic mean response time for passengers is 53 s and 88 s respectively – a difference of 68%. For the SS1/JoS (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 on the RO-PAX vessel. The implications of this finding is that the current RTD used in IMO MSC Circ 1238, which is derived from the assembly trials on a RO-PAX vessel are not appropriate for all ship classes and different RTD should be used for cruise and 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 14 – Comparison of RTD for public spaces on SS1 (thick solid), JoS (thin solid) and ER (dashed)



CONCLUSIONS

This paper has outlined 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 results generated, relevant, credible and realistic. Furthermore, the response time data set represents the largest response time data sets ever collected – on land or sea. Three response time data sets were presented, two from the RO-PAX ferry, SuperSpeed 1 and one from the cruise ship Jewel of the Seas. The key findings from this work include:

- All RTD were found to be log-normal, 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;
- RTD from the two SS1 trials are essentially identical. This suggests that if assembly trials are repeated with a sufficient number of different people but in the same physical environment and exposed to the same notification conditions, the RTD generated will be identical.
- The RTD for SS1 is almost identical to that generated from the earlier trial conducted on a different ship, but belonging to the same class as the SS1 i.e. RO-PAX ferry. Taken together, these last two points suggest that the RTD generated for the SS1 trials may be used to represent the expected RTD for RO-PAX ferries without cabins.

- The RTD derived for passengers in cabins on the JoS was found to be statistically significantly different to the RTD generated for passengers in public spaces. Thus it is essential that for vessels with a significant number of cabins, that two response time distributions are used to represent the RTD for the vessel.
- The RTD for passengers in public spaces on the JoS was found to be statistically significantly different (producing longer response times) to the RTD for passengers on the SS1. Thus the RTD used to represent passengers in public spaces on cruise ships is different to that for RO-PAX vessels without cabins. This is an important finding that suggests different RTDs are required for different classes of vessel.

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

ACKNOWLEDGEMENT

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