QUANTIFYING HUMAN PERFORMANCE DURING PASSENGER SHIP EVACUATION

ROBERT CLARKE BROWN

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requirements of the University of Greenwich
for the Degree of Doctor of Philosophy

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DECLARATION

I certify that this work has not been accepted in substance for any degree, and is not concurrently being submitted for any degree other than that of Doctor of Philosophy being studied at the University of Greenwich. I also declare that this work is the result of my own investigations except where otherwise identified by references and that I have not plagiarised the work of others.

Robert Brown	Date
Edwin Galea	Date
Peter Lawrence	Date

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ABSTRACT

Despite continual improvements in the shipping industry related to structural design, operational practices, onboard technology and regulations, accidents *still* occur that result in sinking or capsize. When this happens to passenger ships, the results are often shocking and devastating with loss of life, sometimes numbering in the thousands. For this reason, the International Maritime Organization (IMO), which regulates the maritime industry, provides guidelines for evacuation analyses for passenger ships [1]. The scope of work presented in this dissertation fills gaps in our understanding of human performance during the evacuation process on passenger ships, particularly as it relates to passengers' alarm response time, the influence of response time distributions on total assembly time predicted by the evacuation model maritimeEXODUS, passenger movement onboard during the assembly process, and methods for validation of evacuation models in general.

The research carried-out was experimental in nature and involved a total of 5582 passengers onboard three large passengers ships – a ferry without cabins, a ferry with cabins and a cruise ship. All passengers had paid for their voyage and, prior to boarding, had no knowledge that an experiment was being conducted. The experiment was carried-out as a typical assembly exercise, which started with sounding of an alarm and ended when all passengers had been assembled. Passenger response to the alarm was recorded using digital video cameras and routes to assembly stations and associated times were captured using a novel infrared light detection tracking system. The dataset collected represents the most comprehensive collected to date for passenger response and movement during assembly trials at sea.

Analysis of the data has provided important insights into the nature of response time distributions for passengers on ferries and cruise ships. It was found that response time distributions generally took a lognormal shape, which is consistent with response time distributions measured in the built environment. Response time distributions generated from repeat trials on the same ship were statistically similar and could be combined to produce a single distribution for each ship - a powerful result suggesting that if the response times and demographics of a sufficiently large number of people are characterised for a given type of structure, an assembly exercise repeated under similar notification conditions should result in a similar distribution. Another key finding was that response

time in cabin areas was *not* similar to that in public areas on the same ship. In addition, response times for passengers in public areas on ferries was found to be statistically similar, while public space results for the cruise ship were different. This suggests that different response time distributions should be used for different ship types.

Passenger movement results have enabled the development of two unique datasets for use in validating ship evacuation models – one validation dataset which is relevant for ferries without cabins and the other for cruise ships. The validation method developed enables a clear, yet objective means by which ship evacuation models can be assessed using the experimental data collected. It is felt that the suggested validation protocol and acceptance criteria developed form a reliable basis for validating ship evacuation simulation tools.

This research has resulted in the submission of two information papers to the IMO suggesting credible response time distributions relevant for different ships and different areas onboard, as well as a detailed method for conducting validation of ship evacuation models. The recommendations being made from this work are significant since, if accepted by the IMO for inclusion in the regulations, will influence the design and construction of all new passenger ships worldwide.

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List of Abbreviations

AAT	Alarm Activation Time
AC	Alternating Current
APP	Adobe Premiere Pro
AS	Assembly Station
ASET	Available Safe Evacuation Time
CAD	Computer Aided Drafting
CCTV	Closed Circuit Television
CS	Cruise Ship
DIP	Dual In-Line Package
DXF	Drawing Interchange File
EPC	Euclidean Projection Coefficient
ER	Eurostar Roma
ERD	Euclidean Relative Difference
ERP	End of Response Phase
FOV	Field of View
FPS	Frames per Second
FRA	France
FSEG	Fire Safety Engineering Group
FSS	Fire Safety Systems
GB	Giga Byte
GER	Germany
GPS	Global Positioning System
ICEHR	Interdisciplinary Committee on Ethics in Human Research
ID	Identification
IMCO	Inter-Governmental Maritime Consultative Organisation
IMO	International Maritime Organization
IR	Infra Red
ISO	International Standards Organization
JoS	Jewel of the Seas
LED	Light Emitting Diodes
LOA	Length Overall
LSA	Life Saving Appliances

MAIB	Marine Accident Investigation Branch
mEX	maritimeEXODUS
MI	Marine Institute of Memorial University
MS	Microsoft
MSC	Maritime Safety Committee (of IMO)
MV	Motor Vessel
NOR	Norway
OP	Olympia Palace
PAX	Passenger
RCCL	Royal Caribbean Cruise Lines
RF	Radio Frequency
RFID	Radio Frequency Identification
RINA	Royal Institution of Naval Architects
RO-RO	Roll-on Roll-off
RO-PAX	Roll-on Roll-off Passenger
RSET	Required Safe Evacuation Time
RTD	Response Time Distribution
SAR	Search and Rescue
SC	Secant Cosine
SHEBA	Ship Human Evacuation Behaviour Assessment
SNAME	Society of Naval Architects and Marine Engineers
SOLAS	International Convention for the Safety of Life at Sea
SS1	SuperSpeed 1
STCW	Standards of Training, Certification and Watchkeeping
TAT	Total Assembly Time
UK	United Kingdom
UN	United Nations
UoG	University of Greenwich
UREC	University Research Ethics Committee
USA	United States of America
UTC	Coordinated Universal Time
VR	Virtual Reality

"*Believe me, my young friend, there is nothing — absolutely nothing — half so much worth doing as simply messing about in boats. Simply messing... about in boats — or with boats. In or out of 'em, it doesn't matter. Nothing seems really to matter, that's the charm of it. Whether you get away, or whether you don't; whether you arrive at your destination or whether you reach somewhere else, or whether you never get anywhere at all, you're always busy, and you never do anything in particular; and when you've done it there's always something else to do, and you can do it if you like, but you'd much better not*." Kenneth Grahame, The Wind in the Willows [2].

1 Introduction

1.1 Background

Humankind has been travelling on the world's oceans for millennia. Pre-historic boats were simple in construction; while nobody knows for certain, the first boats were possibly dugout canoes [3], which enabled indigenous peoples to fish, hunt, transport people and goods, and to engage in combat. The world's oldest known ship was discovered in 10 m of water near Portsmouth, UK in 1997 and has been carbon-dated to 6448 years ago [4]. It was of wooden construction and simple in design, yet measured approximately 33 m in length.

As technology and building techniques developed, ships became more complex and enabled the movement of large numbers of passengers and their vehicles, both for commuters, as well as those taking trips further afield. The first roll-on/roll-off passenger (RO-RO / RO-PAX) ferries were developed in the 1830s [5] around rail systems and provided an efficient method for transporting people and goods across waterways.

On 29 June 1900, the Hamburg Amerika Line launched the world's first cruise liner – the *Prinzessin Victoria Luise* – a vessel designed solely for the purpose of ocean cruising (Figure 1). The ship went aground less than six years later in Jamaica on the evening of 16 December 1906, was safely evacuated the next morning and declared a total loss two days later [6]. While safety has always been a concern in the shipping industry, it was not until the sinking of the Titanic in 1912 with a loss of 1506 lives that the world took a systematic interest in ship safety, particularly that of passenger ships [7]. The loss of the Titanic led directly to the International Convention for the Safety of Life at Sea (SOLAS), signed in

London, UK on 20 January 1914. SOLAS is "…generally regarded as the most important of all international treaties concerning the safety of merchant ships" [8] and has the main objective of specifying *minimum* standards for ship construction, equipment and operation.

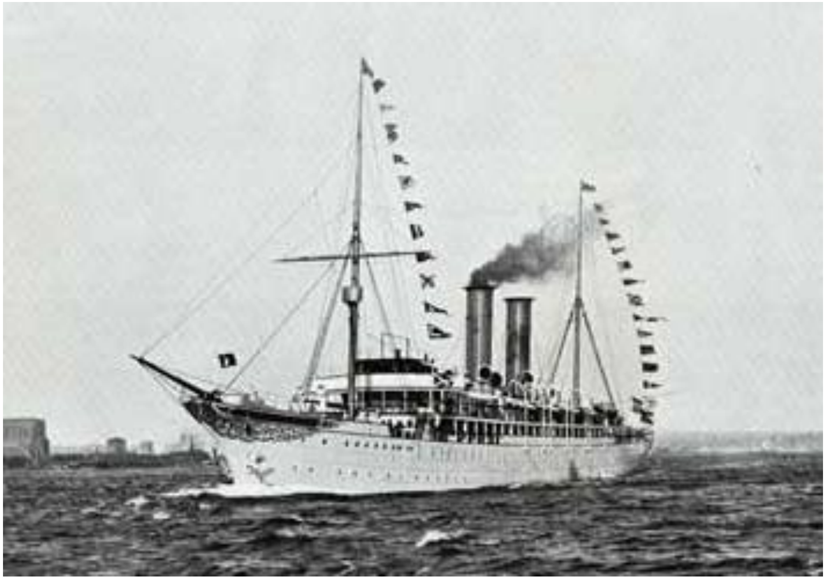


Figure 1 The Prinzessin Victoria Luise – the world's first purpose-built cruise ship [6].

Following the Titanic disaster, in 1922 Cunard Line built the first cruise liner equipped for around the world cruising, *Laconia*, which provided a comfortable means of transatlantic transportation between Europe and North America. However, transoceanic travel peaked in 1957 and started declining in 1958 [9] after Pan American Airlines introduced nonstop air travel between Europe and New York. By the 1960s, cruise ships were used primarily for recreational purposes – a way to vacation at sea – with Princess Cruises becoming the first of today's modern cruise lines focusing on leisure travel [9]. The cruise sector has grown substantially since that time – according to [10], in 1970 some 500,000 people worldwide vacationed on cruise ships, as compared with a staggering 22,000,000 in 2014 [11].

Despite the introduction of SOLAS and increasing levels of regulation, training and onboard technological developments, the incidence of passenger ship accidents requiring evacuation is surprisingly common. In the 20 years from 1978 to 1998, over 5,300 passengers died in ferry accidents worldwide. This is an unfortunate statistic that has not changed greatly since 1998 and the result is that ferry travel is approximately 10 times more dangerous than travel by commercial airliner [12]. Transportation statistics for the United States in 2008, report that fatality rates for transport by ferry are second only to those by motor vehicle (Figure 2) and the same trend is seen for the United Kingdom between 2004 and 2013 (Figure 3). Since 2005, a total of 72 passenger ship losses have been reported in the Allianz 2015 Shipping Review [13] as depicted in Figure 4. Further reported by [13], there were a total of 1,592 ship losses between 2000 and 2010 (Figure 5), where cruise and passenger ships make-up 6.3% of the total.

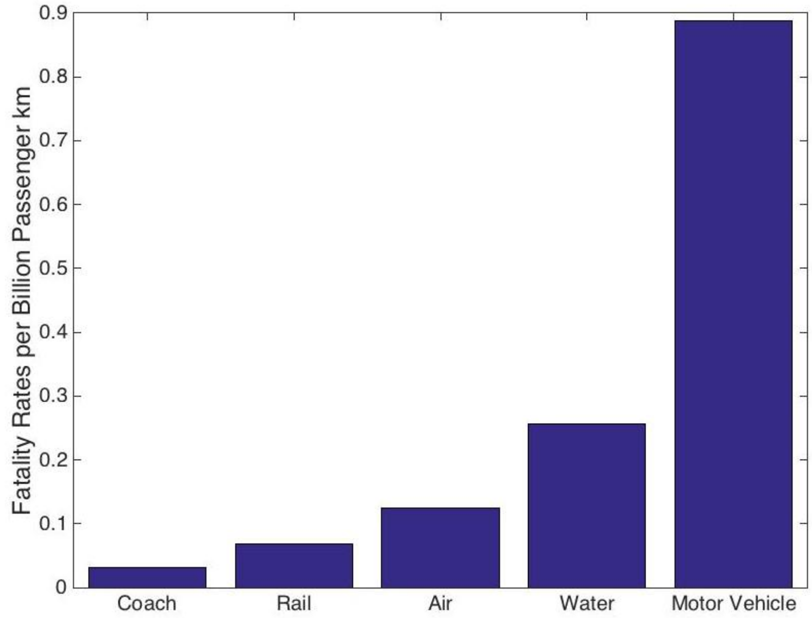


Figure 2 Fatality rates per billion passenger km travelled in the US, 2008 [14].

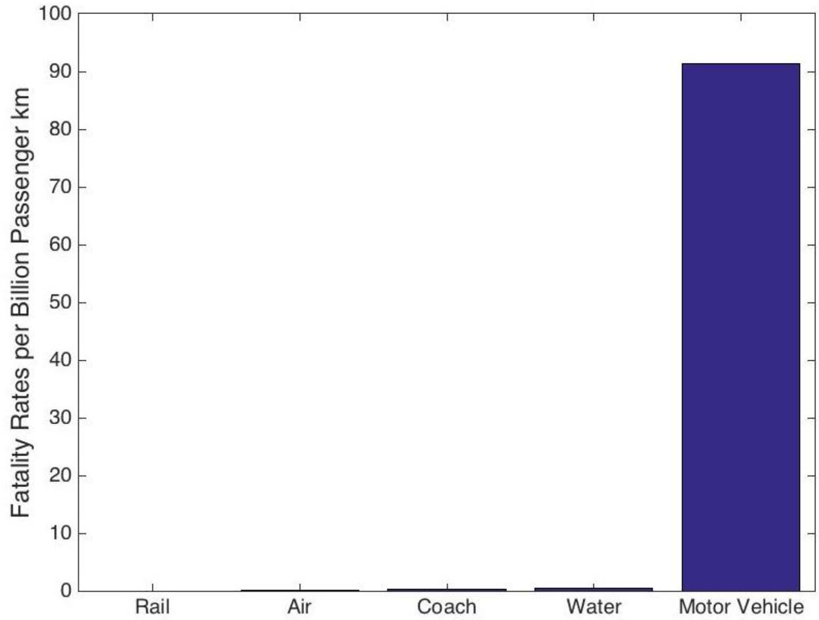


Figure 3 Average annual passenger fatality rates per billion km travelled for UK 2004-2013 [15].

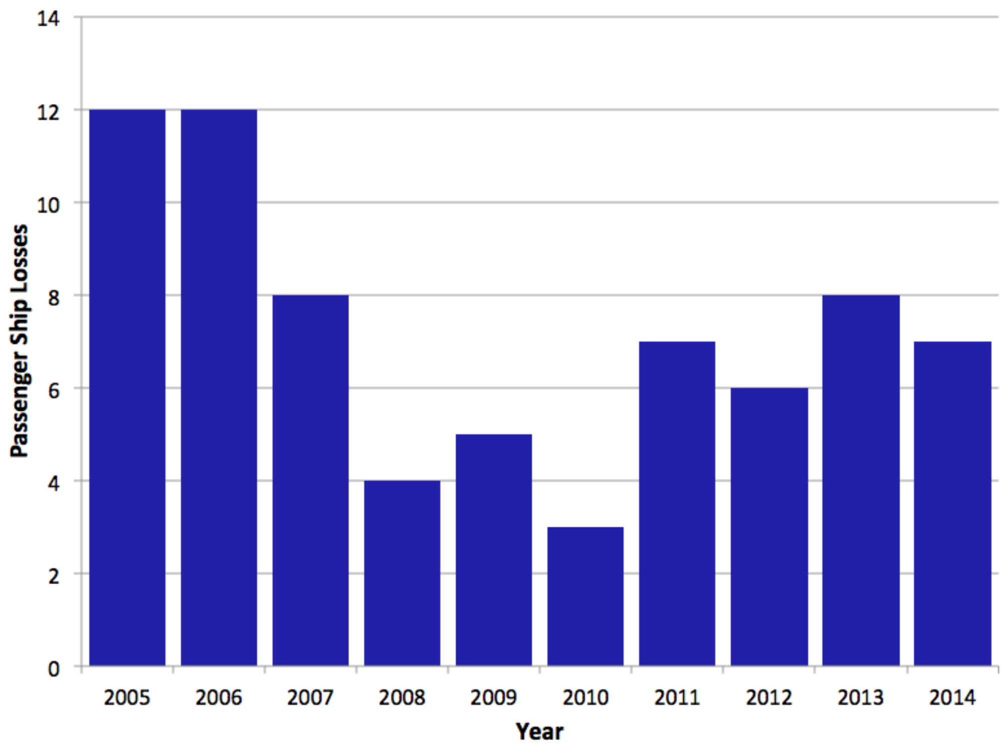


Figure 4 Passenger ship losses 2005-2014 [13].

A survey of passenger ship incidents between 1990 and 2002 [16] indicates that the three predominant causes for evacuation from passenger ships are fire, collision and grounding. The article [16] suggests that while fire was historically considered to be the most relevant issue resulting in evacuation from passenger ships, analysis shows that collision and grounding are even more critical since these types of accidents generally leave less time for evacuation than fires do. The authors of [16] argue that while the probability of fire (2.6×10^{-3} for cruise ships) is higher than grounding or collision (1.1×10^{-4} and 6.9×10^{-4}, respectively), the potential for loss of life is considerably higher for grounding and collision events (1.5×10^{-1} and 1.3×10^{-1} respectively) compared with fire events (1.4×10^{-2}).

Design of ships in modern times is based on rules established by classification societies (e.g. Lloyd's Register (UK), American Bureau of Shipping (USA), Bureau Veritas (FRA), Germannischer Lloyd (GER), Det Norske Veritas (NOR)) and international and national regulations. The most important regulatory body for the shipping industry is the International Maritime Organization (IMO) - a specialized agency of the United Nations responsible for developing regulations and measures that improve the safety, security and prevention of pollution for international shipping.

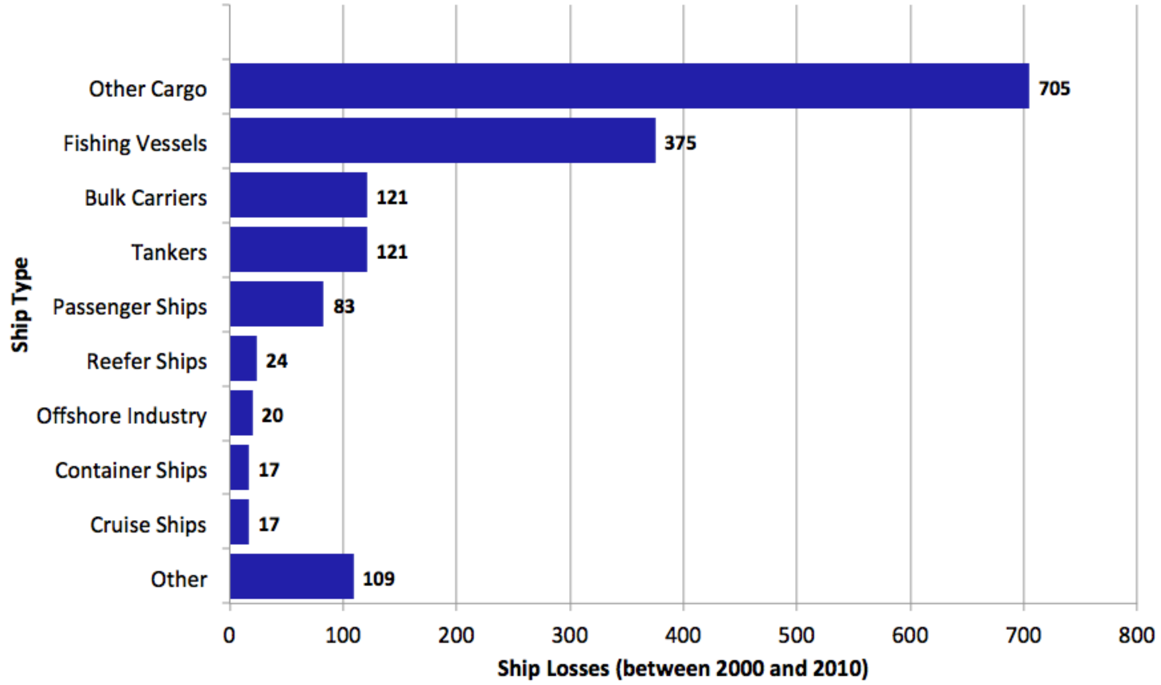


Figure 5 Ship losses between 2000 and 2010 by ship type [13].

Originally named the Inter-Governmental Maritime Consultative Organization (IMCO), the IMO was established through a UN convention in Geneva in 1948 and met for the first time in 1959. Currently, the IMO has 170 member states [17]. In 1982, the name was changed to what it is currently. The IMO sets forth a wide range of requirements with the ultimate aim of ensuring safety of vessels at sea. In addition to the development of regulations to help prevent accidents in the maritime sector, the IMO also makes provisions for emergency response if accidents occur. Of particular relevance for passenger ships, the IMO provides guidance through SOLAS and the Life Saving Appliance (LSA) Code [18] on such things as emergency alarms (LSA Code Section 7.2), two-way communications, muster lists (SOLAS III/8 and III/37) thermal protective aids for passengers (SOLAS III/7 and III/22), lifeboats (SOLAS III/21), provision of rescue boats (SOLAS III/21), lifebuoys (SOLAS III/7.1 and III/22) and lifejackets (SOLAS III/7, III/22 and III/26) [19].

Table 1 gives a summary of the IMO's most recent maritime risk statistics for 2006-2010 for ships worldwide that are subject to its conventions and instruments [20]. It presents the number of lives "at risk" (i.e. travelling or working at sea) in comparison to the number of lives lost at sea each year. The data presented in this table can be a little misleading, as it appears to show that the total ratio of lives lost at sea to those travelling at sea is decreasing over the period. However, when one considers the potential impact that a *single* passenger ship disaster might have on these numbers, it becomes clear that the risk (in the classical quantitative sense) is high for this mode of transportation. Consider Equation (1):

$$Risk = Probability \times Consequence \qquad (1)$$

Where:

Probability = likelihood of an accident

Consequence = severity of an event

To illustrate the point, if we assume that the probability of a passenger ship accident happening does not change much from year to year for any given region, then the consequence (injury and/or death of passengers) will increase as the vessel capacity increases. Thus, if more and larger vessels are constructed, it is reasonable to expect that risk (according to Equation (1)) in the industry, as a whole will increase.

Table 1 Ratio of lives lost (seafarers and passengers) to total lives at risk for ships subject to IMO Conventions and other instruments [20].

	2006	**2007**	**2008**	**2009**	**2010**
Lives Lost – All Ships	1,825	525	1,160	699	250
Estimated Seafarers	$1.232\text{x}10^{6}$	$1.277\text{x}10^{6}$	$1.246\text{x}10^{6}$	$1.266\text{x}10^{6}$	$1.371\text{x}10^{6}$
Estimated Passengers	$1.647\text{x}10^{9}$	$1.700\text{x}10^{9}$	$1.914\text{x}10^{9}$	$2.155\text{x}10^{9}$	$2.077\text{x}10^{9}$
Total Passengers & Seafarers	$1.648\text{x}10^{9}$	$1.701\text{x}10^{9}$	$1.915\text{x}10^{9}$	$2.156\text{x}10^{9}$	$2.078\text{x}10^{9}$
Ratio (Best Estimate)	$1.11\text{x}10^{-6}$	$3.09\text{x}10^{-7}$	$6.06\text{x}10^{-7}$	$3.24\text{x}10^{-7}$	$1.20\text{x}10^{-7}$

The risk associated with post accident emergency response is mitigated in various ways, such as using the results of evacuation analysis findings to improve vessel design, conducting drills with both passengers and crew, improving training requirements and technologies (e.g. through use of simulation), equipment and machinery onboard and systems to locate and count individuals as they assemble. We will not know if these efforts are effective unless the rate of accidents starts to decrease, thereby counterbalancing the increased severity imposed by increasing the capacity for passengers.

While all sinking events with loss of life are significant, the data presented in Table 1 includes two severe events in 2006 – the loss of the passenger ships *MV Senopati Nusantara* (500 fatalities) and *MS al-Salam Boccaccio* (1,026 fatalities) which together make-up more than 80% of the total lives lost in shipping accidents that year. Similarly, the data for 2008 comes largely from one event – the loss of the passenger ship *MV Princess of the Stars* (800 fatalities) which alone accounts for almost 70% of the total losses in that year. The data presented in Table 1 ends in 2010 and does not include such events as the loss of the *MV Spice Islander I* (in 2011 with 2,976 fatalities), the *MV Sewol* (in 2014 with 304 fatalities) and the *CS Costa Concordia* (in 2012 with 32 fatalities but with the potential for a much higher number). Again, all of these vessels were subject to the conventions and instruments of the IMO.

1.2 Summary of Research Area and Objectives

SOLAS III/21.1.3 [19] specifies the maximum time it should take to prepare, board and launch survival craft from a passenger ship:

> *All survival craft required to provide for abandonment by the total number of persons on board shall be capable of being launched with their full complement of persons and equipment within a period of 30 min from the time the abandon ship signal is given after all persons have been assembled, with lifejackets donned.*

But how long should the process of assembling all passengers and lifejacket donning take (the step just prior to abandonment)? These are important considerations in passenger ship evacuation and represent the main focus of the work presented in this dissertation; that is, passenger response to alarms and passenger movement to assembly stations. The research presented here does *not* consider donning of lifejackets. SOLAS II-2/13.7.4 [19] requires that:

> *Escape routes shall be evaluated by an evacuation analysis early in the design process. The analysis shall be used to identify and eliminate, as far as*

> *practicable, congestion which may develop during an abandonment, due to normal movement of passengers and crew along escape routes, including the possibility that crew may need to move along these routes in a direction opposite to the movement of passengers. In addition, the analysis shall be used to demonstrate that escape arrangements are sufficiently flexible to provide for the possibility that certain escape routes, assembly stations, embarkation stations or survival craft may not be available as a result of a casualty.*

This Regulation further refers to the IMO Circular: "*Guidelines for evacuation analysis for new and existing passenger ships*" (IMO MSC.1/Circ.1238) [21]. A more detailed overview of this document is presented in Chapter 2 but, in summary, the circular provides guidelines for the approved process and requirements for performing an evacuation analysis of a given ship design. Two methods are offered - one using simplified calculation procedures (the so-called hand-calculation method) and the other using advanced calculation procedures (typically through specially designed software). The research presented in this dissertation provides supporting data to fill knowledge gaps in the advanced calculation procedures, namely: (1) the nature of passenger response to alarms and (2) how to validate ship evacuation modelling software with experimentally obtained data. The term *response time* has different meanings, depending on the field of application. For instance, response time in search and rescue (SAR) refers to the time between notification of an incident and time of departure from the SAR base [22]. Response time in the context of emergency evacuation is often referred to as a person's pre-movement or pre-evacuation time in the built environment. Since the IMO uses the term response time for maritime applications, it is the term used throughout this dissertation.

It is worth noting that since this research began in April of 2009, there have been at least fourteen passenger ship accidents (outlined in detail in Chapter 2) that have resulted in over 4,000 fatalities. These accidents have all involved vessels that were subject to the conventions and instruments of the IMO. The timing of these accidents and the research presented in this dissertation also bracket the 100-year anniversary of the sinking of the Titanic in the North Atlantic and the subsequent loss of 1,503 passengers and crew. Much has been done to improve passenger ship safety since the Titanic but, clearly, much more work remains. The uniqueness and comprehensive nature of the research presented in this dissertation has resulted in an improved understanding of human behaviour and performance during simulated emergencies on passenger ships. It is intended that these efforts will further result in improvements to international regulations at the IMO and ultimately save lives through improved ship design.

There are inherent risks in all areas of the transportation sector. As shown in Figure 2 and Figure 3, fatalities in the maritime passenger transportation sector rank second only to those in the motor vehicle category. Despite a focus on preventative measures, we can reasonably expect that accidents will continue to happen in the passenger ship sector. Thus, until such time as accident prevention is 100% effective, it is important for naval architects to understand and plan for the efficient evacuation of passengers and crew at sea. Being able to realistically model the evacuation process for a given ship design is an important part of the design process in order to identify areas for improvement to ensure efficient evacuation, if required. Having confidence in the accuracy of evacuation simulation results is difficult unless the mathematical model has been validated, which requires not only an understanding of the vessel parameters but also the behaviour and performance of humans that are contained within.

Quantifying human behaviour and performance in any situation is a challenging task, which makes modelling even more challenging. The Oxford English Dictionary online [23] defines *behaviour* as the “manner of conducting oneself in the external relations of life; demeanour, deportment, bearing, manners”. Skinner [24] suggests that behaviour is a primary characteristic of living things and that as a subject matter, does not become accessible only with the invention of a tool such as a microscope. He further elaborates that, from the perspective of independent scientific investigation, our familiarity with behaviour (“we all know thousands of facts about behaviour”) puts us at a *disadvantage* because we are inherently biased about certain aspects of behaviour that may not be supported by proper scientific rigour.

Skinner explains succinctly that:

> *Behaviour is a difficult subject matter, not because it is inaccessible, but because it is extremely complex. Since it is a process, rather than a thing, it*

> *cannot easily be held still for observation. It is changing, fluid, and evanescent, and for this reason it makes great technical demands upon the ingenuity and energy of the scientist. But there is nothing essentially insoluble about the problems which arise from this fact.*

The behaviour of humans is naturally complex but, as Skinner suggests, this does not mean that the problem of understanding behaviour cannot be solved through a process of careful and systematic investigation. Human performance can be characterised in any number of ways, including: physiological (physical function), psychological (mental and emotional function), sociological (cultural and social function). While these are all important areas for scholarly activity, this dissertation does not attempt to delve into what may be happening *between the ears*, but rather how people tend to behave *outwardly* in the scenarios presented. This dissertation puts particular focus on the novel research methods employed in order to collect human performance data (Chapter 3) required to answer the different research questions posed, which relate mainly to how people behave in ship emergencies.

In general terms, the ship evacuation process can be divided into two steps – the initial process of *assembly*, in which passengers gather in pre-identified safe locations onboard where they can be counted and receive further instructions; and the secondary process of *abandonment* in which passengers move from the assembly areas to life-saving appliances (such as slides, chutes, lifeboats and liferafts) to get away from the ship. The abandonment process tends to take place only for cases where it is clear that the ship is in peril and will not safely remain afloat. This dissertation will only deal with the initial step of *assembly* in the ship evacuation process.

In many ways, the evacuation process onboard ships is similar to that in buildings where occupants must first respond to the evacuation cues (visual, olfactory or auditory, including alarms) and then move to a place of safety before exiting the building. As with ships, the geometry and occupants' familiarity with the layout of a building play a role in the effectiveness of the evacuation in terms of time to evacuate, congestion levels that arise and the flow rates of people through exits.

The evacuation process for buildings has been studied in detail since the 1960s and 70s when Fruin and others [25][26][27] began characterising walking speeds of people in the built environment. Since then, safe building evacuation time has been written as a performance-based Equation (2):

$$RSET < ASET \tag{2}$$

Where RSET is defined as the *required* safe evacuation time and ASET is the *available* safe evacuation time. Thus, a design is considered safe when the time available for evacuation exceeds the time required [28][29][30]. In the context of ship evacuation, we can define two sets of RSET/ASET values, one set associated with the assembly onboard the ship and one set associated with the abandonment from the ship. For the assembly process, ASET is arbitrarily set as the given pass/fail criterion in the IMO guidelines and RSET is the time required for the passengers to assemble, which is determined by the evacuation simulation software. In reality ASET would be determined by a combination of fire and stability software which would be used to determine the point at which it was no longer possible for passengers to safely assemble.

For the abandonment process, ASET is the time at which it is no longer possible to launch the lifeboats. This would be determined by ship stability software that would be used to determine the point at which the vessel took on a 20° heel. The RSET would be the boarding, abandonment and sail away time (i.e. the time to get the passengers from the assembly stations into the lifeboats and to launch the boats and safely sail away a safe distance from the ship).

More recently, Galea et al. [31] developed a framework (illustrated in Figure 6) to describe human behaviour during evacuation, in which the overall evacuation time is divided into two main phases – the Response Phase and the Evacuation Movement Phase. While [31] presents this framework in the context of evacuation from buildings, it can also be applied to passenger ship scenarios. The focus of this dissertation is on the response phase (specifically the collection of individual passenger response times on different ships) and the evacuation movement phase up to the end of the assembly process (specifically the collection of individual assembly times to provide a basis for evacuation model validation).

Strictly speaking, for passenger ships, the evacuation movement phase would also include abandonment from the ship, however, this is not considered here.

From Figure 6, the response phase is divided into three distinct stages: notification, cognition and activity [31]. In a real situation, the *notification stage* begins when passengers identify the first cues that an evacuation may be required – this could be an event observed visually, an unusual sound (or alarm), an unexpected vessel movement, or an unusual smell (such as smoke). In the context of the research presented in this dissertation, the notification stage always began with the sounding of the ship's alarm.

At the end of the notification stage, the passenger starts to disengage from whatever his/her activity was at the sounding of the alarm. This new stage is referred to as the *cognition stage*. During this stage, the passenger becomes focused on the evolving situation related to the alarm. The cognition stage typically ends when the passenger begins performing different tasks that may have been considered during the alert stage in order to get ready to move away from the area – the *activity stage*.

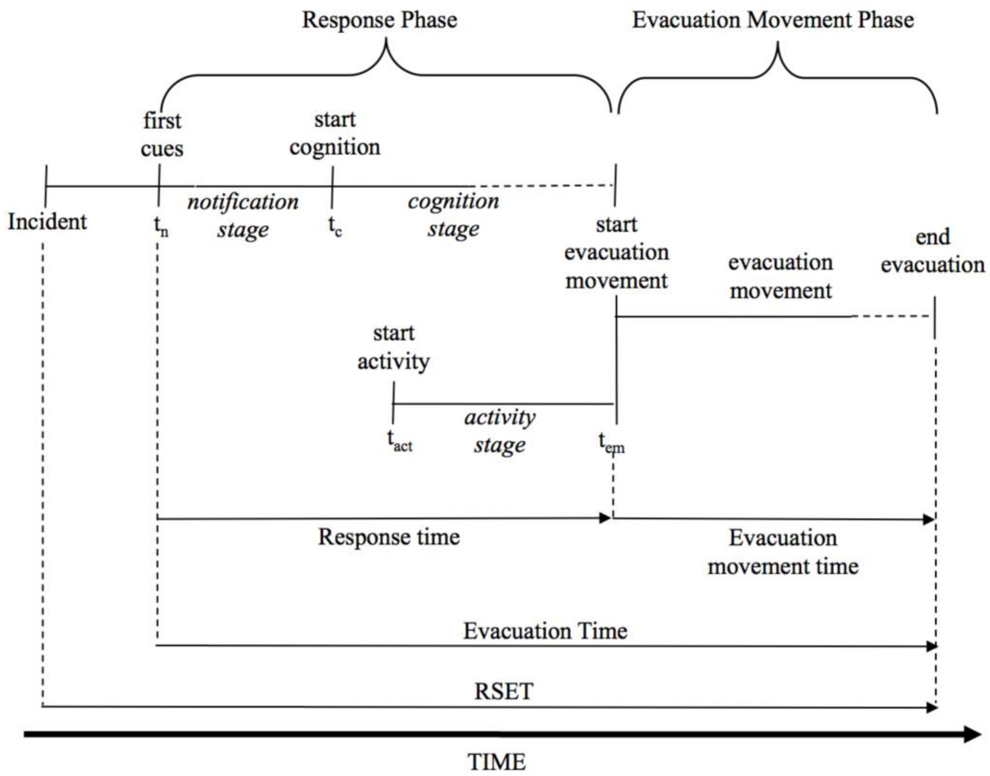


Figure 6 Depiction of the required safe evacuation time (RSET), showing the different subcategories of emergency response behaviour [31].

The tasks undertaken in the activity stage fall into one or both of the following categories:

- Action tasks: physical activities involving movement within the area (e.g. packing a bag, putting on a coat, finishing a drink/meal).
- Information tasks: activities involving the acquisition or conveyance of information (e.g. asking someone what is going on, telling someone to do something).

The activity stage ends when all of these tasks have been completed. This point is also the end of the response phase and the beginning of the evacuation movement phase – when passengers move toward the assembly station. The response *time* then is the cumulative time taken to complete the notification, cognition and activity stages.

While it would be useful to be able to precisely identify the start and end of each stage of response behaviour, in practice it is generally not possible. It would be very difficult, for example, to determine precisely when someone has detected the first cues that may require an evacuation (with the exception of the sounding of an alarm). It is also generally not possible in practice to determine the transition time between the cognition and activity stages. For example, identifying when someone has stopped talking about their current activity and has started talking about how to respond to the cues they are receiving, unless it were possible to audibly follow the conversation during analysis. This is not a practical consideration, given the number of passengers involved in the analysis, background noise and the variety of different languages being spoken. While it is generally possible to determine when passengers begin the activity stage, it is *not* possible to identify when the cognition stage ends, as it could continue throughout the activity stage.

While a naval architect designing a vessel has little control over what the passengers will do in the event of an emergency, it is generally understood that ship design for evacuation can be carried-out in such a way as to improve the flow of large numbers of passengers from their initial locations throughout the ship to the assembly stations in order to be ready for evacuation if required.

Thus, the main objectives for the research presented in this dissertation were to:

1. Address knowledge gaps in our understanding of passenger response time on large passenger ships;
2. Collect validation data for passenger ship evacuation models;
3. Use the data collected to develop a dataset for validating ship evacuation models; and
4. Suggest improvements to international regulations that govern passenger ship evacuation analysis, which are based primarily on the findings of Objectives 1 - 3.

1.3 Overview of Key Research Questions

Loss of life on passenger ships can occur through a wide range of events, including onboard violence, illness, suicide and accidental man overboard. It is not the intent of this dissertation to investigate all manner of events onboard ships that result in loss of life. The focus here is to examine more closely what happens during large-scale, low probability - high consequence events such as fire, capsize or sinking that require the movement of large numbers of passengers in response to a call to assemble (i.e. the first step in the process of preparing to abandon ship). Clearly, the most effective means for ensuring the safety of those onboard is to prevent such incidents from happening at all. The naval architectural engineering profession and associated scientific community has been quite successful at improving ship design to resist capsize and sinking following different types of structural and system failures, however, these advancements are unlikely to ever result in complete prevention of incidents that may require assembly and abandonment at sea. Thus, it is important to make evacuation design decisions, particularly those relating to the vessel's general arrangement, in such a way as to allow for efficient movement of passengers to assembly stations.

Successful ship abandonment can be divided into distinct phases, which are defined by different human behaviours. As noted in the previous section, the individual's initial reaction to evacuation cues (including alarms) up to the point that he/she starts purposeful movement away from their initial location towards the assembly station is generally referred to as the pre-evacuation phase and the time it takes as the individual's response time. The response time of passengers plays a significant role in how efficiently the assembly process is completed [32]. For example, if all passengers respond to cues/alarms at exactly the same (highly unlikely in practice), one might expect greater levels of congestion to develop (assuming sufficient numbers of passengers are onboard), which would lead to delays in completing the assembly. Computer-based evacuation simulation models exist so that a ship's general arrangement can be assessed for evacuation scenarios. However, it is important that such models be based on realistic actions that passengers may undertake and the associated times representative. This is a difficult dataset to collect in a way that gives confidence in the usefulness of the results.

It follows from the preceding discussion that some important questions remain concerning the evacuation of passenger ships and it is the response to these questions that forms the basis for this dissertation. The work presented herein is experimental in nature and the data collected and associated analysis provides answers to each of the four main research questions that follow:

1. *How do we collect realistic passenger ship evacuation data while ensuring the safety of passengers and balancing the responsibility and requirements of the Captain and crew, research team, ship owner and regulatory authority?*

Being able to collect realistic ship evacuation data is important to enable continued development of safety regulations and evacuation models used for ship design. It is important that such datasets be collected in-situ onboard ships with actual, paying passengers and in sufficient numbers to provide datasets with statistical significance. While it is important that the needs of the research team be met, this work can only be carried-out through careful discussion and planning with the ship's Captain and crew, the ship owner and under the requirements of relevant research ethics and regulatory authorities. The research team must have a solid understanding of the data requirements and determine the best means for collecting it. It will be shown that, with the proper level of understanding and planning, this can be done safely at sea in a reliable and realistic manner. Related sub-questions that must be considered when answering question #1 are:

1a) What are the regulatory requirements for conducting an evacuation assessment of a passenger ship and what knowledge gaps exist in these requirements?

1b) What are the key components of people's evacuation behaviour and how can we measure it on passenger ships?

1c) Can an experiment be designed and executed that will allow us to fill the knowledge gaps noted in (a) and measure behaviour identified in (b)?

1d) Are the data collection methods noted in (c) reliable, feasible and safe to use with large numbers of passengers?

1e) Are there any significant ethical concerns for conducting such full-scale experiments and, if so, how are they addressed?

2. Can we collect representative and detailed response time data for passengers responding to alarms on passenger ships?

Collecting response time data for passengers enables a better understanding of the main factors that determine passenger performance when responding to alarms. It will be shown that a large number of passenger response times can be successfully and safely collected onboard different passenger ships and that response behaviour varies, depending on where individuals are located onboard the ship at the time of the alarm and the type of ship they are on. Some related sub-questions that must be considered when answering question #2 are:

2a) Given the arduous task of assessing passenger behaviour from video methods, how do we ensure reliability of the data capture methods?

2b) What mathematical form do passenger response times take when developed as statistical distributions and how well does this form match the data sets collected?

2c) Is response behaviour different on different ships or in different regions of the same ship?

2d) Do population demographics significantly influence passenger response behaviour (e.g. males vs. females, age, presence of travelling companions or family members)?

2e) Can we expect response behaviour on a given ship to be the same with a different population of passengers?

2f) Do different response time distributions produce significantly different results when used to model evacuation behaviour?

3. *How do we objectively determine the degree of agreement between ship evacuation model predictions and experimental data?*

Objectively determining how well ship evacuation model predictions compare with experimentally produced data sets is of key importance when attempting to validate such models. The term *objective* is deliberately used here as it is not reasonable to be *subjective* when comparing models results to experimental, as is suggested in harmless statements such as "…model results compare well with those obtained from experiments…" which are often written without much thought about their meaning. This is particularly important for the work discussed in this dissertation because models that predict the nature of evacuation from passenger ships can influence how a ship is designed and whether or not it is considered to meet regulatory requirements. This has implications for both vessel cost and the safety of those onboard. In answering research question #3, we must also determine answers to the following:

3a) What quantities or variables provide the best indication of how well model predictions compare with experimentally obtained data?

3b) Do numerical methods exist to quantify how well the overall *shape* of two curves compare with each other?

3c) Do numerical methods exist that enable us to quantify how *proximate* two curves are to each other, in a global sense?

4. *Can we collect a dataset for use in validating ship evacuation models?*

To date, it has not been possible to fully validate ship evacuation models that determine if a given ship design meets the requirements set forth by the IMO. This represents a significant gap in the knowledge for passenger ship evacuation modelling, as well as a potential problem for ships assessed using such tools. If we cannot systematically, formally validate the predictions made by ship evacuation models, then are we not just watching dots move about the computer screen and hoping that the predictions are realistic? As noted above, the implications of this issue are potentially quite serious and wide-reaching since they have a direct impact on the design of passenger ship general arrangements all over the world. With some of the largest passenger ships carrying more than 6,000 passengers and 2,000 crew the risk is considerable. It is obvious why this knowledge gap exists – validating evacuation models requires a reliable dataset defining the behaviour and performance of large numbers of people in a variety of situations and environments. It is clearly a challenging task. Research question #4 represents the culmination of all the research efforts in this thesis and answering it is carried-out through a series of smaller but important sub-questions:

- 4a) What datasets are required for model validation?
- 4b) What ship types should be tested so that the validation data sets are most representative?
- 4c) What level of accuracy is required in the dataset?
- 4d) What pass/fail criteria should be suggested in the method?
- 4e) Are the dataset and validation method relatively easy for software manufacturers to understand and use for validating their software and will models have difficulty meeting the required performance?
- 4f) Will it be possible for software developers to "fudge" validation results?

The remainder of this chapter will present the thesis scope, discuss the novel nature of the work performed and provide an outline of the chapters that follow.

1.4 Thesis Scope

The work presented in this dissertation is based on research carried-out as part of the SAFEGUARD project. SAFEGUARD was funded through the Sustainable Surface Transport funding scheme of the European Union Seventh Framework Programme, as well as by the Research and Development Corporation of Newfoundland and Labrador and Transport Canada through its Marine Safety Department. The project represents a significant research effort with a project consortium comprised of nine partners located in Europe and Canada: BMT Group Ltd. (UK), Fire Safety Engineering Group of the University of Greenwich (UK), Offshore Safety & Survival Centre of the Marine Institute (Canada), Bureau Veritas (France), Principia Marine (France), Safety @ Sea Ltd. (UK), Color Line Marine AS (Norway), Royal Caribbean Cruise Lines (Finland) and Minoan Lines Shipping AS (Greece).

Given the complexity of the project, it is important to understand that all partners contributed significantly to the work that was carried-out. It is also important to understand that the work presented in this dissertation was carried-out solely by me as part of my PhD studies or work that I was significantly involved in. In particular, this includes:

- A review of literature (Chapter 2).
- Determining methods for data acquisition, including a variety of tests performed to characterise the best system for tracking passengers on ships at sea (Chapter 3).
- Planning and conduct of sea trials on the three different ships (Chapter 4).
- Development of standardised scripts for the Captain and crew, information leaflets provided to passengers and the development of questionnaires provided to passengers (Chapter 4).
- Initial analysis of video collected (Chapter 5), associated inter-rater reliability tests, subsequent detailed analysis of passenger response time and development of response time distributions (Chapter 6).
- Analysis of passenger movement data and total assembly time for passengers on each vessel (Chapter 7).
- Development of a method for validating ship evacuation model results using the collected response time and route data (Chapter 7).
- Comparative evacuation modelling for a hypothetical ship design developed by the University of Greenwich (UoG) to demonstrate the impact of the newly collected response time datasets on the modelling results (Chapter 8).
- Providing recommendations for improvements to international regulations governing passenger ship evacuation analysis protocols (Chapter 6 and Chapter 7).

Additional efforts by the project team that did not involve me are not presented here. This includes development and testing of new benchmark scenarios for ship evacuation analysis, modelling efforts involving the other ship evacuation models EVi [33][34][35][36] and ODIGO [37][38], fire modelling and analysis of questionnaire data. In addition, given the scope of work laid out for my studies and the depth and breadth of data collected, there are additional aspects of the datasets that it was not feasible to delve into as part of this dissertation but should be examined at a later date to provide further insight in the field.

1.5 Novelty of Research Undertaken as Part of this Thesis

The research presented in this dissertation is novel in a number of ways:

1. It is the first time that human alarm response time has been characterised with actual, paying passengers onboard different types of passenger ships at sea that is of quality sufficient for statistical significance.
2. It presents a means by which individual passenger routes can be accurately collected onboard ships and, indeed, in other environments during the assembly process.
3. It provides a method for validating passenger ship evacuation analysis models through the use of full-scale sea trials data collected during experiments onboard different types of large passenger ships.

1.6 Thesis Outline

This dissertation is organised into eight chapters that outline the main areas of work undertaken. A brief summary of each chapter is given here.

Provide an overview of the ship evacuation process, the relevant regulatory framework, previous relevant evacuation studies, methods for data acquisition and existing ship evacuation models. Chapter 2 will present a detailed review of the relevant literature regarding what typically happens during a ship evacuation. Given that every ship evacuation is different, this is a challenging task and what is provided is meant to give a general understanding of the important processes that passengers may be required to undertake in order to evacuate from a ship in distress. The chapter then gives a detailed review of previous studies to define human evacuation behaviour which are considered most relevant to the work in this dissertation. This review includes previous ship evacuation studies but also studies that have been undertaken in the context of the built environment that may be considered relevant to passenger ships. A review of the complicated regulatory environment as stipulated by the IMO is then provided in detail. This is a vital piece of the ship evacuation puzzle as it is the main driver for determining design requirements and ultimately whether a vessel is considered safe from an evacuation point of view. Given its importance to an experimental study such as this, the chapter then provides a review of the different technologies and methods reported in the literature that relate to the *measurement* of human evacuation behaviour at full scale. Finally, an overview of different evacuation models is presented, starting with building evacuation models and then examining the different ship evacuation models available.

Determine the requirements for data acquisition and outline the associated developmental testing undertaken. Chapter 3 first examines the data required in order to meet the project objectives. This chapter then focuses on the main data acquisition methods, namely video recording, automatic path tracking and questionnaires. The synchronisation methods and positioning of video cameras is presented, along with associated testing to confirm reliability of the video record for capturing passenger response time and also for confirming that the chosen automatic path logging technology was accurate. The chapter also provides a detailed outline of the different path logging equipment tested, the tests undertaken and results for each in the context of preparing for system procurement for the trials. Finally, this chapter presents additional testing that was undertaken with the tracking system to demonstrate its capability for future investigations into movement of people in the built environment.

Plan and conduct large-scale experiments on three different types of passenger ships. Chapter 4 outlines the details of the planning and logistics required to successfully carry-out the trials onboard 3 large passenger ships – a ferry without cabins (Color Line *SuperSpeed 1* in the North Sea), a ferry with cabins (Minoan Lines *Olympia Palace* in the Adriatic Sea) and a cruise ship (Royal Caribbean Cruise Lines' *Jewel of the Seas* in the North Sea). Logistical considerations for conducting experiments on this scale are very important and without detailed planning, unexpected issues can arise that could result in collection of irrelevant or poor quality data, loss of data or failure of the project. Given that there are real health and safety risks associated with assembling passengers at sea, as well as potential financial risks to the ship's operation on the chosen routes, the ship owners, Captains and crew would be unwilling to facilitate the experiments without a detailed level of planning and consultation. This chapter provides a detailed explanation of the experimental methods and trial plans that were developed for *each* of the three ships in order to successfully answer the research questions posed while ensuring the safety of all involved. This chapter provides information about the ethics approval received and outlines elements of the project that were common to planning the trials on all three vessels. Sections are then provided that outline the planning details relevant for each ship tested.

Assemble and provide an overview of the data collected. Following each set of trials on the ships, all collected data sets were backed-up to a redundant online data storage server at the UoG to ensure security of the data collected and to enable analysis to commence as early as possible. Video analysis was undertaken by three members of the UoG project team (including the author) to determine general population demographics and the response time for as many passengers as possible. This was a meticulous process that took many months to complete and required considerable initial testing and development to ensure consistency between the analysts. Chapter 5 outlines the details of the video analysis methodology, along with the methodology used to analyse the IR data collected. An overview is also provided of the quantity of data collected and the general nature of it in terms of quality and any problems encountered when compiling the data for analysis.

Conduct a detailed analysis of the response time data in conjunction with demographic and ship-specific information. Chapter 6 outlines the analysis undertaken of passenger response time data distilled from video analysis for the three ships. The analysis shows how passenger response time is statistically different depending on the ship type, as well as the region of the ship in which passengers are responding. Analysis also suggests if it can be expected that different passengers will respond to an alarm in a similar manner within the same structure and under the same conditions. Finally, this chapter provides detailed definitions of passenger response time as a function of age, gender, location on the ship and whether or not they may have been part of a group of travelling companions. A comparison is also provided with existing response time distributions provided in the literature and sums-up with recommendations for updating IMO regulations using the new response time distributions collected.

Provide an overview of the individual passenger path data collected and develop a ship evacuation modelling validation dataset. Chapter 7 provides an overview of the passenger movement data collected using the automatic tracking system during trials on all three ships. While the dataset is rich in position data throughout the assembly process, the summaries provided in this chapter will give, for each ship, the first known location for each passenger after the alarm and final assembled time and location. An overview is then provided that describes the modelling carried-out with the maritimeEXODUS [39][40][41][42][43] software in which, the general starting location for passengers, ship geometry and measured response times were used. A particular focus is placed on the mathematical method of functional analysis chosen for objectively comparing the experimentally obtained assembly curves to those from modelling. This chapter concludes with an assessment of the method chosen and suggests the acceptance criteria that should be considered for objectively validating ship evacuation models. Recommendations are then provided for updating the IMO regulations using the validation datasets developed.

Assess the impact of the new response time distributions using a hypothetical ship model in maritimeEXODUS software. Chapter 8 outlines the results of comparative modelling carried-out with a hypothetical passenger ship design in maritimeEXODUS. Modelling uses the IMO evacuation analysis guideline requirements to provide baseline results, as well as the different newly developed response time distributions presented in Chapter 6. Results demonstrate the impact that the different response time distributions (RTDs) have on predicted total assembly time.

1.7 Chapter Summary

A background of passenger ships and the development of the cruise ship industry have been provided in this chapter. From this we have seen two important trends – the number of people travelling and vacationing at sea is increasing every year; and accidents that result in loss of life happen with surprising regularity. Given that passenger ships, particularly cruise ships, are also increasing in passenger capacity, these trends are concerning. An introduction to the International Maritime Organization (IMO) has been provided and the important role that regulation plays in establishing safety of passenger ships outlined. Of particular importance is the IMO document MSC.1/Circ.1238 [21] - evacuation analysis guidelines for new and existing passenger ships, which forms the basis for much of the research presented in the remainder of this thesis.

The main concepts associated with human behaviour in evacuation situations have also been introduced. Particular focus is placed on a framework developed by Galea et al. [31], which divides the main phases of evacuation behaviour into the *response phase* and the *evacuation movement phase*. It is the characterisation of these two phases of evacuation behaviour that this thesis is primarily concerned with quantifying.

The objectives and key research questions have been identified in this chapter and the novelty of the research performed has been identified as; (1) the first time that human alarm response time has been characterised with paying passengers onboard different types of passenger ships at sea; (2) the first time a method for accurately collecting individual passenger routes during the assembly process has been provided; and (3) a method for validating passenger ship evacuation analysis models has been proposed. These are important aspects of the work carried-out which, it is hoped, will have a direct impact on future passenger ship designs through recommended improvements to the governing regulations at the IMO.

Human behaviour during emergency evacuation from buildings has been studied and modelled for many decades, however the same cannot be said for passenger ships. Chapter 2 will present the relevant literature as it relates to human behaviour during evacuation from both buildings and passenger ships, as well as the associated methods used to collect human behaviour data. The regulations that govern passenger ship design for evacuation analysis are also discussed in detail as well as models that have been developed for predicting evacuation behaviour.

2 Literature Review

As discussed in the preceding chapter, a goal of this dissertation was to improve upon our understanding of human behaviour during emergency assembly on passenger ships in order to improve and validate evacuation models. Understanding and quantifying human behaviour during the assembly process on ships requires knowledge of ships and typical emergency response activities of passengers and crew, as well as the regulatory environment that governs ship design. This chapter outlines the relevant literature that defines the emergency response process on passenger ships, the regulations governing ship design for improved evacuation, as well as previous ship evacuation studies. The chapter also presents previous efforts to define human performance and behaviour in the context of ship evacuation, including measurement techniques for determining evacuation behaviour in general. The chapter concludes with a discussion of the well established field of building evacuation modelling, followed by a review of ship evacuation models, with a particular focus on the ship evacuation model used in this work – maritimeEXODUS, developed at University of Greenwich.

2.1 Emergencies on Passenger Ships

Response to emergencies on passenger ships varies widely, depending on the complexity and severity of the incident that requires a response. While a variety of means (e.g. lifeboats and liferafts) are normally provided to enable swift and efficient abandonment from a ship if required, it is generally accepted that the ship itself is its *own best lifeboat* in an emergency, as long as it is not at risk of capsize or sinking [44][45][46]. Ship abandonment is a very uncertain process at the best of times but the evacuation of several thousand inexperienced, untrained passengers in inclement weather represents an enormous challenge. The “what then” that follows a successful abandonment is equally worrisome. Thus, regulations and classification society rules that are followed by naval architects prescribe specific requirements around ship structure, subdivision and stability (SOLAS II-1), and fire protection (SOLAS II-2) [19] to ensure a vessel remains afloat even after an accident which results in flooding.

In December 2006, SOLAS adopted a new passenger ship regulation establishing design criteria for a passenger ship to be capable of safely returning to port under its own propulsion following a fire or flooding damage - SOLAS II-2/21 (Casualty threshold, safe return to port and safe areas) [7]. For a vessel to be deemed capable of returning to port, it must be designed so that the essential systems remain operational after an incident and a designated safe area is available to ensure the health and safety of passengers and crew [44]. While the concept of safe return to port offers significant reduction in risk to passengers and crew for reasonably foreseeable events that might otherwise result in an evacuation being called, the possibility will always exist that evacuation may be required at sea.

Vanem and Skjong (2004) [47] suggest that controlling risk in passenger ship emergency evacuation is mainly related to controlling and minimising the total evacuation time, which is comprised of awareness time, travel time, embarkation time and abandonment time, as depicted in Figure 7. Interpreting the figure, we see similarities with what was presented by Galea et al. [31] in Figure 6 in which passengers must interpret the notification cues and become aware of the need to evacuate, move towards a safe location onboard, board life saving appliances and then abandon. From the figure below, we also see that each stage can begin before the preceding one ends (i.e. passengers can begin to embark LSAs before all have completed the assembly. The paragraphs that follow provide an overview of passenger ship incidents where the importance of time required/available for evacuation was an important factor in many cases.

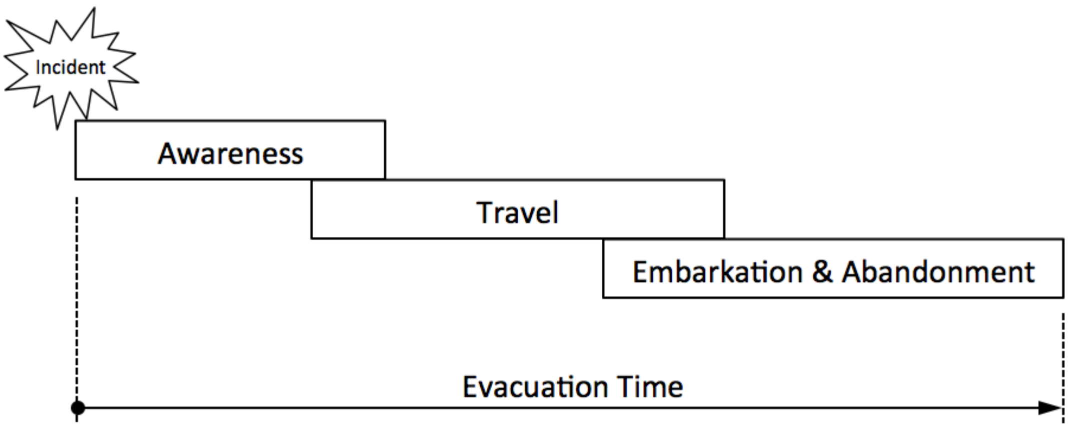


Figure 7 Vanem and Skjong's [47] representation of the stages of the evacuation process.

The sinking of the Titanic in 1912 is one of the best-known passenger ship disasters with a significant loss of life at 1,506 souls [48]. However, the worst recorded maritime disaster took place on 30 January 1945 onboard the MV Wilhelm Gustloff. The ship was carrying approximately 9,343 refugees and wounded (including an estimated 5,000 children) when it was struck by torpedoes and sunk. Only 904 survivors were rescued, resulting in the loss of a staggering 8,439 lives [49]. Although these two disasters took place many decades ago, accidents involving passenger ships still happen with startling frequency. It is worth noting again that since the research presented in this dissertation began in April of 2009, there have been at least fourteen passenger ship accidents that have resulted in over 4,000 fatalities [50]. These accidents have all involved vessels that were subject to the conventions and instruments of the IMO. A summary of some relevant passenger ship disasters since 1987 is provided below in Table 2. In addition to the disasters listed in Table 2, there continue to be frequent reports of ferry and cruise ship incidents, such as the following examples taken over the last *three* years:

- 10 February 2013 in Gulf of Mexico, the cruise ship *Carnival Triumph* experienced an engine room fire, which left the vessel adrift and without power or sanitation with approximately 4,000 passengers onboard [55].
- 9 March 2013 in the Gulf of Mexico, cruise ship *Carnival Elation* (capacity 2,052 passengers) had to be towed back to port by tugboat after losing steering gear power [55].
- 14 March 2013 in the Caribbean, cruise ship *Carnival Dream* lost power with over 4,000 passengers onboard [72].
- 22 July 2015 in Jamaica, Royal Caribbean Cruise Lines cruise ship *Freedom of the Seas* (capacity 3,634passengers) experienced a machinery room space fire, which injured one crew member [55].
- 15 August 2015 in Ormoc City (Philippines) the ferry *MV Wonderful Stars* caught fire while docked and all 550 passengers safely disembarked. One month earlier in the same port, the *MV Nirvana-B* capsized shortly after leaving port, killing 60 [52].
- 9 September 2015 in the Caribbean, the cruise ship *Carnival Liberty* experienced an engine room fire while in port, with over 3,300 passengers onboard. No injuries were reported [55].

- 22 October 2015 in the Greek Islands, the cruise ship *Splendour or the Seas* (capacity 2,076 passengers) experienced a fire with 21 passengers and crew suffering smoke inhalation [54].
- 25 October 2015 in Hong Kong a ferry carrying 174 people collided with an unknown object, lost power and took on water at about 1900h, no casualties were reported. Hong Kong's worst maritime disaster in decades happened in 2012 when a ferry collided with another vessel, killing 39 passengers [51].
- 20 December 2015 in Indonesia, a ferry carrying 188 passengers capsized and sank. 37 were saved, 3 bodies were recovered and 78 remain missing [53].

While many of these incidents did not result in loss of life or significant number of injuries, all could be considered high risk, given the number of persons onboard.

As explained by Galea et al. (2002) [73] the term evacuation (on ships) generally refers to two separate processes – *assembly* (or the more traditional *muster*) and *abandonment*. The former (assembly) refers to the process of moving everybody onboard to a safe location near lifesaving appliances and to ensure an accurate count of passengers and crew can be conducted. The latter (abandonment) refers to the process of getting people off the ship in order to move clear of the immediate hazard. For passenger ships, emergency response activities onboard will vary from ship to ship and depending on the event. Crew members will be assigned particular responsibilities that depend on their training, experience and rank onboard. Passengers are not generally assigned a formal role in the emergency response organisation onboard. Rather, these individuals are normally provided with a safety briefing and, depending on the voyage type and duration, may be required to complete an assembly exercise in order to become familiar with emergency procedures onboard, where to go, what to do when there and sometimes where to find and how to don a lifejacket.

Table 2 Summary of significant passenger ship incidents since 1987.

Year	Country	Ship Name	Type	Cause	Lost	Saved	Ref
1987	Philippines	Doña Paz	Ferry	Collision resulting in fire and sinking	4,341	37	[56]
1987	UK	Herald of Free Enterprise	Ferry	Capsize and sinking	193	346	[57]
1990	Denmark	Scandinavian Star	Ferry	Fire	158	N/R	[58]
1994	Estonia	Estonia	Ferry	Capsize and sinking	852	137	[59]
2000	Greece	Express Samina	Ferry	Striking	80	453	[60]
2002	Senegal	Le Joola	Ferry	Capsize	1,864	N/R	[61]
2006	Caribbean	Star princess	Cruise	Fire	1	3812	[62]
2006	Canada west coast	Queen of the north	Ferry	Striking and founder	2	99	[63]
2006	Egypt	Al-Salam Boccaccio 98	Ferry	Cargo fire causing sinking	1161	350	[64]
2008	Philippines	MV princess of the stars	Ferry	Capsize	~800	~40	[65]
2011	Tanzania	MV Spice Islander	Ferry	Capsize	2,976	610	[66]
2012	Italy	Costa Concordia	Cruise	Capsize and sinking	32	4,197	[67]
2013	Philippines	MV Thomas Aquinas	Ferry	Sinking	~120	N/R	[68]
2014	Italy	Norman Atlantic	Ferry	Fire	30	N/R	[69]
2014	Korea	Sewol	Ferry	Capsize and sinking	304	172	[70]
2015	China	Dong Fang Zhi Xing	River Cruise	Capsize in storm	442	12	[71]

Prior to the sinking of the *Costa Concordia*, SOLAS III/19 required that passenger ships embarking on a voyage of more than 24 hours duration should undertake an assembly exercise with all passengers within 24 hours of their embarkation. Clearly this is not adequate for passengers if an emergency occurs *before* the assembly exercise happened, as was evidenced by the sinking of the Costa Concordia. The IMO, in a post Costa Concordia review, recommended interim measures to improve cruise ship safety: "…member states should recommend that passenger ship companies conduct a review of operational safety measures to enhance the safety of passenger ships."

Subsequently, the IMO adopted amendments to SOLAS III/19 at the 92nd Maritime Safety Committee (MSC) in June 2013, requiring that for voyages of 24 hours or more, assembly drills should be completed for embarking passengers *before* leaving port from *every* port of embarkation and should include instruction for passengers on:

- description of emergency signals and appropriate responses,
- lifejacket locations and when/how to don them,
- where to assemble when the emergency signal is sounded,
- method of accounting for passengers during the assembly,
- how information will be provided during an emergency,
- what to expect if an evacuation is ordered,
- instructions on whether passengers should return to cabins before assembling (with specifics on medications, clothing, lifejackets, etc.),
- description of key safety systems and features,
- emergency routing systems and recognizing emergency exits, and
- who to seek out for additional information.

The amendments also require that passenger vessels:

- record the nationality of all passengers,
- limit bridge access to only those with specific operational responsibility,
- establish bridge team procedures for agreeing upon and implementing ship passage planning, and
- provide additional lifejackets at or near the assembly stations.

Of course, the details will vary depending on geographic region, crew experience and sociocultural response to such procedures. From the response to the Costa Concordia disaster, is clear that serious accidents in the maritime industry can have an impact on the governing regulations [74].

While an analysis of the incidents listed in Table 2 is not provided here, it is useful to consider some details that are relevant:

- *Dona Paz* sank 2 hours after collision and crew did not give any orders or attempt to organise the passengers [56].
- From survivor accounts [64], *Al-Salam Boccaccio* began taking on water and after 2 hours, passengers had still not been assembled and were told *not* to put on lifejackets because it might cause other passengers to become afraid.
- *Costa Concordia* Captain did not call an assembly or give direction to his crew to organise passengers [67].
- *Sewol* Captain did not call passengers to assemble, but rather suggested they remain in cabins.

We see a very different outcome if comparing the result from these disasters (for which there was significant loss of life) to other serious passenger ship incidents in which the Captain and crew quickly assembled passengers in case there was a need to abandon:

- The cruise ship *Le Boreal* experienced a serious engine room fire in the remote area of the Falkland Islands on 18 November 2015. The Captain quickly ordered the abandonment of all 347 passengers and crew, and all were safely evacuated [75].
- The cruise ship *MV Explorer* capsized and sank in Antarctic waters on 11 November 2007. The Captain ordered the abandonment of all 154 passengers and crew onboard and no serious injuries were experienced [76].
- The cruise ship *MS Calypso* experienced a serious engine room fire on 6 May 2006. The Captain ordered all 708 passengers were assembled and crew had them board the lifeboats to be ready for evacuation if required. The vessel was towed to port in Southampton and all safely disembarked, not needing to abandon in the lifeboats, however they were *ready* to respond immediately, if ordered by the Captain [77].

From these examples, it is clear that assembling passengers as early as possible in an emergency offers the best chance at survival if abandonment is required.

The IMO convention on Standards of Training, Certification and Watchkeeping (STCW) Section A-V/3 Paragraph 5 discusses methods and training for control of situations involving passengers. This is an important component of crew training for passenger ships, however, a crew member's effectiveness in a real emergency remains largely unknown.

Shetiwy [78] discuses the impact crew has on the process of assembling and evacuating passengers, particularly where crew manning levels, training and experience are concerned. He notes that crew assertiveness on commercial airliners is of key importance to ensuring passengers evacuate as quickly as possible in an emergency but does the same hold true for passenger ships? His paper provides an overview of the regulatory guidance and legislative requirements for crew training and manning levels along with three case studies of passenger ship losses. However, a detailed assessment is not given that would suggest definitive ways to improve on the current situation.

Pyman and Lyon [79] note from their research that ships which sink within a few minutes of an incident (for all types of merchant ships, not just passenger ships), 86% of those onboard died. The authors further note that from a study of the incident reports for passenger ship accidents, crew performance plays a large role in the success of the evacuation. The crew onboard the *Prinsendam* (1973) was described as being effective and well-trained and was able to evacuate 600 passengers safely using lifeboats, including many elderly. However, by contrast the *Lakonia* (1963) under similar conditions and approximately the same number of passengers onboard had a much worse outcome, [79] with reports that the crew was ineffective. It is recognised that while there are many more factors that determine the outcome of an incident, the crew's influence can be important.

It is interesting to note the loss of the Costa Concordia cruise ship - while the loss of life in this incident was lower than many other incidents noted above, this event [67] should perhaps be considered as a "what not to-do" from the point of view of the individuals onboard with responsibility for managing such an incident. The accident happened at 21:45:07 local time – the night of 13 January, 2012, with a total of 4,229 persons onboard

(3,206 passengers and 1,023 crew) in favourable weather and oceanic conditions. Under command from the vessel's Master, the ship passed at a *planned* yet *unsafe* known distance from the shore at high speed (15.5 kts) when it collided with "Scole Rocks" at the Giglio Island enroute to Savona, Italy. The vessel immediately lost propulsion and consequently experienced a full blackout. The ship turned to starboard due to the prevailing wind and current conditions and grounded at Giglio Island a little over an hour later at approximately 23:00, seriously heeled at 15° to starboard. Analysis by the accident investigation team showed that the Master reported the seriousness of the situation after 16 minutes and in-flooding water had reached the bulkhead deck in the aft region of the ship after about 40 minutes (at 22:27). In all, an unprecedented 5 watertight compartments were flooded due to piercing of the hull on the port side of the ship. These compartments contained machinery and equipment vital for propulsion and steering of the ship, as well as ballast and bilge pumps. The breach was measured to be 53m long – 18.3% of the vessel's length [67]. As the situation unfolded, the search and rescue (SAR) authorities were alerted from *shore* at about 22:00 rather than by the vessel Master, and SAR activities began mobilizing at 22:16 – 25 patrol boats, 14 vessels, 4 tug boats and 8 helicopters. The Master alerted the authorities of the breach at 22:26 and made a full distress call at 22:38 at the insistence of the local SAR authority. Of particular relevance to the work presented in this dissertation is that the order to abandon ship was made at 22:54:10, but it was not preceded by an effective general emergency alarm and several passengers testified that they did not hear the signal-voice abandon ship announcements made. The first lifeboats were lowered at 22:55 and the crew (with Master) abandoned the bridge at 23:20, leaving a single officer onboard to coordinate the abandonment effort. The vessel's heel significantly increased at 24:00 to 40° and reached a maximum of 80°. The Master notified SAR authorities at 00:34 on 14 January that he was onboard a lifeboat with other officers of the vessel, despite the fact that a significant number of passengers were still onboard at that time. Initial rescue operations, saving 4,194 passengers and crew, were completed by 06:17 and three additional individuals were saved on 15 January. In all, 32 persons were lost in this disaster – 27 passengers and 5 crew.

The accident investigation report [67] concluded that after the incident had occurred, the fact that the general emergency alarm was not activated immediately led to a delay in the management of the phases of the emergency that followed, particularly ship abandonment. Furthermore, the lack of a direct order from the Bridge to the crew, who had responsibility for assembly and abandonment, hindered their ability to manage the abandonment phase and contributed to passengers onboard taking initiative to act appropriately. The report further notes that deck crew were disoriented and did not perform a significant role in management of the emergency or the abandonment and that the Cruise Director arbitrarily sent passengers *away* from the assembly stations, requesting they return to lounges. Some crew told passengers to return to their cabins and that the event was only a blackout and would be resolved soon. Some passengers testified that it was completely dark in their cabins and they could only locate lifejackets using light from their mobile phones. From the information presented in the accident report [67], it becomes clear that after the incident had occurred there was considerable confusion onboard among those responsible for managing the emergency, which was particularly driven by the fact that the Master provided no direction. Not calling a full assembly of the vessel early in the timeline when it would have been easier to account for passengers and board/launch lifeboats with the vessel at low angles of heel meant that a large portion of those onboard had to use embarkation ladders to move to the water level in order to board rescue craft. This also helps illustrate the importance of time in the evacuation equation, and it is generally accepted that loss of life in this disaster would have been significantly higher had the vessel been in deeper water and had it not been so close to shore, making it easier for SAR to perform its duties.

It is also worth noting at this point an accident report presented by the Marine Accident Investigation Branch (MAIB) [80] that is relevant for the research presented in this dissertation, as it informs the development of protocols and due consideration of the safety of research participants. In this accident, shore-side personnel from P&O Ferries were brought onboard the vessel to perform an evacuation drill during the annual servicing and deployment of its vertical evacuation chute system. During the exercise, a member of the shore side staff became stuck inside the chute while wearing a lifejacket, resulting in strangulation for a significant period of time such that she died before rescue could be completed. It is important to understand that, while we are all faced with a level of risk throughout our daily lives, performing evacuation exercises onboard ships can significantly increase one's risk exposure and as researchers, we must keep this risk uppermost in mind at all times. It was with this information in mind that the protocols and methods presented were developed.

2.2 Behaviour of People in Emergency Situations

2.2.1 Overview

Section 1.2 explained that the evacuation process can divided into two phases – response and evacuation movement. A framework developed by Galea et al. [31] was presented in Figure 6 which further divided the initial response phase into notification, cognition and activity stages which fully define the response time. This framework can be applied to evacuation behaviour in buildings as well as maritime settings and has been used in the analysis of response phase behaviours for university libraries [81][82][83], the world trade centre disaster [81] and retail settings [81].

Not all individuals will respond to alarms in the same way, and it is unlikely that the same individual will respond the same way twice, since the process tends to be stochastic in nature due to the complexities of the different response stage behaviours outlined: notification, cognition and activity. According to Sime [84], the time taken by people in responding to information concerning fires is as important as actions taken *after* this response. This may be because delaying one's response to an incident may preclude future evacuation options since individuals may become incapacitated due to toxic gases and evacuation routes may not be available.

When a serious incident occurs, the first indication that a response is required may come from the incident itself or could simply be an alarm; this has already been defined as the *notification stage*. On ships, whether emergency communication (such as a call to muster or abandon ship) is a bell, whistle, siren, or word of mouth, it is imperative that it be understandable by the people receiving it. In addition to people being aware of the signals, it is also important that people know what action is required of them [45]. An individual's response to an incident or alarm will vary depending on the person's experience with the environment and any number of stimuli and relevant experiences the person may have had in the past. The notification stage ends when people respond to the cues by mentally and/or physically disengaging from what they were doing previously and recognise that something unusual may be happening in their environment. At this point, individuals may be alerted that something is happening but have not yet begun physical movement. If this is the case, it marks the start of the cognition stage of response behaviour.

During the cognition stage, people begin interpreting the information available from the notification cues and possibly other sources such as related cues, announcement details or staff intervention as they decide how to respond. This, according to Galea's framework [31], occurs by three broad types of behaviour:

1. If the initial notification cues are insufficient to convey that there is a need to evacuate, people may continue with their previous activity until further information has been received, at which time one of the next two types of behaviour occur.
2. If individuals clearly understand the evacuation cues, they may immediately begin evacuation movement without undertaking other activities. For this case, the end of the cognition stage also marks the end of the response phase and the start of evacuation movement.
3. If individuals acknowledge the notification cues but begin a series of action and/or information tasks, this marks the start of the activity stage. In this stage, cognition about the event may also be occurring at the same time as the activities. Thus, for this type of behaviour, the cognition stage would run parallel to the activity stage. The end of the cognition stage is not well defined and so is taken to end at the end of the activity stage.

The activity stage begins when individuals perform information and or action tasks that were thought of in the cognition stage, such as:

1. Action task: person physically carries out an activity (e.g. in the same location, in the immediate vicinity or at another location)
2. Information task: person seeks, gives or exchanges information about the incident, required course of action in the same location, in the immediate vicinity or at another location. This may include social interaction with others and what distinguishes an information task (involving movement) from action is the goal of the movement – to obtain or provide information.

Therefore, response time should be considered dependent on a range of separate but distinct behaviours that require an individual to disengage from pre-alarm activities (notification time) time to consider the cues (cognition time) and time to complete all action and information tasks (activity time) before starting decisive movement to an exit or place of safety. The duration of the response phase for each individual in a given population is distributed across a range of possible times and in evacuation modelling, as with a real situation, the progress of an evacuation is affected by the interaction between people, their environment, the time at which they start responding to cues and how quickly they move.

These paragraphs have outlined the general aspects of evacuation behaviour relevant for both ship and land-based emergencies. While human behaviour during ship evacuation is a relatively new field of study, behaviour during building evacuation has been studied extensively since about the 1960s and provides a useful basis for understanding ship evacuation behaviour. The two sub-sections that follow provide a detailed review of the relevant literature first for buildings and then for ships.

2.2.2 Human Behaviour in Land-Based Evacuation Situations

Studies on pre-evacuation behaviour of people have been conducted in four ways [90]: evacuation drills (announced and unannounced), post-fire surveys, laboratory investigation and computer simulation. They suggest that, while drills may provide an opportunity to observe how people react to given controlled scenarios, behaviour in an actual emergency may be very different due to the associated mental stress. This is supported by the work of Ozel in 2001 [91]. In their study, face-to-face interviews were conducted with 650 survivors of a high-rise office building fire. Of these, 595 were considered valid and used to characterise the behaviours. From the results, the estimated pre-evacuation time showed a strong lognormal form for both male and female interviewees and that females tended to respond more quickly than males. They found that people who had received emergency training were more likely to respond sooner than those who did not and the education level of the people interviewed had no effect on their pre-evacuation time. Also relying on survivors' recall of real events in buildings, Brennan [92] provides details from post-fire investigations for an office building and an apartment building. It was found that for the apartment building, age played a significant role in response to the incident since many of the occupants were over 75 years of age and took a long time to prepare to evacuate. About 30% of the occupants were asleep and did not wake for the alarm and it was reported that some who were woken fought to go back to sleep, despite the alarm.

Proulx and Fahy (1997) [85] reviewed five evacuation case studies in midrise and highrise buildings. The case studies examined data that was collected from occupants during evacuation drills in both apartment and office buildings. Data from two fires was also reviewed – one in an apartment building and the other in an office building. The authors found a large variation in delays to start the evacuation process for the different buildings. While one may expect a person's response to an actual fire would be faster (due to cues such as smoke or feeling threatened), interestingly, it was reported that the delay before starting to evacuate was often *longer* in the actual fires because of the ambiguity of the cues perceived during the notification stage. Furthermore, it was found that during evacuation drills, the response time in the office building was faster than in the apartment buildings and that one of the apartment buildings perceived as having a good alarm system tended to have shorter response times. This is an interesting and important result from Proulx and Fahy's research as it points to the importance of clarity of the notification cues provided. For all cases, it was found that the distribution of response times took a lognormal shape. Some factors in Proulx and Fahy's study that may have played a role in making the office building response times faster include that occupants could adequately hear the alarm, they had good visual access compared with those in the apartment buildings, they had been trained how to respond to alarms, and a fire warden had been assigned to assist. The authors of [85] felt that important differences between office and apartment buildings rests in the fact that for the former, all occupants are generally capable adults who are awake and fully dressed, whereas in apartment buildings, some individuals may have to awaken, get dressed, find children and look for neighbours before being able to begin evacuating. This research provides some insight for response times on passenger ships which consist of not just one single homogeneous type of space but a combination of many types of spaces in which some passengers may be asleep while others are dressed and moving about the ship.

Response time was defined by Kuligowski (2003) [86] as "…the average time interval to respond to the corresponding cue…" but does not provide a meaningful explanation of what "respond" actually means. The author goes on to specify that for certain evacuation models for hotels (analogous to cabins on passenger ships), a mean response time of 6 seconds was used for people who were awake and 10 seconds for people who were asleep but does not give an indication of the shape of the response time distribution and what defines the end of the response behaviour. It does seem very optimistic that individuals sleeping in hotels would be moving toward an assembly point within a period of 10 seconds so the definition of "response", in this instance is uncertain and needs to be clarified. While there may be differences between response time on passenger ships when compared to buildings, the same factors may influence how quickly passengers respond, or how quickly there are *able* to respond to the cues received.

Spearpoint (2004) [87] discusses the impact that pre-evacuation (response) time distributions have on overall evacuation time in buildings. His analysis was used to investigate how congestion might occur at a constriction when all occupants begin to move at the same time (uniformly distributed response time), compared with when there is a simple triangular-shaped distribution of response times (symmetric and skewed). Simulations were performed using the Simulex model [88][156]-[168] with a simple room, as well as with a hypothetical building consisting of 3 floors. Results showed that the response time distribution used can have a significant impact on total evacuation time modelled. Large response time distributions resulted in evacuation times that were independent of occupant density, whereas occupant density was found to be more important when the response time distribution was small. Thus, the range over which the response times are taken must be carefully considered, as well as the shape of the curve used. Spearpoint also found that results for the simple room were similar to those computed for the more complex structure.

Nilsson and Johansson (2009) [89] conducted unannounced evacuation experiments in a theatre, with analysis focussed on determining whether people are influenced by others during the initial stages of an evacuation. They identified three separate behaviour types during the notification and pre-evacuation phase and found that people were influenced more by their neighbours than others in the theatre who were more distant. This research is relevant, particularly for cruise ships which tend to have large theatre spaces onboard.

Hostikka et al. [93][94][95] measured response time of occupants in a public library and office buildings (one large and one medium sized) in Finland. They used video cameras to capture response time and noted that positioning of the cameras was the most challenging issue to ensure a suitable view of occupants could be captured. The public library was part of the Helsinki University of Technology and consisted of two floors with 6 exits, response times for 42 people were collected with an average of 36 s and a lognormal distribution provided the best fit to the dataset. A total of 189 occupants were involved in the study, including about 33 staff members. While the population demographics are not provided, it is assumed that the group was primarily university students, which may not represent behaviour of the broader population in other structures.

The second evacuation trial discussed by Hostikka et al. [93][94][95] was of a large office building with 7 floors with 4 street-level exits. Artificial smoke was used to “direct” occupants away from certain areas and video cameras were used only in stairwells to capture flow rates. An RFID system was used to estimate response time when occupants entered a stairwell, thus the actual response times for each person would be less than those recorded. A mean response time is not provided but the minimum and maximum values were 30 s and 4 min, respectively. A total of 281 workers were involved in the evacuation exercise.

The third evacuation trial discussed by Hostikka et al. [93][94][95] was of a medium-sized office building with 4 floors and 5 exits. Artificial smoke was, again, used to direct occupants away from certain areas and video cameras used to monitor doorways and stairwells for capturing flow rates. A total of 139 people were involved in the trial and using RFID to estimate response time was not found to be effective since a very low number of occupants were registered by the system. While the RFID-based estimates of response time for these experiments provides *some* measure of response time, it cannot be considered accurate and gives no insight as to what occupants were actually doing immediately after the alarm. In addition, Hostikka et al. [93][94][95] identified a low RFID read-rate for many of the tests, suggesting that if RFID is used for estimating response time, it can only be expected to capture a small portion of the population involved.

Kobes et al. (2010) [28] carried-out a broad-based literature review of building safety and human behaviour in fire and found that pre-movement time is a more important aspect of required escape time than that required to move to a safe place. More importantly and not surprisingly, research has shown [28] that there is a connection between delayed evacuation and death or injury in the event, particularly for residential buildings and hotels. It is not certain if the same applies to passenger ships but as noted in Section 2.1, this appears to be the case.

Purser and Bensilum (2001) [96] conducted a series of monitored evacuation studies in a range of different buildings and recommended strategies for applying behavioural data to design standards. Of particular relevance in Purser and Bensilum's studies was the presentation of pre-evacuation response time. They defined pre-movement as beginning at the alarm or cue and ending when travel to an exit begins. In all cases described (retail store with a food hall, theatre and an apartment building), the response time distributions were skewed to the left and took a lognormal form. The authors indicate that data summarised for a variety of building types show excellent lognormal model fit to the pre-movement dataset with long distribution tails observed particularly in cases where warning systems and fire safety management implementation were poor. They found that in a mixed dataset (i.e. not a particular building type), the mean pre-movement time was 53.4 s and the 95th percentile was 256.8 s. When the data is broken into alarms that provide vocal instructions and just sounds, the mean response time is 0.51min (95th % 2.43) and 2.15min (95th % 7.11min) respectively. Clearly the type of notification has an impact on how people respond. The authors reached some important conclusions from this work but perhaps one of considerable importance is this:

> "Although the detailed behaviour and emergency evacuation times of individual building occupants may be somewhat unpredictable, the behaviour and evacuation times of occupant groups and building populations are amenable to prediction and quantitative description suitable for engineering design purposes".

This is an important conclusion as it supports many of the conclusions drawn in this dissertation about the application of such human behaviour datasets.

There are clear differences between the nature of building evacuation and ship evacuation. One would expect ship motions to play a role in the evacuation movement process simply because of the kinematics of the processes involved. The environment onboard ships may also produce disorientation of passengers who do not have familiarity with the ship they are on, or indeed ships in general. In evacuation situations, this disorientation may be made worse by the fact that items such as furniture may have moved, creating obstructions, or passengers may have to move in an upward direction to assemble, rather than downward as would be the case in most building evacuations. Despite these differences, it is still reasonable to expect that in the early stages of an emergency, the nature of people's response to notification cues would be similar. Thus, it is reasonable to expect that the distribution of response time on ships should also take a lognormal form as observed in the built environment. This is demonstrated in Chapter 6.

2.2.3 Human Behaviour in Ship-Based Evacuation Situations

Considering that the IMO guideline for passenger ship evacuation analysis (IMO MSC/Circ.909) was released only in 1999 because "The Committee, noting that computerized simulation systems are still under development, decided that a simplified evacuation analysis method was needed…", it is not surprising that there have been just a few dedicated studies to better understand and quantify the human element in ship evacuation.

Useful information regarding the factors that affect ship evacuation time can sometimes be gleaned from accident and investigation reports, as well as video captured by passengers onboard and by the media onshore. However, it is generally more reliable to carry-out focussed, well-planned studies to provide answers to questions of human behaviour and performance during the ship evacuation process, since the details of "opportunistic" data are generally unknown and may be misleading in the global sense of an incident (where and how was it collected, when did the first notification become available and what happened before the data was collected). As discussed in Section 1.2, evacuation from ships can generally be broken into two main phases – assembly and abandonment. Because much of the research is used to inform the development of evacuation models, the research has tended to focus on the assembly and boarding process, rather than abandonment. This section will outline the key research studies carried-out to characterise human behaviour in ship evacuation, with a particular focus on the assembly process.

While the focus of this section is on the assembly phase of the evacuation process on passenger ships, however, it is worth noting research led by the author [97] as part of the FIRE EXIT [43][101][102][103] project which investigated the range of human behaviours and performance specifically for the abandonment phase of an ship evacuation by quantifying the movement for over 250 research participants through a 6m vertical evacuation chute, a 12m inflatable evacuation slide, a davit-launched liferaft and a davit launched lifeboat. This research was the first of its kind to quantify hesitation at the beginning of the abandonment process, steady-state movement on slides and chutes, the boarding process for liferafts and lifeboats and the time required to reach a seated position inside rescue craft. The research quantified task performance according to stationary activities, as well as translation activities considering the distances travelled (e.g. sliding down a slide or scrambling down a vertical chute). Part of this work included quantification of the lifejacket donning process. Results showed that trained people using vertical evacuation chute systems were more than twice as fast as those who had no training and that for abandonment by slide and chutes, males tend to be faster than females. Lifejacket donning time was found to have a lognormal distribution with a mean of 38.5 +/- 11.8s.

A manual produced by Poole and Springett (1998) [98][99] provides practical information based on real tragedies rather than strictly on theory. It is intended as a way to provide active seafarers with some knowledge about general passenger behaviour, crowd behaviour and behavioural response to emergencies at sea. Very practical and thoughtful discussion is provided, including that crew behaviour *should* differ from that of passengers. This manual may be useful for highly trained seafarers who have experience and a good understanding of their ship, its LSAs and take an active role in an evacuation. However, crew members who do not fit this description, such as the onboard hotel staff, restaurant staff and entertainers, may not benefit greatly from it. This is an unfortunate aspect of the maritime industry as these individuals are often the ones left to deal with passengers one-on-one because the highly trained seafarers are required to carry-out tasks with technical equipment such as fire-fighting, preparation and launch of life-saving appliances and control systems operation.

Poole and Springett (1998) [98][99] give eight so-called *fallacies* in emergency evacuation that, while not fully based in detailed investigation, are worth stating here as the concepts help frame some of the research in this dissertation:

1. Individuals start to move as soon as they hear an alarm. Passenger response time in an important aspect of evacuation behaviour that must be better understood;
2. Motivation to escape underpins any movements or actions a person may carry out. Passengers will often continue with their pre-alarm activity and not attempt to "help themselves". This was witnessed numerous times during the sea trials undertaken in

this research and often times passengers were reluctant to do anything unless told to do so by a crew member;

3. Time to evacuate depends only on the time it takes to move to and through an exit. Closely related to assumption #1 above, this is discussed in some detail Chapter 7;
4. People are likely to move toward the exit to which they are nearest. Often passengers will take a known route to get where they need to go rather than the shortest. This was observed numerous times throughout the trials carried-out in which passengers sometimes moved from one assembly station to a more distant one;
5. People move as individuals without considering others. The presence of a crowd impacts a person's movement and passengers will often attempt to help other passengers. Furthermore, in dense crowds, people are often forced to move with the crowd rather than chose their own path. Family units tend to move as family units rather than alone;
6. Signage helps ensure people find a route to safety, however, anxiety and narrowed attention often means peripheral cues go unnoticed. One example that was observed during the research carried for this dissertation saw passengers wait significant periods of time in congested areas trying to reach an assembly station, rather than simply following the signs to a different assembly area, which was completely uncongested;
7. All people involved are equally able to physically move to an exit. Elderly people observed often required assistance on stairs, people in wheel chairs had to use elevators. Effects of alcohol will impair an individual's motor skills and individuals with less experience on ships will tend to be less stable moving about; and
8. People will not necessarily be safe because they will panic. While a powerful concept, the term panic is often used inaccurately in the context of evacuation where people do not necessarily enter a sudden state of uncontrollable anxiety or irrational behaviour.

Further to point 8 above, Ockerby [100] carried out research to prove the assumption that "panic is a natural occurrence in passenger ship emergencies" is generally the result of media reporting of such incidents rather than what happens in reality.

The two sub-sections that follow will focus on studies particularly relevant to the work presented in this dissertation – response phase behaviour and evacuation movement behaviour onboard ships.

2.2.3.1 Response Phase Behaviour

Until about 2007 when the revised IMO evacuation analysis guidelines were released, the representation of how people on passenger ships respond to notification cues was largely informed by evidence from the built environment on shore.

For ships, Section 7.2 of the LSA code [18] sets the requirements of alarm signals - a man overboard alarm consists of 3 long blasts, for example. While these alarms are generally understood by and intended for the crew, certain alarms are also relevant for passengers onboard – a general alarm consists of 7 short blasts and 1 long; a fire alarm consists of continuous ringing of the ship's bell. Do passengers know what to do when hearing these alarms? There is no requirement for the alarm to be accompanied by an announcement, except in the case of abandon ship, which can *only* be given as an announcement by the person in control – normally the Captain. Research presented in Section 2.2.2 suggests that the clarity of the alarm signal influences the response behaviour of people in buildings (i.e. alarm systems that provide clear information tend to result in faster response time). Thus, it stands to reason that the same should also be true for passengers on ships.

One of the first ship-specific research project that quantified response phase behaviour was FIRE EXIT [43][101][102][103] - a research project funded through EU Framework Programme 5 from 2003-2005. The research project involved a total of nine partners from Europe and Canada with the objective to characterise human performance for ship evacuation scenarios. Data was collected with the aim of improving simulation for the assembly and abandonment processes on ships and represented a significant step forward in the field. The final data collection exercise in the project was intended to gather passenger response time and relevant assembly data that could be used for ship evacuation model validation purposes. Two exercises were conducted onboard the *MS Eurostar Roma* – a ship owned at that time by Grimaldi Ferries AS (Italy). The first trial was conducted on 18 April 2005, outbound from Civitavecchia (port for Rome) and the second on 22 April 2005 returning from Barcelona. The vessel was a RO-PAX ferry with a capacity for 1,400 passengers, 100 crew and 120 cars. Data collection was undertaken using 12 digital video cameras positioned throughout the ship in locations where passengers were expected to be located at the alarm and at entrances to assembly points. Two additional roving cameras were used to capture different views and passenger behaviour throughout the ship. Research team members were also positioned at the assembly stations to record (using a stopwatch) the arrival time for different passengers at the assembly stations.

Galea et al. (2007) [103] note that during the trial, passengers were given a large number of warnings that a drill was to happen. It is expected that this had an impact on the measured response times and the authors concluded that these response time distributions produced should only be considered appropriate in cases where passengers would be expected to receive significant forewarning that an evacuation will be required. This forewarning also resulted in some passengers proceeding to the assembly stations with lifejackets donned *before* the alarm was sounded, making the assembly station arrival time dataset collected unreliable. Analysis of passenger response time produced a dataset of 67 response times in public areas of the ship and 127 response times in cabin areas. It was found that the distributions produced from both areas of the ship were lognormal in shape – a significant departure from the uniform random distribution used in the first IMO evacuation analysis guidelines (described in Section 2.3 below). Despite the weaknesses in the FIRE EXIT response time dataset (small numbers of response times collected, fully announced and data collected on only one ship), results were used to improve upon the IMO evacuation analysis circular used at that time (MSC/Circ.1033 was updated to MSC.1/Circ.1238, described below in Sections 2.2.3 and 2.2.4 respectively) through the adoption of new passenger response time distributions for the both the day and night cases [103]. The day case distribution was developed using passenger response to the alarm in public areas, while the night case distribution was developed from passenger response to the alarm in cabin areas. Comparisons are made between FIRE EXIT response time data and the research from this dissertation in Chapter 6.

Subsequently, Deere et al. [32] carried-out evacuation modelling with the maritimeEXODUS model to demonstrate the difference in total evacuation time using the FIRE EXIT response time distributions compared with the IMO response time distribution used at that time (uniform random). It was found that using new the lognormal response time distributions produced a more realistic prediction of evacuation performance than the uniform random distribution, particularly for build-up of congestion.

Research by Vanem and Skjong (2004) [16] also suggests that the response time will be influenced mainly by the signaling and alarm systems. While cues such as signaling and alarm systems will play a role in the *nature* of passenger response time, to date research has not identified this as the primary influencing factor. Indeed, one of the aims for the work presented in this dissertation is to determine if the factors influencing passenger response time can be measured reliably and whether they are repeatable on different ships of the same general type.

Given that the literature provides little guidance on the response time characteristics of passengers during ship evacuation, research question 2 (Section 1.3) is a relevant and important question to ask – *Can we collect representative and detailed response time data for passengers responding to alarms on passenger ships*? Providing answers to this question will result in reliable response time datasets that can be used to more accurately model response behaviour onboard passenger ships and to improve our understanding of the impact of response time for different areas of different ship types.

2.2.3.2 Evacuation Movement Phase Behaviour

Analysing human behaviour in emergency scenarios is difficult to do through experiments, as suggested by Lee et al. (2003) [104], due to the complexities of human factors such as cultural differences, gender, age and behaviour under stress. Lee et al. [104] consider that the effect of vessel motions (obviously not an issue in the built environment on shore) is a *dominant* factor in ships since motions directly affect people's performance, particularly the elderly and those with physical disabilities. In early iterations of ship evacuation modelling and in the absence of better, more relevant data, a reasonable first-order approximation for passenger behaviour and movement was to assume land-based evacuation settings were appropriate but with the vessel's geometry. However, making design changes of a passenger ship layout based on results from such a first order approximation of evacuation behaviour and performance may be dangerous, considering that passengers may not understand or perform as well in the maritime setting as onshore.

Walking speeds were measured by Hwang et al. (1991) and Fukuchi et al. (1998) [105][106] to characterise the speed of Asians on flat floors – 0.98 to 1.39 m/s, Katuhara et al. (1997 and 1998) [107][108] of the National Maritime Research Institute of Japan on an anchored ship from 1994-1997 measured the movement of participants along a pre-defined evacuation route with video cameras and showed movement speeds to be 1.4m/s in passageways and 0.7m/s on stairs, where maximum group density was 3.0 persons/m^2. Neither of these studies involved people walking in motions and Katuhara's work, while using up to 120 individuals, only involved students with an average age of 20 years so results may not be representative of the broader population.

Murayama et al. (2000) [109] of the Research Institute of Marine Engineering of Japan conducted walking tests in a moving corridor. Participants were subjected to static list angles between +/- 20° as well as dynamic motions to 10° with a cycle time of 5 and 10 s. Murayama's experiments in motion showed that walking speeds were about 70% lower than for the stationary case, however these tests involved only 6 participants so may not be representative of how motion affects walking speed for the broader population.

The effects of motion and structural changes may cause disorientation of individuals in an emergency evacuation. This is particularly the case for passengers on ships which experience rolling motions (about the ship's longitudinal axis), pitching motions (about the ship's transverse axis), heave (up and down) and combinations of these. In addition, unlike the built environment, which generally requires people to move in a downward direction to evacuate, evacuation from passenger ships may require people to move in a downward or upward direction to reach lifeboats, depending on their location onboard. This could be further complicated by onboard equipment which may have shifted due to the incident or, if the ship is in a damaged condition and laying on its side or at a significant angle, a complete change in vessel geometry from the point of view of the passenger, making planned or known evacuation routes unavailable.

Koss et al. [110] performed an experiment in 1997 to determine walking speeds on a ship in corridors and on ladders at the Australian Maritime Engineering Cooperative Research Centre. Koss et al. found that walking speed tended to increase as the trim (static angle about the ship's transverse axis) in a downward direction increased, but for trim in an upward direction, he found walking speeds were similar to those in the even keel condition. This study involved 67 male and female participants between the ages of 8 and 25 years and so, again may not be representative of the broader population. In addition, details for the ship tested are not known but the width of the corridor was reported as 1.2m so it should be noted that these results do not necessarily hold true for more open spaces on ships.

The work of Bles et al. (2001) [111] conducted at the TNO Human Factors facility in the Netherlands examined the effects of simulated ship motions in corridors using a 4m x 2.4m x 2.3m cabin mounted on a hydraulic system. The experiments involved a large number of participants – 150 in total ranging in age from 18-83 years. Contrary to the results published by Koss et al. (1997) [110], Bles et al. (2001) [111] found that for trim angles in the upward direction, one could expect a 35% decrease in walking speed, on average. Bles et al. also found that for cases with dynamic motion, increasing the angle and cycle time resulted in a decrease of walking speed up to 15%. While this research presents useful insight into how motion and angles of trim affect walking speeds of people on ships, the tests were carried-out in a simulated environment with a limited range of motions and over relatively small distances (4 m maximum).

In 2004, Lee et al. [112] provided a discussion of the St. Malo passenger ferry evacuation (described in detail by Lockey et al. [114]) which took 77 minutes to fully evacuate the 308 passengers onboard – more than nine times the total evacuation time of 8 minutes that had been recorded during a drill with the vessel in a stationary condition. This incident provides a good example of the potential impact of performing an evacuation analysis that does not account for vessel motions or passenger psychological state.

Lee et al. (2004) [112] further presented the results of their experiment in which a 10m x 1.2m x 1.9m corridor mock-up was used on the deck of a ship to provide measures of walking speed and flow rates with different angles of trim (+/- 20deg) and heel (0-20deg). Two experiments were conducted using this rig – one with motion and the other without. Walking speed for unidirectional and contra flows were measured and flow rates through a doorway were measured. Participants were students from the Korea Maritime University and included 18 males and 3 females, all of whom wore lifejackets throughout the tests. Results showed a different trend for downward trim walking speeds, which were slower instead of faster as presented by Koss et al. (1997) [110]. In addition, Lee et al. report that for upward trim, the speed did not decrease as much as reported by Bles et al. (2001) [111]. One reason suggested is that the floor surface materials were different in Lee's experiment, (i.e. carpeted and thus less slippery than for the others). Lee et al. do not discuss the potential impact of the population used, nor does he discuss the impact of the participants' ages and the fact that they were predominantly male. The population differences between the work of Lee and Bles are significant and likely have a major impact, considering the much wider age range in the experiment by Bles. Contraflow situations in Lee's experiment reduced walking speeds by up to 60%. Lee et al. recognise some of the challenges faced in planning his experiment and recommended that additional research be carried-out to quantify the effects of ship list angles on greater numbers of female participants, different ages and persons with mobility issues. He also recommended further studying the effects of motion using a motion simulator.

The FIRE EXIT [43][101][102][103] project (2003-2005) also produced a large database of walking speeds for passenger ship scenarios using a specialized test rig called SHEBA – the Ship Human Evacuation Behaviour Assessment facility [101]. The SHEBA rig measured 10m x 2m with a short stair run at one end. The facility was mounted on hydraulic rams capable of tilting it to angles up to 25° - static as well as dynamic motions. The interior of SHEBA was set-up to look like a ship's passageway, complete with handrails. Testing was carried-out in SHEBA to measure walking speeds for males and females across a range of ages and for different angles of static heel, as well as for dynamic roll motions simulating a ship in the damaged condition, rolling about a longitudinal hinge [113]. SHEBA testing also included measurement of individual passenger walking speed in conditions of simulated (theatrical) smoke of differing optical densities and in different lighting conditions, as well as group performance and contra-flow conditions and movement up and down stairs. Although the SHEBA datasets were used to update existing data regarding pedestrian dynamics on ships, it must be recognised that the test conditions were still somewhat artificial and only rolling motion was possible.

It is worth also considering the effect of having multinational passengers and crew in large numbers onboard a passenger Ship. As a North American who has spent time in the UK, this researcher has experienced first hand the effect that unexpected interactions have on pedestrian flow when forgetting to walk on the correct side of the pavement – is this a factor that noticeably affects the evacuation time for groups of multinational passengers in emergencies at sea? According to Jewkes and Aloisi (2012) [115], the Costa Concordia, at the time of the disaster, had 38 different crew nationalities onboard, and two thirds were there to entertain and take care of passengers, heavily outnumbering the number of qualified seafarers onboard. Oldenburg et al. (2009) [116] indicates that 80% of the world's shipping fleet is manned with multinational crews and reports show that casualties occur more frequently on ships with mixed crews than not. Given the international nature of passenger ships, this is an additional question that may require further investigation.

2.3 Regulatory Environment

Ships sailing international waters are bound by the regulations provided by the International Maritime Organization (IMO). These regulations are then adopted by IMO's member countries and enforced accordingly under each administration. The IMO has no responsibility for enforcing or policing the regulations set out in its various treaties. Furthermore, ships sailing in domestic or inland waterways are not bound by IMO regulations; but rather those set forth and enforced by the country in question. The various conventions and instruments of the IMO are continually being updated in response to ship accidents and resulting investigation reports, but also as new technologies and datasets become available. Thus, the IMO also plays a role in driving the international research agenda in merchant shipping.

2.3.1 SOLAS

As previously noted, SOLAS is generally regarded as the most important international treaty concerned with the safety of merchant ships [8]. The convention in force today (held in 1974) has been updated and amended regularly and is generally referred to as "SOLAS 1974, as amended". SOLAS has the main objective of specifying *minimum* standards for ship equipment, construction and operation [8]. The Convention prescribes several certificates as proof that this has been done and control provisions allow contracting governments to inspect ships of other contracting states if there are grounds for believing a vessel does not comply substantially with the Convention requirements (known as port state control). SOLAS is divided into 14 Chapters, however, not all are relevant to the research presented here; a short summary of relevant chapters and regulations is provided below. Chapter I outlines general provisions and definitions, including SOLAS I/1, which states "Unless expressly provided otherwise, the present regulations apply only to ships engaged on international voyages". Of particular relevance here is SOLAS I/2, which defines the terms *passenger* and *passenger ship* as follows [19]:

(a) A *passenger* is every person other than:

(i) The master and the members of the crew or other persons employed or engaged in any capacity on board a ship on the business of that ship; and

(ii) A child under one year of age.

(b) A *passenger ship* is a ship which carries more than twelve passengers.

Given this somewhat simplistic definition, it is clear that regulations governing passenger ship safety need to be broad in scope in order to cover all manner of vessels carrying passengers - from river ferries and dinner cruise ships all the way to cruise ships like *MS Oasis of the Seas* with capacity for over 6,000 passengers. With this in mind, SOLAS I/3 provides some exceptions to the specifications in Regulations 1 and 2 that are relevant for the topic of passenger ships as discussed in this thesis [17][19]:

(a) The present regulations, unless expressly provided otherwise, do not apply to:

(i) Ships of war and troopships.

(ii) Ships not propelled by mechanical means.

(iii) Wooden ships of primitive build.

(iv) Pleasure yachts not engaged in trade.

The IMO provides a wide array of regulatory documents relevant for passenger ship safety, including; medical and sanitation (MSC/Circ.1129), ships with cabin balconies (MSC/Circ.1187), systems and services to remain operational for safe return to port and orderly evacuation and abandonment after a casualty (MSC/Circ.1214), recommendations for decision support system for Masters on PAX ships (A.796(19)), stability in damaged condition (SLS.14/Circ.356), guidelines for evaluation of fire risk of external areas on passenger ships (MSC.1/Circ.1274) and guidelines for evacuation analysis for new and existing passenger ships (MSC.1/Circ.1238) – a document which guides much of the research found herein. Its development is outlined in the following paragraphs and important details contained within, throughout the remainder of this section.

2.3.2 MSC/Circ.909 – Interim Guidelines for a Simplified Evacuation Analysis of RO-RO Passenger Ships

At the 71st session of the IMO's Maritime Safety Committee (MSC) in May 1999, it was noted that SOLAS II-2/28-1.3 requires RO-RO passenger ships built after 1 July 1999 to undergo an evacuation analysis as part of the design process. MSC noted that since computer-based evacuation simulation was still under development, a simplified evacuation analysis method was required and thus approved IMO MSC/Circ.909 – Interim Guidelines for a Simplified Evacuation Analysis of RO-RO Passenger Ships. The stated purpose of the IMO MSC/Circ.909 guidelines was to provide information on how to execute a *simplified* evacuation analysis for a ship at the design stage and use analysis results to:

1. Identify and eliminate as far as practicable the congestion that may develop during a ship abandonment due to the normal movement of passengers and crew along escape routes, accounting for the possibility that crew may need to move along the same routes in the opposite direction as passengers; and
2. Demonstrate that planned escape routes are sufficiently flexible to provide for the chance that certain routes, assembly and embarkation stations, or life saving appliances (LSAs) might not be available due to the causal incident.

This simplified analysis method is based on a macro model adapted from methods developed for simulating building evacuations [40]. The simplified method uses passenger awareness time in responding to an incident, travel time to reach assembly and LSA embarkation stations and the LSA boarding and launching time in order to compute the overall evacuation time. To meet the requirement, the total evacuation time for RO-RO passenger vessels must be not more than 60 minutes if the vessel has up to 3 main vertical fire zones and 80 minutes if it has more than 3.

2.3.3 MSC/Circ.1033 – Interim Guidelines for Evacuation Analyses for New and Existing Passenger Ships

At its 75th session held 15-24 May 2002, MSC offered the possibility of performing an evacuation analysis by two distinct methods – either a simplified or an advanced method. For the first time, computer-based evacuation analysis of passenger ships was permitted, through MSC/Circ.1033 [117]. The advanced method for performing an evacuation analysis of a ship requires that the assembly stations and escape routes be identified in the general arrangement drawings used and that the evacuation time estimate be based on four idealised benchmark scenarios:

- Case 1: Night case
- Case 2: Day case
- Case 3: Night case with reduced evacuation route availability
- Case 4: Day case with reduced evacuation route availability

Additional scenarios thought to be relevant may be considered as appropriate but are not required by the Circular.

The process of evacuation from passenger ships is naturally very complex, as identified in the previous section. Thus, performing an evacuation analysis of a given vessel design is not meant to encompass all manner of evacuation scenarios that a ship may encounter in an emergency. The Circular outlines some important assumptions that must be made about the vessel, the passenger population and the benchmark scenarios [117]:

- passengers and crew should be represented as individuals, each with specified abilities and response times
- unless otherwise stated, planned escape routes (per SOLAS II-2/13) should be fully available and passengers and crew should make use of these routes when evacuating
- passenger load and initial distribution should be based on the IMO Fire Safety Systems (FSS Code), Chapter 13 [118]
- a safety factor of 1.25 should be used in the calculation to account for assumptions made, model omissions and the limited nature of the benchmark scenarios, specifically:
    - crew will immediately be at their evacuation duty stations to assist
    - passengers will follow the directions of crew and signage (i.e. route selection is not predicted by the model)
    - smoke, heat and toxic fire products present do not affect the performance of passengers or crew

- the model does not consider the effect of vessel motions, heel or trim on passengers, nor does it consider family group behaviour

Two main performance standards are presented in the Circular. The first relates to overall evacuation time, which is presented graphically in Figure 8 and by Equations (3) and (4):

$$1.25\,T + {}^{2}/_{3}\,(E + L) \leq n \qquad (3)$$

and

$$(E + L) \leq 30\;min \qquad (4)$$

Where:

T = travel time (as defined in the Circular Annex) which is a random quantity due to the probabilistic nature of the evacuation process

E = embarkation time (life saving appliance boarding) time

L = life saving appliance launching time

n = maximum allowable evacuation time; for RO-RO passenger vessels, equivalent to 60min and for passenger vessel other than RO-RO, equivalent to 60min for ships with no more than three main vertical fire zones and 80min for ships with more than three main vertical fire zones.

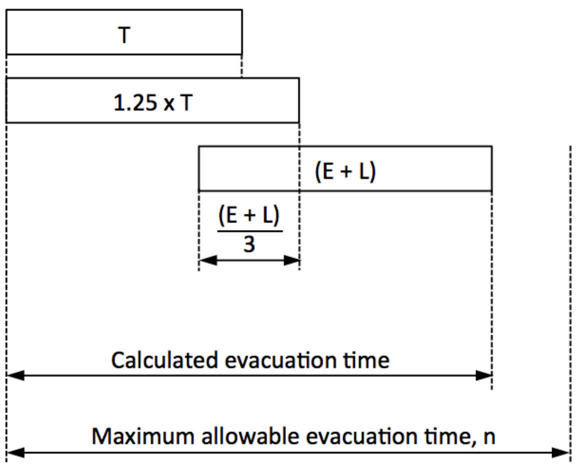


Figure 8 Depiction of the time-related performance standard set-out in IMO MSC/Circ.909, MSC/Circ.1033 andMSC.1/Circ.1238.

It should be noted that Equation (3) deals with the process of LSA embarkation and launching, which is not the focus of this dissertation. However it is still important to consider this when understanding the entire ship evacuation process. The Circular indicates that the quantity (E + L) should be based on either the results of full-scale trials on similar types of ships and evacuation systems; from data provided by manufacturers (including a safety factor); or (if neither of these two options is available, 30 minutes should be used). These requirements are in compliance with SOLAS III/21.1.4.

In the overall performance standard presented in Equation 1 and depicted in Figure 8, it is understood that the process of embarkation into life saving appliances may begin before all passengers have been assembled, hence the reason why only 2/3 of the total (E + L) is factored into the overall evacuation time. While it is likely that the proportion 2/3 was arbitrarily chosen, in the absence of published data, it at least accounts for realistic expectation of what is likely procedure in an emergency – boarding and launching LSAs when ready rather than starting the process only after all onboard have been assembled.

SOLAS III/21.1.3 states "All survival craft required to provide for abandonment by the total number of persons on board shall be capable of being launched with their full complement of persons and equipment within a period of 30 minutes from the time the abandon ship signal is given after all persons have been assembled, with lifejackets donned". Further, the IMO Life-Saving Appliance (LSA) Code 4.4.3.1 states that "Every passenger ship lifeboat shall be so arranged that it can be boarded by its full complement of persons in not more than 10 minutes from the time the instruction to board is given." If we think about what this means for a moment, it is somewhat alarming and obvious that this standard was created when lifeboats were smaller in size and rated capacity. With most large cruise ships now carrying lifeboats that are at least 150 person capacity, this provides 4 seconds on average for each person to board and become seated inside; the same goal must be met for all lifeboat designs. The LSA Code specifies that no lifeboat shall be approved to accommodate more than 150 persons, however exemptions can be made - the lifeboats on the world's largest cruise ship, *Oasis of the Seas*, are rated to carry 370 persons each [119] which means, on average, each passenger has 1.6 seconds to board and become seated if the requirement is to be met. Clearly, the lifeboat design must allow passengers to board through more than one entrance and in multiple queues. While this requirement may seem impossible to meet, it is important to also understand that these craft must undergo a wide range of certification tests, which are witnessed by a recognised certifying authority and, thus, must meet the prescribed regulation before being approve for use. How quickly the lifeboats can be boarded in practice during a *real* emergency under varying conditions is not currently known. It is also worth considering the potential impact of research published by the author [120], the rated capacity of a vessel does not always mean the craft will have enough space to fit them all. How this likelihood would affect the overall evacuation process is unknown.

Given what the regulations allow regarding evacuation time, we should also consider whether passengers should be more thoroughly trained onboard so they know what to expect if required to perform an emergency evacuation. It is suggested by the Royal Institution of Naval Architects [121] that "a little training could go a long way and the fact that cruise passengers have little in the way of lifeboat training is a shocking revelation in a world where other modes of transportation, most notably the airline industry, take a far more proactive role in reinforcing safety procedures for passengers." Given what is at stake, perhaps legislative and international regulatory requirements should be considered "a floor and not a ceiling", however, from personal discussions with crew members on a variety of ships, there appears to be skepticism that this will happen any time soon as there is potentially a significant cost difference between the two.

The second performance standard in MSC/Circ.1033 [117] relates to overall congestion on the vessel during the assembly process. It specifies that congestion levels of 4 persons/m^2 or greater may be significant to the overall assembly process on a passenger ship. It is further identified that if congestion at this level or greater is found to persist for longer than 10% of the simulated overall assembly time, then it should be considered significant.

For vessels that do not meet the required performance standards, the Circular offers corrective actions, depending on whether the vessel exists or is still at the design stage:

- Vessels at the design stage: modify arrangements that affect the evacuation system in order to meet the required performance and re-test.
- Existing vessels: review onboard procedures and take appropriate action to reduce congestion in key problem areas identified in the analysis.

Given that the software for performing advanced evacuation analysis is not prescribed, Annex 3 of MSC/Circ.1033 [117] also provided guidance on the different validation and verification tests that software should demonstrate a capability to perform. Four forms of model *verification* are provided for which evacuation models should undergo (a procedure that is also highlighted in ISO document ISO/TR 13387-8:199 – Part 8: Life Safety - Occupant Behaviour, Location and Condition). These are: Component Verification (Table 3) to demonstrate that the software components perform as intended (seven different tests); Functional Verification (Table 4) to demonstrate the software has the different capabilities and functions required to perform a ship evacuation analysis; Qualitative Verification (Table 5) to demonstrate *qualitatively* that behaviour capabilities built-in to the software are capable of producing realistic results (five different tests); and Quantitative Verification (Table 6) to show that software predictions compare well with data from evacuation demonstrations. No formal means of software validation is provided.

Table 3 Evacuation model verification guidance for category 1 - component testing, as provided by IMO MSC.1/Circ.1238.

1. Component Verification		
Determine that software components perform as intended for different elementary test scenarios and to ensure the major sub-components function properly, through 7 tests:		
Required Tests	*a. Maintain set walking speed in a corridor*	One person in a corridor 2m wide and 40m long walking at 1m/s should cover the distance in 40s
	b. Maintain set walking speed up a staircase	One person on a stair 2m wide with a 10m length measured on the incline walking at 1m/s should cover the distance in 10s
	c. Maintain set walking speed down a staircase	As in (b) but with the person moving downward
	d. Exit flow rate	100 persons exiting a room 8m x 5m with a 1m exit at the midpoint of the 5m wall should not exceed a flow rate of 1.33 persons per second over the entire period
	e. Response time	10 persons in a room as described in (d) with response times uniformly distributed over the range 10s to 100s all start moving at the appropriate time
	f. Rounding corners	For a 2m wide L-shaped corridor 10m x 10m, 20 persons approaching the corner will successfully navigate the corner without penetrating the boundaries
	g. Population demographics parameters	Generate a group of 50 males 30-50 years old with walking speeds as specified in the circular and demonstrate that the distributed walking speeds are consistent with those in the circular.

Table 4 Evacuation model verification guidance for category 2 – functional verification, as provided by IMO MSC.1/Circ.1238.

2. Functional Verification
Determine that software can exhibit different capabilities required to perform intended simulations. Developers comprehensively set-out the range of model capabilities and assumptions and provide a guide for their correct use. This is task specific and must accompany the software in the form of technical documentation.

Table 5 Evacuation model verification guidance for category 3 – qualitative verification, as provided by IMO MSC.1/Circ.1238.

3. Qualitative Verification		
Determine qualitatively that behavioural capabilities built into the model can produce realistic behaviours. Five different tests are outlined for the verification process.		
Required Tests	***a. Counter-flow – two rooms connected via a corridor***	Create two rooms 10m x 10m joined by a corridor. Generate a population of 100 occupants having instant response times. Step 1: randomly locate all occupants in one room at the maximum density possible and run the simulation so that all occupants move from one room to the other, recording the time that the last person enters. Step 2: repeat with an additional 10, 50 and 100 persons in the opposite room with identical characteristics. Run the simulation so that when people move, a counter-flow situation is created. The resulting recorded time for the last person entering should increase as the number of persons in the counter-flow increases.
	b. Exit Flow – crowd dissipation from a large public room	Create a room 20m x 30m with two doors on each 30m wall. Randomly distribute 1,000 males with instant response time and distributed walking speeds. Step 1: run the simulation with all 4 doors open and record the time when the last person leaves the room. Step 2: close two doors (on the same wall) and re-run the simulation, recording the time when the last person leaves the room. The time to empty the room from Step 1 to Step 2 should approximately double.
	c. Exit route allocation	Create a section of a ship measuring 18m x 10.9m containing a central corridor adjoined by 12 cabins. The cabin area should be populated with 23 males with instant response times. Persons in cabins 1, 2, 3, 4, 7, 8, 9 and 10 should be allocated the main exit and the remainder to the secondary. The expected result is that the passengers move through their allocated exits.
	d. Staircase	Create a room 8m x 5m with a 12m long corridor 2m wide connected to the centre of the 8m wall. The corridor has stairs in the upward direction at the opposite end. Populate the room with 150 males with instant response times. The result should be congestion at the exit with steady corridor flow and congestion at the base of the stairs.

Table 6 Evacuation model verification guidance for category 4 – quantitative verification, as provided by IMO MSC.1/Circ.1238.

4. Quantitative Verification
Determining if model predictions compare well numerically with reliable data generated from evacuation demonstrations.

2.3.4 MSC.1/Circ.1238 – Guidelines for Evacuation Analysis for New and Existing Passenger Ships

The MSC, at its 83rd session on 3012 October, 2007 adopted updates to MSC/Circ.1033 mainly to include more realistic response time distributions for the day and the night cases within the advanced simulation method. The distributions take a lognormal form, rather than the uniform random distribution used in MSC/Circ.1033, and were based on research results from the FIRE EXIT [103] project led by UoG and involving the author, prior to the present research. The updated Circular became MSC.1/Circ.1238 and while it and its predecessors are only provided as *guidelines* within the regulations, it is the responsibility of individual IMO member governments to decide whether to incorporate all or part of the guidelines into their national legislation or merely leave them as guidelines. Current activity at the IMO is recommending that these move from being guidelines to requirements.

While MSC.1/Circ.1238 goes a long way to enabling an understanding of the evacuation performance of passenger ships, there are still significant gaps that must be addressed. For this reason, Paragraph 9.1 of the circular requests that member governments provide "…information and data resulting from research and development activities, full-scale tests and findings on human behaviour, which may be relevant for the necessary future upgrading of the present Guidelines". In lieu of such data, the circular makes some assumptions which, it is hoped, are covered by the safety factor = 1.25 described above:

- crew and passengers do what they are supposed to do in an emergency;
- passengers are not intoxicated;
- passengers are ambulatory;
- passenger mobility is not adversely affected by vessel motions;
- all LSAs are fully available and functioning properly;

- passenger response to alarms is well-represented by the lognormal distributions provided for day and night cases and for all ship types; and
- evacuation models predict results that are realistic and reliable (i.e. are validated).

It is not known if 1.25 is an adequate safety factor to account for the gaps identified, since research has not been carried-out to adequately address any of the above points. However, the research in this dissertation attempts to provide answers for the final two points in the above list by providing answers to research questions 2, 3 and 4 from Section 1.3:

2. Can we collect representative and detailed response time data for passengers responding to alarms on passenger ships?
3. How do we objectively determine the degree of agreement between ship evacuation model predictions and experimental data?
4. Can we collect a dataset for use in validating ship evacuation models?

The circular also provides the following important clarification in Paragraph 18 of Annex 3 which identifies the gap regarding *quantitative* verification/validation of evacuation models:

> *At this stage of development there is insufficient reliable experimental data to allow a thorough quantitative verification of egress models. Until such data becomes available the first three components of the verification process are considered sufficient.*

This is an important statement which has guided much of the work presented in this dissertation.

2.4 Measuring Human Performance During Evacuation

Characterising human performance in evacuation studies is a complex task that requires a range of data collection methodologies, depending on the activity being assessed and the purpose of the assessment – basic research, simulation development or simulation validation. Kuligowski and Milke (2005) [122] note that no standardised dataset has been specified for use in evacuation models – it is the model developer's choice as to which dataset to use or which to blend together as a single reference on human behaviour and performance. For the work carried-out in this thesis, it was necessary to measure passenger response time, assembly routes and associated times in the many different locations throughout the ships where passengers would be normally located. Research has been carried-out in the built environment to characterise human performance for more than four decades so a review of data collection methods from this sector are given first.

2.4.1 Measuring Evacuation Performance in the Land-Based Environment

Bandini et al. (2007) [123] provide a qualitative evaluation of technologies and techniques that can be used for data collection involving crowds of people and indicates that data collection and assessment represents a critical issue for pedestrian dynamics. They offer five different means for acquisition of crowd data:

1. ***Direct Observation/Investigation*** – by the observer being physically present or through analysis of video after-the-fact. This method relies on the observer's experience and can be used to determine numbers of people, flow dynamics and data that technology cannot detect such as emotional state. Analysis of video after-the-fact would be useful for the research planned in this dissertation, since direct observation during the trial would be too unreliable and lack repeatability.
2. ***Scene Analysis*** – used when people cannot be tracked individually and includes use of video or photos, as well as image processing techniques. In low densities, these methods can be automated and often enable estimation of the number of people, densities, flow rates and evacuation times.
3. ***Proximity Sensing*** – technologies that use sensors to detect passage of people at known locations (usually restricted, small spaces). Typically these techniques cannot be used to determine individual or crowd speeds or crowd densities but are good at counting people in controlled situations. For the research planned, these methods would not be possible, since sensors would have an impact on the behaviour of passengers and potentially restrict or slow their movement.
4. ***Continuous localization Systems*** – provide continuous positioning information indoors and outdoors (e.g. GPS). These methods can be used to track individuals and crowds precisely, including speed and density of crowds, and flow rates.

However, for testing within metallic structures like ships, these types of systems would not provide reliable measures, even if they worked at all.

5. ***Sensor Networks*** – often hybrid solutions of multiple systems, sensor networks can provide continuous localization information. These are suitable for indoor and outdoor situations and have potential for use in pedestrian dynamics applications but had not been used at the time of the publication. Bandini et al. [123] also indicate that this could include integration of RFID and wireless networks, which may be useful for the research planned in this dissertation.

Sharma and Gifford (2005) [124] installed RFID antennae in the ceiling above two exits from a classroom at the University of Michigan and monitored 5 participants as they exited the room, comparing the actual exit time with the RFID measured exit time. RFID tags were mounted to 0.25” foam backing and attached to participants’ shirts. For the four tests conducted, participants’ exit time was recorded and compared with the actual. The authors measured an 80% read rate for the first two trials and 100% for the last two. They did not provide a comparison between the actual and RFID-measured exit times, however, it was concluded that RFID could be an effective tool for monitoring individuals exiting a room during an evacuation trial, since they were able to determine which exit was used and who exited. In their paper, they outline some of the issues described by other authors attempting to use RFID for human tracking, in particular that the human body (because of its high water content) tends to absorb the system’s radio signals in an unpredictable way, thus reducing the reliability of the overall system in counting and locating tagged individuals. They did recommend that future testing should be done with larger groups of participants and over a larger area, however, following an extensive search of the literature, reference to this work could not be found. While the results of this study suggest that RFID may be useful in measuring movement of people in planned evacuation trials, the population size used does not give confidence in the reliability of the results. Furthermore, the authors instrumented only two exits, which does not provide enough information to assess whether an RFID system could be effective in a more complex structure for tracking people.

Hostikka et al. (2007) [93][94][95] performed three evacuation studies in Finland – in a public library, office building and a large shopping centre while monitoring people with surveillance cameras and RFID technology. The RFID system used passive tags attached to plastic badges and it was found that at least a 50% tag read rate could be expected if proper alignment and measurement of power for tag readers was carried out before the trials. For the trials in the library, they found that the RFID system performed poorly, capturing fewer than 50% of evacuees as they exited (when compared with video surveillance). For the office building, the successful read rate was much better, ranging from 81.3% to 95.0% over four tests that the tags delivered to participants were read at least once. The overall read rate, however, considering all read points was closer to 60% and only 17% of the tags were read successfully at *all* points. Hostikka et al. concluded that "Video cameras are the primary measurement technique in evacuation tests." In addition to flow rates through doorways, video cameras were used to successfully capture occupant response time in some of these experiments.

Hostikka et al. [93][94][95] further discuss the feasibility of using pre-existing closed circuit television (CCTV) camera systems for evacuation experiments. They identified that while CCTV video is typically lower quality than dedicated digital video cameras used in their experiment, it is generally of sufficient quality to determine evacuation behaviour in buildings. The authors also noted that CCTV systems operate typically at a lower frame capture rate than digital video, which means that the accuracy can be lower, however in crowded evacuation situations with typically lower walking speeds, this is not a problem. It is worth considering the use of CCTV systems for the research presented in this dissertation, if pre-installed on the ships tested and if the pre-determined set of views is acceptable for the requirements of the research.

2.4.2 Measuring Evacuation Performance in the Maritime Environment

It is reasonable to expect that measurement of the evacuation behaviour of people in ship evacuation situations can generally be accomplished using techniques that are useful in buildings. However, the use of specific technologies can be impacted by the fact that modern ships are metallic structures that may interfere with certain measurement systems. In addition, from a logistics point of view, planning and executing ship human behaviour studies on ships can be more complicated than for buildings by the fact that ships move but buildings do not.

The work of Bandini et al. (2007) [123] presents a useful categorization of data collection methods for pedestrian dynamics. However, since the time of publication, different systems have been developed to utilise sensor networks onboard ships for tracking peoples' locations and movement (e.g. to find a family member) and also for muster checking during emergencies [125]. These technologies have not been used for pedestrian evacuation dynamics studies and permanently installed systems were not available for the research presented in this dissertation. More recently, the Monalisa Project [126] presented a pilot application of an indoor positioning system for people. The system was implemented and installed on cruise ship *Ruby Princess* (3084 passenger and 1200 crew capacity) and uses RFID readers installed permanently throughout the ship, with passengers expected to carry a smart card tag. The project experienced some calibration problems in the early stages but these were adjusted and the proponents indicate it has been a success. While not explicitly stated in [126], it should be understood that these systems do not provide any data if passengers do not actually carry a smart card tag.

Vanem and Ellis (2010) [127] carried-out a thorough analysis of the cost-effectiveness for using an RFID-based monitoring system to improving evacuation from passenger ships. Their work was part of the MarNIS project funded by the EU through its 6th Framework Programme and considered the main functions that a monitoring system should have (in order of importance):

- Automated counting of passengers at the assembly stations;
- Automated counting of passengers at embarkation of lifeboats and LSAs;
- Identifying passengers with special needs in an emergency evacuation;
- Assisting with the crew procedure of "sweeping" the ship to ensure no passengers are left behind;
- Enabling decision support during an event by recommending routes that avoid congestion; and
- Ensuring that all crew are in place to assist with the evacuation process.

While the authors concluded that such a system could help ensure an effective emergency evacuation, at the time of publishing, it was not found to be cost-effective. Vanem and Ellis, however, suggest that perhaps a system with reduced functionality, positioned only at assembly stations would prove cost-effective. In addition, if the system were also capable of providing other benefits such as improving boarding procedures, for making payments in onboard bars and shops or for tracking luggage and inventory, a vessel-wide tracking system may meet cost effectiveness criteria and also reduce risk to life at sea.

More recently, different technologies have been developed that employ a range of sensors to track equipment and different assets, which are thought to also have the capability to track people on ships. In particular, Ubisense [128], Ekahau [129] were noted by Sharma and Gifford (2005), however these systems are not considered appropriate for temporary data collection trials in the shipboard environment as they tend to offer enterprise level solutions for large-scale industry and would likely be cost prohibitive and logistically challenging to install and operate for a research application. There is also the Cricket system [130][131], which uses devices positioned at known locations within a structure that emit periodic ultrasonic "chirps" that are heard by listening devices attached to a person or asset of interest. The cricket system can measure the position of the listener to within 10cm of its actual location, however, this accuracy is adversely affected by the presence of obstacles and the authors suggest that system scalability and ease of deployment would make this technology impractical in a complex environment such as a passenger ship where the number and density of users may be high.

The MEPdesign project made use of RFID technology for determining when passengers arrived at assembly stations during a large-scale sea exercise on the *MF Kronprins Frederik* sailing on the Baltic Sea. A total of 592 passengers participated in an assembly exercise which was monitored using RFID technology [132]. The exercise was undertaken in an effort to determine if group behaviour information could be accurately modelled using the EVAC building simulation model. While the RFID system performed well (585 reads out of the total 592 involved), the authors felt that the full-scale exercise was too artificial to be considered a useful validation of the modelling. It did, however, demonstrate that RFID technology may provide a viable method for tracking passenger movement during an assembly onboard a passenger ship.

2.4.3 The Suggested Way Forward

Based on what is provided in the literature, video cameras should offer the best option for determining passenger response time on ships, since they are relatively inexpensive, reliable, enable a wide range of mounting options, are easy to operate and provide a record that can be reviewed many times if required.

In addition, the literature suggests that RFID technology offers the best solution for automatically tracking the movement of passengers in order to develop a validation dataset. Despite some known challenges in reliability of read rates for RFID, the literature indicates that a read rate of at least 50% can be expected.

2.5 Validation Data for Ship Evacuation Models

Multiple attempts have been made by researchers since the late 1990s to collect data suitable for validation of ship evacuation models, however a validation method has not yet been put forward that has been accepted by the evacuation modelling and regulatory communities. The research that has been carried-out is described in this section with a discussion of any weaknesses observed for each.

Yoshida et al. (2001) [133] carried-out a full-scale ferry evacuation trial in the port of Onahama, Japan in 1997, involving 356 students and teachers from a local high school, each of whom was given a unique identification number. To collect data, they used a total of 26 video cameras for identifying the different participant ID codes, along with a bar code reader at the assembly stations where each student scanned their code on arrival. The trial consisted of participant movement from the time of the alarm through to abandonment from the ship using liferafts and slides. Simulations were performed numerically and results for arrival time at assembly stations compared reasonably well with the experimental findings. Yoshida et al. did not provide a numerical means by which results could be compared and it can be seen from inspection that the numerical results tend to predict a greater number of passengers arriving in the early stages of the evacuation than was the case for the experiments conducted. No guidance was provided for future methods of evacuation model validation. In addition, while the experiment involved a relatively large number of participants, the value of the validation data is questioned due to the large number of young school-aged children in relation to adults.

The MEPdesign project [132][134][135] took place in Europe between 1998 and 2001 and investigated the mustering and evacuation of passengers. The project examined the *total performance requirement* for evacuation as stated in SOLAS (Annex 5, Resolution 4) that maximum evacuation time for RO-RO passenger ships with up to 3 main vertical zones should not exceed 60 minutes. This included the abandonment phase in which evacuation slides and chutes are used or lifeboats launched, but also the assembly phase that precedes it and for which human performance is an important part of the process. The authors suggest some very useful aspects of the human performance as being:

- Reaction to alarms;
- Walking speed under different conditions of ship rolling and list;
- Way-finding;
- Group binding;
- Noncompliance with instructions from crew; and possibly
- Panic.

Over 1200 passengers were interviewed or provided questionnaires on selected routes operating in the Baltic Sea over a 3 day period, which provided the project team with basic information on passengers' attitudes toward safety and emergencies, as well as group habits and behaviours onboard.

Full-scale evacuation trials were carried-out by Gwynne et al. in 2003 [43] onboard a 31m x 8m tour boat operating on the Thames River in London to collect validation data for the maritimeEXODUS ship evacuation model. A total of 111 participants were located throughout the two decks of the vessel and five different evacuation exercises were performed, using different exits for each trial. Using maritimeEXODUS, the authors simulated the trial conditions and compared the model results to the trial results. It was found that the model results differed by the trial results by only 6.6% on average, with numerous qualitative similarities between the two. The authors then modelled the vessel's planned evacuation procedure and found that it had potential to produce long evacuation times due to poor placement of lifejackets that passengers needed to collect and don. Using the model, they suggested modifications to the mustering procedures relating to lifejacket storage location that could significantly improve the expected evacuation time. This research demonstrates that evacuation models can be used to test the efficacy of evacuation procedures onboard passenger vessels. While the collected data was used to provide a measure of evacuation prediction performance for the maritimeEXODUS model, a detailed quantitative assessment was not made between the shape and magnitude of the measured and predicted assembly time curves. It must also be recognised that the research was carried-out on a relatively small boat in calm conditions so it is not known if the results are representative of larger ships in open waters.

Hostikka et al. (2007) [93] suggest that for performance based design to be considered reliable, simulation tools used must be validated for the given type of application. They further indicate that for evacuation models, experimentally obtained information on human behaviour during evacuation situations is needed; not just flow rates of the various evacuation routes, but details of the decision making processes of the evacuees. This is important for the research presented in this dissertation, since one of the stated goals is to develop a validation dataset for ship evacuation models.

2.6 Evacuation Models

2.6.1 Overview

An evacuation model is defined by Galea (2008) [136] as a computer-based software tool used to study the movement of people from a structure under emergency conditions. Lee et al. [104] state that an evacuation model is: "…a system or methodology that simulates and evaluates the effect of evacuation factors" and because the evacuation process depends largely on evacuee behaviour, various evacuation factors can have a significant effect on the outcome of each simulation. Evacuation models allow researchers, fire safety engineers and architects to determine the evacuation efficiency of a structure and, therefore, help assess its safety for evacuation situations.

The alternatives to evacuation modelling are either adherence to traditional building codes or full-scale evacuation test [136]. The former tends to be restrictive, incapable of producing an optimal evacuation design solution and provides no rational means for novel designs; while the latter can be expensive and logistically challenging to organise, represents a risk to the population used and only produces a single point on the distribution of likely evacuation times.

Evacuation models can be broadly divided into two groups – those that are available for people to use (either for free or by purchasing a user license); and those that are used by developers through consultancy in which modelling results are provided to the end user. In their 1999 review of evacuation models, Gwynne et al. [137] suggested four categories under which evacuation factors for simulation and modelling are defined:

1. Enclosure configuration: essentially geography of the structure, including exits (arrangements and geometry).
2. Procedures implemented in the structure: includes configuration knowledge of the occupants, staff/crew training and activities and familiarity of individuals with exit locations.
3. Environment in the structure: heat, humidity, toxins, smoke and any other environmental factors that may impact an occupant's ability to navigate and make decisions.
4. Behaviour of occupants: all influences, incorporating group, social affiliation, adoption of specific roles, response to the emergency, travel speeds, ability of an individual to carry-out required actions.

More recently Kuligowski et al. [138], in their 2010 review paper, discussed evacuation modelling generally within the context of the four categories and identified that modelling methods fall into one of three categories:

1. Movement models: these models move agents in a building without accounting for human behaviour. These types of models are useful for showing congestion or bottlenecks with the building being simulated.
2. Behavioural models: these models incorporate agents that perform actions, as well as movement toward a specified exit. Typically these models also incorporate decision-making by the agent and/or actions performed because of conditions in the building.
3. Partial behavioural models: these models calculate agent movements begin to simulate their behaviour such as response time, overtaking, smoke or smoke effects. The difference with this type of model and type 2 lies in the fact that decision-making is not explicitly modelled.

A structure being examined is treated either as a discretised region or a continuous network. For discretised regions, the floor plan is divided into either a grid pattern on which only one person can occupy one node at any point in time and people move from node to node at each point in time, or a series of rooms and corridors in which people move from space to space. For continuous regions, occupants are not tied to a series of discrete regions (cells or spaces) but rather move from one point to another according to rules limiting the distance between people, and walking speeds [137][138]. Evacuation models tend to provide either a global view of occupants (the model tracks group densities and mean group walking speeds at given times and locations) or an individual view (the model tracks all individual occupants as they move throughout the structure). The individual view of occupants clearly provides much more detail for the user. Occupants' knowledge of the structure can be modelled in a similar way, in which individuals have either a global knowledge of the structure (people know the best and fastest route to the exits from any location in the structure) or individual knowledge (people decide which route to choose depending on the environmental conditions and choices presented to them). Both forms of individual perspective presented here provide greater levels of detail for the user but are more computationally intensive [137][138].

The behaviour of occupants in evacuation models can be categorised in one of five ways according to [137][138]; no behaviour (only movement is simulated); implicit behaviour (behaviour is simulated implicitly by giving individuals characteristics that affect their movement throughout the simulation, such as response time); conditional behaviour (actions are assigned to individuals or groups based on local conditions as *if-then* rules); artificial intelligence (attempting to simulate human intelligence); and probabilistic (for conditional models, this method assigns probabilities to the rules so that variability in predictions can produced in repeat simulations).

The environment in the structure (fire, heat, toxins, smoke, motion) is represented in evacuation models in different ways. Some models include sub-models that simulate the required environment, while others enable the import of environment data from other sources so that it can be used in identified locations within the structure at required times in the simulation. The way in which the environment affects occupants within the model depends on the behaviour model used. It is worth noting that a wide range of behaviours can be modelled, such as responding to alarms, resolving conflicts, drive to evacuate, change speed or direction of movement, overtaking, exit selection and, if toxic agents are considered, crawling, staggering, incapacitation and death.

2.6.2 Building Evacuation Models

Researchers first began quantifying pedestrian dynamics and developing associated mathematical models for buildings in the 1960s. The work of Fruin [25], Predtetschenski and Milinski [26], and Peschl [27] identified pedestrian walking speed and crowd flow rates (including through doorways) as a function of density for level spaces and on stairs, which led to the development of early pedestrian movement models such as PEDROUTE [139][140]. Evacuation research in buildings is a relatively young field of study with one of the first papers in the field being published in 1982 by Stahl [141], which dealt with modelling the emergency egress of people from buildings during fire. At the time of Gwynne's model review paper in 1999 [137], a total of 22 building evacuation models were described – 16 that were available and 6 that were under development. Kuligowski's review paper in 2010 [138] discussed a total of 26 different building evacuation models - 17 currently available publicly, 6 available through consultancy and 3 under development, categorizing the different models according to their features.

Some examples of building evacuation models identified by [138][137] are:

- buildingEXODUS [137][142][143][144]
- STEPS [145][146][147][148][149][150][151][152][153][154][155]
- Simulex [156][157][158][159][160][161][162][163][164][165][166][167][168]
- FDS+Evac [93][169][170][171][172][173][174][175][176][177]
- Pathfinder 2009 [178][179]
- PedGo [180][181][182][183][184][185][186][187][188][189][190][191][192]
- Legion [193][194][195]
- MassMotion [196][197]

The website "Evacmod.net" [198] provides a regularly updated information and discussion forum for the evacuation modelling community, purporting itself as a website that is "…made by the evacuation modelling community **<u>for</u>** the evacuation modelling community". The site lists a total of 64 different evacuation models and 3 lift/elevator models. Some of the models listed are no longer available and some are relevant for the transportation sector, namely maritime, air and rail.

Kuligowsi et al. (2010) also notes which building evacuation models have been validated and the method of comparison: codes, drills/experiments, literature or past experiments, other models or third party. In all, Kuligowski states that 24 out of 26 models have undergone at least some form of validation and in most cases (17 out of 24), models have been validated by two or more of the methods listed above.

2.6.3 Ship Evacuation Models

While evacuation models have existed for the built environment for about three decades, models that simulate evacuation from passenger ships are relatively new and seem to have grown, largely, in response to the evacuation simulation requirements at the IMO. Models are based on a range of governing principles that are generally the same as for the building evacuation models (e.g. discretised grids representing the decks with agents following cellular automata rules or continuous movement towards a target with the deck represented as topological graph) with algorithms run within a Monte Carlo framework to allow for representation of the stochastic nature of the evacuation process. At the time of publishing in 2003, Lee [104] indicated that although evacuation modelling was widely used for design of buildings, ship evacuation modelling was only just beginning to be studied extensively because of difficulties in collecting appropriate data for shipboard environments. Lee's paper provides an excellent overview of the state-of-the-art in ship evacuation modelling at the time of publishing and which states that effective ship evacuation analysis needs to account for; (1) the geometric model of the ship, (2) the evacuation algorithm, (3), the effects of the ship's motion and listing and (4) the behaviour of the passengers. These are, in essence, the same four categories presented by Gwynne et al. [137] and are common among evacuation models for the built environment, with the obvious exception being point (3). Gwynne et al.'s factor (environment in the structure) does not cover motion effects in buildings but in terms of the impact modelling outcomes, the description "…environmental factors that may impact an occupant's ability to navigate and make decisions" still fits. The sections that follow provide an overview of current ship evacuation models, identifying any shortcomings and making comparisons where relevant.

2.6.3.1 IMEX (Intelligent Model for EXtrication simulation)

IMEX [199] was designed to simulate evacuation from large structures, including passenger ships. It models an individual's attributes, evaluates evacuation time and procedures and includes a dynamic ship motion model. Although the authors present this model as being the most accurate ship evacuation model at the time, it does not appear to have undergone a meaningful validation process to confirm this claim and they caution that their technology is not yet mature. It is interesting to note that in their publication, Kim et al. (2004) [199] predict passenger movement based on a model they term "pynamics" – a combination of physics and dynamics, which calculates interactions between the physical environment, as well as walking speeds. Thus, a force-based pedestrian dynamics model and an intelligent human behaviour model use Newtonian equations to describe the physical and psychological factors of passenger movement. According to Wang et al. (2014) [200] this method suffers from known drawbacks (which are not explained) and it is not clear that how route choice behaviour is calculated in the simulation. One of the benefits of this model is that the impact of vessel motions is included in the movement model so that motion effects are calculated automatically.

2.6.3.2 SIMPEV

SIMPEV was recently developed for simulation of evacuation from passenger ships. Park et al. (2015) [201] provide an overview of their model, which uses a velocity-based algorithm with walking direction grid and flocking, as well as leader-follow and counterflow-avoidance algorithms for modelling group behaviour. The paper by Park et al. [201] presents detailed results from a validation of the SIMPEV model using the validation datasets explained in Chapter 7 of this dissertation and as outlined in [202][203][204]. The SIMPEV model satisfied the validation requirements with all error ranges within those of other models that have undergone validation with these datasets.

2.6.3.3 CityFlow-M

This model, described by Wang et al. (2014) [200] is based on the pedestrian traffic simulation model "CityFlow" (with "-*M*" referring to the maritime evacuation version). It is produced by the City University of Hong Kong and is an agent-based microscopic pedestrian simulation model. In this model, the geometry is divided into zones, which are connected to one another to create a network structure for simulation. The model is implemented in two levels of behaviour – strategic and tactical at the macroscopic level and operational at the microscopic level. The macroscopic level deals mostly with long-term route selection and the microscopic level determines local movement of agents at each time step. As with the SIMPEV model, Wang et al. [200] present detailed results from validation of the CityFlow-M model using the validation datasets explained in Chapter 7 of this dissertation and as outlined in [202][203][204]. Wang indicates that CityFlow-M was in reasonable agreement with the validation dataset tested, however a full account of the validation results was not provided. The authors [200] indicate that the model is still under development and work will continue by optimising the approach to evacuation route assignment, as well as the addition of new parameters to account for human behaviour in response to vessel motions.

2.6.3.4 EVACUSHIP

Brumley presented this model in 2002 [205] as part of his Doctoral thesis. He indicated that, while onshore building evacuation theory had been adopted by the maritime sector for evacuation analysis of ships, there were many deficiencies in this approach. Brumley felt these deficiencies were due to fundamental differences between the psychological and physical state of individuals involved, as well as the means of logistical management of the shipboard and onshore cases. Brumley investigated the effect of safety knowledge on evacuation wayfinding behaviour and the influence of vessel motions (dynamic and quasi-static) on evacuee motor performance. Brumley's research culminated with the development of the early ship evacuation model "EVACUSHIP", which incorporated algorithms to model passenger wayfinding on ships and attempted to account for the effect of vessel motions. It is not known if this model was fully developed or if it is currently in use, however, it seems unlikely because there have been no published works regarding its development or use since 2003. For the same reason, it is unlikely that this model has been validated by any method.

2.6.3.5 Yuan et al. and Neighbourhood Particle Swarm Optimization Method

A new ship evacuation simulation model based on the *neighbourhood particle swarm optimization method* is described in [206], in which each passenger (agent) is represented as a particle and their behaviours updated by individual, neighbourhood and social attributes, along with environmental information such as the vessel layout and motions. The authors do not discuss whether other features (such as fire modelling) are available within their model. In the paper, the method was demonstrated using a room with a single door. Increasing the size of the door significantly reduced the total evacuation time for door sizes up to 4 m, but beyond this, door size had no effect on evacuation time. In addition, it was found that evacuation time was not impacted by small to medium angles of ship heel and trim (to about 15°), after which the heel angle had a significant impact on evacuation time. Yuan et al. (2014) [206] did not present results for simulations in complex structures typical of ship layouts but did discuss the results of IMO verification test 8 (Section 2.3.3), which gave promising results. At this time it is not certain whether the model has been advanced beyond this current state and it seems unlikely that validation has taken place.

2.6.3.6 VELOS (Virtual Environment for Life on Ships)

The VELOS model [207] is a recently developed software system based on agent modelling of ship evacuation that incorporates the use of virtual reality (VR) techniques to enable multiple users to become immersed in the evacuation process as avatars. It was suggested by Ginnis et al. (2010) [207] that this could include ship designers who are assessing a particular vessel arrangement and who may wish to view its evacuation performance “first-hand”, or trainers who may wish to test different evacuation methods without having to undertake full trials. The VELOS model is capable of importing data from external computation packages for environmental parameters such as sea-keeping and fire and the model is said to predict the behaviour of agents and agent groups (such as families). However, the authors do not specify exactly how this is done or what the behaviour model is based on.

The model is reported to be capable of performing the IMO passenger ship evacuation analysis requirements [21] for *both* the simple method and the advanced method, and three of the four required verification methods have been carried-out successfully [207] – component (presented in Table 3); functional (presented in Table 4); and qualitative (presented in Table 5). However, the fourth test – quantitative verification (presented in Table 6) could not be completed because at the time of publication for [207], the authors state that there was insufficient reliable experimental data to permit a thorough quantitative verification analysis of ship evacuation models.

2.6.3.7 EVi

EVi (EVacuation index) is an evacuation modelling software tool developed by Safety at Sea Ltd. (a member of the SAFEGUARD project team) in the UK which uses a continuous space modelling approach and consists of two main models – macroscopic and microscopic [33][34][35][36]. The *macroscopic* model predicts high-level activities such as getting from one location to another and the *microscopic* model makes predictions at the agent level and ensures agents avoid boundaries and each other according to pre-defined rules (containment, collision avoidance, lane formation and conflict resolution). According to [206], the focus for this model was to incorporate fire dynamics simulation results into evacuation modeling, however human behaviours were not sufficiently explored in the local movement model. EVi claims to be able to predict pedestrian movement in any environment and has been used model circulation and evacuation on ships, offshore installations and buildings [208].

The geometric model of the ship's layout is developed in a pre-builder called "EVE" and is developed from existing representations of the vessel such as CAD drawings and general arrangements. Agent distributions and evacuation plans are added to this model, and semantics, which relate to additional information agents receive from the environment such as signage can also be added. Environmental modelling details are provided by the user through a database and a graph topology is formed from shape definition linked with doors so that routes are formed through these spaces. These routes, when reviewed in the real world, are the path plans that the agents follow to get from the initial location to assembly stations.

Pennycott and Hifi present EVi model extensions in [209] that enable the simulation of flooding on passenger ships and its effect on evacuation, including passenger motion induced interruptions, handrail dependence, obstacles, debris and speed reduction factors based on heel angle. Their research demonstrates that flooding and the consequent events affect overall evacuation behaviour of passengers.

While not used by the author, EVi was part of the blind modelling test using the validation datasets explained in Chapter 7 of this dissertation and as outlined in [202][203][204] and was found to meet the validation requirements set forth.

2.6.3.8 ODIGO

ODIGO (which stands for "I guide" in ancient Greek), developed by the French company Principia, is a software tool that simulates crowd movement onboard ships [37][38]. It is an integrated tool, which includes a pre-processor, a simulation engine, and a post-processor. The model can represent public and cabin spaces on ships, as well as open decks and staircases. The ODIGO simulation engine uses a multi-agent method with cognitive/ reactive characteristics that can move anywhere in geometry, provided that they respect margin distances between each other and walls. The user defines features of agents and the starting positions for each are made using random allocation, as with the other models reviewed here. The agents act according to predefined objectives (e.g. go to assembly station, cabin, or lifeboat) and several objectives may be joined together. Although ODIGO is used mainly for evacuation simulation, it can also be used to simulate crowd movement in other non-emergency situations onboard, such as; embarkation /disembarkation, movement from theatres after a show onboard and queues in restaurants.

The ship geometry is generated using the ODIGO pre-processor with .dxf files that outline the vessel's general arrangement. As agents move, they must avoid the walls of the environment in a process called *containment*. As other agents are introduced, *collision avoidance* must be used to prevent people from running into each other and as the number of agents increases, lane formation is modelled. Individual agents can also be programmed with specific objectives, which allow the definition of crew procedures and specific passenger movements to be defined. According to Pradillon (2003 and 2004) [37][38], the effects of smoke, heel and trim can also be introduced into the environment, with agents responding accordingly.

While not used by the author, ODIGO was part of the blind modelling test using the validation datasets explained in Chapter 7 of this dissertation and as outlined in [202][203][204] and was found to meet the validation requirements set forth.

2.6.3.9 AENEAS

The AENEAS model [200][210][211][212] is an agent and grid based model which represents the ship's deck as uniformly distributed rectangular grids on which passengers can only move from one grid to another step-by-step according to a set of local cellular automata modeling rules. The user defines routes taken by agents and the model is reported by its developers Meyer-König et al. (2002) [210], Peterson et al. (2003) [211], and Meyer-König et al. (2005) [212] to be capable of simulating the effect of vessel motions on passengers as they move through the discretised structure. This is accomplished by applying a slope-based speed reduction factor to passenger walking speeds. As with other grid-based models (e.g. ODIGO and maritimeEXODUS), this method of modelling is very efficient in terms of computational effort, but how it represents reality is somewhat limited because of the rectangular discretization.

AENEAS is not capable of modelling the presence of smoke or fire and their influence on passenger evacuation behaviour. Meyer-König et al. (2002) [210] indicated that the model would be validated as part of the German-funded BYPASS project through a practical evacuation trial on a cruise ship. However, no published record of this activity could be found and it is assumed not to have happened.

2.6.3.10 maritimeEXODUS Model Overview

EXODUS [137][142][143][144] is a suite of software-based tools for simulating the movement of large numbers of people within complex built structures. EXODUS consists of three distinct models that are designed to enable demonstration of compliance of a design with codes and requirements relating to evacuation, training of staff members and aspects of accident investigation:

- airEXODUS: designed for applications in the aviation industry
- buildingEXODUS: designed for applications in the built environment, such as supermarkets, hospitals, cinemas, rail stations, airport terminals, high rise buildings and schools.
- maritimeEXODUS (mEX): designed for the maritime environment for vessels such as large cruise ships, roll on-roll off (RO-RO) ferries and fast catamaran ferries, mEX can also can be applied to the offshore oil and gas environment. mEX has a few distinguishing features compared with the other models in the EXODUS suite, namely the inclusion of heel and trim angles and their effect on people's movement, the need for adding life-saving appliances such as lifeboats, liferafts, slides and chutes, and the added step in the evacuation process of retrieving and donning lifejackets.

As the model used in the work presented in this thesis, a more detailed overview is provided of maritimeEXODUS, its components and some relevant features. This model takes into account the people-people, people-fire and people-structure interactions. The model computes the trajectory of individual passengers as they move through the discretised ship's structure to reach the assembly stations and then disembark, using either slides or chutes into liferafts, or directly into davit launched liferafts or lifeboats.

maritimeEXODUS (mEX) simulates behaviour and movement of individuals according to a set of heuristics that are categorized into five interacting sub-models (Figure 9) operating within a particular geometry. Enclosure geometry is defined either from a geometry library, constructed using the tools provided in the software, or by importing a computer aided drafting (CAD) drawing in the drawing interchange format (DXF). The *geometry* is covered by a mesh of individual nodes that are assigned a range of attributes to represent the environment being simulated, including free spaces, seats, stairs, and life saving appliances. Each node represents a region of space that can be occupied by a single person and nodes are connected to each other by a system of arcs that define how a passenger is able to move between nodes.

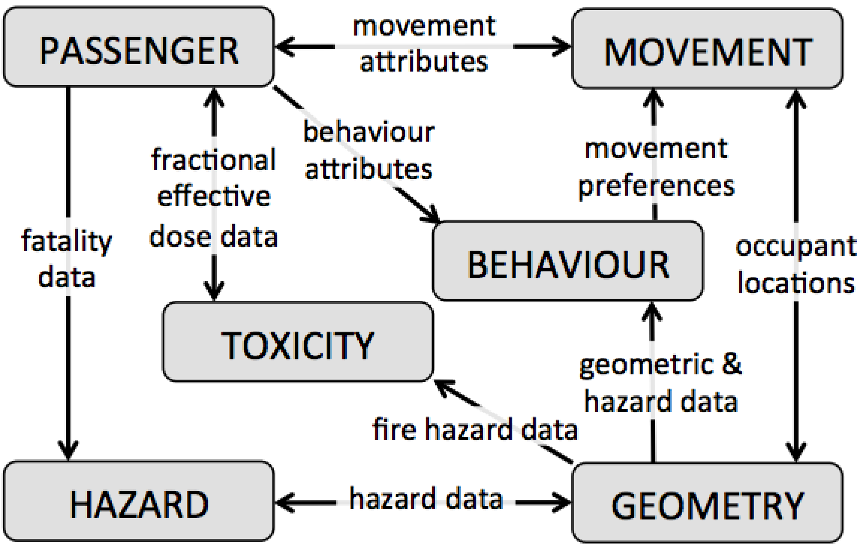


Figure 9 Interactions between the different maritimeEXODUS sub-models recreated from [213].

The *movement* sub-model controls physical movement of people in the simulation from their current position to the most suitable neighbouring position, or waiting if no suitable location exists. Movement may include behavioural aspects such as overtaking, sidestepping, or other evasive actions.

The *behaviour* sub-model controls a person's response to the current situation, depending on his/her personal attributes (from the *passenger* sub-model) and passes the decision to the movement sub-model. The behaviour sub-model operates on two levels: global and local. Global behaviour determines the individual's overall strategy while local behaviour determines response to a local situation.

The *passenger* sub-model describes the individual as a collection of fixed attributes (e.g. gender, age) and variables (e.g. walking speed, response time and agility) that may change throughout the simulation, depending on inputs from other sub-models.

The *hazard* sub-model controls the atmospheric and physical environment by distributing pre-determined fire hazards (e.g. heat, smoke, toxic products) and the opening/closing of exits and availability to life saving appliances (LSAs).

The *toxicity* sub-model determines how toxic products (controlled by the *hazard* sub-model) affect exposed individuals and communicates this to the *behaviour* sub-model, which in turn communicates to the *movement* sub-model controlling the individual's movement.

Unlike several of the other ship evacuation models presented in this section which claim to predict the impact of a vessel's dynamic motions on walking speeds of passengers, maritimeEXODUS is capable of simulating only the effect of a vessel's static heel and trim on passenger walking speeds, as it is felt that there is insufficient reliable data on which to base behavioural models.

mEX was part of the modelling test using the validation datasets explained in Chapter 7 of this dissertation and as outlined in [202][203][204] and was found to meet the validation requirements set forth.

2.7 Chapter Summary

Emergencies involving passenger ships are surprisingly common. The nature of the evacuation process on passenger ships is discussed and some recent relevant incidents have been presented at the beginning of this chapter to emphasise the importance of this research area. Evacuation modelling is a broad research area that must, by its nature, consider a wide range of parameters, such as the structure in which people are found (generally buildings and mass transport), the environment within that structure (e.g. motions, fire, smoke and toxins), as well as the movement and behaviour of the people within. Early evacuation models dealt with egress from buildings but, more recently, this has been extended to passenger ships and other modes of mass transport. Thus much of the research and experience gained from the building sector has provided a strong foundation from which to build ship evacuation models. In this chapter, where relevant, a discussion has been provided outlining what the literature offers regarding behaviour and modelling in the building environment before moving on to what has been studied that specifically relates to passenger ships.

Evacuation in the context of passenger ships refers to the processes of assembly and abandonment. This dissertation and the literature review presented was focussed on the assembly process alone, which consists of the response phase and the evacuation movement phase.

From the review presented, we see that many of the same concepts developed and studied in the built environment can be applied to passenger ships. In particular, the work of Purser and Bensilum was useful as it demonstrated that the distribution of response time for people in buildings took a lognormal shape for all cases examined, as did the work of Hostikka et al. in Finland. Kobes et al. produced an important result that is particularly relevant for his research - that response behaviour is a more important aspect of required safe evacuation time than the evacuation movement phase and that there is a direct relationship between a delayed evacuation response time and the likelihood of death or injury.

A description of the FIRE EXIT project has been provided and it was shown that this research produced the first response time datasets for passenger ships. It was also demonstrated that, despite shortcomings in the dataset, the response times collected were lognormally distributed and used to form updates to the IMO evacuation analysis guidelines. Attempts at collecting a validation dataset during FIRE EXIT were less than successful and this review has shown that validation data for ship evacuation models is still not available in the literature.

Research to collect data regarding passenger movement on ships has been discussed with results from numerous researchers provided, in varying degrees of reliability. Much of this research has been carried-out in mock-ups onshore and trials carried-out on ships have often used populations that are not representative of the general travelling public. More research is needed in this area, particularly to define movement of people in the expected range of motions that can be experienced on a ship at sea. This, however, is not a goal of the research presented in this dissertation.

The IMO regulations governing passenger ship safety and evacuation analysis are discussed in this chapter, including SOLAS and how it defines the term *passenger ship*, but a particular focus is placed on the development of the IMO evacuation analysis guidelines, starting from MSC/Circ.909 to the current MSC.1/Circ.1238 and outlining the performance standards required. It is explained that, while the latter circular represents an improvement over previous versions of the circular (particularly with respect to response time distributions), further data is required. This is because it is not known if the response time distributions used provide an adequate representation of behaviour on different ship *types*, if the representation of nighttime behaviour is accurate or if the distributions are representative for all ships of the *same* type. In addition, the circular identifies that ship evacuation models still require a suitable validation dataset. These gaps in the regulations form the basis for much of the work presented in this thesis and conducting research that helps fill these gaps will provide answers to the research questions posed in Section 1.3.

The literature provides some guidance on how to measure human performance during egress from buildings. This is discussed in this chapter and it is shown that many of the techniques developed for the built environment should also work onboard ships. The research by Hostikka et al. in Finland was particularly useful in demonstrating the benefits but also the shortcomings of RFID technology for tracking people in egress studies. It was concluded that this technology may offer a useful method of data acquisition in the research described in this dissertation. Hostikka's work also suggested the benefits and identified possible drawbacks of using pre-existing CCTV cameras for measuring human evacuation behaviour. In addition, the MEPdesign project carried-out in the early 2000s presented details for one of the first assembly exercises monitored using RFID technology and showed that the technology could be used successfully onboard ships to monitor assembly exercises.

Finally, this chapter examined general evacuation model characteristics and provided a brief overview of building evacuation models, followed by a more detailed discussion of ship evacuation models. We have seen that most ship evacuation models have been developed using building evacuation model techniques and concepts and that one of the main drivers of ship evacuation models has been the development of the IMO evacuation analysis guidelines. All ship evacuation models are designed to be able to undertake the required IMO analysis, however, the models differ in features provided (e.g. some models include vessel motions, some models include fire and smoke).

This review of literature has provided the rationale for work presented later in this thesis as it has identified the main gaps in the literature and regulations that require further investigation, namely improved response time data and validation data for ship evacuation models. While most building evacuation models noted in this chapter have undergone at least some form of validation, the same cannot be said for ship evacuation models. Until the research presented in this dissertation was completed, a validation method was not available due to lack of data. Since the development of the validation method described in Chapter 7, a total of five models have been validated – three as part of the project and two independently.

The chapters that follow will present, in detail, the development and testing for data acquisition methods to collect passenger response time and passenger movement data (Chapter 3); the preparation and methodology for sea trials on three different ships (Chapter 4); the methods for data analysis and an overview of the dataset collected (Chapter 5); detailed analysis of data to present new passenger response time distributions (Chapter 6); detailed analysis of passenger movement data and development of ship evacuation model validation datasets (Chapter 7); and results of comparative evacuation modelling using the maritimeEXODUS model, in order to show the impact of response time distribution on evacuation model results (Chapter 8).

3 Data Acquisition

3.1 Data Requirements

In order to provide answers to the research questions posed in Section 1.3, it was necessary to collect two specific datasets for each ship – passenger response time to the ships' alarm and passenger assembly routes and associated assembly times. Furthermore, an important consideration in this work was the repeatability of the data collected. It was planned from the outset to perform repeat trials on all ships in order to: improve the reliability of the data collected, to provide redundancy in the event of data loss on any given set of trials, and most importantly, to provide answers regarding the *nature* of passenger behaviour onboard ships during simulated emergencies. Specifically, the research was to determine whether passenger behaviour for the ships tested could be considered representative or typical of passengers on other ships of the same type and under the same types of conditions. This chapter outlines the data acquisition methods considered and investigated, along with detailed assessments of the methods chosen.

3.2 Response Time Data Collection Methodology

Response time has been defined in Section 1.2 as the time elapsed between the first cue indicating a need to evacuate and the point at which an individual begins purposeful movement away from their original location. For the research presented herein, the sounding of the ship's alarm was the first cue that there was a need to evacuate. As outlined in Section 1.2, response time is best characterised by observing an individual's behaviour a little before the alarm, during the alarm and until they make purposeful movement away from their starting location. It is important to understand that large passenger ships are very complex environments involving many different types of functional spaces designed for passengers to inhabit, such as restaurants, cafes, discos, bars, cabins, lounge and recreational areas such as swimming pools, games rooms and theatres. Thus, it is important for the research to examine passenger behaviour in as many of the different areas as possible in order to gain insight into the different factors influencing the response phase of the process.

Given the complexities of human behaviour and the need to collect response behaviour for as many people as possible, direct observation of passengers is impractical and unreliable. Furthermore, the presence of the researcher would certainly influence the behaviour of the passengers and result in a spurious dataset. From previous research experience [97], [214] and as discussed [4], [215], the use of video cameras is considered an appropriate method for capturing response time data. There are several important factors that must be considered when choosing and setting-up cameras for collection of passenger response. These are outlined in the sections that follow, with a discussion of the methods chosen for this research.

3.2.1 Camera Field of View

Field of view (FOV) defines the range of observable area that is recorded by a camera. In the context of the research presented in this dissertation, FOV determines the proportion of a given area of the ship in which a camera records the activity of passengers and the number of passengers whose response time can be measured. Figure 10 presents examples of closed circuit television (CCTV) cameras found onboard the cruise ship tested in this study and the associated field of view. For cases where cameras built-in to the ship were used, the team had no control over the FOV. In cases where ship-mounted cameras did not provide the FOV required, additional cameras were brought onboard by the research team to meet the research needs (Figure 11). For some cases where a wider FOV may be required, clip-on wide-angle lenses were purchased that could be attached to the cameras when mounted.

3.2.2 Camera Resolution

Camera resolution provides a measure of the amount of detail that can be seen in an image. As the image resolution increases, so does the amount of detail that can be observed in the image. However, as the resolution increases, the size of associated video files also increases. The correct balance between resolution and storage must be determined when choosing a video system – high-resolution systems require considerably greater storage space and tend to use more battery power (described in Section 3.2.5 below) and may not provide any discernable benefit for the data collected.

(a)

(b)

Figure 10 Examples of camera type and location (left) and field of view (right) for CCTV cameras found onboard a cruise ship - (a) micro fisheye and (b) dome style

Figure 11 Example mounting location (left) and field of view (right) for a team-mounted camera in the bar area of the RO-PAX ferry without cabins.

Resolution must be high enough to allow the analyst to determine basic information about passengers (gender, approximate age, etc.) and what passengers are doing just before and throughout the response phase. This includes passengers in the foreground as well as in the background areas of the FOV. Greater resolution will enable the analyst to collect more information about passengers and their actions, particularly those in the background areas. This is an important consideration, given the size and complexity of the different public spaces onboard passenger ships, possible limited supply of cameras for capturing response phase activity and logistics associated with mounting (i.e. more cameras requires greater setup time).

3.2.3 Frame Rate

A video camera's frame rate is the number of frames (images) recorded per second (FPS). Modern video frame rates vary depending on the region and industry; for example the European broadcast standard is typically 25FPS while the North American standard is typically 30FPS. Sometimes frame rate can be set, depending on the video capture system being used and its application - security systems, for example, are generally not meant for broadcast and have a greater storage volume requirement so often use lower frame rates in order to optimise storage space. Thus, it is important to consider frame rate in research applications where the quantifiable data comes from the video record timeline. As frame rate is reduced (i.e. fewer images are captured per unit of time), more time elapses between images captured than for higher frame rate cameras and the error associated with timing for certain events will tend to increase. This is because the time of the actual event can only be determined *after* the event has taken place at the time of the next image in the sequence. Figure 12 illustrates how choice of video frame rate can influence measurement error. Three events are illustrated in Figure 12 (red lines with arrows) with the actual time of the events provided as T_{act}. Considering the example frame rates presented (25 FPS and 7 FPS), an analysis was carried-out to demonstrate the maximum measurement error resulting for each frame rate. The maximum absolute error will occur when a desired event occurs immediately after an image has been captured. Thus, for random events that are uniformly distributed between each frame captured, the mean difference for 25 FPS cameras is 0.02 s ± 0.0115 s and the maximum difference approaches 1/25 s or 0.04 s, while for 7 FPS cameras, the mean difference is 0.0714 s ± 0.0413 s and the maximum difference approaches 1/7 s or 0.1429 s. While these levels of absolute error are not expected to be significant in comparison to other sources of error, it is useful to understand how camera frame rate can influence measurement errors, particularly when presented with different measurement options (e.g. portable cameras purchased specifically for the research or cameras already installed onboard the ships, which are typically set at lower frame rates).

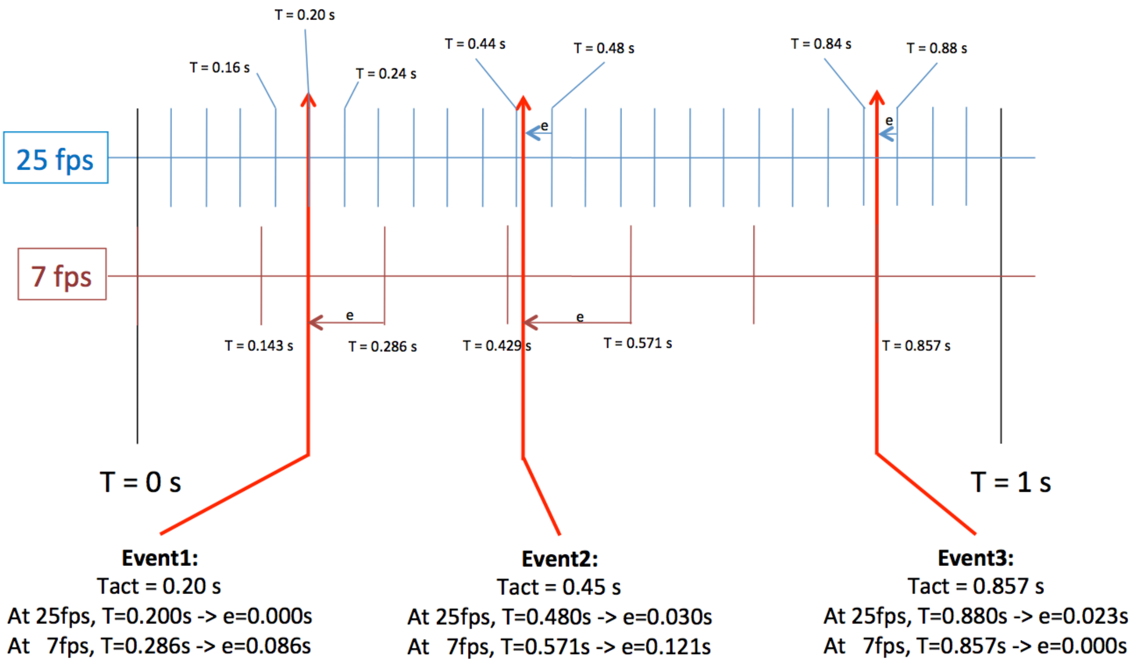


Figure 12 Illustration of measurement error for events in video, based on the camera frame rate.

3.2.4 Camera Mounting Position and Method

It is important to consider the camera mounting method for any video capture system, particularly one that must be mounted quickly and for a relatively short durations, as was the case for the research presented in this dissertation. Aside from concerns over possible theft in public locations (a twofold problem due to the expense of having to replace equipment but, more importantly, the loss of data), it is important to ensure that the mounting system will enable secure mounting of the cameras to prevent them from falling and causing damage or injuring an unsuspecting passenger. Versatility of the mount is also important for shipboard applications to ensure that cameras can be mounted without requiring modifications to the vessel and can be oriented easily in order to view the required area without a great deal of effort or time. This is important for logistical reasons to make it easier when setting up for the trial but it is also important that the research team members can install, adjust and operate (i.e. start recording) the cameras in a way that does not capture the attention of nearby passengers and affect their response and evacuation behaviour during the trial. The range of camera mounting methods chosen for this research are shown in Figure 13 and consist of two main types – magnetic and friction clamp (illustrated in Figure 14). The magnetic mounts enable fast and stable attachment to iron-based surfaces. The magnetic mounts included a simple ball joint system for enabling flexibility for camera orientation, with a strong magnet at the base for mounting to ferrous surfaces. In situations where magnetic clamps could not be used, or if greater flexibility in camera orientation was required for a given location, clamp-based (friction) systems were used along with articulated arms. These mounting methods were less compact than magnetic mount systems but enabled a greater range of mounting and orientation options if required.

Figure 13 Digital video camera and different mounting methods used.

Figure 14 Digital video cameras and mounting options - magnetic (left) and friction clamp (right).

3.2.5 Camera Storage Capacity and Battery Life

The video system storage capacity and battery life must be chosen to ensure that the camera can be started as early as required before the trial and remain recording until the trial has been completed. If storage capacity or battery life limits are reached before the trial is complete, there will be loss of data, which is an unacceptable situation. The cameras chosen for this research were all fitted with extended life batteries that enabled up to 8 hours of recording. All cameras chosen had build-in hard disc drives for recording video for at least 8 hours. Thus, video files could be directly transferred to computers for backup following each test. It should be recognised that camera and video recording technology are continually improving. When this research was undertaken, the video cameras used were state-of-the-art in consumer-grade technology. In the last 5 years (since the trials were completed), solid-state storage has become the norm and camera options (e.g. resolution and frame rate, low light quality, camera size) have improved substantially, except for battery life.

3.2.6 Synchronisation

Ensuring that all data sources are synchronised to a known common source is of critical importance for determining response phase behaviour across the entire range of the ships tested. There are a number of different ways in which this could be accomplished:

1. *Visual* – use of video annotation from a common, known source such as GPS, or display of a common action that can be seen by all cameras. This could be an individual performing a specific, well-defined action that all cameras record (e.g. using a "clapper board" or a clear body movement such as raising a hand or bringing hands together), however, this only works if *all* cameras are in the same location and if the cue is of a duration long enough to be recorded (i.e. a short burst flash of light would not be reliable since its duration is so short that it would be unlikely to be seen by all cameras). For this reason, visual-based synchronisation was not appropriate for the research described here, since the size of the passenger ships meant that cameras would be separated by large distances and/or physical obstructions. One method considered was to display a working stopwatch to all cameras one-at-a-time after all cameras had been set to record but before the test began. This method requires significant time to complete, particularly when the individual with the stopwatch is

required to move across multiple decks for large ships in the range of 300m length. It would also be difficult to ensure that all cameras had clearly recorded the stopwatch time being displayed. Finally, synchronising in this way would draw the attention of passengers to the presence of the cameras and could influence their behaviour during the test.

2. *Auditory* – use of an identifiable sound that is recorded by all cameras at the same time. Given that a ship's alarm system activates at the same time in all parts of a ship, cameras that record audio can be synchronised during analysis after the trial has been completed using the start of the alarm signal as the common reference point. All cameras installed by the project team were capable of reliably recording audio and this method was tested successfully and confirmed as being reliable.

In the event that a blended video synchronisation method is required (e.g. when using closed-circuit television (CCTV) security-type cameras that do not record audio, along with systems that do record audio), all non-audio cameras must use a common annotation time and the research team must how that time relates to the audio synchronisation reference. This is usually possible since CCTV camera video is generally fed to a central monitoring location and recorded using a single digital video recorder. Without paying careful attention to camera synchronisation, the resulting data collected would be of little or no value for determining passenger response time since the behaviour could not be reliably related to the alarm time.

3.2.7 General Planning to Collect Response Time Data

The initial stage of planning for collection of passenger response time on each ship included determining locations where passenger behaviour should be recorded. This began with a detailed review of the general arrangement (plan view layout) drawings for passenger spaces on each ship. Representatives for each of the ship owners provided these drawings and were consulted to ensure that passenger activities and access to the different spaces was clearly understood, along with the research team's approval to record video in the desired locations (e.g. recording video inside passenger cabins and in casino areas was prohibited). It was then assessed whether any existing ship-mounted cameras could be used and how many team-owned cameras should be used.

Prior to testing on each ship, a draft trials plan was developed to outline camera locations. Several visits were made to each ship in the months leading-up to the trials to confirm and finalise:

1. Where passengers were likely to be located when the alarm was sounded (in order to record the largest number of representative passenger response times as possible);
2. The best possible FOV (considering the space and possible lighting issues) and whether or not wide angle lenses were required;
3. The availability of appropriate mounting fixtures on the ship and the type of mounting system to use; and
4. How noticeable the research team member mounting the camera was likely to be to the passengers (so as not to affect passenger behaviour by making them aware they were being recorded).

Approaching the trial planning in this way reduced uncertainties relating to data quality and enabled faster setup on the test day.

In total, up to 40 team-owned cameras and 94 ship-mounted cameras were used to record passenger response time behaviour on each of the three ships. Detailed discussion is provided of the planning and set-up process for each ship in Chapter 4 - 30 team-owned cameras on the first ship - a RO-PAX ferry without cabins (outlined in Section 4.8); 106 cameras were used (94 ship's own CCTV cameras and 12 team-owned video cameras) on the second ship - cruise liner (outlined in Section 4.9); and 40 project team-owned cameras were used on the third ship – a RO-PAX ferry with cabins (outlined in Section 4.10).

3.3 Validation Data Collection Methodology

3.3.1 Overview

A comprehensive data set of passenger route and assembly times was required in order to develop a validation protocol for ship evacuation modelling. This data set required knowledge of individual passenger routes, including starting locations at the time of the alarm, assembly station used and individual assembled time. There are a number of possible means by which this data could be acquired. Choosing a data acquisition method required consideration of a variety of factors, such as:

- complex nature of the shipboard environment;
- logistics of transporting equipment to the ship;
- ease of being able to deploy the system components and operate;
- cost of the system; and
- system accuracy and reliability for counting all passengers at the correct time for each location onboard.

A great deal of effort was put into investigating the different technologies available, testing the most promising options and developing capabilities where required and possible. Details of this process are outlined in this section.

3.3.2 Technologies for Tracking People

Various commercially available technologies for counting and tracking people exist. These systems range from expensive, highly-complex video capture with software analysis such those offered by Vitracom [216], Axis Communications [217], Infodev [218] and Acorel [219] to simple, inexpensive mechanical devices such as turnstiles and light beams that register an individual as having passed a given location when the beam detection has been interrupted. While these technologies are capable of providing accurate data for certain applications (e.g. generally low density crowds, single file movement of people or for permanent installations), their usefulness in evacuation studies onboard large ships for short-term installations is limited. This is due to considerations such as cost, ease of setup, number of measurement points and ability to recreate individual routes though the structure from start to end location.

Previous efforts at collecting comprehensive full-scale human movement data (as required for this research) within complex structures have been limited largely due to the associated data analysis. This is particularly true for large passenger ship evacuation situations, in which attempts were made using video footage to manually track individuals through a vessel [32][103]. In such cases, depending on the complexity of the structure, the analyst may be required to track each individual through multiple video camera locations.

Attempting to track a handful of individuals this way can be extremely tedious and prone to error; thus tracking thousands of passengers individually, across numerous large ship decks would be unthinkable. Automated video tracking systems can provide an accurate measure of the *number* of people crossing a given point of interest but, as yet, such methods lack the ability to identify specific individuals across a range of cameras. In addition, these systems require a birds-eye-view of the targeted individuals. For this reason, installation of video equipment can be difficult due to the low headroom that is typically available on ships [220].

Different technologies other than video can be used to automatically determine the route of individuals in a variety of environments. These include radio frequency identification (RFID), infrared (IR), global positioning system (GPS) and wireless sensor networks. Past research [123], [221] compared the use of two systems - video and IR for determining the *trajectories* of individuals walking. The IR system detected changes in temperature in the relevant field of view in order to track people's trajectory but it was found to be difficult to track the same individual from one field of view to the next. It was recommended [221] that a blended approach of video and IR could be used to determine the trajectories for people walking.

Due to the limitations of some of these technologies inside the shipboard environment, logistical considerations (e.g. cameras - very labour intensive and prone to error, particularly when tracking large numbers of people throughout a large and complex structure) and budget, given the large number people to be tracked, it was decided early in the project that two main technologies would be investigated – RFID and IR. Publications arising from this dissertation [202][203][204][222][223][224][225][226][227][228][229] outline the results of testing that compared the use of RFID and IR tracking systems. Both systems rely on similar underlying concepts - devices are mounted throughout a structure that generate uniquely identified fields (RF or IR) and passengers wear a device (referred to here as a *tag*) that allows for their unique identification as they move throughout the structure and pass through each field. If a sufficient number of unique fields are generated, then as a person moves around the structure, their tag enables logging of the different field IDs and the time they were passed. The systems tested were chosen based on careful consideration of their operability (likelihood of reliable, accurate measurement of individuals), logistical considerations (size, transportability, ease of setup, regulatory requirements) and cost.

One important consideration for the systems chosen is that for the technologies to work, the population must agree to participate and wear a device for the purposes of the trial. Since the trial may take place at any time, the participant population must be prepared to wear the device for an extended period of time (possibly all day/night) and so it must be comfortable, not interfere with normal activities and if possible must blend in with their normal attire. For example, attaching tags to a hat or cap, while ideal for detection, may not be acceptable for the participants and they may choose not to participate.

Figure 15 provides a simplistic depiction of how the chosen automatic path tracking systems operate – individuals begin in the *starting area* on the right-hand side of the figure and move to the *assembly area* on the left. Three separate fields are generated within the structure and people can take one of two possible routes to reach the assembly area – the upper corridor or the lower one. People first move through field 1 (red) and the time they do so is logged. After walking through field 1, some people choose to walk route 1 (upper corridor) to reach the assembly area so that they have to pass through field 2 (blue). The rest of the people choose the lower corridor and have to pass through field 3 (green) to reach the assembly area. The devices worn by all individuals enable measurement of the field passed and the associated time.

After a test, data (.csv text files) can be easily assembled determine key components of the process for individuals moving from the starting area to the assembly area, such as the route chosen by each individual, the time each individual leaves the starting area, the time each individual arrives at the assembly area, average walking speed and total distance travelled for each individual (if the distance between each field is known). If one were to scale-up the size and complexity of the environment shown in Figure 15, it becomes clear that as long as the structure is sufficiently well defined by unique fields and all people wear devices for tracking, the performance and basic behavioural characteristics of individuals and groups moving through the structure can be documented relatively easily.

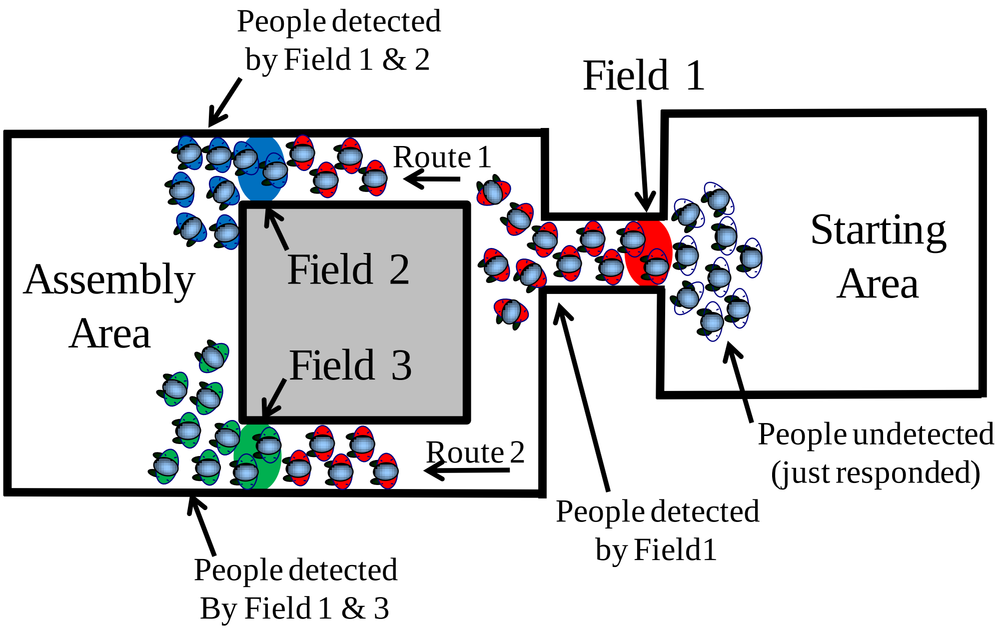


Figure 15 Example of automatic path tracking concept, following individuals from a starting area to an assembly area by one of two possible routes.

Sections 3.3.3 - 3.3.6 provide details of the proof-of-concept testing carried-out with the RFID and IR tracking systems in building corridors and on the ships, in order to determine which should be purchased to meet project needs. Section 3.3.5 then identifies the system chosen and the reason for choosing.

3.3.3 Initial Proposal - Using RFID to Track High Density Flows of People

3.3.3.1 RFID System Overview

Radio frequency (RF) energy is defined by Industry Canada [230] as "…a form of electromagnetic energy on the electromagnetic spectrum that covers microwaves, X-rays and visible light". RF energy is generated when a source current is supplied to an antenna, which then excites the electrons inside the antenna and cause the energy to move outward as electromagnetic waves [230]. RF energy typically transmits in the frequency range 3 kHz to 300 GHz. The idea of using RF energy for identification and tracking of goods and people has been around since at least 1948 when Stockman [231] concluded that "…considerable research and development work has to be done before the remaining basic problems in reflected-power communications are solved, and before the field of useful applications is explored." In the 1960s, the first commercial applications of RFID were seen with the implementation of tag devices attached to merchandise in stores [232] and in the 1970s, RFID expanded to animal and vehicle tracking and automation of certain processes in factories [232]. In the 1980s and 90s, RFID technology entered the mainstream as it was deployed on toll roads in the U.S. and in various parts of Europe for easier collection of tolls from regular users. Since the 2000s, RFID has become a part of everyday life for most in the developed world, with applications (and potential applications) expanding constantly.

In basic terms, the way RFID works is simple. A tag (a microchip with an antenna) is attached to something (vehicle, tool, product in a warehouse or a person) and a reader (a device with one or more antennae) reads the data on the microchip using RF energy [127]. RFID systems fall into one of two categories: passive and active and are generally used for communication over short distances. While *active* system tags have a built-in powered transmitter, *passive* systems use tags that rely solely on the RF energy detected from the reader in order to transmit information contained on the tag's chip back to the reader. Thus, with RFID-based tracking of people, all data that is received from tags is stored on a computer network attached to the readers. Active tags are capable of transmitting their information over greater distances compared with passive tags. Active tags tend to be larger and more expensive than passive tags but are also typically more robust.

While RFID technology has been predominantly used to track the movement of goods and equipment in warehouses, retail stores and construction sites, it has recently been deployed for tracking people both in practice (e.g. for monitoring the progress of the passenger ship assembly process in an emergency [127][233] using RFID systems installed onboard during construction and thus carefully positioned and tested) and in evacuation research generally [94][95][124]. The IMO (MSC.1/Circ.1238 [21]), along with [95][124][220] have all identified the importance of validating evacuation models that simulate movement of people and the difficulties associated with doing so. Sharma and Gifford [124] discuss the difficulties with using video capture and analysis methods for collecting validation data and note the potential for use of RFID technology to automatically collect individual behaviour and performance. Part of their discussion includes a summary of the drawbacks associated with RFID tracking of people – namely the difficulty of reading tags when in close proximity to materials that absorb RF energy, such as water (which makes-up as much as 75% (by weight) of a human body [234]). This RFID characteristic alone makes use of this technology somewhat unpredictable for reliably tracking the movement of individuals within large crowds, since it is possible that a portion of the tags will not be read, thus, creating inaccuracies in the validation dataset.

Orientation of RFID reader antennae with respect to tags is also of key importance to improving tag read rates and [94][95] suggest that when using RFID in evacuation studies for crowded scenarios, read rates of higher than 50% can be expected as long as the proper antennae alignment and power required are found through experiments. Sharma and Gifford [124] found that mounting the antennae overhead or at chest-height produced the best results if they were also parallel to typical tag orientation rather than perpendicular, which would expose a much smaller proportion of the tag's surface area to the antennae field and thus result in lower read rates than would be the case for better-aligned reader orientations. However, for the study outlined in this dissertation, the options for mounting and orienting readers is much more limited than for building applications. While results from Sharma and Gifford's experiments [124] indicated that the RFID system did not always count all individuals (possibly due to a faulty tag), they concluded that RFID is an effective tool for tracking movement of individuals at given points for the proof-of-concept tests undertaken. They felt that future work should include instrumenting a larger, more complex structure and to perform experiments with larger numbers of participants.

For the research presented in this dissertation, a variety of RFID systems and options were investigated prior to purchasing a system for testing. The three most important considerations for choosing a test system were cost, ease of setup and size. Size was important for the planned application due to concerns from ship owners about how the system would look when installed on the ship; since tests were to take place during regular voyages with passengers who had paid for their passage, ship owners wanted to ensure the passengers' enjoyment of the experience onboard.

Ultimately, a passive RFID system, manufactured by Alien Technology Corporation, was purchased for testing. It consisted of an Alien model ALR-8800 reader and a pair of Alien model ALR-8610 circular polarised multi-static antennae (Figure 16), meaning the antennae were capable of both *generating* an RF field and *receiving* tag transmission data for logging. This system was designed to operate in the European ultra-high frequency (UHF) band in the 865.7 - 867.5 MHz range with power levels of 2W effective radiated power and is compliant with European radio regulations. The system was designed to read electronic product code (EPC) Class 1 Generation 2 UHF tags. In addition to the RFID system, various types of EPC Class1, Generation 2 UHF tags were purchased in different form factors, specifically; peel and stick labels (Figure 17) plastic wrist/ankle hospital-style bands (Figure 18) and silicone wristbands (Figure 19).

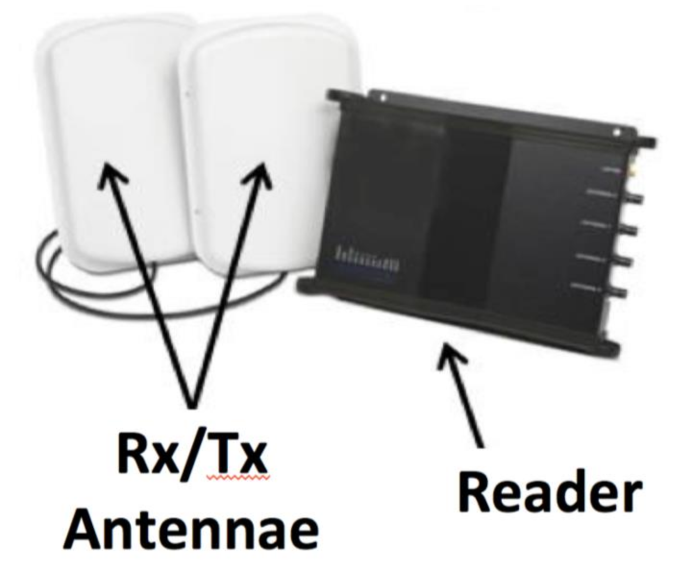


Figure 16 RFID system tested, showing transmit/receive (Tx/Rx) antennae and reader.

Figure 17 Example of a passive "peel and stick" RFID tag considered.

Figure 18 Hospital-style RFID wrist/ankle band [235].

Figure 19 Silicone-style RFID wrist band [236].

Using the RFID system purchased, a series of tests was undertaken first in a corridor at the UoG and then on-board the SuperSpeed 2 ferry during a voyage round-trip from Larvik, Norway to Hirtshals, Denmark.

3.3.3.2 RFID Corridor Tests at UoG

The UoG corridor tests were conducted on 2 July, 2009 in a 1.89m wide corridor. The RFID antennae were placed on the floor, opposite to each other resting at a slight angle off vertical against the corridor walls (Figure 20). The antennae were powered by the reader, which was connected to a laptop computer for data logging. All cables were routed along the edges of the corridor and overhead so that the group could walk through the RF field without tripping hazards. A total of 12 participants wore RFID tags on their wrist and were assembled at one end of the corridor before each test run. When ready, they were asked to walk together as a group past the antennae while keeping their speed, position and group density consistent from test to test (Figure 21). When the group reached the opposite end of the corridor, they awaited instructions before, again, walking past the antennae to return to the original starting point.

Analysis of test results showed that the maximum read rate was 75% for tests where participants were permitted to walk normally (i.e. with arms swinging by their side). One test case was conducted in which participants were asked to fold their arms, thereby partially shielding the tags. For this test, it was found that the read rate decreased significantly to just 17%.

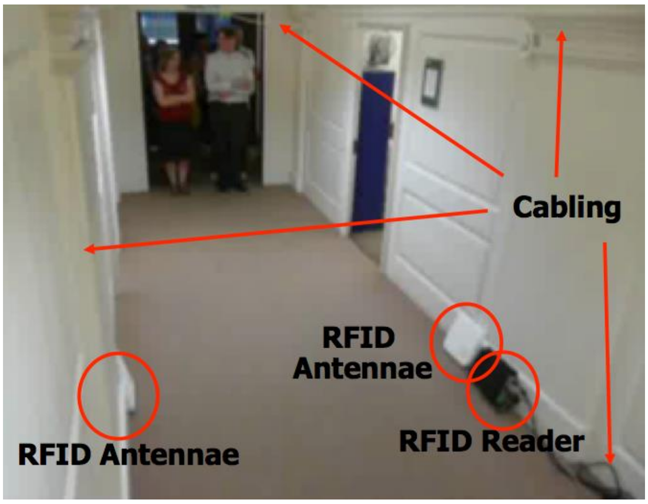


Figure 20 RFID corridor test setup at UoG.

Figure 21 RFID corridor test at UoG, showing antennae at the floor and tags on individuals' wrists.

3.3.3.3 RFID Tests at Sea on SuperSpeed 2

Three at-sea tests were carried-out in a 2.4m wide passageway (Figure 22) onboard the SuperSpeed 2 ferry on 16 July, 2009. For these tests, nine participants volunteered to wear passive RFID tags. The mean read rate for all three trials was 85.7%, which demonstrated that the RFID system *could* work within metallic environment of a passenger ship. However, there was concern that none of the cases tested produced a 100% successful tag read rate; this would represent a problem for developing a validation dataset from full scale trials at sea. For this reason, it was decided that further investigation was required to ensure the most accurate method of tracking passengers during the sea trials planned in the project.

Figure 22 RFID system test on SuperSpeed 2 showing antennae (circled) and cabling (yellow) to connect both antennae.

3.3.4 Final Proposal - Using Infrared to Track High Density Flows of People

In sourcing RFID equipment, a member of the UoG project team made contact with a UK-based company called *RFID Centre Ltd.* and, in explaining the project requirements, it was recommended that a more reliable technology for this type of application might be infrared. The following sections outline how infrared technology works and the variety of tests undertaken to determine reliability of the system.

3.3.4.1 Infrared System Overview

Infrared (IR) light transmission has been used for decades as a means for wirelessly carrying information and signals. IR light is found on the invisible portion of the electromagnetic spectrum, just below the visible light band and is used regularly by people as a form of wireless communication to remotely control devices such as televisions, garage door openers and children's toys [237].

Past research by Bandini et al. and Kerridge et al. [123][221] compared the use of two systems - video combined with IR for determining the trajectories of individuals walking. The IR system detected changes in temperature in the relevant field of view in order to track people's trajectory but it was found to be difficult to track the same individual from one field of view to the next. The IR technology use as presented here has not previously been employed for tracking individuals in evacuation research.

The IR system utilised in this research (*TagMobile*) consists of two main components – an IR light field generator (beacon) and an IR light field detector (tag) (Figure 23).

Figure 23 IR beacon (left) and tag (middle) showing CD (right) for scale.

The beacon, shown with the translucent lid removed in Figure 24, uses a microprocessor and light emitting diodes (LEDs) to emit pulses of IR light in specific patterns that represent specific binary codes for identifying the beacon. The ID code is set using dual in-line package (DIP) switches configured in a specific order. Typically, a single packet of information emitted includes a "start" command, the code sequence for the command, a device address and an "end" command. In order to be detected, the IR signal requires line-of-sight (i.e. it will not transmit through opaque objects or around corners), however reflection is possible off mirror-like surfaces and it will transmit through clear objects such as glass. Interference is sometimes a problem with IR because of the everyday IR light sources such as sunlight and fluorescent bulbs. In order to reduce the effects of interference, IR-based electronics tend to respond to a particular frequency range of IR light and receivers have filters that block out unwanted frequencies.

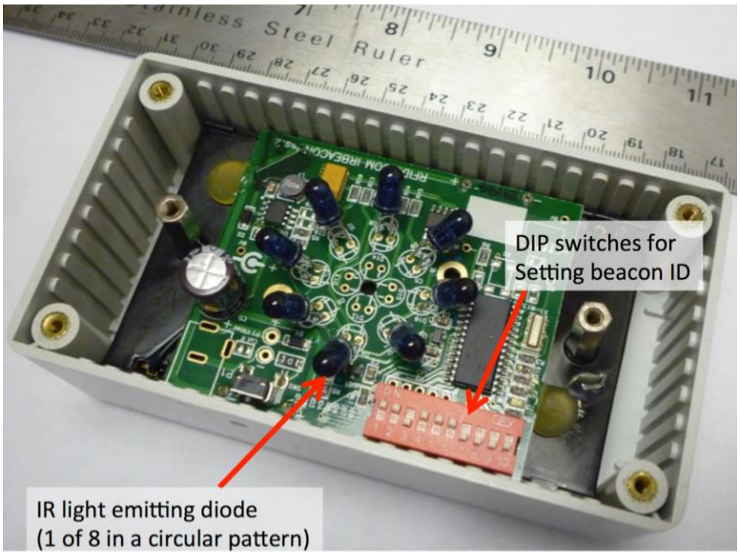


Figure 24 Interior components of IR light generating beacon.

The size of the field generated depends on the input power and number of LEDs used. The TagMobile system beacons rely on battery power – 6 x AA batteries (i.e. 9V) with the circuit board mounted directly to the battery holder and all housed in a small plastic case (Figure 25). Thus, beacons are relatively inexpensive to purchase, autonomous (not required to be near an AC power source or computer network) and relatively light for mounting/positioning. Unlike RFID systems, the IR system tested does not need to be connected to a computer in order to enable position logging.

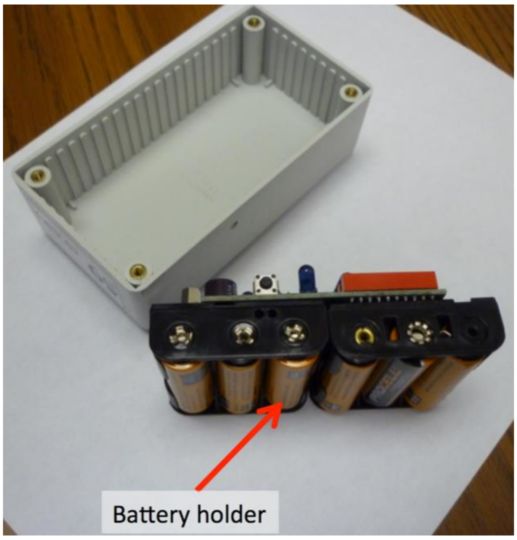


Figure 25 Interior components of IR light generating beacon removed from case.

The tags, which are powered by single 3V watch-style batteries, (shown in Figure 26 with the translucent cover removed) are attached to lanyards and worn around an individual's neck outside a person's clothing. Tags contain IR light detectors mounted on a circuit board that sample for IR light every second (i.e. at a frequency of 1Hz). Signals detected are processed by microprocessors in the tag that store the beacon ID information in non-volatile memory. The microprocessor in each tag contains a simple clock system that measures the number of 1 second "ticks" since start-up and reverse calibrates to actual time of day based on the clock settings of the computer used to download data *after* testing has been completed. The tag logs time of entry into a field and time of exit.

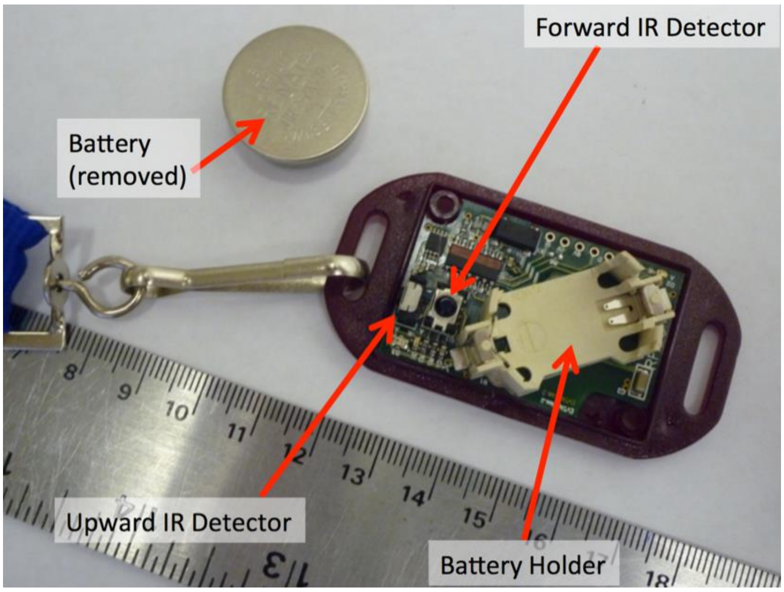


Figure 26 Interior components of IR detecting tag.

3.3.4.2 Infrared Early Stage Testing

Initial pilot testing with the as-delivered test version of the TagMobile IR tracking system were carried-out in a corridor at UoG. The system consisted of 10 tags, each with a single IR light detector and six beacons with a fixed output power. Tests in the corridor at UoG with this system suggested that the read rate was higher and more reliable than that observed for RFID in a dense group of 10 people.

Based on the corridor testing, two at-sea IR system trials were then conducted onboard the SuperSpeed 2 ferry on 16 July 2009 (the same date as the RFID trials described in Section 3.3.3.3). Ten crew members wore IR tags and an 11th person from the UoG project team lead the group along the desired path. Prior to the commencement of the test trial the crew were instructed to wear the tags, and to follow the lead in as dense a group as possible. The path taken for both trials is shown in Figure 27. Start and end points are highlighted in the figure at the same location and arrows indicate the direction of travel for test 1 which loops around decks 7 and 8 in a counter clockwise direction past beacon IDs 19, 15, 33, 34, 42, 55 and 19. The path for test 2 took the opposite direction as test 1 and had participants move in a clockwise direction along points 19, 55, 42, 34, 33, 15 and 19. Figure 28 shows a screen capture from a video camera placed on the ship to monitor the trials. The camera was mounted on deck 8 near IR beacon 19 (see Figure 27).

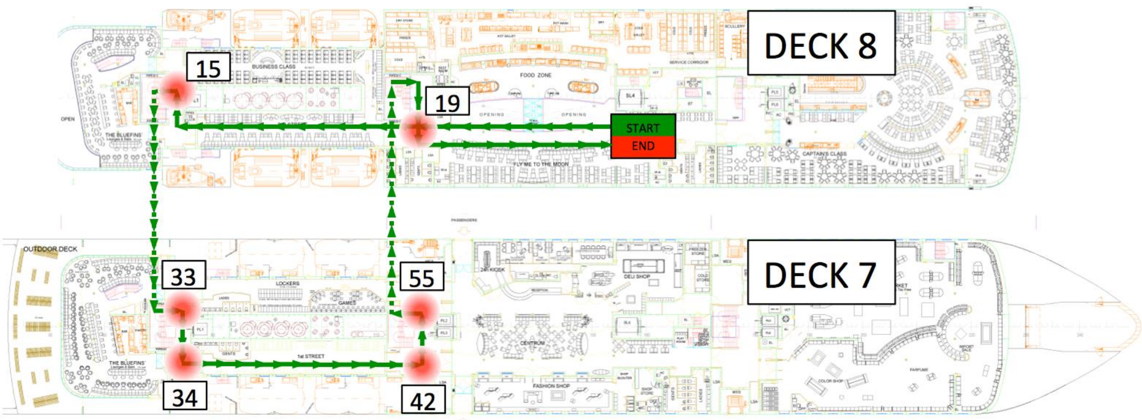


Figure 27 The path followed during the initial shipboard IR system test trial.

Figure 28 The participants of the trials are identified by green arrows while the group lead is identified by a red arrow.

The IR data was downloaded from the tags following the test trials and stored in electronic form for further processing and analysis. Table 7 presents a data summary for the IR beacon IDs that were read by each participant's tag. Non-shaded cells indicate a successfully read IR beacon while shaded cells indicate a non-read.

Table 7 Results of the two test trials. Non-shaded cells indicate a successfully registered IR beacon while shaded cells indicate a non-read.

Pers. #	**Test Trial 1 path**							**Test Trial 2 path**						
1	19	15	33	34	42	55	19	19	55	42	34	33	15	19
2	19	15	33	34	42	55	19	19	55	42	34	33	15	19
3	19	15	33	34	42	55	19	19	55	42	34	33	15	19
4	19	15	33	34	42	55	19	19	55	42	34	33	15	19
5	19	15	33	34	42	55	19	19	55	42	34	33	15	19
6	19	15	33	34	42	55	19	19	55	42	34	33	15	19
7	19	15	33	34	42	55	19	19	55	42	34	33	15	19
8	19	15	33	34	42	55	19	19	55	42	34	33	15	19
9	19	15	33	34	42	55	19	19	55	42	34	33	15	19
10	19	15	33	34	42	55	19	19	55	42	34	33	15	19

It can be seen from the table that the early model IR system (with just one IR detector per tag) was capable of measuring at a read rate of 96% for test 1 and 91% for test 2 (94% successful overall). Though still not 100% successful, the result was better than for RFID and demonstrated that the system could work in a shipboard environment. On consultation with the manufacturer, the team was informed that it would be possible to modify the IR system design in order to better meet the research needs identified and improve the read rate for passengers wearing tags.

3.3.4.3 Infrared Corridor Tests with Modified System

The UoG team, including the author, worked with the manufacturer to identify required system modifications that would make it more suitable for use in evacuation studies. Tag redesign included the addition of a second IR detector (one facing upward and one facing outward as shown in Figure 26) and an indicator light to provide a bright flash upon tag entry to or exit from an IR field. The sampling rate for tags was discussed with the manufacturer who indicated it could be increased in order to improve on accuracy of the readings. The obvious trade-off was, however, that increasing sampling rate would reduce battery life (doubling the frequency to 0.5Hz sampling would cut battery life by a factor of about 2), so it was decided to keep the sample rate at 1Hz. Redesign of the beacon resulted in an increase in the number of possible unique beacon IDs to a maximum of 239 and enabling variable power settings so that field size could be set to one of four ranges, depending on the application. Two versions of the modified beacons were provided for testing – one with 8 LEDs and one with 12.

Tests were then carried-out with the modified system to define the static field size for both beacon options (8 LED and 12 LED). The tests were performed in a 1.89m wide corridor at UoG with the beacon mounted at a height of 2.1m above the floor for two orientations – facing the walker (depicted in Figure 29) at the end of the corridor with the tag moving directly towards the beacon and side mounted (as depicted in Figure 30) with the tag moving towards and past the beacon.

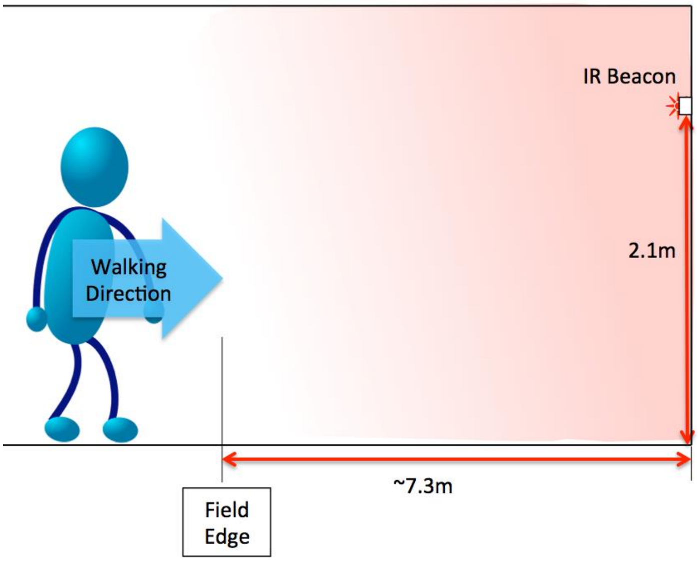


Figure 29 Illustration of IR field geometry (med low power) when walking directly toward a beacon mounted at the end of a corridor.

Results from these tests are provided in Table 8. For side and overhead mounting options in which a walker approaches and moves past a beacon, the IR field is approximately symmetric in its *actual* geometry, the *apparent* field geometry as detected by an IR tag worn by a person walking through it is not symmetric, since it appears to be smaller after passing and walking away from the beacon. This asymmetry is the result of tag shadowing caused by the wearer's body as he/she moves away from the beacon. This shadowing effect causes the IR field to appear larger on the side being approached, as illustrated in Figure 30. The fact that tags can be shadowed at times tends not to be serious issue for tag detection with a moving group because even with high-density groups, tags tend not to be completely shadowed the entire time an individual is walking through the field. Also, an important tag setting requires that a field must go undetected for 3 seconds before it is registered as having left the field. In addition, when individuals are walking, their tag tends to bounce around on the lanyard, which improves the detection performance as the tag is essentially "looking" in multiple directions as it passes through the field.

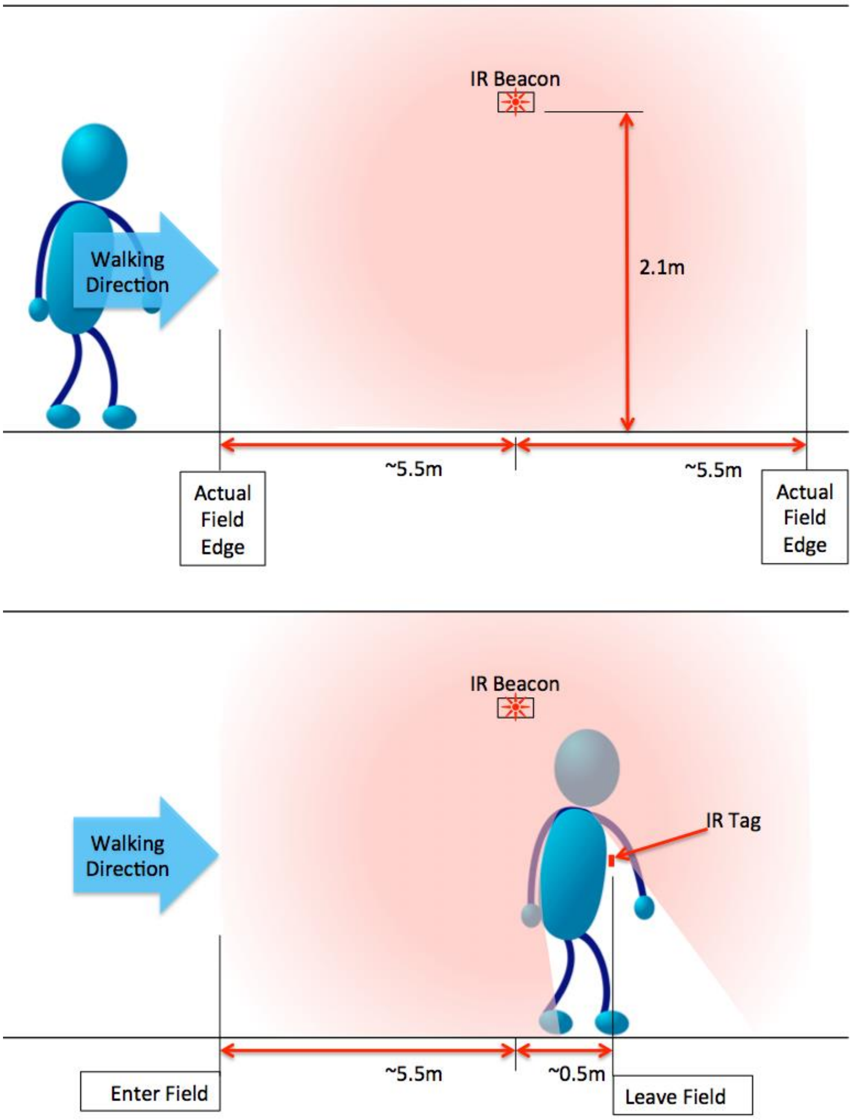


Figure 30 Illustration of apparent IR field asymmetry (med low power) caused by tag shadowing.

Considering the field sizes measured and the planned application, it was decided that the 8 LED beacon would be most appropriate for tracking people, since slightly smaller field sizes would enable more accurate location of people wearing tags (while not being so small as to not count people passing through the field). Also, fewer LEDs would use less battery power.

Table 8 IR system static field sizes for 8 and12 LED beacons, variable power.

Power Setting	Facing Beacon (m)		Side Mounted Beacon							
			Approach from East				Approach from West			
			Enter (m)		Leave (m)		Enter (m)		Leave (m)	
	8 LED	12 LED	8 LED	12 LED	8 LED	12 LED	8 LED	12 LED	8 LED	12 LED
Low	6.30	10.10	2.59	5.08	0.40	0.30	3.54	4.99	0.40	0.30
Med Low	7.30	14.36	5.53	6.10	0.70	1.10	5.82	6.08	0.50	1.00
Med High	13.60	22.92	9.00	9.86	3.60	3.80	8.91	10.47	3.70	3.83
High	18.40	27.44	11.58	12.38	3.80	4.20	10.53	12.05	3.80	4.10

The modified system was then used for a series of group tests in the same corridor at UoG to determine the success rate for counting tags in a dense crowd. A beacon was set to medium-low power and mounted on one side of the corridor at a height of 2.1 m above the floor, facing the opposite wall. A total of ten tags were distributed among a group of 23 volunteers who were instructed to walk past the beacon as a group while keeping speed, position and group density consistent from test to test (Figure 31). Participants were asked to raise a hand when their tag flashed brightly to indicate entry into the field. All tests were video recorded for later analysis. It was found that the number of people within the IR field did not affect field size (i.e. IR field size was constant) and tags were detected 100% of the time.

Following these early-stage tests with the Tagmobile IR system, it was decided that IR showed more promise than RFID as a technology for reliably tracking movement of people in high density crowds during the research trials being planned. A detailed discussion of the decision-making process is provided in Section 3.3.5.

(a) (b)

Figure 31 IR corridor test (a) tagged people (down arrows), IR beacon out of view (up arrow) and IR tag (circled) (b) tagged people raising hands when tag is detected with IR beacon out of view (circled).

3.3.5 Choosing a System to Automatically Track People's Movement on Ships

Results presented in the preceding sections demonstrate which system – IR or RFID – had better performance characteristics for counting tags that passed through a measurement field and the time at which this happened. While there were pros and cons associated with each system, it was found that the IR system performed the required data collection better than RFID; even in very large, dense crowds the IR system always counted 100% of people wearing tags. However, a drawback of the IR system is that the data for each individual is stored in the tag; this is different than the RFID system for which data is stored in an attached computer. This means that for the IR system, data is not collected unless tags are retrieved. To choose a system for procurement, it was also important to consider logistical issues. These are outlined under the headings that follow.

Powering requirements for the RFID system could be problematic, since these devices required AC power, for which an electrical outlet may not be available in the locations where antennae and readers were required. By comparison, the IR system operated solely on battery power and, thus, beacons could be positioned in virtually any location to create a measurement field.

Cabling for power and signal transmission were not required for the IR system, however the RFID system required cables to be connected to all components (except tags) for powering and transmission/recording of signals from the tag antennae and readers. While this may not be a significant concern for permanent installations of RFID equipment, temporary installations (such as planned for this research) would require significant time to set-up safely so that passengers did not trip on cables and to ensure that all components were working. In addition, the ship owners were concerned that the research equipment used might lessen the passengers' enjoyment of their experience onboard.

Physical size of the equipment was important to consider, since it would affect the shipping options for getting equipment to the different ships and ability to store it. Without doubt, the RFID system would require a great deal more space for storage and shipping in comparison to the IR system. While the RFID tags tend to be considerably smaller than IR tags and lanyards, the RFID system space requirements for cabling, antennae and readers would be considerably greater than that required for an equivalent IR system.

Ease of operation for the system was also an important consideration. For the IR system, operation was quite simple and was easy for all team members to understand. The RFID system operation was found to be much more complicated from the point of view of both start-up but also for data parsing. Further, it was only capable of reading when a tag entered a field, whereas the IR system provided time of entry into and departure from each field.

Ease of setup was quite important to consider when choosing a path logging system, since the amount of time and personnel available to setup the equipment was quite limited due to vessel access. The RFID system was found to be quite time consuming to setup due to the size of the antennae and readers and the need to mount the antennae in a specific manner. Also, installing cabling was quite time consuming for RFID and increased the chance of accidental trips, as well as possibly making passengers more aware of the equipment being used, thereby influencing passenger behaviour onboard during the trials. By comparison, IR system setup was exceptionally easy as beacons could be installed using Velcro strips.

Cost was considered in two ways – the cost of a complete system to meet the needs of the project, including tags; and the incremental cost should it be necessary to expand the number of fields required, or the number of people tagged. It was found that a complete system capable of measuring at 30 locations for up to 3,000 passengers was about the same cost for both IR and RFID. Increasing the number of tags and measurement points beyond this amount was where gains were seen with the IR system. Although IR tags are considerably more expensive than passive RFID tags (approximately by a factor of 15), IR beacons are much less expensive (by a factor of approximately 60) than RFID antennae/reader equipment needed to generate a single measurement field. This suggests that, if needed, additional IR beacons could be purchased at a relatively low cost and placed throughout the structure, thus allowing for more granular definition of occupant routes. Scalability of the RFID system in this way would be much more expensive. Further, since RFID tags are quite fragile they are generally used only once, whereas IR tags are quite rugged and can be used many times and do not require replacement often.

Regulatory issues for operation of equipment in different geographic regions was also important to consider, since it may be necessary to travel abroad to board a vessel for trials. IR light generation is not regulated according to geographic region, which makes it quite flexible for operation around the world. However, since generation and transmission of RF is highly regulated according to region, the RFID system could be quite limiting since a system purchased for use in Europe cannot be used in North America or Asia. While it was not the intent of this research to conduct trials outside Europe, it was important to consider future uses for the system.

Component durability was considered important since the system was to be shipped significant distances and deployed on different ships with tags distributed among thousands of passengers over which the research team had little control. RFID tags tend to be much more fragile than IR tags which can be reused many times. RFID power and signal cables tend to become damaged after significant use as well.

Customer support was the final factor considered. A company located in Derbyshire, UK manufactured the IR system. The research team had regular contact with technical personnel throughout the equipment vetting process. This proved to be quite important because the manufacturer allowed the team to make significant modifications to the IR system (as noted) to ensure it provided optimal performance. While there are many options available for RFID equipment, most of this equipment is manufactured overseas and it was not possible to request modifications to the technology. In addition, it was often difficult to reach suppliers for equipment samples to test.

Taking all different factors into account, a weighted decision matrix was developed (Table 9). The factors were weighted between 1 and 5 according to their importance for the research, with more important factors given a higher weighting. The factors considered most important were performance (since data quality was crucial), ease of setup (trial execution logistics was quite important) and system cost (procurement of a basic working system was of key importance). Lesser important system factors included component durability and size (since the system was not likely to be handled roughly during setup and transport to ships would be accomplished using reinforced protective cases. Also, larger systems would result in marginally increased shipping costs). The IR and RFID system factors were then scored and a weighted score calculated by factor for each system.

Table 9 Decision matrix for IR tracking system vs. RFID.

Factor	**Weight**	**IR**		**RFID**	
		Score (max 5)	**Weighted**	**Score (max 5)**	**Weighted**
Performance	5	5	25	3	15
Powering	2	4	8	2	4
Cabling	2	5	10	2	4
Size	1	4	4	2	2
Ease of Operation	3	4	12	2	6
Ease of Setup	4	5	20	2	8
System Cost	4	3	12	3	12
Unit Cost	2	3	6	2	4
Regulations	2	5	10	2	4
Component Durability	1	4	4	3	3
Customer Support	2	5	10	2	4
	Totals		**121**		**66**

Taking the sum of the weighted scores for each system suggested strongly that the IR system was the best choice for the intended research. As noted above, the main disadvantage with the IR system was that occupant route data is not collected unless tags are returned following a test. To mitigate this risk, a focus was placed on procedures the team could follow to improve the likelihood of IR tag retrieval during the tests.

3.3.6 Detailed Validation of IR Tracking System - Corridor

After all sea trials were completed, it was decided that additional testing of the IR system would be undertaken to determine the reliability of its measurements. Furthermore, from experience gained when using the system during sea trials, it was hypothesised that it might also be capable of providing other useful measures of crowd movement such as instantaneous crowd density for unidirectional and contraflow situations. This section presents the methods, execution and results of an experiment carried-out to provide a validation of the IR tracking system.

3.3.6.1 Experimental Design, Setup and Conduct

The experiment was organised and undertaken by the author at the Marine Institute (MI) in St. John's, Newfoundland, Canada using a single IR beacon in a corridor (Figure 32). Ethics approval was received from the Interdisciplinary Committee on Ethics in Human Research (ICEHR) at Memorial University. Testing was carried-out in an east-west oriented corridor at MI with a total of 24 adult participants. Population demographics were not collected explicitly, however, all participants were above the age of 18 and consisted of 13 males and 11 females, all able-bodied.

Figure 32 Corridor layout for Marine Institute tests.

The experiment was designed to give a measure of the IR system error for participant entry into and exit from the field for different walking speeds and group configurations. Since the IR tag sample rate was set to 1 Hz, it was hypothesised that the IR system would produce less accurate results for faster walking people than for slower walking people. In addition, given that the IR system reports the time of entry into and exit from the IR field, it was further hypothesised that the system could also be used to automatically provide a measure of crowd density at any point in time during a test if field size is known, as illustrated in Figure 33.

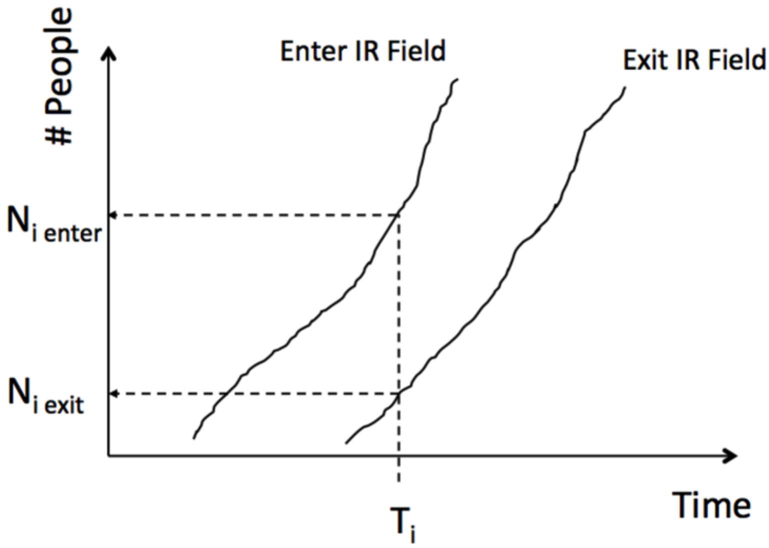


Figure 33 Illustration of how IR system data can be used to easily compute crowd density.

If the floor area of the IR field zone is known, then the density of the crowd (D_i) within the field at any time T_i can be calculated using Equation (5):

$$D_i = \frac{(N_{i\,enter} - N_{i\,exit})}{A_{IR\,Field}} \quad (5)$$

Where:

D_i = Crowd density at time T_i (people/m^2)

$N_{i\,enter}$ = Number of people that have entered the field by time T_i

$N_{i\,exit}$ = Number of people that have exited the field by time T_i

$A_{IR\,field}$ = Floor area covered by the IR field (m^2)

A matrix of six different tests was developed (Table 10), which were carried-out in random order with a repeat of each. Test variables were *group type* (single file, unidirectional group and contraflow group) and *walking speed* (normal and very slow). To determine if there were differences depending on the direction of approach to the beacon, each test condition was carried-out in two separate parts whereby the group walked from one end of the corridor to the other, took a short break, reformed and then walked back to the starting point.

Table 10 MI walking tests - order and description.

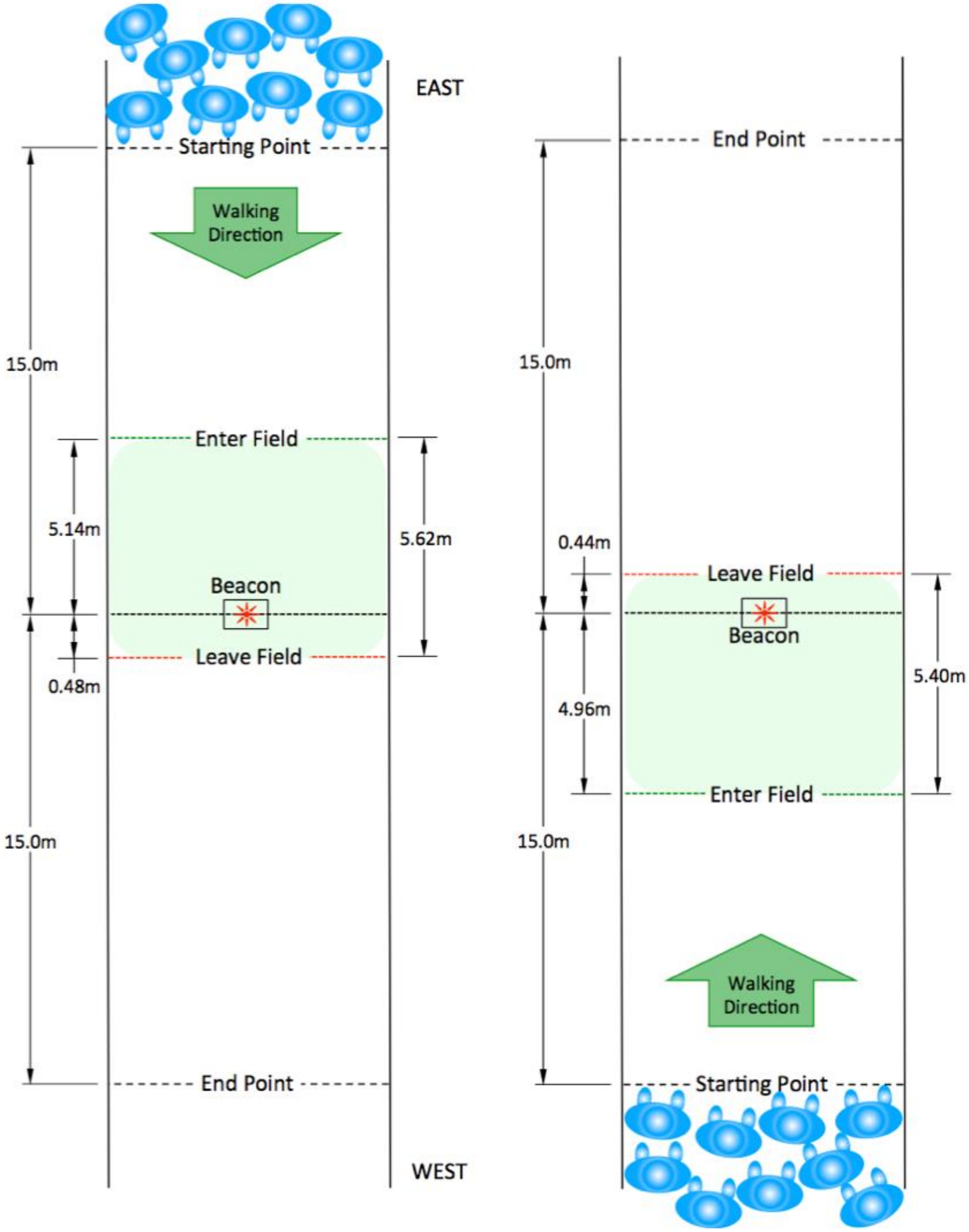
Test No.	Group Type	Speed	Repeat
1	Single File	Normal	1
2	Group – Unidirectional	Slow	1
3	Group – Unidirectional	Normal	1
4	Single File	Normal	2
5	Single File	Slow	1
6	Group – Unidirectional	Slow	2
7	Group - Contraflow	Normal	1
8	Group - Contraflow	Normal	2
9	Group - Contraflow	Slow	1
10	Single File	Slow	2
11	Group - Contraflow	Slow	2
12	Group – Unidirectional	Normal	2

A beacon set to medium-low power was mounted in the centre of the corridor ceiling (2.43 m height). As discussed in Section 3.3.4.3 and presented in Figure 30, while the actual field geometry is approximately symmetric, the *apparent* field geometry is asymmetric and depends on the direction of approach. Thus, the field geometry was measured for both directions of approach to the beacon (eastward and westward) and marked on the floor with duct tape. The test geometry is presented in Figure 34. In addition to field extents, the beacon position was also marked on the floor with duct tape.

Two additional lines were marked at a distance of 15m to each side of the beacon position. These lines were used as the start/end points for each test and enabled calculation of participants' average walking speed. Digital video cameras were mounted to the ceiling above each duct-tape line so that the *actual* times of interest could be recorded for each test. Cameras were synchronised to a known time-of-day reference by using an air horn that was audible in each video feed.

Following the briefing and informed consent process, participants each donned an IR tag and were brought to the starting point in preparation for the first test. All cameras were started and the synchronization completed using the air horn.

The author walked with the group at all times in order to maintain consistency in walking speed and to ensure density did change significantly from test to test. On completion of the experiment, data was downloaded from all tags and backed-up to a secure network-based server along with video from all cameras. Video was analysed using commercially available software Adobe Premiere Pro and the IR tag data was assembled in an MS Excel spreadsheet for each test condition.



(a) (b)

Figure 34 Corridor layout for IR system trials at Marine Institute: (a) Approaching beacon from east; (b) Approaching beacon from west.

3.3.6.2 Results and Discussion

As discussed, the test data was used to validate the IR system accuracy for: counting participants walking past the beacon and time of entry into and exit from the field. Results were also used to determine if crowd density could be accurately measured at any point in time using the IR system. Walking speed, direction of approach to the beacon and group configuration (single-file, unidirectional or contraflow) were all assessed for each test to determine if there were any correlations with IR system function.

It was found that the tag detection rate for all tests was 100%. It was further observed that direction of approach to the beacon (i.e. east-west compared with west-east) did not have an effect on the measured system performance. Results for time of entry/exit are given in Table 11 and indicate that for slow walking speeds, the IR system lags the actual entry into the field by 3.5 s on average for single file tests and 3.9 s for unidirectional group tests. A similar trend was observed for measurement of exit from the field, which for slow walking speeds the IR system tended to lag the actual exit from the field for both single file and unidirectional group tests by less than 1 s on average. However, for normal walking speeds, the IR system often registered field entry/exit before it actually happened in the synchronised video. It is unclear why this is the case, as it is contrary to what would be expected – with a constant sampling rate of 1 Hz, one might expect that the IR system lag would be greater for faster walking speeds. It is hypothesised that this anomaly relates to the orientation of the tag as the wearer is walking – for very slow walking speeds, the tag remains facing forward in a relatively consistent position, whereas at normal walking speeds, the tag tends to move around a great deal more and perhaps is more likely to detect unexpected IR light reflections from the beacon. This hypothesis requires further investigation.

Contraflow test results (Table 11) showed similar mean values for IR system measurement time on entry to the field (3.3 s for slow and -0.1 s for normal walking speeds) but with higher variability than seen for the single-file and unidirectional group results. This is likely due to the fact that most participants had to turn their body to the side to manoeuvre around each other and sometimes people bumped into each other (Figure 35). Both these factors would result in the tag orientation changing more than for slow, straight-ahead movement of the tag through the field.

Table 11 Marine Institute test results – time difference between actual and IR measures.

Comparison of Actual Time to IR-Measured Time (sec., +ve = IR lagging):		Single File (seconds)		Unidirectional Group (seconds)		Contraflow Group (seconds)	
		Slow	Normal	Slow	Normal	Slow	Normal
Field Enter ($T_{IR\_Enter} - T_{Act\_Enter}$)	Mean	3.5	-0.4	3.9	-0.3	3.3	-0.1
	SD	1.6	1.1	2.2	1.4	3.0	1.8
Field Exit ($T_{IR\_Exit} - T_{Act\_Exit}$)	Mean	0.3	-0.03	0.9	0.3	0.7	0.3
	SD	1.5	1.0	1.1	1.2	1.5	1.2

Results for all tests were then used to determine the IR system's capability for measuring crowd density. For each test, the number of people that had entered the field and the number that had exited were used with the method presented in Figure 33 to determine the number of people within the field ($N_{i\ enter} - N_{i\ exit}$) at 1 s intervals for both the IR system and actual. Results for single file (slow and fast), and unidirectional (fast only) are summarised in Table 12. Results for slow group tests (unidirectional and contraflow) are not available, since the group size was not large enough to fill the IR field area so that people were entering the field at one side and leaving at the other side at the same time.

It can be seen from the table that, while it is possible to count the number of people within the IR field at any point in time, error rates for the tests conducted suggest that the IR system does not provide a reliable means for doing so. Furthermore, because of the apparent asymmetry of an IR field caused by direction of approach to the beacon, measurement of congestion for contraflow situations will not be accurate.

Figure 35   Corridor tests at Marine Institute (top: unidirectional; bottom: contra-flow).

Table 12   Results summary for crowd measurement tests (number of people in field).

	Single File, Slow			**Single File, Fast**			**Uni-directional Group, Fast**		
	Video	IR	Diff.	Video	IR	Diff.	Video	IR	Diff.
Mean	6.8	4.7	2.1	4.0	4.4	-0.4	19.2	14.0	5.2
St. Dev.	0.65	1.02	1.21	0.84	1.69	1.60	1.92	1.00	2.59
N	109			74			5		
% Error	31.1%			10.5%			27.1%		

It is hypothesised that it may be possible to use two beacons set to the same ID and mounted on a jig at an angle to each other so that the entry point for one beacon is at the same location as the exit for the other beacon (and vice versa). By mounting the beacons in this way, it may be possible to generate an IR field that is symmetric regardless of the direction of approach. This concept is illustrated in Figure 36 but requires testing to determine its viability.

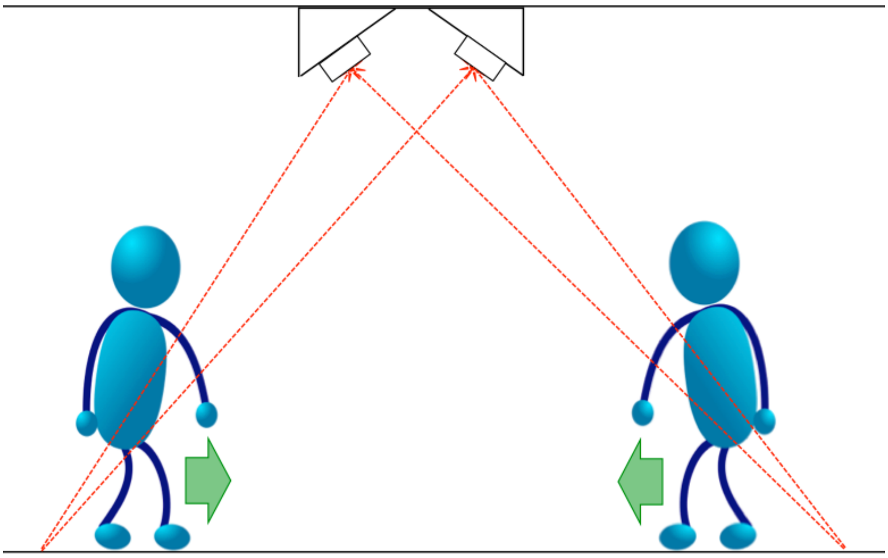


Figure 36 Illustration of density measurement concept using a jig and two beacons set to the same ID.

3.3.7 Detailed Validation of IR Tracking System - at Sea

The planning and conduct of the sea trials will be discussed in detail in the chapters that follow, however, it is worth presenting here the results of validation testing carried-out with the IR system in-situ during trials on the cruise ship *Jewel of the Seas*. To test the accuracy of the arrival times derived from the IR system, video cameras were installed at two entrances to Assembly Station B (AS B). This enabled a comparison of the arrival time derived from the IR system with the arrival times manually determined from the video cameras. In addition, this analysis allowed for a comparison of the total number of passengers passing through the entrance to the assembly station as counted by the IR system with the actual number that could be seen in the video. Both chosen locations were on the ship's starboard side on Deck 5 – one location at the forward end of the assembly station and one near midships, as depicted in Figure 37. The forward location (at beacon location 53, camera UoG12 - Figure 38a) was a doorway with a vestibule leading to the assembly station. The location near midships (at beacon 50, camera UoG10 - Figure 38b) was a doorway that opened directly into the same external assembly station. These two locations were selected as they represented examples of locations in which the beacons were expected to perform well (i.e. beacon location 50) and those that would pose a challenge for the beacons (i.e. beacon location 53).

The difference in performance is expected because of the position and orientation of the beacons with respect to the flow of passengers. Beacon 50 was located on the outer deck of the vessel, generating an IR field parallel to the assembly station doorway and perpendicular to the line of travel of passengers passing through the doorway. Because of the orientation and mounting position for Beacon 50, there is virtually no shadowing effect from the passenger's body on the tag (Figure 39a). However, at Beacon 53, the mounting position was over the doorway inside a vestibule, pointing out to sea (i.e. in the same direction as the flow of passengers into the assembly station). As a result, there is potential for shadowing of the beacon by passengers' head and upper torso as they walk under the beacon, particularly because the presence of a vestibule around the doorway limits the height at which the beacon can be mounted (Figure 39b).

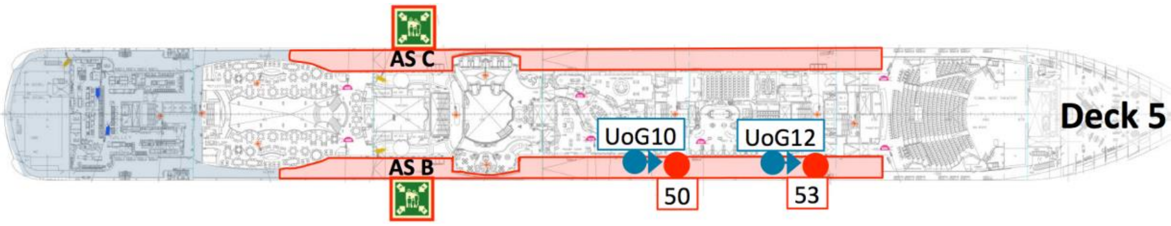
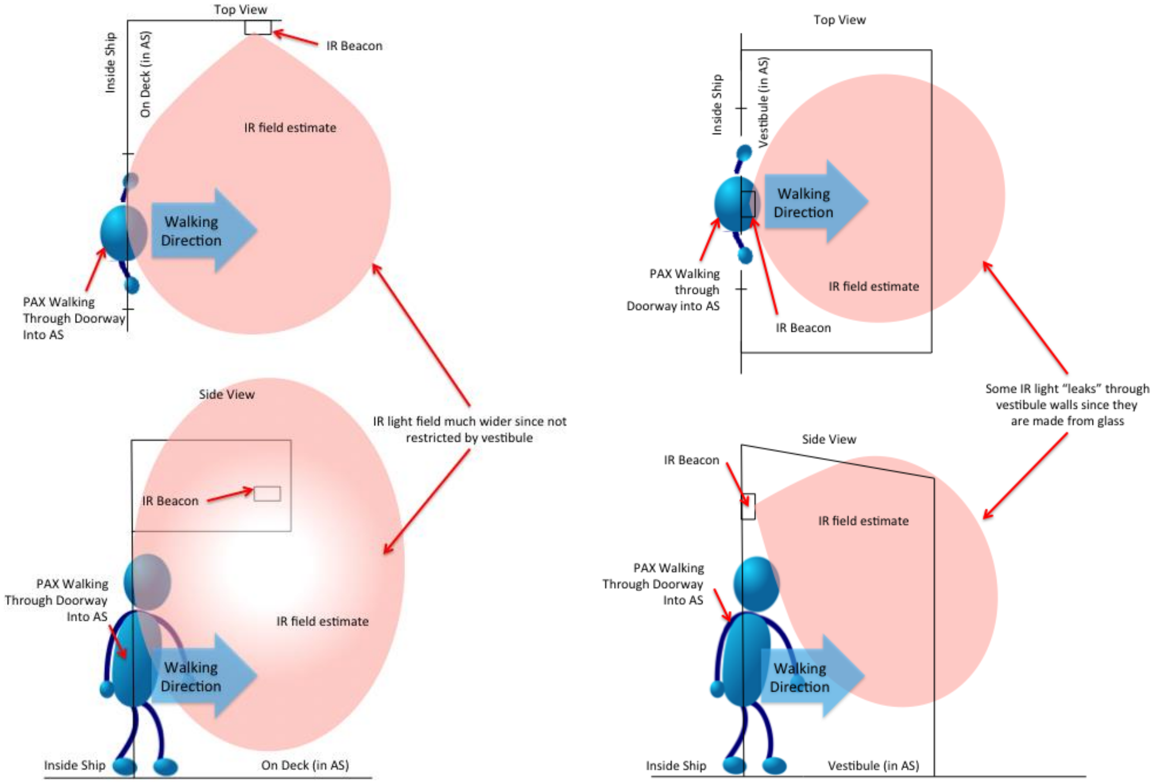


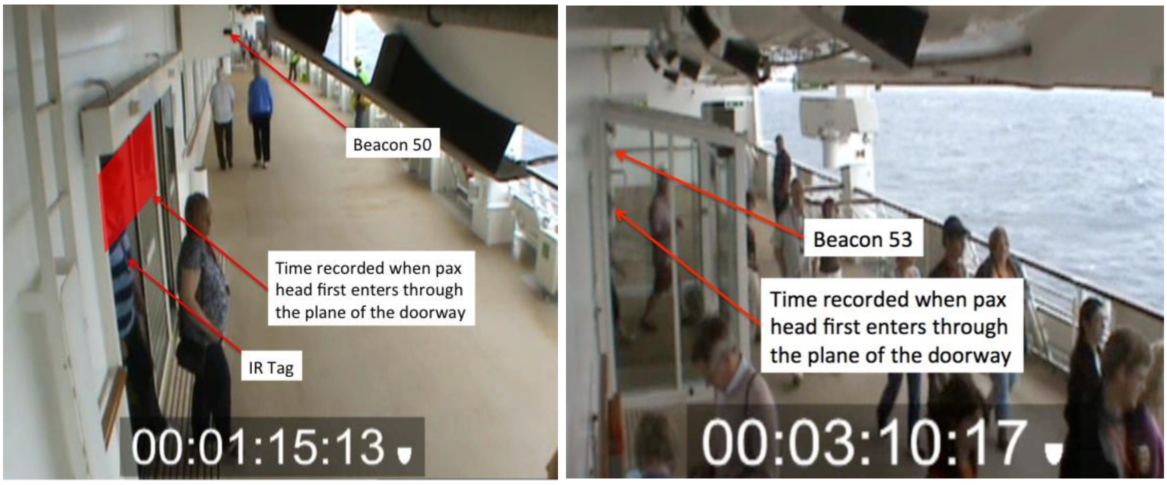
Figure 37 Comparison of the IR and video systems took place on data collected from camera UoG10 and IR beacon 50 plus camera UoG12 and IR Beacon 53.

When analysing the video for both locations (Figure 39), the time at which a passenger's head first passed through the plane of the doorway was taken as their entry time. The passenger's head was chosen because as congestion on deck increased, often the head was the only part of the passenger that could be clearly seen. Because a comparison was being made to the IR data, times were recorded only for passengers that could be clearly seen wearing or holding an IR tag. In addition, because of the way the IR tag data was analysed, the entry times were recorded only for passengers who entered the assembly station and remained there. In some cases, it was necessary to make a subjective judgement of whether a passenger had actually assembled in the relevant assembly station e.g. when a passenger entered into the assembly station and walked out of the view of the camera.



(a) (b)

Figure 38 Depiction of IR fields at (a) Beacon 50 where beacon is expected to perform well; and (b) Beacon 53 where beacon is not expected to perform as well.



(a) (b)

Figure 39 Sample video views (a) Beacon 50 when the 6th passenger arrives; and (b) Beacon 53 when the 21st pax arrives.

From an examination of other entry points to assembly stations on this ship, it is anticipated that these two locations encompass the expected range of beacon/tag performance in terms of passenger count and time lag between the IR system arrival time and the actual arrival time from synchronised video.

Results of the comparisons are provided below in Figure 40 and Figure 41 and Table 13. It can be clearly seen that the IR data collection system matched quite closely with what was measured using the video system for both locations. For the doorway near midships (Beacon 50, Camera UoG10 - Figure 39a, Figure 40) the IR system agreed with the video system and counted 20 tagged passengers that passed through the door. In addition, the IR system produced passenger arrival times that consistently lagged the video results by 2.95 s ± 0.53 s (maximum difference was 3.88 s and minimum difference was 1.72 s).

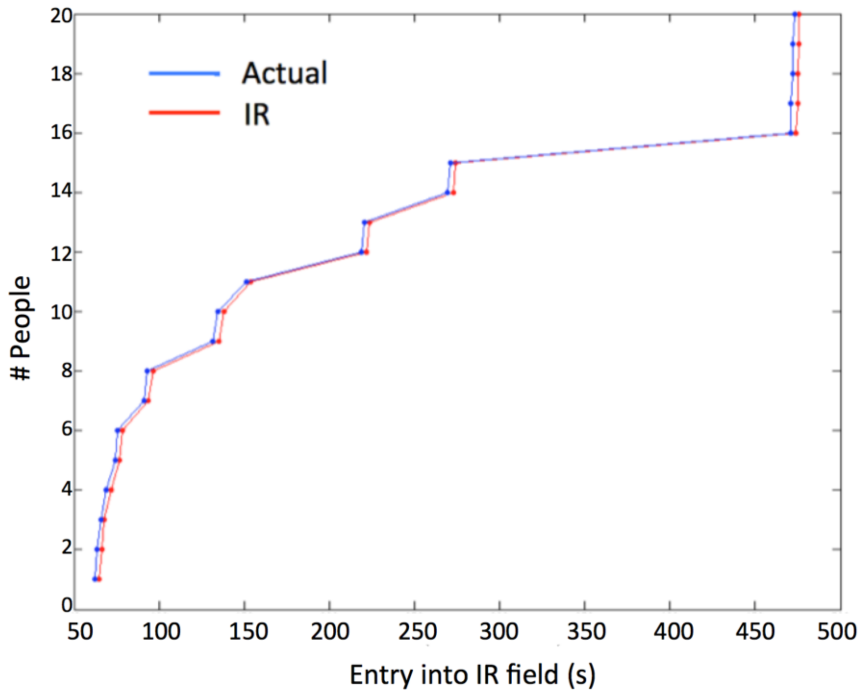


Figure 40 Comparison of passenger arrival time at Beacon 50 and camera UoG10.

For the forward location (Beacon 53, Camera UoG12 - Figure 39b, Figure 41), the IR system also agreed with the video and counted 138 tagged passengers that passed through the door. The IR system produced passenger arrival times that consistently lagged the video results by 5.04 s ± 1.11 s (maximum difference was 9.92 s and minimum difference was 2.00 s). It is noted that the IR system accurately counted the number of passengers even in the high density situation encountered at this location.

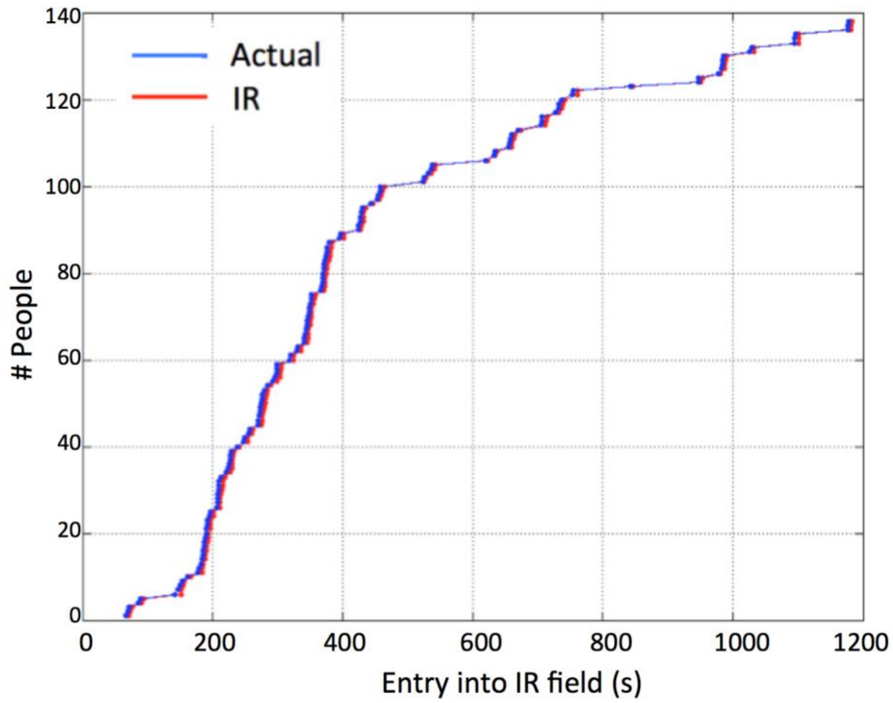


Figure 41 Comparison of passenger arrival time at Beacon 53 and camera UoG12

Thus the IR measured times are expected to be, on average, between 2.95 s and 5.04 s (with a maximum range of 1.72 s to 9.92 s) lagging the actual measured time as derived from the video data. As a percentage error, this varies from 0.3% to 7.2%. Although this in-situ test was carried-out after the system had been chosen and utilized in the sea trials, it supports the decision to use IR technology rather than RFID. Furthermore, the results suggest that the IR system provides an accurate measure of the arrival time for passengers when compared with a synchronised video system, despite a small lag between the actual arrival time and what the IR data collection system actually measures. In addition, the IR system accurately counts the number of people that arrive at the measuring location, even in high-density situations.

Table 13 Results summary for IR system comparison to video on Jewel of the Seas.

Location	**No. People**	**Mean Difference (seconds)**	**Standard Deviation (seconds)**	**Minimum Difference (seconds)**	**Maximum Difference (seconds)**
Beacon50/UoG10	20	2.95 (lag)	0.53	1.72	3.88
Beacon 73/UoG12	138	5.04 (lag)	1.11	2.00	9.92

Using the IR system, one can reliably determine arrival times at each assembly station. While using a video camera system to determine passenger arrival times tends to provide a more precise measure (sub-second) of when a passenger actually arrives through a doorway, unless the passenger then stays in that assembly station and within the field of view of the camera, it is impossible to determine whether he/she has actually stayed in the assembly station or moved to another location outside that assembly station and, thus, can give erroneous results for arrival time. This issue can be avoided when using the IR system as it can continuously record the passenger's location determining whether he/she has left the assembly station or not. Furthermore, as previously noted, the video analysis process would be much more time consuming and error prone and the passenger route, particularly individual starting locations, would not be known.

3.4 Chapter Summary

Improvements in technology have enabled researchers to collect human evacuation behaviour data in increasingly unique and realistic environments. While aspects of behaviour must be observed and assessed manually, other methods allow for automatic determination of behaviour. This chapter has provided an overview of the data required to provide answers to the research questions identified in Chapter 1 and has proposed methods for doing so.

Response behaviour, particularly response time is best assessed using video cameras positioned in multiple areas of the ships. The cameras used must have adequate resolution and field of view in order to determine what passengers are doing. The frame rate should be sufficient to accurately characterise the associated time and cameras should have sufficient storage capacity to capture the entire process. The camera mounting system should enable cameras to be quickly mounted in the wide variety of locations and orientations required that does not draw the attention of passengers and influence their behaviour. The importance of synchronising different types of video cameras to each other as well as other data sources was identified and methods for doing so outlined.

Collecting data for the validation of evacuation models considered two main technologies that can be used to automatically track passenger movement throughout the trials. These were radio frequency identification (RFID) and infrared (IR) and the basic operation of each has been outlined. The chapter provided a detailed discussion of the methods used to assess each technology through trials onshore in corridors, as well as on ships at sea. Following the different tests, a decision matrix was developed to provide an objective means to choosing the best technology for the requirements. Ultimately, IR technology was chosen since it provided a reliable means by which passenger movement could be measured during the exercises, it was less costly in the long term and logistically less challenging to setup and operate for the trials planned. Results from testing of the IR system demonstrated that it could accurately count people 100% of the time and that was accurate to within about 5 s of actual times (lagging).

The planning process for conducting assembly trials on passenger ships at sea requires careful consideration of how to provide necessary information about the trials to passengers while ensuring their safety but not affecting their behaviour; ensuring the data requirements are met; determining logistics for transport, setup and retrieval of all equipment; and planning the team roles and responsibilities so that the trial is executed safely and successfully. These issues are discussed in detail in Chapter 4, along with a detailed review of the ships tested, their routes and the preparations for boarding.

4 Sea Trials: Preparation and Methodology

4.1 General Overview

The research presented in this dissertation is based on data collected during assembly trials carried-out onboard three different large passenger ships, involving crewmembers and with passengers who had paid for their voyage. A total of five exercises were conducted – two on a ferry *without* cabins, one on a cruise ship and two on a ferry *with* cabins (Table 14). Planning and preparations for the sea trials was a lengthy process that took several months for each ship and required numerous visits to the vessels (sometimes including voyages onboard) to discuss trial logistics with officers and crew and understand the layout of each and where data acquisition equipment would be positioned for the trials, as well as to test the equipment to confirm system effectiveness and best mounting positions.

Table 14 Summary of key trial information.

Trial #	1	2	3	4	5
Vessel Name	SuperSpeed 1		Jewel of the Seas	Olympia Palace	
Vessel Type	RO-PAX Ferry without Cabins		Cruise Ship	RO-PAX Ferry with Cabins	
Ship Owner	Color Line AS		Royal Caribbean Cruise Lines	Minoan Lines	
Trial Date	04/09/2009	05/09/2009	31/07/2010	12/03/2011	14/03/2011
Trial Time of Day	0820h	0819h	0901h	0040h	1912h
PAX Onboard	1,431	1,349	2,292	240	270
Research Team Size	26		25	22	

From an experimental point of view, it would be preferable to conduct assembly drills in an unannounced manner (i.e. no prior information given to passengers before the alarm was sounded), since this would provide the most realistic passenger behaviour in response to and following the alarm. However, risk associated with performing the trials in this way would have been too great. For ethical reasons, the passengers were informed that, *at some time during their voyage,* an assembly drill would take place. Thus the trials were planned as *semi-unannounced* assembly exercises with minimal information provided to passengers about the exercise. This method was unique for monitored assembly trials at sea and required special consideration to ensure that all information provided to passengers was consistent from trial to trial to prevent an unanticipated bias in passenger behaviour and to ensure the safety of those involved. It is also worth emphasising that these assembly trials were conducted while the vessels were at sea during a regularly scheduled voyage. This is unusual as almost all ship assembly drills (whether monitored or not) tend to be conducted while the vessel is berthed in port. It was important to undertake the drills while at sea, since this added to the realism of the exercise and helped ensure that passenger behaviour was more realistic. By the time the vessels had left port, passengers had time to become at least a little familiar with the layout, observe any video-based safety briefings, find their cabin or a place to sit and begin any normal activities such as reading, eating, watching a movie or playing a game.

Many months of planning and careful examination of the ships was carried-out in order to determine best procedures and optimum equipment placement, however, unexpected logistical challenges arose from time-to-time, which will be discussed in this chapter. Despite these challenges, the sea trials were carried-out safely and successfully, with no injuries or concerns reported. The collected datasets provide a large corpus of human performance data relating to the assembly process onboard large passengers ships, which is rich in detail and quality. The trials planning and logistics details are presented here to give the reader an understanding of the ships tested, the nature of the test protocol including similarities and differences for each vessel and any significant obstacles encountered. Sections 4.2 to 4.7 provide an overview of general aspects of the planning process that were common to the data collection for all three ships. The final three sections (Section 4.8 to 4.10) present ship-specific details for the trials plan and how it was executed.

4.2 Ethics Approval

Central to any research involving human participants is the need to consider ethical issues very early in the planning process. Doing so helps to ensure the physical and mental well-being of participants, ensuring that the potential benefits of the research outweigh any risks and that participants understand the consent process, what constitutes consent to participate and that they can withdraw from the research at any point without negative consequence. Finally, considering the research ethics also ensures that the team has procedures in place to protect the identity of participants and any personal data collected in the project.

To this end the project team, with significant contributions from the author, developed an ethics application under the leadership of a senior research fellow in the UoG, Fire Safety Engineering Group (FSEG). It was submitted to the University Research Ethics Committee (UREC) at University of Greenwich on 30 June 2009 and consisted of four main sections to outline details of: the applicants, the project, plan for recruitment of participants, consent, insurance and financial interests. The application also included several annexes documenting the following:

- *Informed Consent:* Informed consent generally implies that the participants review information about the experiments in which they are being asked to participate and then sign a form giving their consent to participate and for the project team to collect information about their participation in the research. It was determined that the consent process itself could negatively impact the planned semi-unannounced nature of the trials and potentially introduce a significant bias in the dataset, which would make the collected data less realistic. It was determined that passengers could consent to participate in the research by wearing an IR tag and completing a questionnaire at the end of the trial. The ethics application for this research, therefore, indicated that informed consent was not required for the stated reasons and also because the data to be collected was not of a sensitive personal nature. Furthermore, passengers were informed that they could not be identified in any video collected, since faces would be blurred in any public use of the video.
- *Participants under 18 years of age:* Unaccompanied children under 18 years of age were not allowed to participate in the research. Also, data would not be collected

from the video record regarding response time for children who appeared to be 11 years of age or younger.

- *Risk assessment:* Conducting a risk assessment is important with any research ethics application as it identifies the main hazards to participants; their likelihood and severity, along with the associated mitigation strategies to ensure participants remain safe throughout the experiments. The main risks were identified in the application to the satisfaction of the ethics committee.

The application was reviewed at the 14 July 2009 UREC meeting date and ethical approval was received for the study in writing on 23 July 2009 (approval letter is shown in Appendix A).

4.3 Information for Passengers

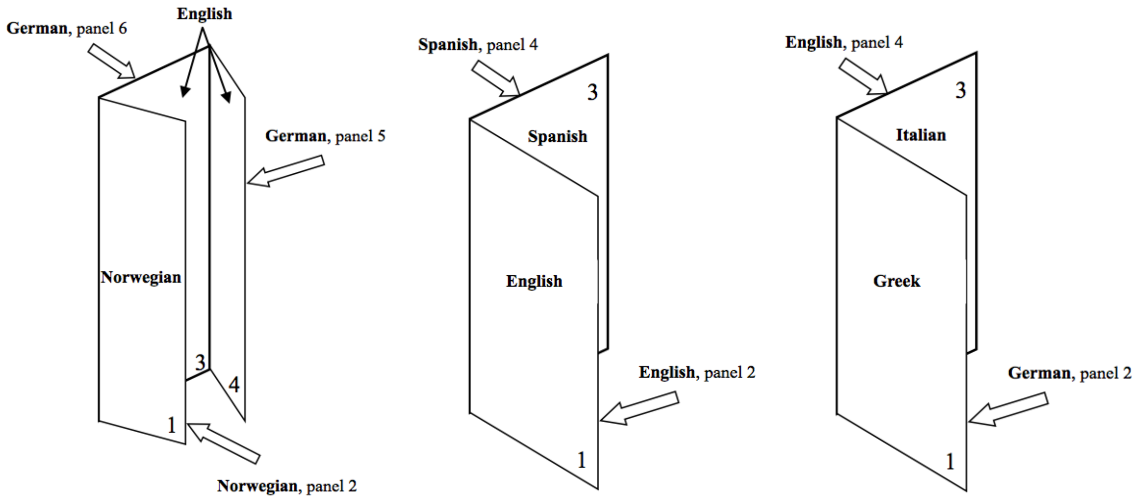
On each ship, information was provided to passengers about the trials. Information was required to help ensure the safety of passengers and that they understood what was going to happen during their voyage, since informed consent was not required as a condition of the ethics approval. The information served two purposes – it gave passengers enough information to ensure their safety, it explained in simple terms how to wear the IR tag and what to do with it after the trial and it let passengers know that their participation in the research was voluntary and how they could go about finding further information after the trial, if desired. Trials information was provided to passengers in two main ways – printed information sheets and verbal information (provided at check-in and onboard the ship from the Captain). Information sheet wording and layout was developed initially by the author and circulated to the rest of the trial team for comments. The development of verbal information for each vessel was developed through trial team discussions, which included the author. Final versions were then produced for each ship and translated by other members of the project team or colleagues within the UoG community.

It was important also to ensure consistency in the information provided from test to test so that all participating passengers received the same briefings from ship to ship. In addition, carefully planning the way in which information was provided to passengers helped ensure that the trials were truly semi-unannounced in nature. This was a very important aspect of the research, since it would be unsafe to carry-out a fully unannounced trial but yet unrealistic and unethical to carry-out a fully announced trial in which the data would be of little value but still exposing passengers to risks associated with the assembly process.

The printed pamphlets provided the following basic information about the experiments:

- An assembly exercise will happen during your voyage;
- You can volunteer to participate;
- You can withdraw at any time;
- What will happen and what you should do;
- How data is being collected and why;
- How and when to wear the IR tag;
- How the research team will protect your identity and data;
- What to do when the exercise is complete (complete a questionnaire and return the IR tag);
- How you can be part of the prize draw; and
- Who are the project partners and where can you find additional information.

In order to ensure consistency of information provided to passengers, the printed information pamphlets remained the same from ship to ship with the exception of the languages in which the text was provided and any minor details relevant for the ship. The information pamphlets were printed on two sides of A4 paper and, depending on the number of languages required, folded either in half (two languages) or in thirds (for three languages) (Figure 42). The ship owner’s representative provided recommendations on which languages should be used.



(a) (b) (c)

Figure 42 Layout for the different information leaflets provided to passengers; (a) ship 1: SuperSpeed 1; (b) ship 2: Jewel of the Seas; (c) ship 3: Olympia Palace.

Scripts developed for check-in personnel and the Captain were also translated into the same languages as the pamphlet. Due to the nature of the different ships and particular details relating to the trials, there were small differences in scripts from ship to ship. In general terms, the check-in staff scripts provided the first opportunity to give passengers very basic information about why they were receiving the pamphlet and IR tag. Staff also encouraged passengers to wear the IR tag right away. Announcements made by the Captain were also developed in a similar way; the first announcement welcomed passengers onto the ship and reminded them that an assembly exercise would happen at some point during their voyage and that they should wear the IR tag. In cases where the exercise took place more than one hour after departure, the Captain made an additional announcement a little before the alarm to remind passengers they should wear the IR tag. The next announcement by the Captain took place after the assembly exercise and announced that the exercise was complete and encouraged passengers to return their IR device and complete a questionnaire. A final announcement from the Captain was made to indicate the ticket number of the prize draw winners and how they could collect their prize.

The scripts used on the different ships, as well as any relevant details about the information provided during trials is given in the sections that follow for each ship.

4.4 Questionnaires

Questionnaires were developed so that passengers could provide detailed information about their experience relevant for the trial. Depending on the vessel being tested, the questionnaires posed between 21 and 24 questions in the same languages as used for the information pamphlets and scripts. Passengers were asked to provide a range of information about themselves, their experience travelling at sea, what they thought was happening when the alarm sounded and what they did. A summary of the questions asked is provided in Table 15. The research team also decided that the questionnaire could be used to link passenger's route and total assembly time by providing a space on the questionnaire in which passengers could record their unique IR tag number. This provided a unique opportunity to examine passenger behaviour in a more detailed manner not previously conducted in evacuation studies.

A detailed analysis of the questionnaire results was considered to be outside the scope of this dissertation (since it does not relate to passenger response time and it was not used to develop the ship evacuation validation dataset). However, it is important for details about questionnaires to be provided here since the author had significant involvement in developing the scope of the questions. It is planned that this dataset will be analysed at a later stage by the author. Details of the questionnaires provided on each ship are given in the sections that follow.

Table 15 Summary of the questionnaire content asked.

Question	Options
Age group	0-19 / 20-39 / 40-59 / 60+
Gender	M / F
Mobility Impairment?	Visual, Hearing, Physical, Other, None
Travelling with a group?	How many, including yourself?
How often do you travel by ship per year?	
No. times travelled on this ship before?	
No. times travelled on a cruise ship before?	
Involved in assembly exercise on a ship before?	Y / N
What did you think when the alarm sounded?	Exercise / real emergency / other
How did you feel when the alarm sounded?	Unconcerned / concerned but safe / worried I might be injured / worried I might be seriously injured
What deck were you on and where when the alarm sounded	Deck no. & restaurant / cabin / theatre / shopping area / exterior lounge / pool / casino / general seating / bar / disco
What were you doing before the alarm	Eating / drinking / sleeping / socializing / shopping / individual activity (e.g. reading) / other
How long before you to started moving to the assembly station?	0-5, 5-10, 10-15, 15 + min
After you were aware of the alarm, did you	Go directly to the assembly area / continue activity / wait for instructions / discuss what to do / search for your group / return to cabin (if relevant)
No. group members moved with you to the assembly area?	
Was it difficult to find the assembly area?	Y / N
Did crew assist you in finding the assembly area	Y / N
What did you use to find the assembly area?	Signage / crew instructions / following other passengers / prior knowledge
How useful was signage?	1-5 (not at all – very)
Did you have to stop due to congestion?	How many times?
Did anything hinder your progress to the assembly area?	Congestion / lack of instructions / lack of signage / insufficient crew / ship motion / confusing announcements / confusing instructions / confusing signage / poor knowledge of the ship layout
How long did it take to reach the assembly area?	0-2; 2-5; 5-10; 10-15; over 15 min
Did you find the assembly exercise stressful?	1-5 (not at all – very)

4.5 Shipping of Trial Equipment

A large amount of trials equipment was shipped to the vessels for each trial. Due to requirements of insurance, handling and local customs and excise, it was necessary to accurately document all the items being transported. All camera equipment, required accessories and supplies were packed into protective cases (measuring 600mm x 460mm x 210mm), along with two-way radios and stopwatches for manually timing the exercises if required (an example of equipment being prepared for shipping is shown in Appendix B - "exploded" view and a case "as packed"). Typically, each camera case contained six digital cameras with required equipment, two two-way radios and two stopwatches. A laminated A4 sheet containing an itemised list of the contents was placed inside each case being shipped. The author was involved at all stages in the packing, weighing and shipping of equipment for all trials.

The IR tracking system was packed into separate cases with each containing 400 tags and lanyards or a combination of beacons and tags with lanyards (Appendix B). Additional materials such as pencils, questionnaires, high visibility vests and caps, and tag storage bags were shipped in separate cases with the rest of the equipment.

For trials on the first ship, SuperSpeed 1, a total of 11 cases with a combined mass of 222.6kg were shipped to Denmark and delivered onboard the vessel before it returned to Norway where it could be accessed by the trials team for trial preparation. For the second ship, Jewel of the Seas, the UoG team rented a people carrier van that could fit all the UoG team members and equipment and drove directly to the port. For this trial, a total of 13 cases with a combined mass of 273.55kg were shipped. For trials on the final ship, Olympia Palace, a total of 7 cases with a combined mass of 166.6kg were shipped to the Minoan Lines main office in Athens and personnel from Minoan Lines transported the equipment by road to the vessel in Patras.

4.6 Trial Team Requirements

This section outlines the research team requirements for the sea trials and the associated skills and responsibilities for each team member onboard each ship. A general description is provided here and specific requirements for each ship are given in the relevant sections that follow.

Two skill-sets of primary importance for all exercises were the *ship liaison* and the *controller*:

- **Ship liaison** was an employee of the shipping company responsible for ensuring onboard activities complied with company requirements. This individual also acted as a liaison between the research team, the ship owners and the Captain of the ship.
- **Controller** was the scientific lead for the project (Professor Galea from UoG) and was responsible for overall control of the trial and the various teams identified. This individual made sure that trial activities were set and run as planned. The controller was responsible for ensuring the trials ran smoothly and for coordinating the activities of the various teams.

A total of six teams are described below. These were made-up of different individuals assigned to the project from within UoG, as well as partners on the SAFEGUARD project. The author was onboard the three ships for all trials carried-out. In most cases, in order to keep the size of the team to a minimum the team members of one group were "recycled" when appropriate by being made part of a different group with different roles once their duties in a particular group have been completed, for example, the entry team became the exit team, with the addition of one person from the setup team. The various teams communicated with each other and the controller by using 2-way radios (i.e. walkie-talkies). Details regarding team make-up and any particulars for the ship being tested are provided in the relevant sections that follow, with a summary for each as follows:

- **Technical team** was responsible for the technical equipment and planning aspects of the trials, and included the author.
- **Setup team** was responsible for installing and verifying the proper operation of the data acquisition equipment (video cameras and IR beacons) according to the trials plan developed for each ship, and included the author. The setup team was scheduled to begin work in the early morning hours before each trial. Depending on the setup requirements, this team was split into sub-groups of two people who

could work together to deploy equipment in different regions of the ship or on different decks.

- **Entry team** was responsible for checking that each passenger had donned an IR tag as they were boarding and that they had received the information leaflet. The size of this group was determined by the number of entry points from car decks (if applicable) as well as for walk-on passengers. The author was not part of this team.
- **Assembly team** issued questionnaires to the participating passengers in the assembly stations at the end of each trial. The assembly team was also responsible for collecting the IR tags from passengers, along with the completed questionnaires. The assembly team was trained how to interact with passengers in an appropriate manner and how to use a stopwatch to time the last person arriving in the assembly stations. The total number of people required for the assembly team for each ship was determined by the number of assembly stations and the number of available entry points to each. Members of the assembly team wore a brightly-coloured vest and hat, and carried a brightly-coloured satchel for holding pencils, questionnaires and IR tags (Figure 43). Prior to the start of the trial, the assembly team members moved to their assigned assembly station and reported to the Controller that they were in position and ready for the trial. Once the alarm had sounded, the assembly team members donned the high visibility jackets and baseball caps and started collecting IR tags and distributing questionnaires from passengers who had entered the assembly station. As the team distributed questionnaires and pencils, they reminded passengers to write their tag number on the top and to keep the prize draw ticket by tearing off the perforated end of the questionnaire. Crew assigned to the assembly stations generally assisted the assembly team members with the distribution of questionnaires and collection of IR tags and completed questionnaires. At the end of the trial the assembly team placed collection baskets in key public areas onboard and roamed around the ship to collect any completed questionnaires and IR tags that had been missed in the assembly areas. The author was not part of this team.
- **Equipment collection team** was comprised of members of the *setup team* (including the author) and was responsible for removing all cameras and IR beacons, and placing them in a safe area at the end of each trial. Removal of the equipment began when the controller notified the team that the assembly process was complete. It was important to remove all equipment as quickly as possible in

order to reduce the possibility of theft or damage, particularly in the case of cameras since all response time data was contained on the camera hard drives and loss or damage would result in data loss.

- **Data transfer team** was comprised of members of the *setup team* (including the author) and was responsible for transferring all data from the video sources and IR tags to laptop computers brought by the team.
- **Exit team** was comprised of the *entry team* plus members of other teams not allocated a role after each trial. This team was tasked with traversing the ship to ensure that all passengers returned their IR tags and questionnaires before disembarking. The author was not part of this team.

Figure 43 Typical assembly team member in trials uniform.

4.7 Passenger Incentives

For voyages less than 24 hours duration, it is not a statutory requirement that the crew conduct an assembly trial. Thus, for trials on the two ferries, passengers' participation was entirely voluntary. For the cruise ship, passengers were required to participate in the assembly exercise, however for all cases the passengers were not required to wear an IR tag or complete a questionnaire. To encourage passengers to wear a tag and complete a questionnaire, it was decided that incentives would be offered onboard all three ships in the form of a raffle for prizes. To qualify, passengers had to record their IR tag number in a space provided on the questionnaires distributed and answer all questions fully. The prizes offered will be described in the sections below for each ship. It is important to note that the value of the prizes was not so great as to encourage unsafe behaviour or to coerce passengers into doing something they would not normally do. Passengers were told to remove and keep the perforated portion of their questionnaire and give the completed questionnaire to a member of the research team. The portion removed had a number matching the number on the questionnaire and, thus, amounted to a unique ticket that the passenger could check following an announcement made by the Captain during the voyage. On completion of the exercise, the Controller and a member of the Assembly team brought all questionnaires to a private location onboard and kept only the questionnaires that met the requirement of being fully completed. The remaining questionnaires were then brought to a meeting area where the Captain randomly chose the winning questionnaires and announced the winning numbers on the ship's public address system.

4.8 Detailed Planning for the First Ship - M/S SuperSpeed 1

This section outlines the detailed planning and procedures developed leading-up to trials on the first ship. Since this was the first vessel tested, it also meant the first operational testing with the IR tracking system, which required a significant planning effort and equipment shakedown process to ensure successful operation.

4.8.1 Vessel Details and Route

The first vessel tested was SuperSpeed 1 (SS1) – a RO-PAX ferry operated by Color Line AS in Norway (Figure 44). Vessel particulars are provided in Table 16 and the route taken by the vessel during the trials is shown in Figure 45 - from Kristiansand in Norway to Hirtshals in Denmark, a voyage of 3 hours and 15 minutes each direction.

Figure 44 Color Line SuperSpeed 1 RO-PAX ferry

The ship contains a mixture of public passenger spaces across three of the vessel's eleven 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. While SS1 does have a small number of cabins onboard (54 in total – 2.8% of the total passenger capacity), during the trials these were used only by truck drivers who are required to log hours of rest as part of the terms of their employment.

Table 16 SuperSpeed 1 Particulars.

Length Overall (m)	213
Beam (m)	26
Draught (m)	6.7
Gross Tonnage (t)	34,231
Maximum Speed (kn)	31
Total Decks	11
Passenger Decks	3
Passenger Capacity	1,928
Crew Capacity	71
Car Capacity	764

Figure 45 SuperSpeed 1 route between Kristiansand (Norway) and Hirtshals (Denmark).

In early September, SuperSpeed 1 sails round trip two times daily from Kristiansand, Norway to Hirtshals, Denmark every day of the week, except Monday when it completes only one round trip sailing (leaving in the afternoon from Kristiansand). On Monday mornings the vessel's crew undertake fire and lifeboat drills without passengers onboard and complete any routine maintenance required on the vessel. The vessel departs Kristiansand at 0800 and on a typical day, each leg of the crossing takes 3h and 15 min with an additional 1 hour turnaround time in Hirtshals before returning to Kristiansand. The schedule is repeated again in the afternoon with the vessel returning to port in Kristiansand by approximately midnight. Business, tourist and casual travellers, as well as truck drivers delivering goods between Norway and Denmark travel the route, a distance of approximately 70 nautical miles.

Two assembly exercises 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 20 minutes after the vessel departed from Kristiansand 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 1,431 and 1,349 passengers were onboard for the first and second trials, respectively.

4.8.2 Pre-Trial Planning

As part of the planning process, the research team made numerous visits to the vessel (initially, visits were made to SuperSpeed 2 and later to SuperSpeed 1 when it was decided to change vessels). Members of the team (including the author) travelled round trip between Larvik in southern Norway to Hirtshals in northern Denmark a total of six times. During these voyages, the team was able to observe the distribution of passengers throughout the ship during typical voyages, test camera mounting equipment and determine if camera field-of-view at each location of interest would enable collection of the passenger response times. The team spent considerable time testing the performance and logistical challenges associated with setup and operation of automatic path logging equipment (both RFID and IR, until the decision was made to use IR tracking for the project). Ship visits also provided an opportunity to hold detailed discussions with the Captain and crew regarding the trials plan and to observe crew and passenger activities during typical voyages to determine any potential logistical challenges that might arise. As part of the site visits, the team reviewed passenger check-in areas for the two different boarding procedures available – those walking onboard and those driving onboard the vessel. Understanding boarding procedures was important to ensure proper distribution of information leaflets and IR tags to passengers.

The research team made the first pre-trial visit to the Color Line vessel SuperSpeed 2 on 25 June 2009. During this visit, the team met with the Color Line shore-side liaison, Captain, Chief Officer and Safety Training Co-ordinator. The team discussed the trials plan at length and received feedback on proposed procedures. The research team also travelled round trip from Larvik to Hirtshals. As part of this pre-trial visit, the research team familiarised themselves with the layout of the vessel and discussed with the Captain and senior officers appropriate times during the voyage to conduct the trial. The research team also undertook a more detailed inspection of the vessel in an attempt to identify possible camera locations and possible RFID/IR antenna/beacon locations. It was estimated initially that 60 cameras would be required to provide sufficient coverage of the vessel to collect the majority of participant response times. In addition to the number of cameras, it was important to identify precise camera positions and the best method for mounting so that the team would be able to act quickly during setup on the trial dates so that only minor modifications in the camera setup plan would be required on the trial days. This would ensure: consistency between tests, efficiency in setup time and reduce the likelihood that logistical problems would arise at the last minute.

Also during this visit, in-situ testing of an RFID system was carried-out to determine its suitability for use onboard ships. As outlined in Section 3.3, the test suggested that the RFID system may be appropriate in this environment. The IR system that was eventually chosen was not tested during this ship visit.

During this visit to the ship, possible passenger escape routes leading to the assembly stations were identified and noted on the ship's plans. From discussions with the Captain and the ship owners it was established that the trial questionnaires should be written in three languages; Norwegian, German and English, since the passengers most frequently travelling this route would be expected to be able to read at least one of these languages.

Following the first pre-trial visit, the research team discussed camera positions and determined that the 60 positions initially identified could be significantly reduced to 30 without a major loss of data quality. It was determined that at least one additional pre-trial visit would be required in order to finalise the camera locations, further test RFID and IR equipment and finalise positions for RFID antennae or IR beacons, depending on which system was chosen for the trials.

The research team undertook a second pre-trial visit to SuperSpeed 2 on 15 and 16 July 2009. During this visit the team travelled onboard the vessel for a total of 4 return trips between Larvik and Hirtshals. Additional in-situ tests were performed with both the IR and RFID equipment and the team conducted further inspections of the ship to finalise the mounting locations and methods for all data acquisition equipment. The proposed timing of the trial was discussed in detail between the UoG team and the Color Line personnel. The time of the trial was chosen to reduce the likelihood of disruption to the passengers and the normal operation of the vessel. Based on the vessel's sailing schedule and an expectation of what passengers would be typically doing at different points throughout the voyage, the project team decided to hold the drill within 30 minutes of departure.

Although all plans were developed for trials onboard SuperSpeed 2, as the trial dates approached the team was notified that the number of passengers booked for the voyages on SuperSpeed 2 were approximately 10% of usual booking numbers. However, for the same dates the voyage on sister ship SuperSpeed 1 had the desired level of passengers booked. Thus, the ship owners suggested to the research team that it would be acceptable if the trials took place onboard SuperSpeed 1 instead. Although the vessel was said to be identical in most aspects to the SuperSpeed 2, it was decided that the author and two members of the research team from UoG would travel to the port of Kristiansand two days earlier than originally planned in order to assess the magnitude of difference between the vessels. In addition, it was necessary to have discussions with the vessel's Captain and his officers, since they were not familiar with the trials plan. While some minor differences were found between the vessels, the team easily made adjustments to the trials plan and the trials proceeded on the dates planned. This required some changes to trial logistics, particularly around transport of the team to join the ship. In the end, the two trials were successfully undertaken on the dates planned.

4.8.3 Data Acquisition Equipment Preparations and Positioning

Following from the numerous vessel surveys described in the previous section, it was determined that a total of 30 battery-powered digital video cameras owned by UoG would be required in order to cover all areas of the ship where passengers would likely be found at the sounding of the alarm. This included the main restaurant, shops, bar (on two decks), airline style seats, business class and general bench-style seating. The positions of the video cameras are shown in Figure 46.

In addition to video cameras, it was determined that a total of 30 IR beacons would be required in order to capture approximate passenger start times and locations during the exercises, as well as the assembly station used and arrival time. The position of IR beacons is shown in Figure 47. A trials plans was developed that also identified the view from each camera location, details of the camera orientation and mounting method chosen.

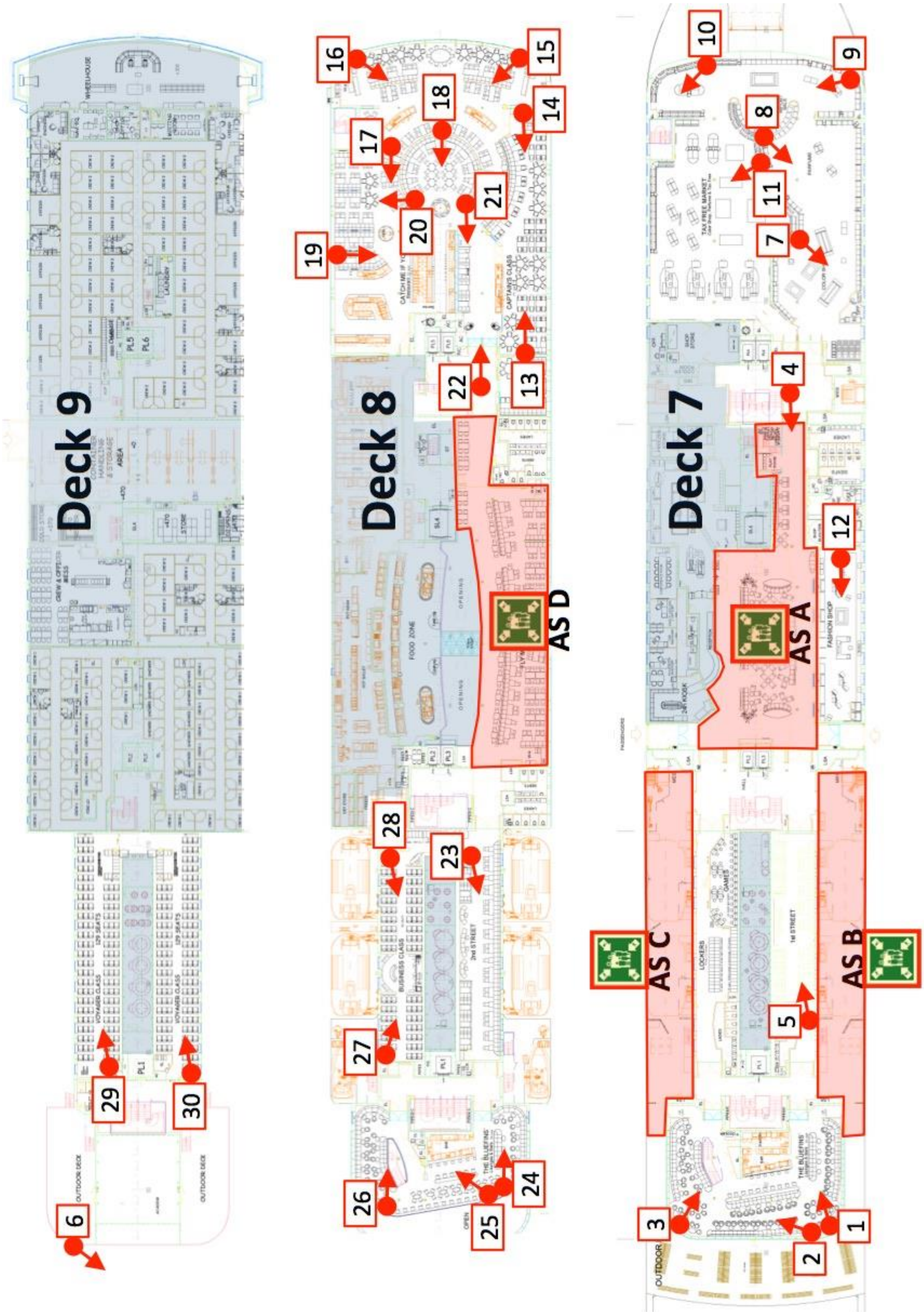


Figure 46 Camera locations (circles) and direction of view (arrows). Note that camera 6 shown on deck 9 views the open deck area on deck 7 at the aft end of the vessel. Shaded areas without thick boarders were not accessible by passengers.

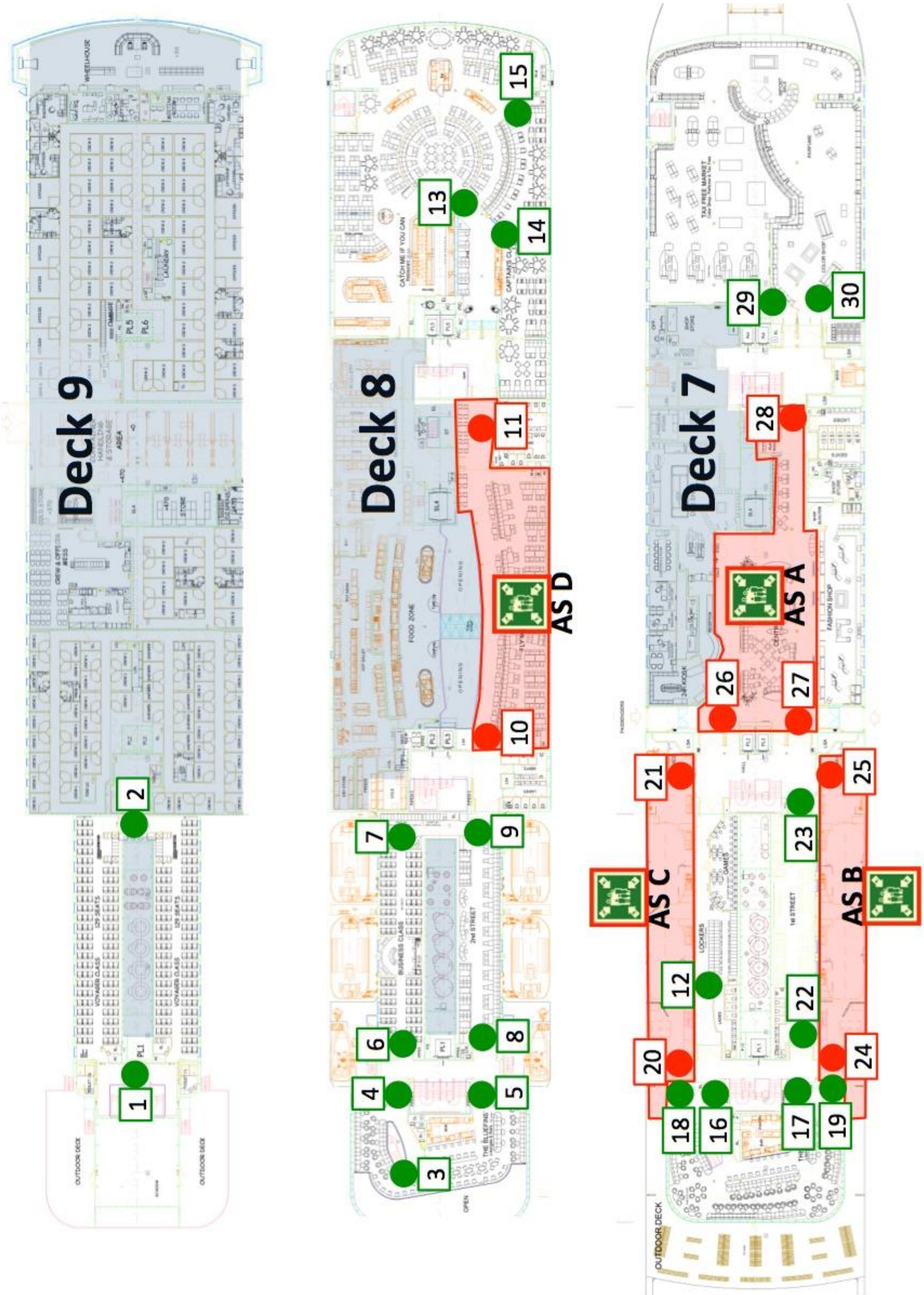


Figure 47 IR beacon locations (circles) on SuperSpeed 1 (circles within assembly stations identify end locations).

In the final stages of preparation for the trials on SS1, equipment was packed in hard-shell cases as outlined in Section 4.5 and shipped by road to the port of Hirtshals in Denmark, where it was offloaded to SS1 and travelled on the next voyage to Kristiansand. In Kristiansand, the team moved the cases to a private work area of the shore-side terminal provided by Color Line and began unpacking IR beacons and tags to prepare them for distribution to the Color Line passenger check-in areas. The team was informed that approximately 1,300 passengers had booked passage for the first trial day, so a total of 1,500 IR tags were unpacked. The IR tags had been set to a “sleep” mode for transport and storage, in which the sample frequency for detecting IR signals was once per minute (as opposed to once per second for “awake” tags). The tag “sleep” mode was the preferred mode for storage since it meant the tags would not record IR beacon IDs within range (the only IR beacon signal capable of being detected in this mode was the “on” signal set by the beacon internal DIP switches, thus tag memory would not be filled with unnecessary information). In addition, tag sleep mode significantly lengthened battery life of the tags. The tags being used in the SS1 trials were laid-out on several tables with an IR beacon set to emit an “on” signal positioned nearby (Figure 48). After being exposed to the “on” signal for a few minutes, the tags were taken to a different table where they could be checked to ensure all were in “awake” mode, counted and lanyards wrapped around the outside for tidier storage at check-in areas and, thus, faster distribution to passengers checking-in. The counted and checked tags were packaged in cardboard boxes in known quantities (Figure 49) along with equal numbers of information pamphlets and on the day before the trial, transported to the different check-in desks in the terminal for walk-on passengers and drive-through kiosks for passengers travelling by car.

At approximately 02:00 on the first trial day, the team boarded the ship and began setting-up IR beacons and cameras in the locations illustrated in Figure 46 and Figure 47. During setup, all beacons were set to the “on” position, since beacon battery life was not a concern if operational for a few days. However, video camera battery life and recording capacity were both more limited in duration so once setup, cameras were left in the off mode until closer in time to the trial. When directed by the trial controller, the setup team walked around the vessel and set the cameras to the “on, recording” position. This was done discretely so as not to draw attention to the equipment and potentially bias the passengers’ behaviour during the trial.

(a) (b)

Figure 48 Shore-side preparation of tags (a) activate tags (activation beacon circled in green) and confirm tags are awake (b) counting and preparing for distribution.

Figure 49 Preparation of tags for distribution to passenger check-in areas.

Figure 50 Setup team installing equipment on SS1.

For additional details of the trial planning and execution process, the reader is referred to Appendix B, Section B2.

4.8.4 Trial Challenges and Outcome

Both trials on SuperSpeed 1 were completed successfully and in a safe manner without injuries, however, the team did experience a few challenges, which resulted in loss of a portion of the dataset. For trial 1, at approximately 04:00, a crew member began executing one of his normal duties - washing the external deck areas of the ship with a high pressure, high volume hose. Unbeknownst to the project team, a beacon (Figure 49, ID #20 - positioned to give assembly time at the aft entrance to assembly station C on the vessel's port side) was damaged by ingress of water and did not provide an IR signal strong enough for tags to detect. This issue was only discovered after the trial was completed when performing a quick review of the data collected. This meant, ultimately, that the assembly data collected during trial 1 was of no use, since the record of passengers assembling was not reliable, particularly at this location.

However, all video data captured during this trial was useful since its purpose was to characterise passenger response time at the beginning of the assembly process. As a preventative measure, when preparing for trial 2, a request was made to the ship liaison that the vessel wash-down not take place on that day. A detailed inspection of beacon ID #20 found that it could not be fixed in time for trial 2. Examination of the beacon setup plan showed that beacon ID #12 could be removed from its location and setup at the beacon ID #20 location, since the original position of ID #12 was non-critical. Trial 2 on SS1 was completed without incident and a complete dataset was collected as planned.

4.9 Detailed Planning for Second Ship – C/S Jewel of the Seas

Given the range of vessels and routes in the Royal Caribbean Cruise Lines International (RCCL) fleet, a senior member of the project team travelled to Miami, Florida, USA 12-16 March, 2010 to meet with RCCL personnel and board several ships to determine the most suitable for the research. Three ships were visited – Independence of the Seas (Freedom Class - 5,730 person capacity, 339m LOA), Majesty of the Seas (Sovereign Class, 3,577 person capacity, 268m LOA) and Jewel of the Seas (Radiance Class, 3,360 person capacity, 293m LOA). The team member boarded each ship with the RCCL safety superintendent, photographed the different key areas onboard each, obtained general arrangement drawings for the vessels, held discussions regarding vessel routing and schedule details, and relevant information about onboard procedures that should be considered. The research team member also viewed the conduct of an assembly trial on each ship. Following detailed discussions among the project team at UoG, the Radiance Class vessel - Jewel of the Seas (JoS) was chosen as the trials cruise ship, primarily due to route, scheduling, vessel size and capacity. While this was the smallest of the three vessels examined, it was felt that using this vessel would still provide a significantly rich dataset, while being manageable for planning and logistics.

Experience gained from the first two trials on SS1 provided valuable experience for the protocol development on JoS. The test protocol and documents developed for SS1 served as a useful starting point for planning on Jos. It is worth noting here that the original plan was to carry-out two assembly trials on JoS, however, the vessel owner was unable to meet this request so just one trial took place. It was determined that this would be acceptable, given the large number of passengers and the range of passenger spaces onboard, which allowed for a comparison of results from one area of the ship with another.

4.9.1 Vessel Details and Route

Jewel of the Seas (JoS), is one of four *Radiance Class* cruise ships operated by Royal Caribbean Cruise Lines International (Figure 51). At the time the trials were conducted, JoS had a capacity of 2,501 passengers and 859 crew. Vessel particulars are provided in Table 17. The route (Figure 52) taken by the vessel during the trial was from Harwich (UK) to St Petersburg (Russia) via Copenhagen (Denmark), a total voyage of about 7 days.

Figure 51 Jewel of the Seas cruise ship [238].

The trial was conducted on the leg of the voyage between Harwich and Copenhagen. The ship contains a wide variety of passenger spaces spread over 12 decks including; staterooms (cabins), restaurants, bars, large retail spaces, theatres, cinemas, gymnasium and sports facilities, a casino, indoor and outdoor general seating areas and general circulation spaces. The drill was conducted on 31 July 2010 at 09:01 on the morning (about 16 hours) after departure from the UK. A total of 2,292 passengers were on board.

Table 17 Jewel of the Seas particulars.

Length Overall (m)	293
Beam (m)	32
Draught (m)	8.1
Gross Tonnage (t)	90,090
Maximum Speed (kn)	25
Total Decks	13
Passenger Decks	12
Passenger Capacity	2,501
Crew Capacity	859
MVZ	7
Assembly stations	26

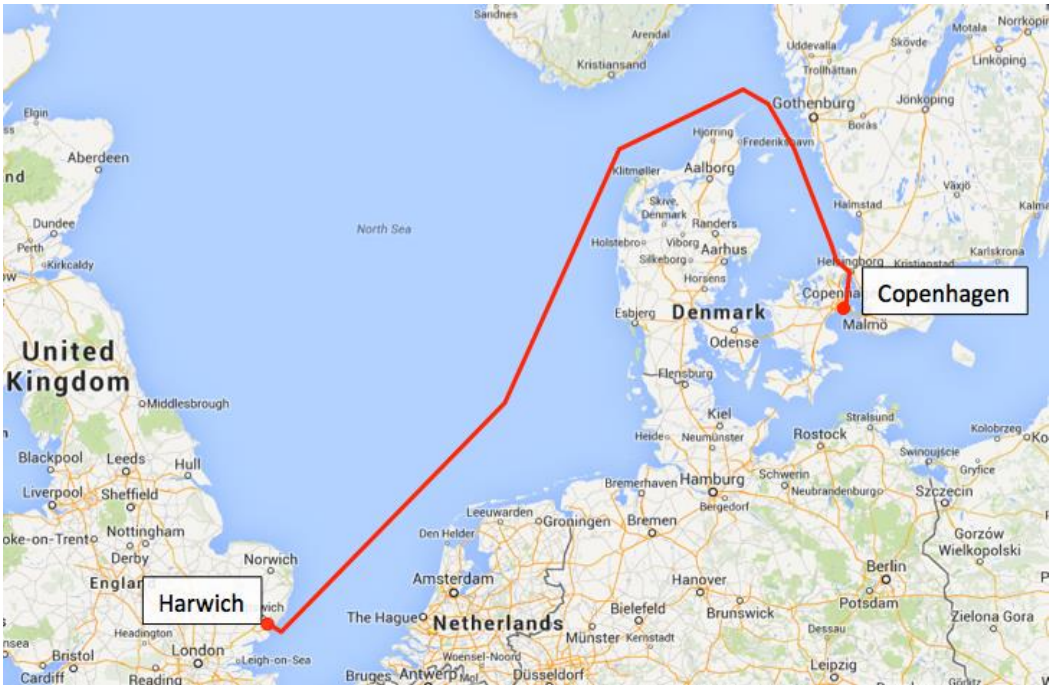


Figure 52 Route for first leg of JoS voyage (approximately 2 days), with trial 3 undertaken on the North Sea, approx. 16 hours after departure at 1700.

4.9.2 Pre-Trial Planning

Despite being the smaller of the three RCCL vessels considered, JoS was a significant challenge to plan for due to the number of passengers involved, the amount of measurement equipment required and the sheer size of the vessel – movement between 12 decks, with each almost 300m long required a well thought-out plan. It became clear from the first planning visit made to the ship that UoG had insufficient video equipment to cover all regions where passengers were likely to be located prior to the trial. Furthermore, the complexity of the assembly station locations and the paths to the assembly stations required a larger number of IR beacons in order to acquire the necessary data.

RCCL personnel suggested ways to address some of these issues – since the vessel had a large number of security video cameras (closed circuit television – CCTV), it was noted that many cameras were positioned along all the passenger cabin corridors, stairs and public spaces, which meant that the research team could make use of the CCTV cameras to record response time data. However, a number of issues had to be resolved, in particular:

- A simple procedure to convert video footage from the ship's video system (.nvf) to a standard format (that could be used by the video analysis software, e.g. .avi or .wmv).
- The ship's video system was programmed to record video only when movement was detected. To measure and determine response times and response time behaviours it was necessary to record continuous video from just before the alarm was sounded to the point when everyone had left the area.
- Determine whether or not it was possible to record video footage from multiple video cameras when recording in continuous mode.
- Determine whether or not the system could record directly to an external memory device or if recorded video could be exported to an external device.
- Determine whether the exact locations of the ships' CCTV cameras provided the coverage required for SAFEGUARD.
- Determine whether the converted video footage provided appropriate quality for the research needs.

- Determine if the CCTV system recorded audio synchronised with the video and, if not, how to synchronise the CCTV video data to the UoG camera data and the IR system data.

Since the initial visit to the vessel while in Miami was only for a few hours, there was not enough time to assess precise camera or beacon locations. The precise positioning of the recording equipment as well as the type of mounts needed for the cameras (i.e. magnetic or clamp) was carried-out during follow up visits.

The second visit took place on 19 May 2010. The author and a member of the UoG research team visited JoS at Harwich International Port in the UK. During this visit the team made first contact with the crew, in particular the security officer who explained the functionality and features of the CCTV system. The team also obtained ship plans indicating the CCTV camera locations and familiarised themselves with the layout of the vessel in order to plan the IR beacon deployment and possibly any UoG cameras in locations that were not covered by the CCTV system.

The third visit took place on 31 May 2010. The author and a member of the UoG research team visited JoS again at Harwich International Port. During this visit the team obtained video samples from a small number of the CCTV cameras. The team also physically located all CCTV cameras that had been previously identified for the trial. The team also identified the areas where UoG cameras would be installed.

The fourth and final pre-trial visit took place on 18 July 2010. The author and three members of the project team visited JoS at Harwich International Port. During this visit, the team met with the Captain and the senior officers to discuss the finalised trial plan. The research team tested 2-way radios to determine if they would function as expected on board the ship (considering the vastness of the vessel). During this visit, a team member also verified the procedure of copying a large amount of video footage from the CCTV system to an external hard disk to ensure that after the trial it would be possible to obtain all relevant video footage.

4.9.3 Data Acquisition Equipment Preparations and Positioning

As noted above, response times on JoS were captured using a combination of digital video cameras installed by the research team and the ship's onboard CCTV security camera system. A total of 106 video camera positions (presented in Figure 53 to Figure 56) were used to capture passenger response time for the trial - 12 battery-powered digital video cameras setup by the project team and 94 shipboard CCTV cameras. Although JoS is much larger and spatially more complex than SS1, using the CCTV camera system simplified the vessel survey and camera planning process considerably.

The JoS CCTV system was comprised of three different types of cameras - colour and black-and-white micro fish-eye cameras, ceiling mounted dome style digital cameras and analogue cameras. All camera feeds were monitored and stored in the Security Officer's office using the commercially available system NiceVision Control Centre software [239].

On 29 July 2010, one day before boarding JoS, the research team met at the town of Weeley (near the port of Harwich) to prepare equipment for the trial. The preparations were carried-out at the research team's hotel (hotel staff provided a private space where the team could work). Nine members of the research team transferred all equipment to the hotel workroom and prepared all information sheets and IR tags for deployment onboard the ship (Figure 64), ensuring tags were activated from sleep mode and counted before being placed in envelopes with specific cabin numbers. Based on information received from RCCL, a total of 2,400 envelopes were printed with the cabin (stateroom) number and the number of people occupying the cabin (excluding children under 11). The envelopes were placed in the passengers' cabins by the JoS crew before sailing (Figure 58).

The location of all IR beacons is shown in Figure 59 and Figure 62. These positions were decided upon during the various pre-trial visits made to the ship and considering the need to measure passenger start and end locations during the trial in the most granular way possible given the number of beacons available. In the early stages of planning for JoS, it was determined that considerably more beacons would be required than was the case for SS1. For this trial, an additional 40 beacons were purchased.

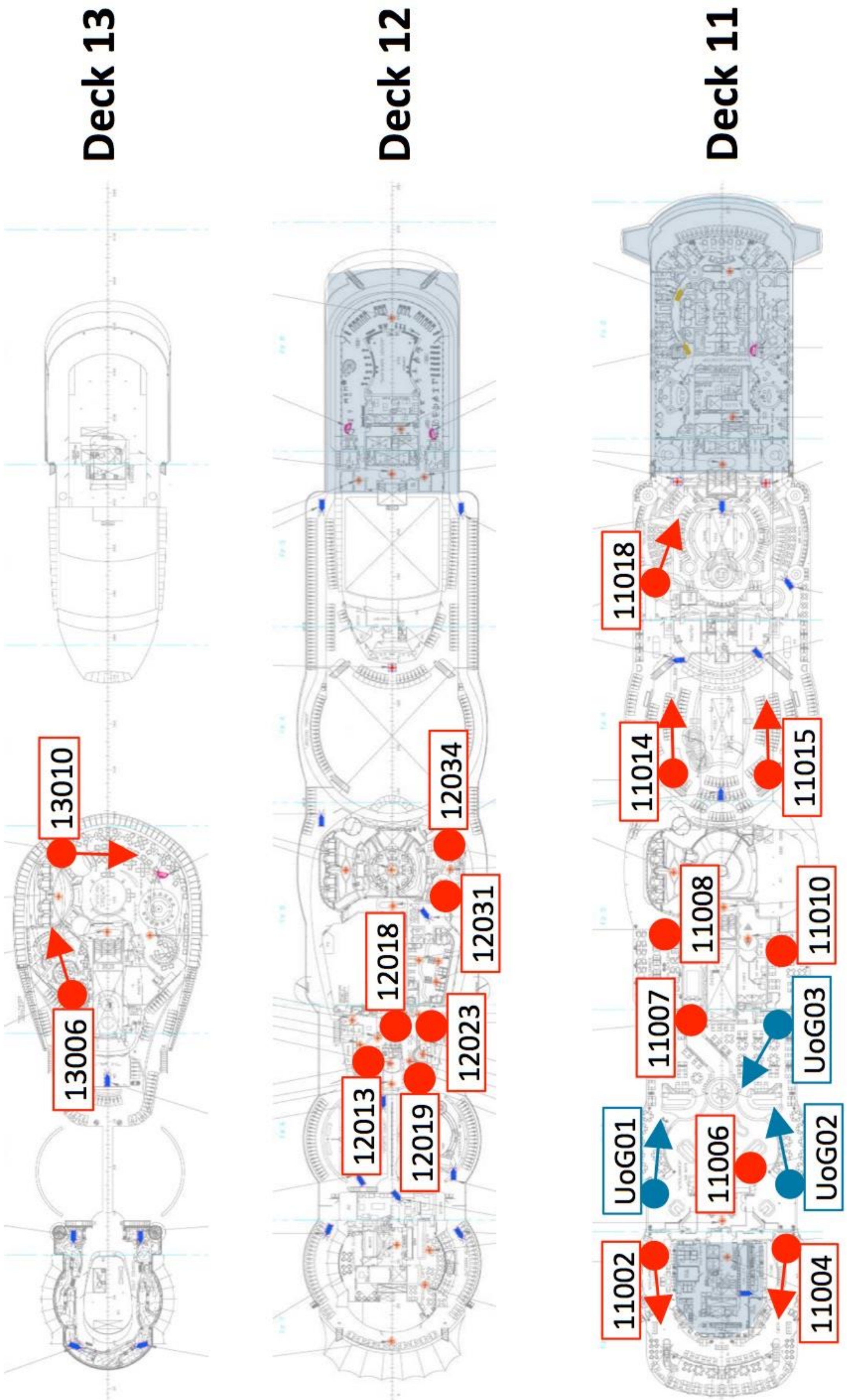


Figure 53 Camera locations on Jewel of the Seas (Decks 11-13).

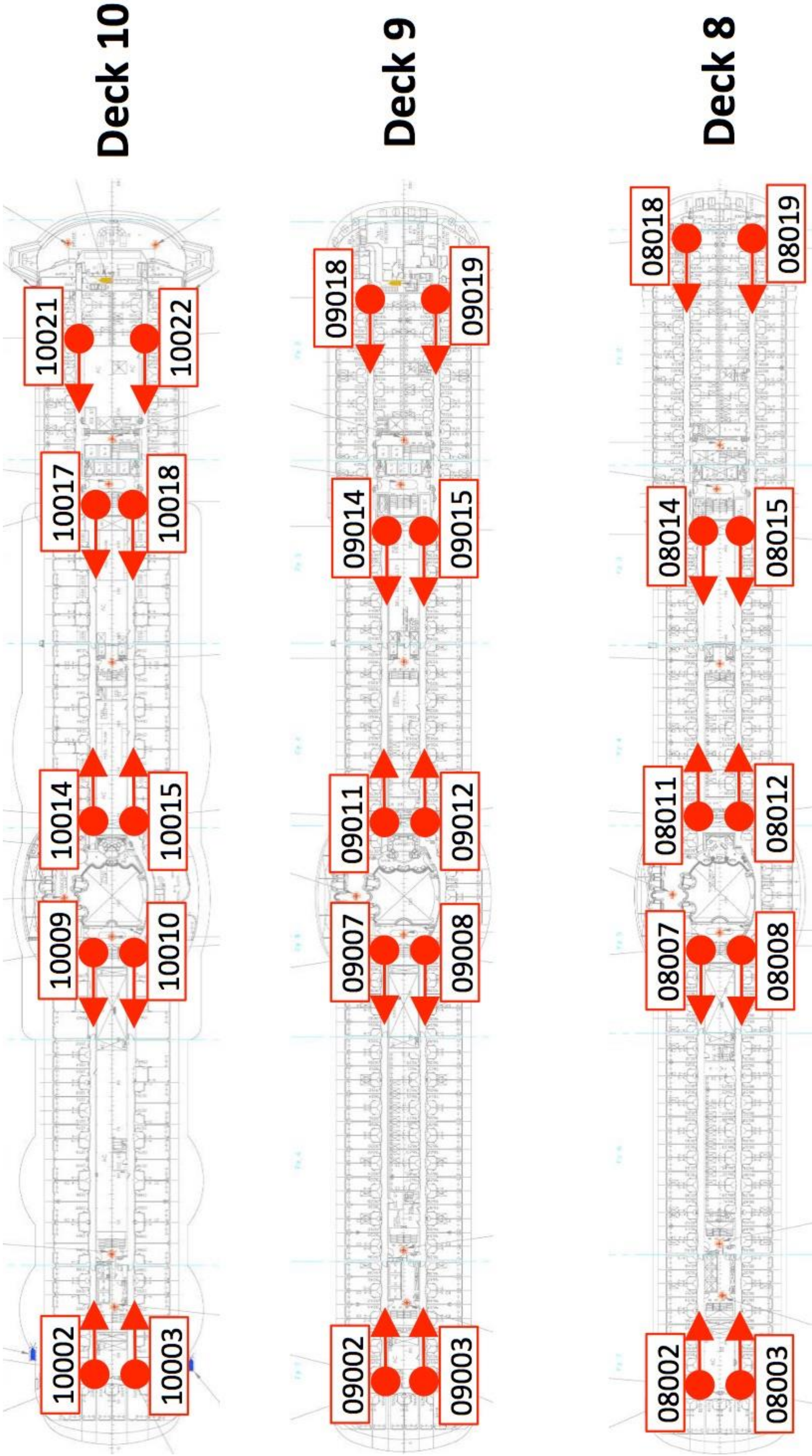


Figure 54 Camera locations on Jewel of the Seas (Decks 8-10).

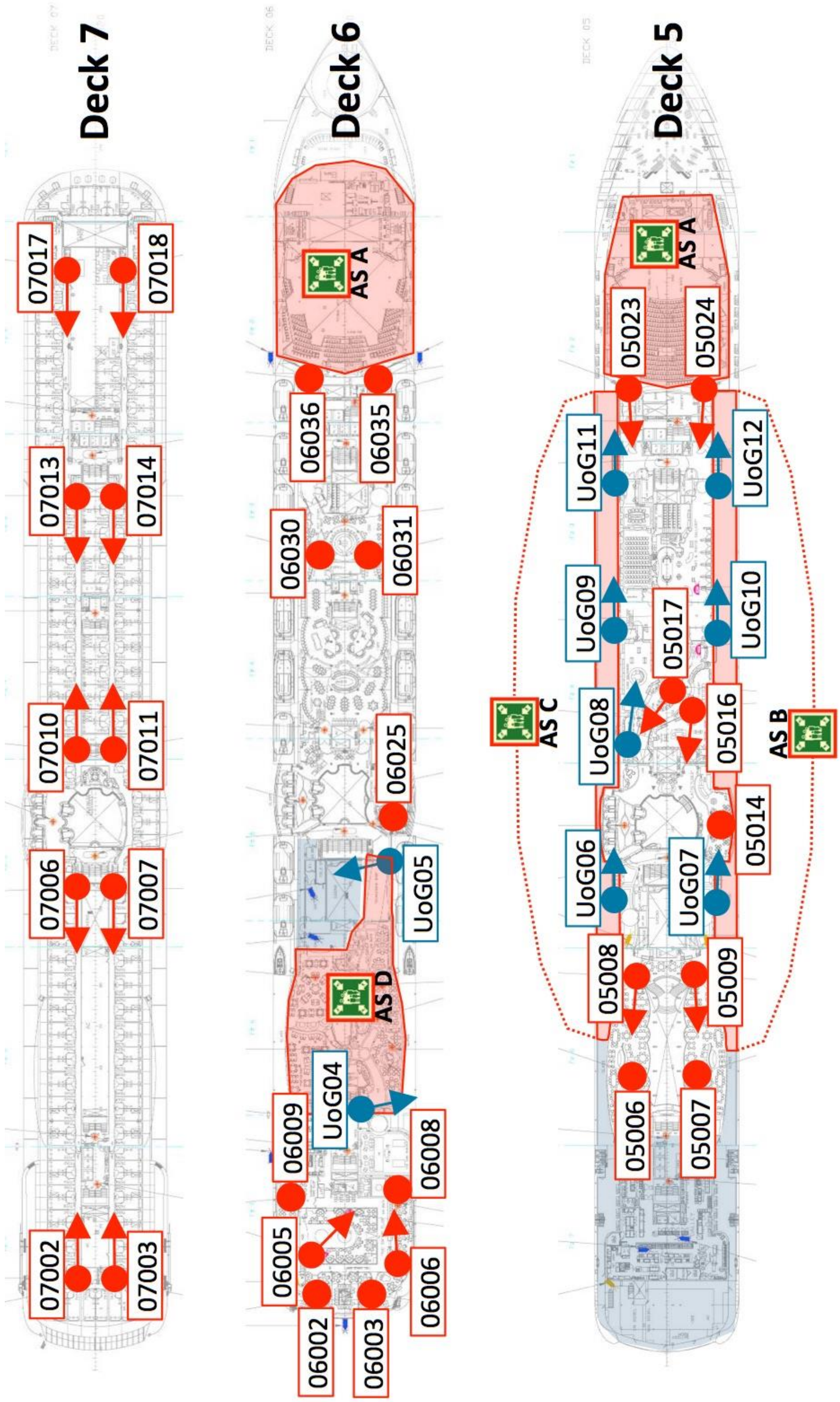


Figure 55 Camera locations on Jewel of the Seas (Decks 5-7).

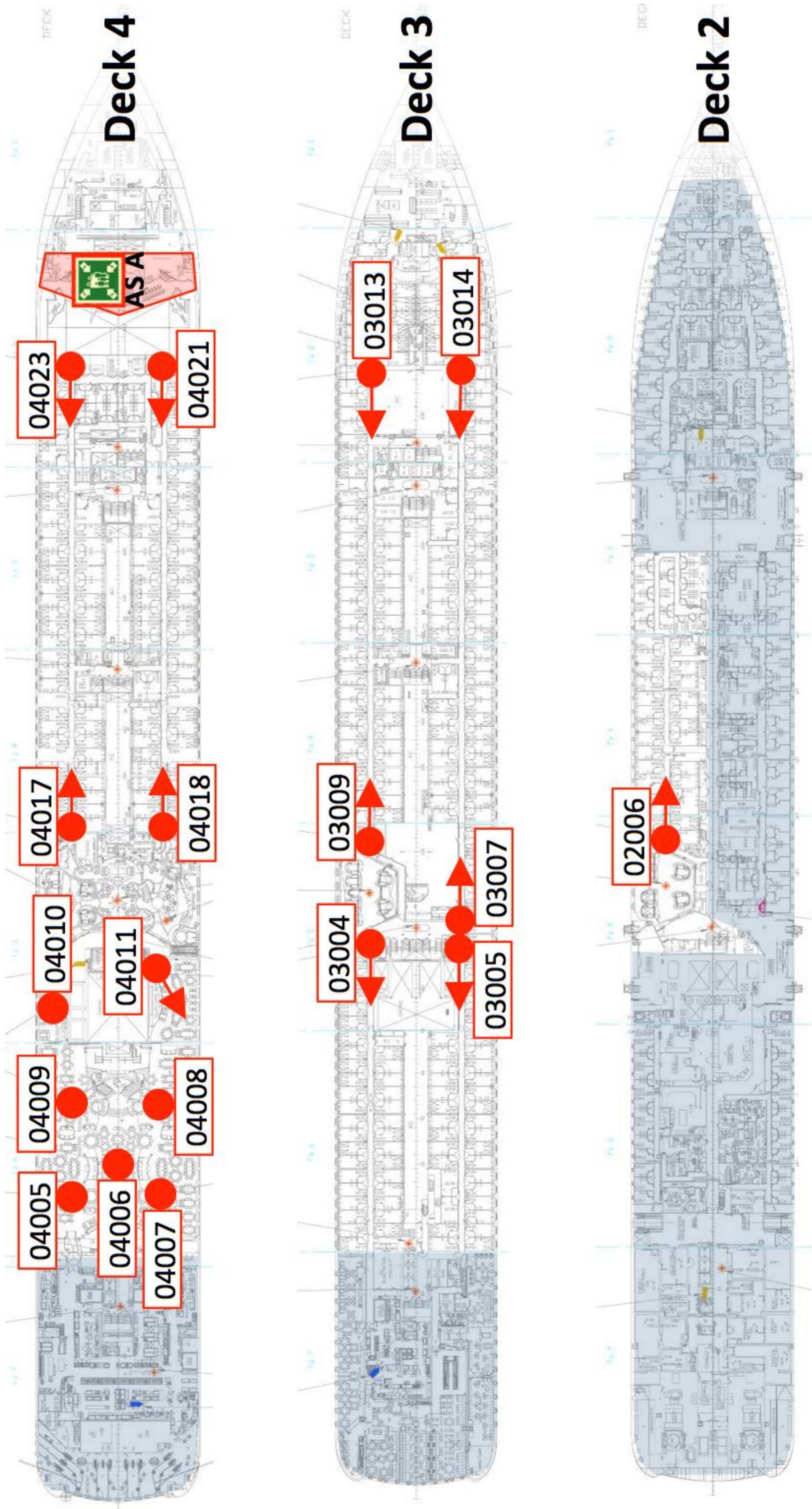


Figure 56 Camera locations on Jewel of the Seas (Decks 2-4).

Figure 57 Preparations for the JoS trial – placing tags and information sheets in envelopes for distribution to JoS staterooms by crew.

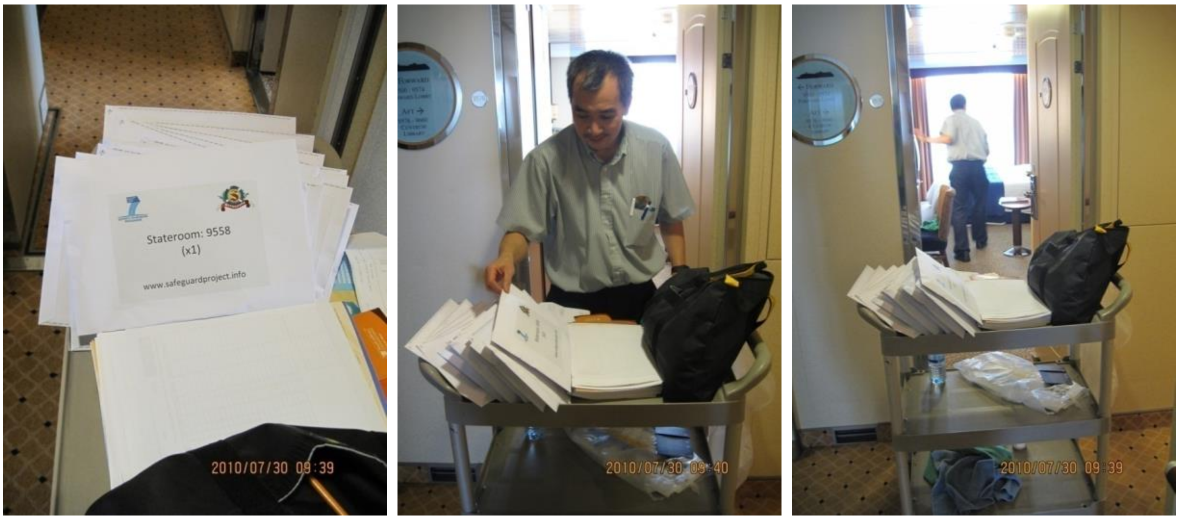


Figure 58 Example of the envelopes containing the information sheets and IR tags, as well as distribution by crew.

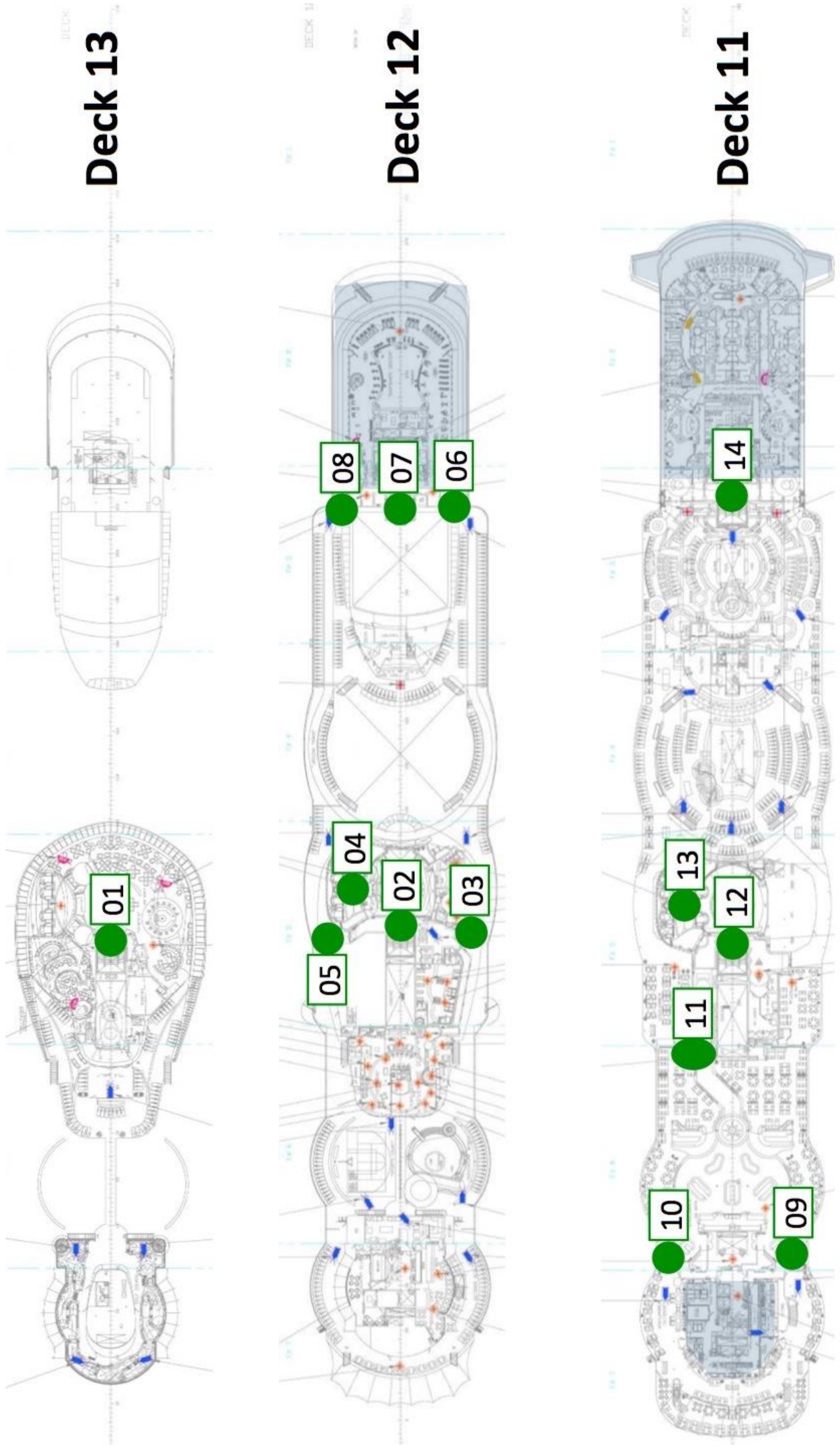


Figure 59 Location of IR beacons for JoS trial (Decks 11-13).

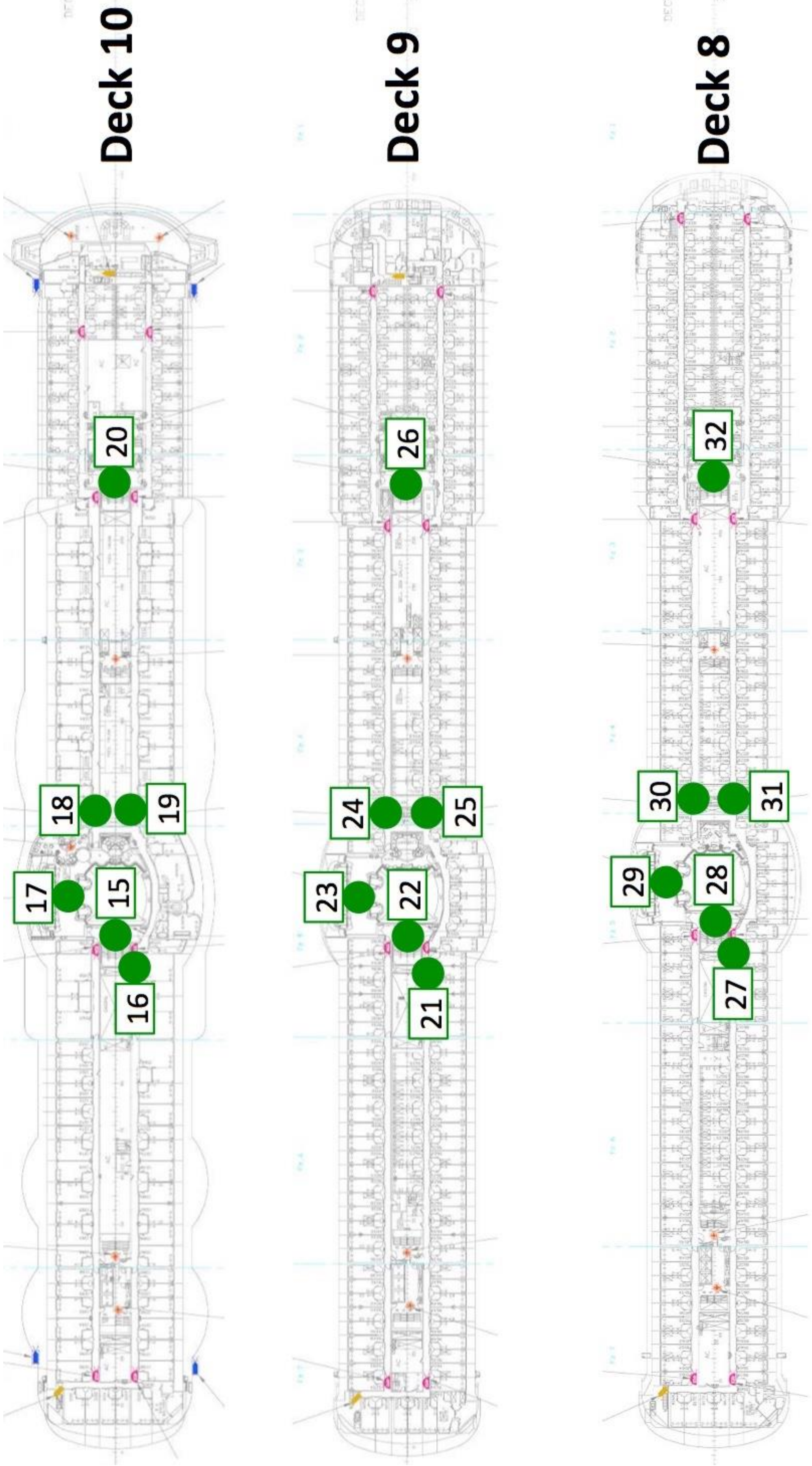


Figure 60 Location of IR beacons for JoS trial (Decks 8-10).

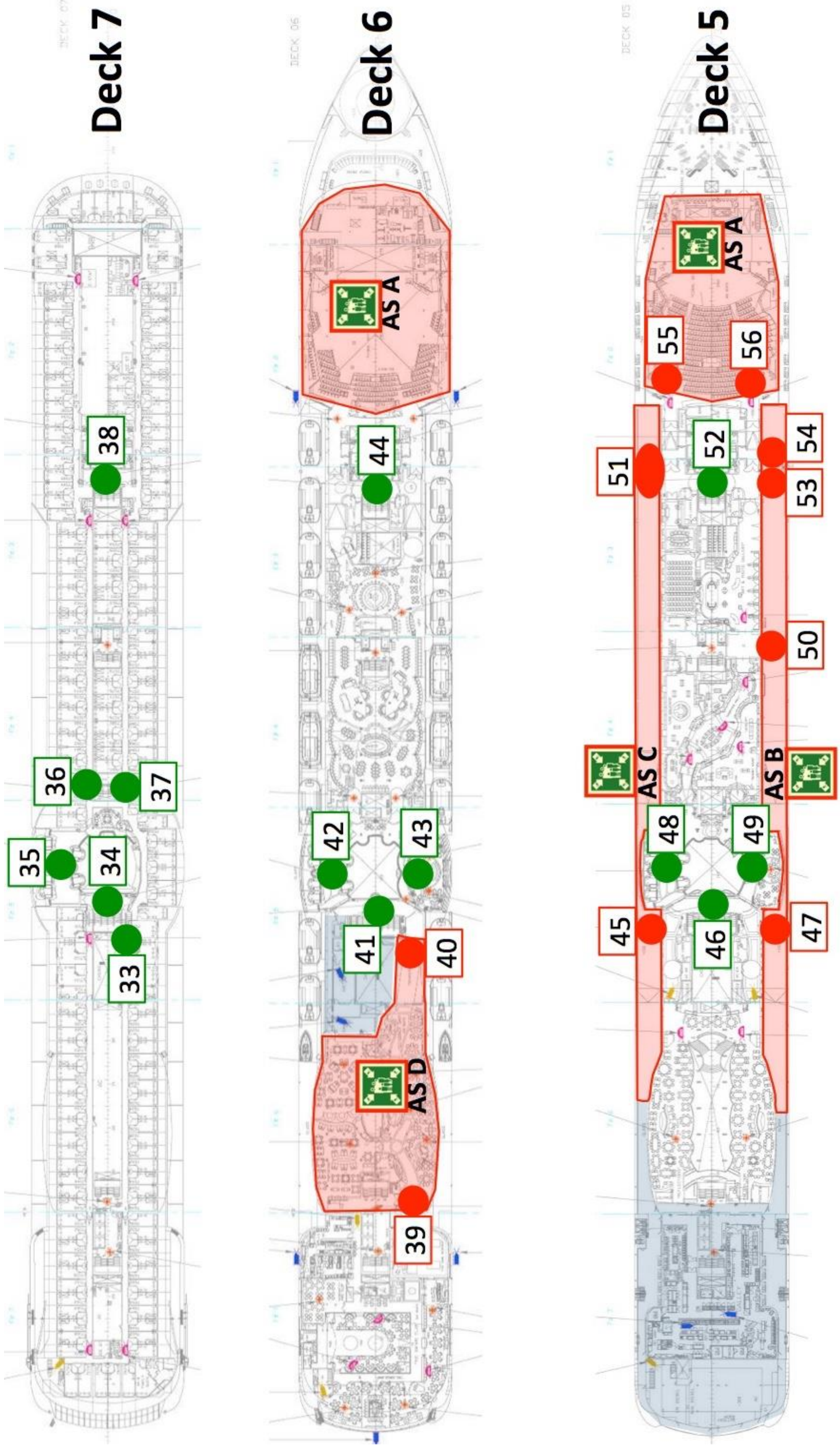


Figure 61 Location of IR beacons for JoS trial (Decks 5-7).

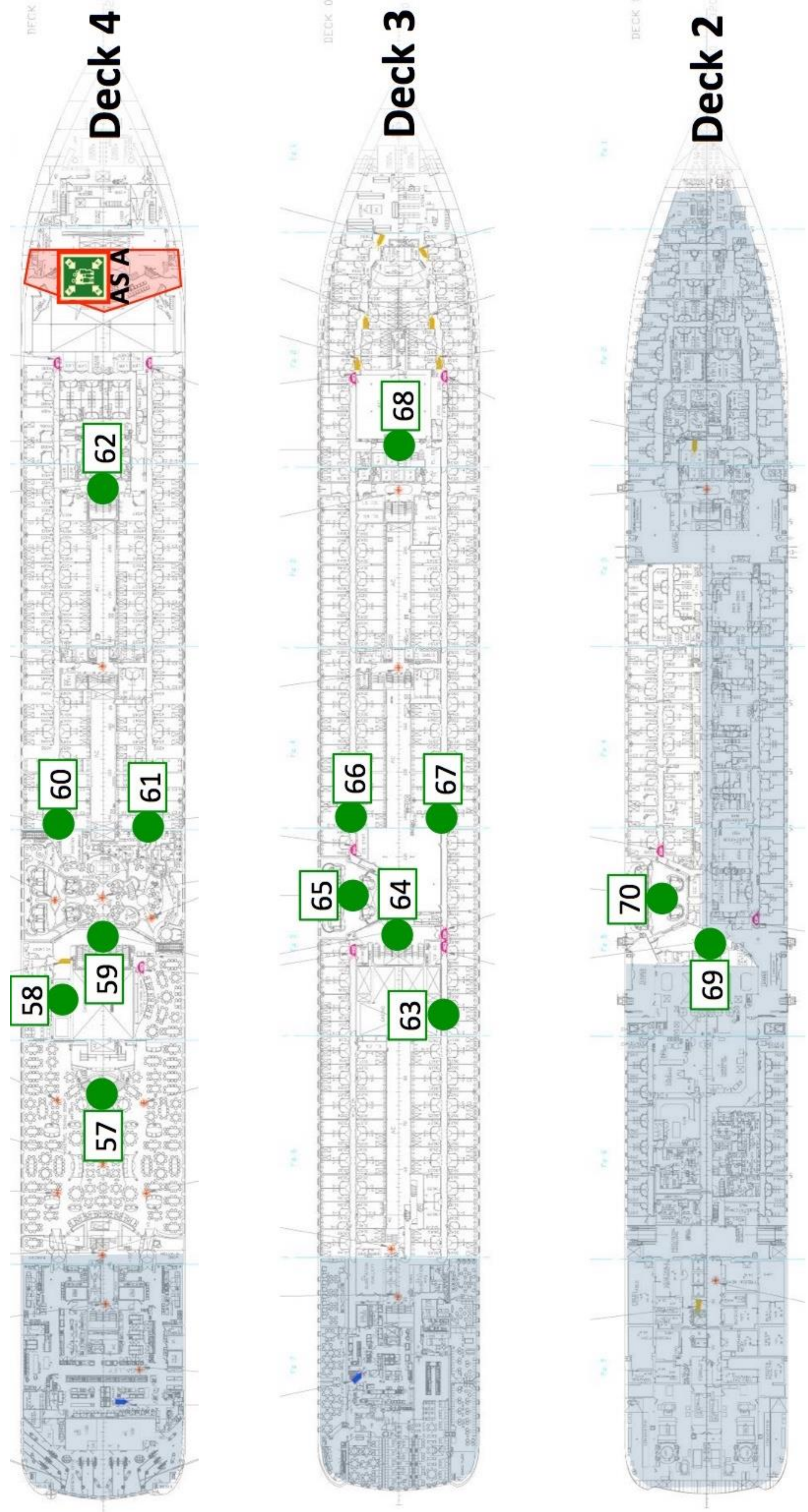


Figure 62 Location of IR beacons for JoS trial (Decks 2-4).

Capturing entry into the assembly stations was of particular importance and, as with SS1, required testing to ensure that no tagged passengers could enter the assembly areas without being counted. It was also important to ensure that passengers could not move from their starting deck to another deck without being counted. On the morning of the trial, members of the setup team began deploying equipment (Figure 63), starting at 04:00 so as to minimise the chance of passengers observing the setup activity, which could potentially affect their behaviour during the exercise.

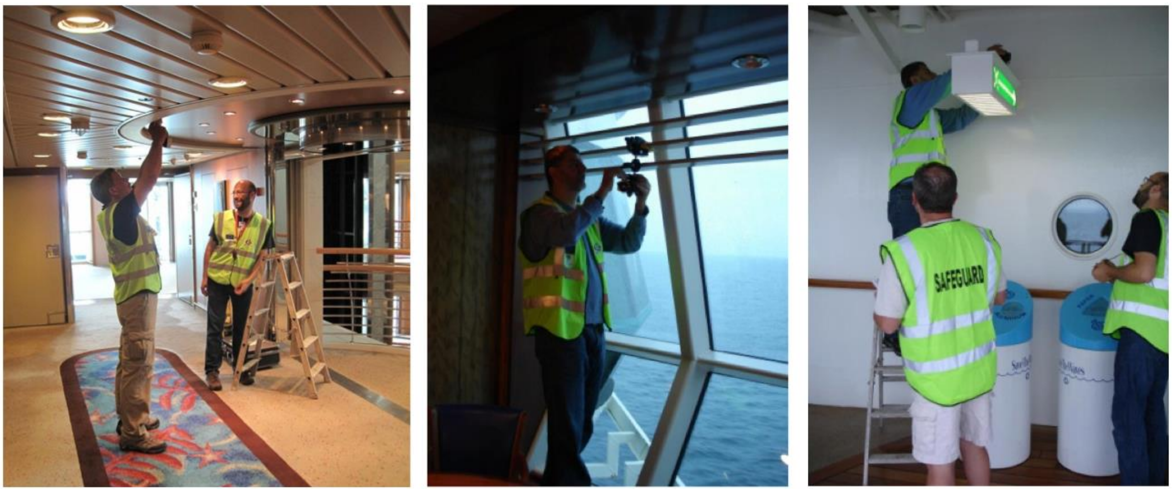


Figure 63   Installation of IR beacons and camera equipment on JoS.

For additional details of the trial planning and execution process, the reader is referred to Appendix B, Section B3.

4.9.4   Trial Challenges and Outcome

The trial conducted on JoS was carried-out successfully and without injuries, and the resulting dataset was of high quality. Challenges associated with this trial related primarily to the pre-trial planning phase. In the early stages of the project, it was agreed that RCCL would permit the conduct of two trials on one of their ships, however, in the early stages of planning RCCL decided to withdraw from the project. The SAFEGUARD project manager and scientific lead held meetings with RCCL personnel and ultimately it was agreed that they would participate, however, RCCL indicated that only one trial would be permitted. The team determined that, while not an optimal situation, it would still meet the project objectives.

In addition, the team (including the author) made many attempts to visit JoS when in port between 31 May and 18 July, 2010, however, due to a recurring incidence of norovirus onboard the ship, each time it arrived in port and discharged passengers, a thorough cleaning was undertaken and no individuals from onshore were permitted to board. Although it was hoped that the final ship visit (which took place 18 July) would occur at an earlier date, the team was still able to complete the final checks and the trial was successfully carried-out on the date planned (31 July, 2010).

4.10 Detailed Planning for Third Ship – M/S Olympia Palace

Planning for trials on the third ship – Olympia Palace (a ferry with cabins) required a similar level of effort as with the first two vessels. It was anticipated that passengers would use this ship in a manner similar to passengers on SS1 and JoS. One of the aims of the trails on this vessel was to capture the response of the passengers from their cabins.

4.10.1 Vessel Details and Route

The Olympia Palace (OP) is a RO-PAX ferry operated by Minoan Lines in Greece (Figure 64). Vessel particulars are provided in Table 18 and Figure 65 shows the route taken by the vessel during the data collection trials - from Patras (Greece) to Venice (Italy), via the port of Kerkira on the Island of Corfu, a voyage of 21 hours in each direction.

Figure 64 Minoan Lines' M/F Olympia Palace RO-PAX ferry with cabins.

The ship contains a mixture of public passenger spaces spread over four of the vessel's nine decks including; cabin areas, airline style seating, large retail and restaurant/catering areas, bars, indoor and outdoor general seating and general circulation spaces. Cabin areas on this vessel make-up the whole of deck 7 and a small section of deck 8.

Table 18 Olympia Palace particulars.

Length Overall (m)	214
Beam (m)	26
Draught (m)	7.1
Gross Tonnage (t)	36,825
Maximum Speed (kn)	31.5
Total Decks	9
Passenger Decks	4
Passenger Capacity	1,922
Car Capacity	821

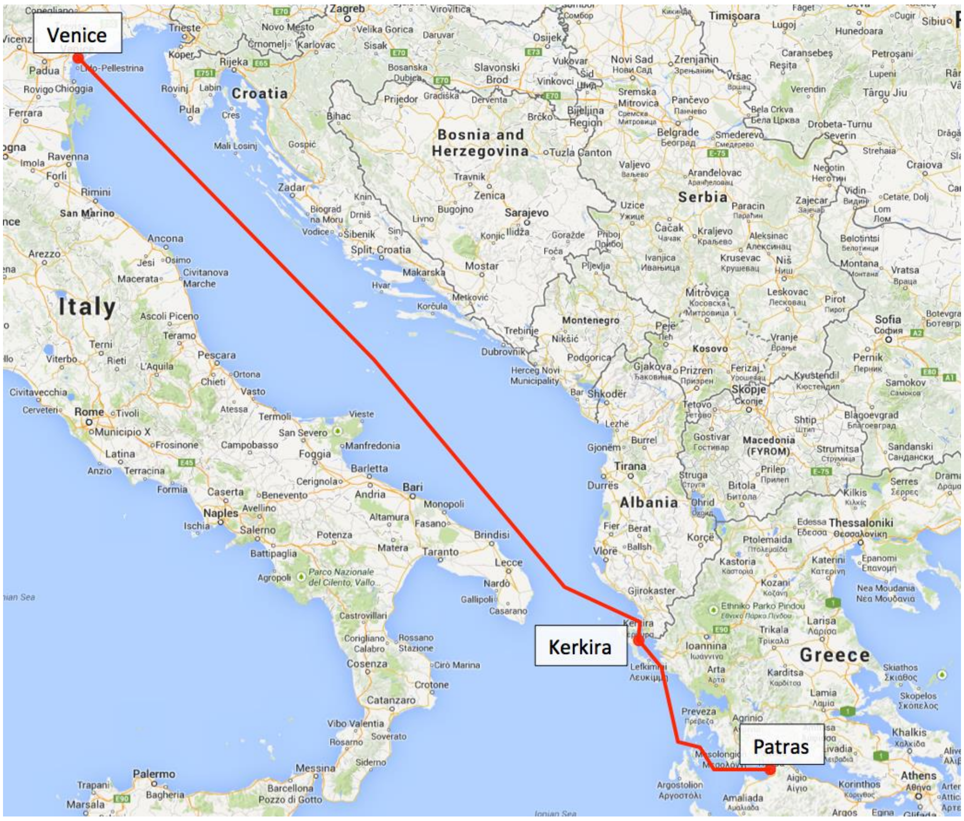


Figure 65 Route for Olympia Palace trials, starting at Patras.

4.10.2 Pre-Trial Planning

A total of four visits were made to the Europa Palace and Olympia Palace in Greece. The first two visits (one to each ship) took place between 06 and 08 September 2010 in Patras by a senior member of the UoG research team. It was determined that the ships were nearly identical, so the information gathered from one ship could be applied to the other. The aim of these visits was for the team member to become familiar with the layout of the vessels, take photographs of the interior space, discuss the trials with the Captain and other Minoan officials, to conduct a preliminary investigation of where cameras and IR beacons could be positioned and to determine how information sheets and IR tags could be distributed to passengers.

The third visit took place on 19 November 2010. One member of the UoG team and the Minoan Lines liaison visited the Olympia Palace at the port of Piraeus, Greece. During this visit, the team confirmed and finalised the locations of cameras and IR beacons, supporting with photographs of each location and the camera' field of view. The team also discussed some trial details with the Captain and his officers.

The fourth and final visit was made on 26 January 2011, this time onboard the Europa Palace in Patras, Greece. The main purpose of this visit was to confirm IR beacon power levels for all locations.

In order to prepare a full test plan, it was determined that the trials would be carried-out on the Europa Palace on 07 and 14 March 2011. The plan allowed for a 1-week period between the first and second trials, due to the ship's schedule and the intent to carry-out the second trial at approximately the same time as the first – just after the vessel had left port in Venice. This plan had the project team board the vessel from the port of Kerkira in Corfu just before 07 March, sail with the vessel to Venice, conduct the first trial after the vessel had left Venice, disembark in Kerkira and carry-out preliminary data analysis while the vessel sailed onwards to Patras. The team planned to board the vessel again when it returned to Kerkira on its way to Venice just before 14 March 2011 and conduct the repeat trial after the vessel had left port in Venice.

4.10.3 Data Acquisition Equipment Preparations and Positioning

It was determined from the various pre-trials visits that 40 battery-powered digital video cameras would be required for each trial onboard the Olympia Palace. The cameras locations viewed all anticipated passenger starting areas, including the outside upper deck, cabin passageways, airline style seating and general seating areas (Figure 66). A total of 51 IR beacon locations were chosen to quantify passenger routes (Figure 67). Most beacons were positioned to capture passenger starting and intermediate locations. Of the 51 beacons mounted, 9 captured passenger arrival at the assembly stations on deck 6.

All data acquisition equipment was shipped by ground transport to the research team's hotel in Patras on the day before boarding so that camera batteries could be charged. Early on the boarding day, all equipment was transported by truck to the vessel (Figure 68) and delivered to the research team's workspace onboard the ship (a small theatre on deck 6). All equipment was unpacked and, as in previous trials, tags were set to "awake" mode, counted and paired with passenger information leaflets and packed into cardboard boxes for distribution to passengers. Four locations onboard the vessel were identified as the places where both walk-on and driving passengers would enter the ship, thus there was no need to distribute tags to the shore-side terminal. Members of the setup team began preparing cameras and mounts for the different locations, according to the trial plan and under direction of the controller, commenced with installation of the cameras and IR beacons. As in previous trials, all beacons were set to "on" mode at the time of installation, however cameras were left off until just before the trial in order to conserve battery life and storage space. All equipment had been installed well in advance of passenger boarding time. Embarkation started 3 hours prior to departure so the entry team arrived at the identified locations just before passengers began boarding. The entry team distributed IR tags and information sheets to the passengers as they boarded the vessel. Most passengers boarded using the walk-on entrance but three other entry areas were manned by the entry team - one amidships on deck 6, one on car deck 4 and one on car deck 3 (not shown in the figure).

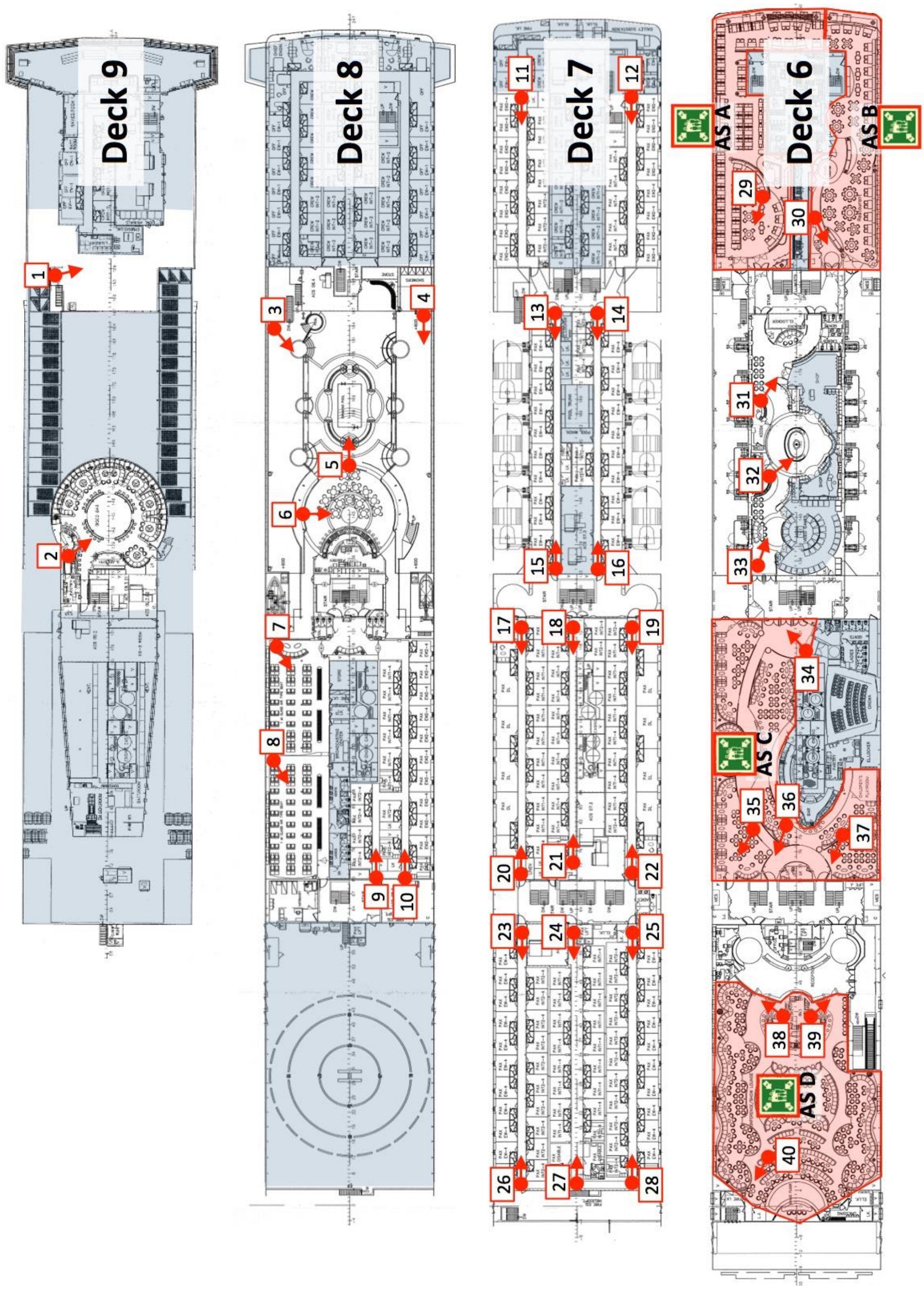


Figure 66 Camera locations (red dots) on Olympia Palace (red arrows show view direction). Grey areas were not accessible by passengers.

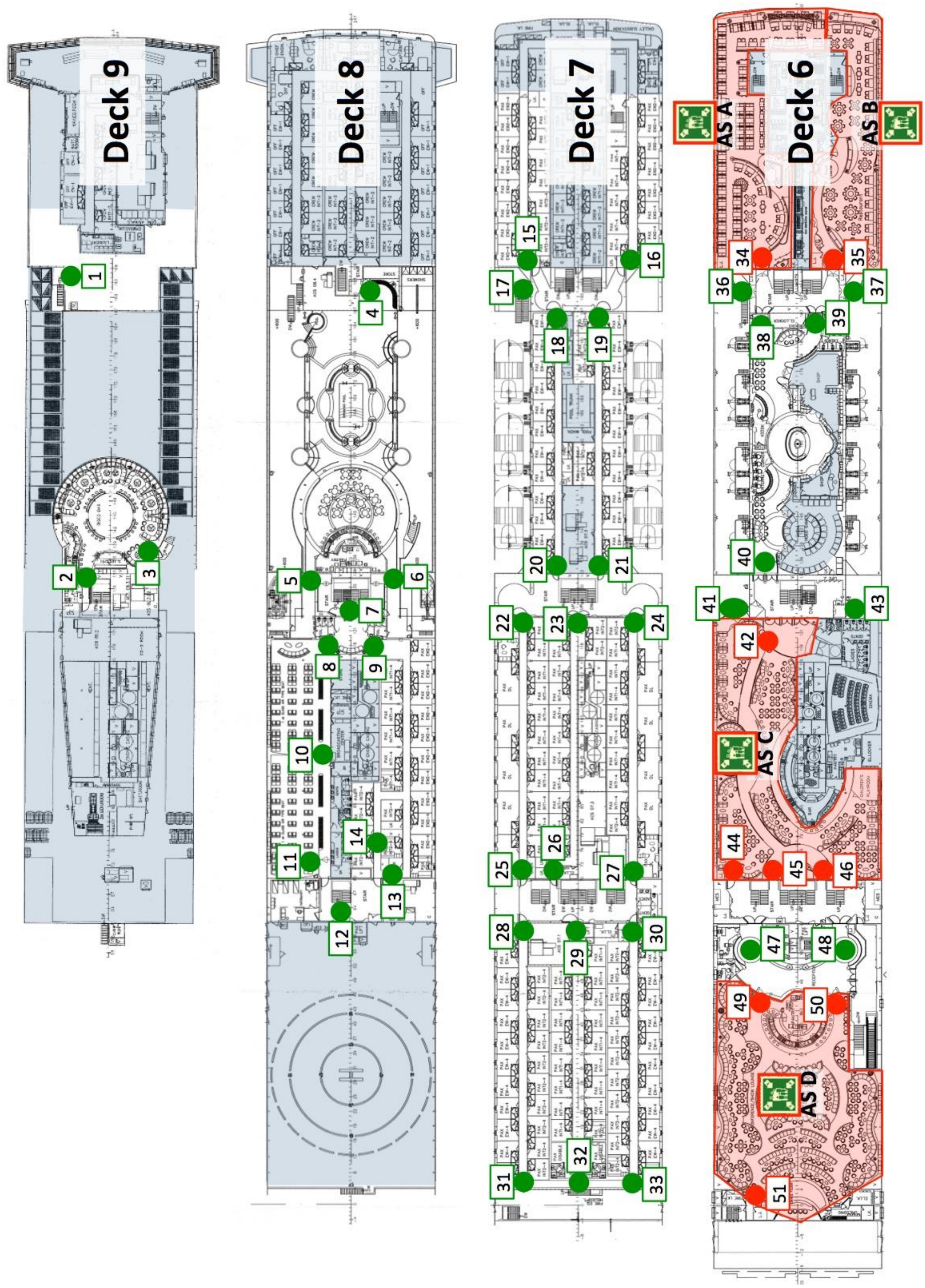


Figure 67 IR beacon locations on Olympia Palace (green circles identify starting and intermediate locations; red circles identify end locations). Greyed areas are not accessible by passengers.

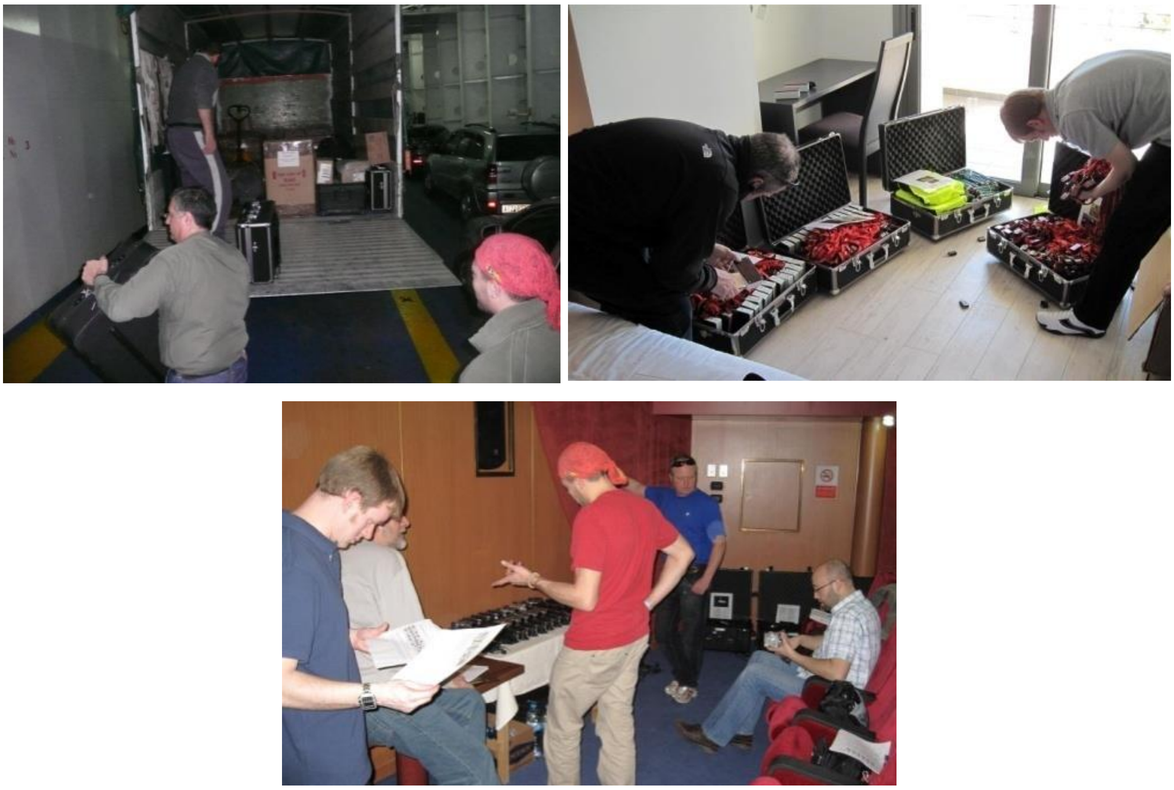


Figure 68 Transport, checking and preparation of trials equipment for Olympia Palace (top left: arriving on the ship; top right: preparations in hotel; bottom: setup in ship's theatre).

For additional details of the trial planning and execution process, the reader is referred to Appendix B, Section B4.

4.10.4 Trial Challenges and Outcome

As described for the other two ships, the trials conducted on OP were carried-out successfully and without injuries, however, some challenges were experienced in the planning and preparation for this vessel, which had an impact on the quality of the datasets produced.

Initial planning was undertaken for the Minoan Lines ship *Ikarus Palace* in autumn 2010 between the port cities of Patras (Greece) and Venice (Italy), a voyage of approximately 21h. Considerable planning took place, which involved the author and required a member of the UoG research team to visit the ship in Greece. A trial plan was prepared, including the identification of camera and IR beacon locations, IR tag distribution procedures, as well as discussions with the Captain and company representative. However in July 2010 the project team was informed that the *Ikarus Palace* had been removed from the planned route and that the two vessels (sister ships) - *Olympia Palace* and *Europa Palace* - would be used on this route instead. As a result, much of the original plan had to be discarded because the layout for the new vessels was completely different than *Ikarus Palace*. Ultimately, this resulted in a project schedule delay from autumn 2010 to spring 2011.

However, due to the civil war crisis that unfolded in Libya in the weeks before the planned dates of 07 and 14 March, the Europa Palace was commissioned to undertake a humanitarian mission to move civilians out of Libya, thus removing the Europa Palace from the Patras-Venice route. Eventually the Olympia Palace was commissioned to perform the Patras-Venice route but several delays with the vessel meant that the scheduled trial date was changed yet again and changed would be required to the way in which the repeat trial was conducted. The first trial took place on 12 March 2011at 00:40, 40 minutes after the vessel had left the port of Patras en route to Venice. Due to the exceptional circumstances, it was necessary for the team to undertake the second trial on 14 March at 19:12; 72 minutes after the vessel had left port in Venice en route to Patras. While not the preferred trial plan, the situation was clearly outside the control of the project team and required a very fast revision of the procedures in order to ensure that no unexpected logistical challenges would arise. It is important to note that most project objectives were still met: for the second trial, the population of passengers was different than the first trial, both trials took place at approximately the same time after leaving port, and both trials took place in the evening hours. Due to the unexpected vessel schedule change, a much smaller number of passengers were onboard for the trip than originally expected.

4.11 Chapter Summary

A detailed discussion of the sea trials methodology and preparations for each ship has been provided in this chapter. This process represented a significant effort by the team, including the author, at all stages. Multiple ship visits were required in the months leading up to the planned trial dates in order to discuss the research plans with the Captain, officers and crew for each vessel. During each ship visit, the location of all equipment was tested and decided upon, the team was provided an opportunity to become familiar with the layout of each vessel and to determine the main circulation routes and entrances to monitor for assembly stations. Visits to each ship also gave the team a change to understand the boarding process for passengers and how information and tracking tags could best be distributed.

In all, five monitored assembly exercises were carried-out successfully and without any injuries onboard three passenger ships – a ferry with cabins, a ferry without cabins and a cruise ship. A total of 5,582 passengers were onboard during the exercises, which represents the largest monitored assembly trials undertaken to date. Challenges experienced during each trial have been presented, along with the outcome for each.

The next chapter will present the methods developed for analysing the video dataset so that passenger response times could be reliably collected. This includes the response behaviour definitions developed and the process of inter-rater reliability carried-out to ensure reliability of the response time dataset produced, given that multiple video analysists were required. The structure of the IR tag dataset is explained, along with the way in which the assembly time data was prepared. The next chapter will then summarise the entire dataset collected, presenting the number of passengers onboard and amount of equipment used, as well as the number of passengers who participated for each ship. The quantity of response time data collected from the video analysis and the number of passengers tracked using IR is given for each ship and a summary of passenger demographics is provided which includes gender, age group, location on the ship, activity at the time of the alarm and group type. Finally, potential sources of measurement error are described.

5 Data Analysis

This chapter provides an overview of the data collected and the methodology for analysing in order to generate a dataset for detailed analysis of response time (Chapter 6) and IR path data to generate a validation data set (Chapter 7). This chapter outlines the detailed video analysis methodology, including the definition of response phase activities and behaviour definitions and the way in which reliability of video analysis was ensured. A discussion of IR data synthesis and analysis methods is provided and then an overview of the data collected onboard each of the three ships in terms of the data quantity, passenger demographics and potential sources of error.

5.1 Response Time Data Analysis Methodology

5.1.1 Overview

As discussed in Section 3.2, video cameras were utilised to collect passenger behaviour data so that passenger response times could be quantified throughout the different areas onboard the ships being tested. Camera mounting locations were discussed for each ship in the subsections of Chapter 4. By performing a detailed analysis of the video footage captured, it was possible to estimate passenger demographics and develop distributions of passenger response time for the different areas of each ship tested. Robust and meaningful analysis methods were required to define the alarm response performance of passengers.

The first step in the video analysis was to determine the nature of response phase behaviours, including what passengers were doing just before the alarm. Typical pre-alarm behaviours were listed after reviewing samples of video and new behaviours were added as observed during the analysis. To develop probability distributions of passenger response time, it was necessary to spend many hours watching (and often re-watching) the video frame-by-frame for each passenger who appeared to respond to the alarm. The subsections that follow provide a detailed overview of how reliability was assured in the process of capturing basic demographic and response data from the videos; and an in-depth discussion of the video analysis methods developed.

5.1.2 Response Phase Behaviours

The passenger response phase behaviour in ship evacuation can be divided into three distinct stages – notification, cognition and activity [31], as explained in Section 1.2. When analysing the video collected during this research, the notification stage always began with the sounding of the ship's alarm. Passengers then moved through the cognition and activity stages and at some point began purposeful movement from their alarm location towards an assembly station. The end of the activity stage typically marked the end of the response phase, for which the total elapsed time was recorded as the response time.

Response phase behaviours for each individual were determined by analysing video footage for the different characteristics and times that could be captured. Thus, it was essential to understand the nature of the response phase and define the points of interest.

5.1.3 Response Phase Data and Definitions

Video data collected during the sea trials was analysed primarily to determine passenger response time following the sounding of the ship's alarm. Of particular interest for this work was the characterisation of two points on the timeline – alarm activation time (AAT) and end of the response phase (ERP). These two points of interest are described below, along with different characteristics sought for each passenger that could be assessed as having responded to the alarm.

1. **AAT - Alarm Activation Time:** Defined as the time at which the ship's alarm was sounded. For each individual who could be seen responding to the alarm, the following additional characteristics were captured, as outlined in Table 19:

    a. **ID:** A unique identifier was given to each analysed individual for each camera view (as depicted in Figure 69). This allowed for checking of results for any passenger if required. Passenger IDs ranged from 1 to the maximum number of passengers whose response time could be recorded for each video. Each individual analysed was identified in a passenger identity key (Figure 69) created using a still image from the video at each location.

Table 19 Demographics and pre-alarm activities captured during video analysis

Variable	**Options**
Gender	Male; Female; Unidentifiable
Age Group	Adolescent (up to 19 years) Young Adult (20-39 years) Older Adult (40-59 years) Elderly (60 and older years) Unidentifiable
Pre-Alarm Activity	Standing Sitting Walking Sleeping In Queue At Cashier Shopping Eating/Drinking Other Social Engagement Self service machine or self service point Emerge from cabin Return to cabin (and then emerge) Playing (e.g. arcade) Swimming At reception desk Return to corridor and then leave Unidentifiable
Group Status	Alone and isolated Alone but within a group of strangers With a group of travelling companions With a mixed family group With a mixed group Unidentifiable

b. **Gender:** The gender for each passenger was recorded as either male or female for cases where it could be clearly estimated from the passenger's characteristics. For cases in which there was uncertainty about a passenger's gender, it was recorded as unidentifiable.

c. **Age Group:** The passenger's age group was estimated according to the broad categories: adolescent, young adult, middle-aged adult and elderly adult. Associated age ranges are presented in Table 19.

d. **Activity:** This characteristic captured the passenger's activity immediately before and up to the sounding of the alarm. A range of observed activities are identified in Table 19.

e. **Group Status:** This characteristic identified whether a passenger appeared to be travelling alone or as part of a group. The different options were:

   - *Travelling alone and isolated*: passenger did not appear to be associated with any other individuals and had no passengers in his/her immediate vicinity.
   - *Travelling alone but near other passengers*: passenger did not appear to be associated with any other individuals but was near other passengers.
   - *Within a group of travelling companions*: passenger appeared to be travelling with group of companions and was with that group at the alarm.
   - *Part of a family group*: a family was defined as a group containing at least one adult and one child (of any age up to adulthood). It was not possible to ascertain the actual relationship between a group of individuals, so this was estimated based on the behaviours observed leading up to the alarm. It was expected that an adult's behaviour during assembly would be very similar, regardless of whether an adult was the parent of a child for which he/she was responsible while onboard. In addition, two adults that appeared to be travelling together and acted as though they were partners were considered travelling companions rather than a family for the purposes of this analysis.

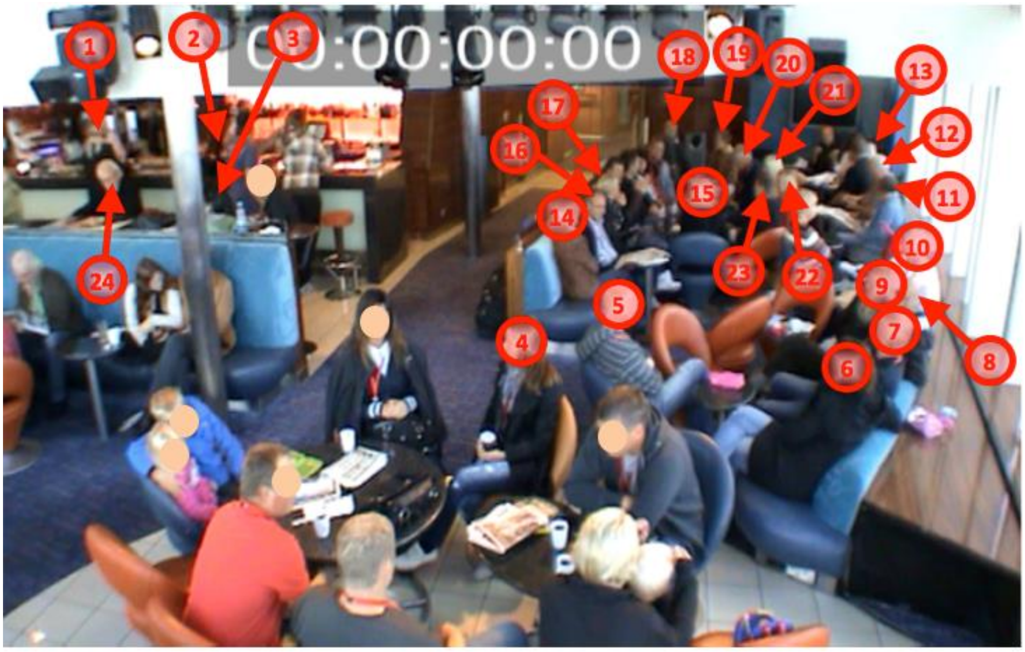
2. **ERP - End of Response Phase:** Defined as the time when a passenger was seen to start purposeful movement away from their current location on the ship. This was recorded when the analyst could clearly see the passenger start walking away and not return during the exercise. The measurement point was when the passenger:

a. Took the first step to move away from the current location.

b. For a seated passenger, when that passenger started walking away after standing

c. In cases where a passenger was partially hidden from view, ERP was recorded as the time when the upper body could be seen moving in the general direction of the assembly station.
d. Was ready to move but prevented from doing so by congestion either in a free space area or within seat rows [Note the exception in point (e) below].
e. If passenger was seen to be waiting for a minor or other group member, then ERP was recorded when the passenger moved on
f. If a passenger had responded but shortly afterwards (i.e. within the same video view) was seen to stop and wait for a group member, was not obstructed by congestion and then when the group member arrived the passenger walked again towards the assembly station, then response time was measured from the *second* time the passenger moved on.

The measurement points described above applies to passengers who are in public spaces as well as cabin areas at the time of the alarm. Some passengers were seen turning around either from a seated or standing position while staying in the same location, in order to get ready prior to moving away. These instances were not considered part of the passenger’s response. In addition, for passengers seated in airline-style seats, ERP was measured when the passenger fully stood and started moving away from the area.



SuperSpeed1

Jewel of the Seas

Figure 69 Example passenger identity key developed during video analysis for SuperSpeed 1 (upper) and Jewel of the Seas (lower).

5.1.4 Video Analysis

5.1.4.1 Overview

Having determined the nature of passenger response time and the main points of interest to be recorded from video analysis, a methodology was developed to complete the analysis of all videos. It was deemed not practical for one person to analyse the large volume video recorded (Table 20). In all, three video analysts (including the author) were trained in the use of the commercially-available video editing software - Adobe Premiere Pro. Since three video analysts were required to complete the analysis in a timely manner, it was important to ensure the reliability of their analysis methods and results throughout the process. This is described in the section that follows – inter-rater reliability.

Table 20 Summary of video data collected in experimental trials.

Vessel	Trial	Hours of footage	Storage space (GB)	No. Response times Captured
SuperSpeed 1	1	49	115	533
	2	45	106	470
Jewel of the Seas	1	76	328	1,241
Olympia Palace	1	9	20	54
	2	7	15	81

5.1.4.2 Inter-Rater Reliability

Given the immense volume of video data collected, it was necessary to use multiple analysts on the project team in order to complete the initial phase of video analysis in a timely manner. Even with well-defined analysis protocols and trained, experienced analysts, there is a risk that the different analysts could unintentionally introduce a bias to the dataset being collected. It was essential, therefore, to ensure reliability of the data analysis at an early stage in the process by establishing and performing objective reliability tests to determine and minimise the variability *between* the different video analysts or *raters* to give a measure of the inter-rater reliability.

It is also possible that some variability could exist *within* a single analyst (*intra*-rater). While an assessment of intra-rater reliability was not formally carried-out, it is important to recognise that the inter-rater spot checks conducted (in which the different raters randomly analysed a sample of each others' video for specific passengers) demonstrated reliability at the inter-rater level and, more importantly, did not result in modification of the methodology at any point. From this, it can be inferred that any variability between raters' results would not be expected to occur in the same way. Thus, the consistency seen *between* the raters provided assurance that the raters *themselves* were remaining consistent throughout the analysis. This is further strengthened by the fact that while the collection of demographics and passenger response times is quite a tedious and time consuming activity, it is not a particularly complex process that requires levels of analysis and interpretation after the terms had been properly defined, discussed, revised and finalised.

Inter-rater reliability has a wide range of application across different fields of research. In simple terms, inter-rater reliability analysis provides a means by which the variability between raters can be assessed. If raters independently perform an analysis of the same dataset, a comparison of results will show if differences exist [240]. If inter-rater reliability is high (i.e. variability between results is low), then raters can be used interchangeably without concern of a rater bias existing in the data collected. If reliability is less than desirable, it will be necessary to determine the reason for the variability, retrain and retest the raters with a new subset of the data until agreement can be reached.

Since three video raters (including the author) were chosen to perform the video analysis, an inter-rater reliability analysis method was developed in order to ensure agreement among the team. The raters (A, B & C) were assessed in pairs and three inter-rater reliability measures were determined – A to B; A to C; and B to C. Prior to commencement of video analysis for the first ship – SS1, a simple database was developed to define the different measures required from the video. This was described in Section 5.1.3 above and consisted of AAT (seconds), ERP (seconds), gender (male, female or unidentifiable), age category (youth, young, middle-aged, elderly), part of a group (Table 19) and activity at the alarm (Table 19). It was decided that an acceptable tolerance for response time would be 1.0 s or less and the level of agreement for all measures for each inter-rater pair should be 90% or greater.

The inter-rater reliability assessment process was iterative in nature. After training, each rater independently analysed the same 10 passengers selected from different areas of the vessel and compared their results with those of the other raters. If the raters' analysis did not achieve the required level of agreement, all three raters met to determine reasons for the discrepancy. Corrective measures were put in place and, if necessary, updates made to the definitions in Table 19. This process was then repeated with a new set of 10 passengers until a level of agreement of at least 90% was achieved. For the work presented, a total of four iterations were required for the first ship to achieve the necessary level of accuracy among the raters. Results are presented in Table 21. Throughout the video analysis (a process which took approximately 12-14 person months of effort to complete), the analysts (raters) carried-out regular spot checks to ensure ongoing reliability of the analysis.

Table 21 Inter-rater reliability testing results

IRR Trial	Passengers Analysed	ERP Agreement	Mean Overall Agreement
1	10	80%	62%
2	10	76%	55%
3	10	83%	77%
4	10	93%	92%

5.1.4.3 Analysis Methodology

Upon completion of the inter-rater reliability testing, the three trained analysts moved onto the full video analysis. The first step in the process of full video analysis was to determine, for each video location, which passengers responded to the alarm and create a passenger identity key (see example in Figure 69) so that each responding passenger had a unique identifier and could be re-examined if the need arose. The passengers were identified according to ship, test day, video location and ID number.

Video analysis was carried-out using commercially available software Adobe Premiere Pro (APP), as noted above and depicted in Figure 70. From the figure, we can see that the APP interface is divided into two main areas – the video window (top right) where the video plays and the video timeline window (bottom right) which can be used to identify points of interest by simply placing markers on the timeline. The data contained in all markers placed on the timeline (marker name and associated text, as well as the marker's reference time) can be easily extracted. A separate APP project file was created for each analysable passenger identified during the analysis process. A member of the UoG project team created a simple executable program using the Perl programming language to extract the marker data from APP project file for each passenger and store as a text file. On completion of the analysis, the text files were imported into commercially available software MS Excel and Matlab for further analysis, which is presented in Chapter 6 and Chapter 7.

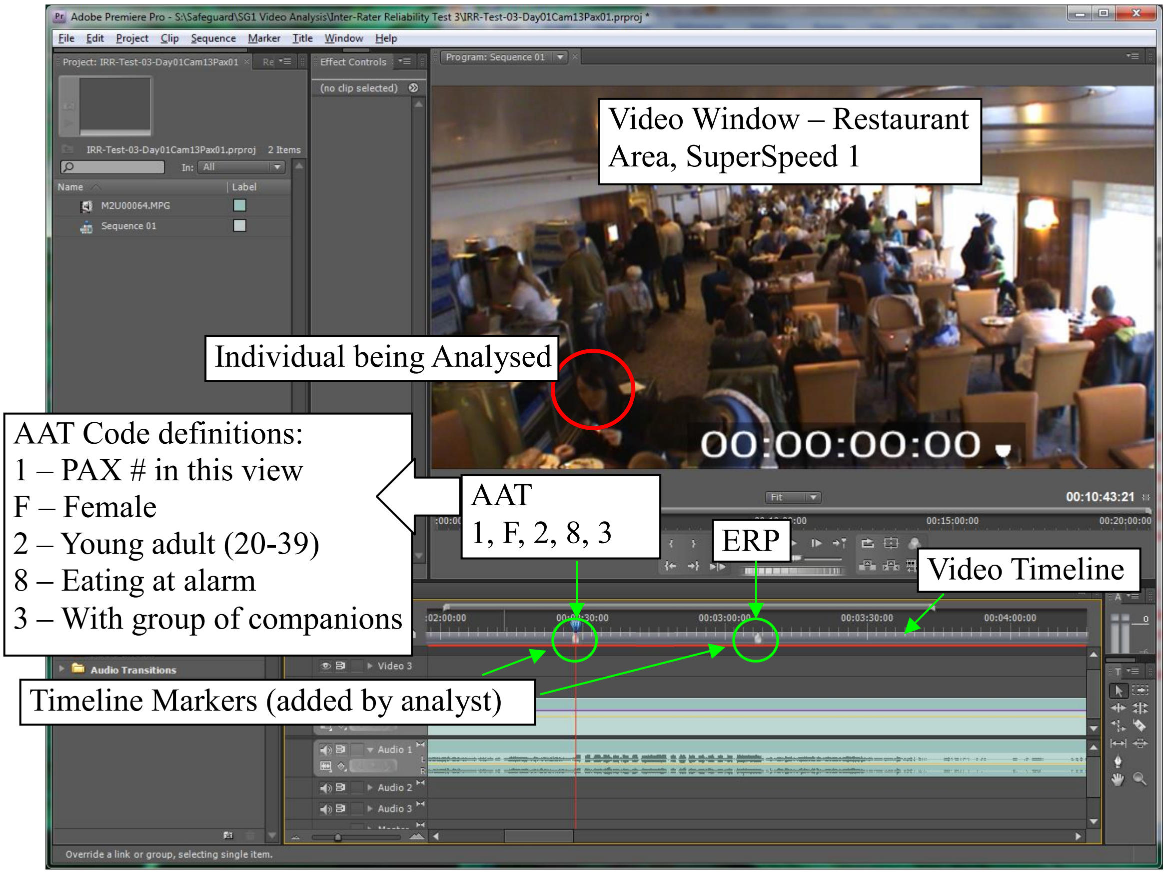


Figure 70 Example of the Adobe Premiere Pro work environment, showing the individual being analysed (red circle) and timeline markers highlighted in green for the times of interest.

5.2 Analysis of IR Tag data

Data was downloaded from IR tags to a laptop computer immediately after tags were collected for each trial. Each tag read was saved to the computer's hard drive as an individual ".csv" text file. A sample tag data file downloaded after trial 2 on SS1 is shown in Figure 71, with a breakdown of the different components of the file. For this particular example – tag ID #2230 - the information provided in the first few lines of data indicate when the most recent battery change took place, as well as the time between the awake/asleep cycles. In the second portion of the data file, we see the passenger's pre-alarm activities – in this case, the first beacon was detected at 06:27:51UTC (beacon #22, located on deck 7 (Figure 47)) in a general seating area near assembly station B. The person wearing this tag beacon remained in the vicinity of beacon 22 and beacon 23 up to and after the sounding of the alarm, walking into and out of the field around beacon 22 several times.

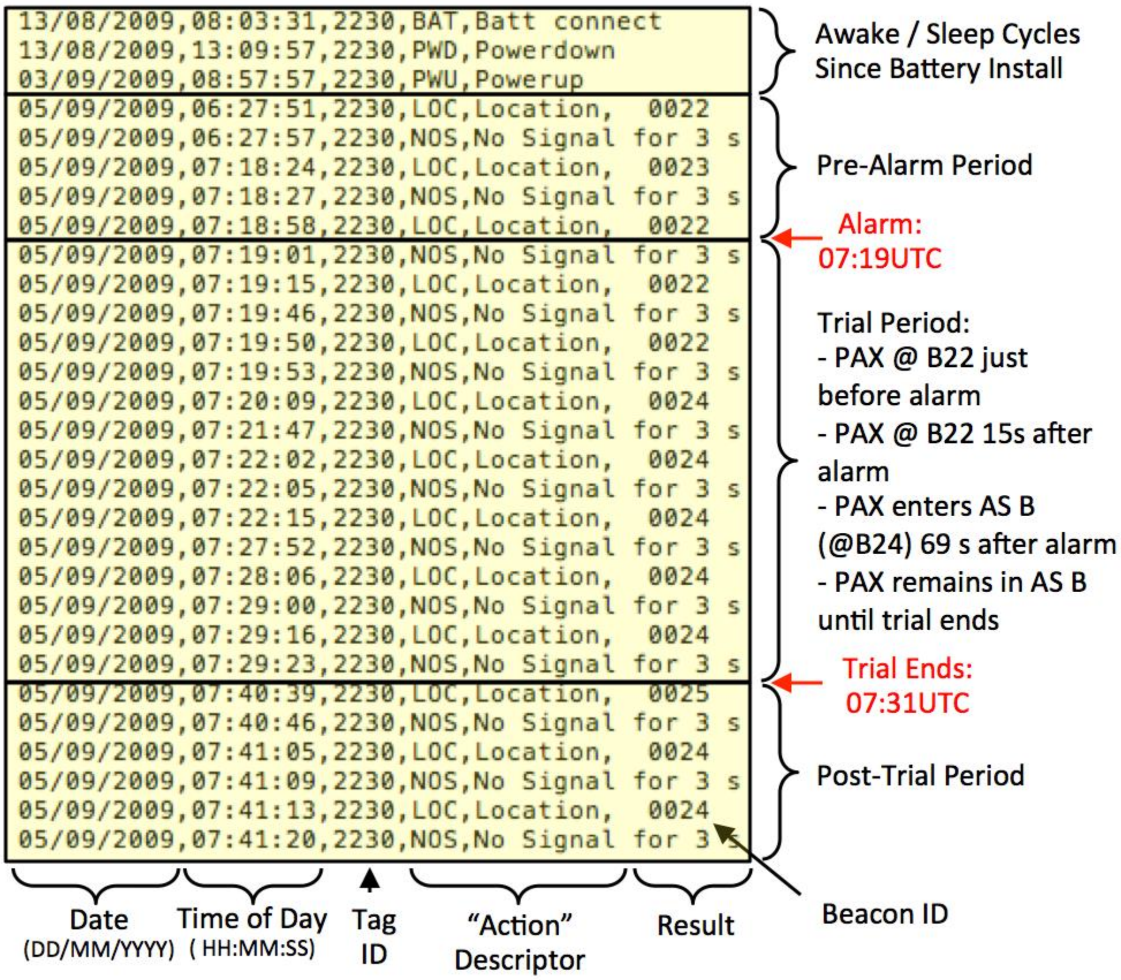


Figure 71 Typical raw data file as downloaded from IR tag #2230.

We know that the passenger first walked into the external assembly station on the starboard side of deck 7 (past beacon 24) at 07:20:09UTC and remained in the area between beacon 24 and 25 until the exercise was over. Given that the alarm time was 07:19:00UTC, and the passenger left his/her initial area 07:19:53UTC, we record this person's assembly time as 53 s.

The data from all passengers was analysed in this way to build a database of passenger locations at the alarm (defined as zones bounded by beacons at known locations), ending locations (defined by beacons at entrances to the different assembly stations) and the time of arrival at the assembly station.

Path data for each individual passenger was captured using a simple executable file developed by a project team member at UoG so that trial results could be stored in a single MS Excel spreadsheet for each test for detailed analysis. Using this data, individual assembly times for each tagged passenger were tabulated for assembly station, and an overall assembly time curve for each trial was plotted, as shown in Figure 72 for trial 2 on SuperSpeed 1. From this, we see that the total assembly time was 595 s or 9.75 min. The number of passengers assembled at each assembly station is outlined in Table 22, including the number of passengers already in the assembly station at the alarm who were wearing tags.

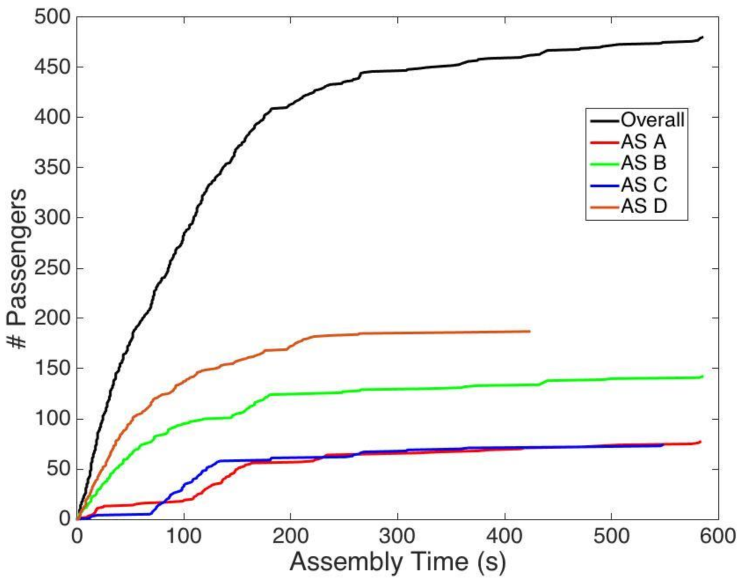


Figure 72 Passenger assembly time curves for trial 2 on SuperSpeed 1 (with passengers already in assembly station removed).

Table 22 Numbers of passengers assembling, by assembly station for trial 2 on SuperSpeed 1.

	AS A	AS B	AS C	AS D	Total
Number already in AS	80	37	28	139	284
Number moving to AS	77	142	74	187	480
Total	157	179	102	326	764

It was observed during the first trial onboard SS1 that some passengers who decided they did not wish to participate gave their IR tag to a member of the ship's crew. Several crew members were seen carrying multiple tags at a time to a place where the tags could be returned to the research team. This often meant that the crew member had to walk past at least one beacon to reach the research team tag storage location, thus registering multiple beacon reads at the same time and suggesting that an equivalent number of passengers had passed that location. Had this activity not been observed, the IR data results may have been confusing to understand, or incorrectly interpreted. As a result, crew members during the remaining four trials were instructed to tell passengers to leave tags on a seat or table nearby if they did not wish to participate. For the remaining trials, no instances of this activity were observed either during the actual trial or subsequently during video analysis. A detailed analysis of IR tag data is provided in Chapter 7, including how the data was used to develop two ship evacuation validation datasets.

5.3 Summary of Trials Results

5.3.1 Overview

A large corpus of data was collected during trials on the three ships. This section presents an overview of the data collected, starting with a summary in Table 23. This table presents an overview of the passenger participation level for each trial, in relation to the total number of passengers onboard, the total assembly time, amount of equipment used and an indication of where some passengers were located at the alarm. In total, 5,582 people were involved in the trails. A large proportion of those onboard agreed to participate in the trials (3,680 in all), with most of these individuals agreeing to complete a questionnaire and wear an IR tag. In addition to IR data collected, it was also possible to capture response time for 2,379 passengers across all trials.

Table 23 General overview of all data collected during the five sea trials.

Trial #	1	2	3	4	5
Vessel	SS1	SS1	JoS	OP	OP
Ship Owner	Color Line AS		Royal Caribbean Cruise Lines	Minoan Lines	
Trial Date	04/09/2009	05/09/2009	31/07/2010	12/03/2011	14/03/2011
# Cameras	30	30	106	40	40
# IR Beacons	30	30	70	51	51
# IR Tags Issued	1,170	1,192	2,299	199	174
# IR Tags Lost (% of total issued)	13 (0.55%)		282 (12%)	43 (12%)	
# PAX on Board	1,431	1,349	2,292	240	270
# Questionnaires Printed / Completed	1150 / 767	1150 / 767	2300 / 1862	400 / 110	400
# in AS at Alarm (% of participating)	- [1]	284 (37%)	36 (2%)	67 (58%)	75 (63%)
# PAX Assembled (% of participating)	- [1]	480 (63%)	1,743 (98%)	49 (42%)	44 (37%)
# PAX Participating (% of those onboard)	902 (63%)	764 (57%)	1,779 (78%)	116 (48%)	119 (44%)
Assembly Time	N/A	9.75 min	27.28 min	11.92 min	5.08 min
# Response Times	533	470	1,241	54	81

[1] As discussed in Section 4.8, IR data for trial 1 is not included here due to a technical problem with one IR beacon at an assembly station.

It is interesting to compare the overall assembly times for each vessel in relation to the number of passengers involved in the trials. The overall assembly time for JoS was 2.9

times greater than SS1 but the passenger population involved in the trials was only 2.3 times greater. Although the trials on OP involved many fewer passengers, the overall assembly time was closer to that of SS1. However, it is important to consider that although both trials on OP involved a similar number of passengers, the total assembly time for the second trial was less than half that of the first. This suggests there may be problems with this dataset, or that it simply had too few passengers involved to make it reliable.

A question remains – what are the reasons for the longer total assembly time on JoS? All vessels were similar in length, the JoS and SS1 trials took place at roughly the same time of day and passenger demographics were similar. However, JoS had 12 passenger decks – 4 times that of SS1, JoS had cabins for each passenger and the range of public space areas on JoS was significantly greater than onboard SS1. In addition, approximately half of the passengers on JoS who could be seen responding to the alarm were in cabins when the alarm sounded. This is supported by the IR data analysis, which shows that the start location for 760 passengers was in cabin areas.

It should be noted that passengers were permitted to move freely around the vessels during these trials. This meant that for each exercise, a proportion of passengers would naturally be located in assembly stations when the alarm was sounded. This is not cause for concern over the quality of the dataset, since the passengers were not told precisely when the trial would take place, only that it would occur at some point during their voyage. It is reasonable, therefore, to assume that they did not go to the assembly station to "wait-out" the start of the planned drill, as was the case during the FIRE EXIT trials [103]. It should be considered normal that passengers would be located in assembly stations at any point during their voyage on a ship, particularly since some were comfortable, internal spaces where passengers could eat, play games, socialise and, in some cases, be entertained. The starting region of all tagged passengers was determined by examining the last two beacon IDs passed prior to the start of the alarm, which would give an indication of the direction of movement. Passengers wearing IR tags who were located in an assembly station at the alarm were counted in this way. In addition, it was determined whether or not these passengers remained in the same assembly station until the end of the exercise or if any left and moved to another assembly station, or if they returned to their starting location. Table 23 shows that on SS1, 23% of participating passengers were in an assembly station at the alarm, while only 2% were in an assembly station at the alarm on JoS. More than half the participating passengers were in an assembly station on OP at the alarm – 58% and 63% for trials 1 and 2 respectively.

5.3.2 Ship 1 – Color Line SuperSpeed 1

The post-trial process of video data backup and IR tag data transfer onboard SS1 are shown in Figure 73. Approximately 14 GB of video data (representing 6 hours of video footage) was collected during the first trial and 11.7 GB of video data (representing 5 hours of video footage) was collected during the second trial. A high proportion of passengers onboard participated in the research by wearing an IR tag (Figure 74).

Figure 73 Project team uploading IR tag data and backing-up video immediately following the first trial onboard the SuperSpeed ferry.

Population demographics and response times were collected from analysis of trials video onboard SuperSpeed 1. Passenger location and general demographics captured from video data is shown in Table 24 to Table 28. A total of 1,003 passenger response times were collected from video analysis – 533 on day 1 and 470 on day 2. Table 24 presents the overall population demographics for gender of the passengers involved, with roughly an even split for day 1 (53% males to 46% females, 1% unidentifiable), but a much larger proportion of males on day 2 (64% males to 34% females and 2% unidentifiable).

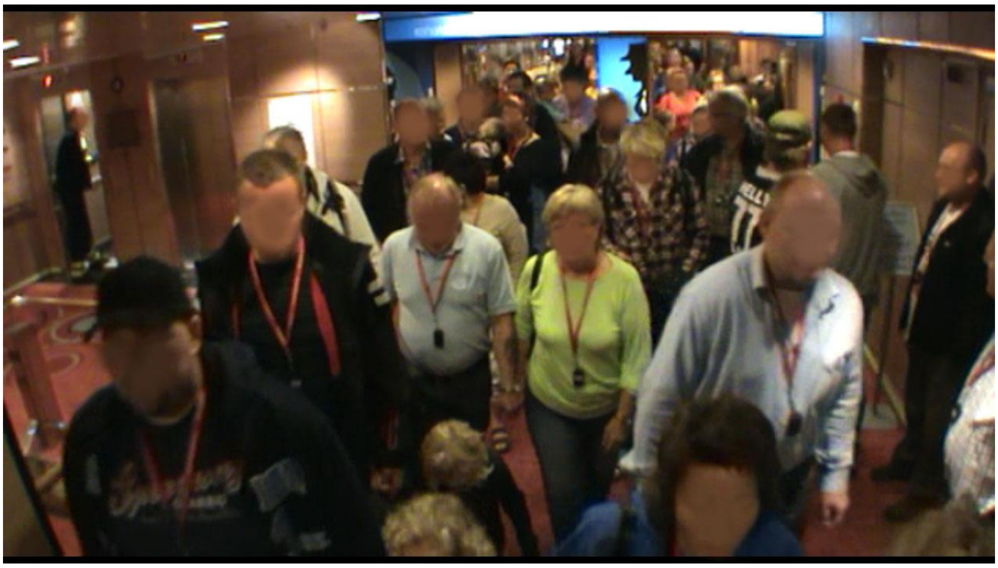


Figure 74 Sample video still image captured on SuperSpeed 1 showing passengers wearing IR tags and moving toward assembly stations.

Table 24 SuperSpeed 1 trial demographics by gender.

	Males	**Females**	**N/A**	**Total**
Day 1	281	246	6	**533**
Day 2	303	158	9	**470**
Total	**584**	**404**	**15**	**1003**

Table 25 shows that most passengers on both days were in the two age groups 20-39 year-olds and 40-59 year-olds. We see from Table 26 that the distribution of passengers throughout the ship was approximately the same for both days, with the highest proportion of passengers in the restaurant and bar areas (57% on day 1 and 54% on day 2).

Table 25 SuperSpeed 1 demographics by age group.

	≤19	**20-39**	**40-59**	**60+**	**N/A**	**Total**
Day 1	42	237	234	4	16	**533**
Day 2	27	236	176	4	27	**470**
Total	**69**	**473**	**410**	**8**	**43**	**1003**

Table 26 SuperSpeed 1 demographics by region of ship.

	Bar	Airline Seats	Shops	Restaurant	General	Total
Day 1	140	111	30	166	86	**533**
Day 2	105	71	45	149	100	**470**
Total	**245**	**182**	**75**	**315**	**186**	**1003**

In Table 27, we see that for both days, most passengers whose response time was collected were sitting at the time of the alarm (70% and 67% for day 1 and day 2 respectively). Group demographics shown in Table 28 suggest that most passengers (71% on day 1 and 68% on day 2) appeared to be travelling with other travelling companions, while only a small proportion (11% and 14% for day 1 and day 2 respectively) appeared to be travelling alone.

Table 27 SuperSpeed 1 demographics by activity at alarm.

	Eating	Shopping	Sitting	Standing	Walking	Other	N/A	Total
Day 1	67	24	372	30	9	22	9	**533**
Day 2	42	39	314	37	11	11	16	**470**
Total	**109**	**63**	**686**	**67**	**20**	**33**	**25**	**1003**

Table 28 SuperSpeed 1 demographics by group type.

	With Travelling Companions	With Family	Alone but near Strangers	Other	N/A	Total
Day 1	376	77	57	3	20	**533**
Day 2	318	70	65	0	17	**470**
Total	**694**	**147**	**122**	**3**	**37**	**1003**

As presented in Table 23, the total number of passengers wearing IR tags on SuperSpeed 1 was 1,666 – 902 (63% of those onboard) for trial 1 and 764 (57%) for trial 2. As noted earlier, a technical problem with an IR beacon located at an assembly station was damaged and, thus, the assembly data are not considered reliable for trial 1. However, it was reported by the Captain that the total assembly time for trial 1 was approximately 12 minutes. For trial 2, the Captain reported the exercise complete at approximately 10 minutes, which is supported by the IR system, which measured the last person entering the assembly station at 9.75 minutes. Of the 2,362 tags distributed to passengers on SS1 over both trials, only 13 tags were lost or stolen (0.55%) of the total. This means that very little data collected was actually lost.

A detailed analysis of passenger response times was performed and is presented as Chapter 6. Similarly, an analysis of IR data is provided in Chapter 7, along with how it was used with response time data to generate a validation data set for SuperSpeed 1.

5.3.3 Ship 2 – Jewel of the Seas

A total of 37 GB of video data (representing approximately 53 hours of video footage) was collected during the trial onboard JoS. Of this, approximately 33 GB (representing approximately 47 hours of video footage) came from the 94 CCTV system cameras and 4 GB (representing approximately 6 hours of video footage) came from the UoG cameras. From this, a total of 1,228 response times were collected. Figure 75 provides sample photographs of the assembled passengers in external and internal assembly stations. Figure 76 depicts the movement of passengers on the main stairway at the midships area of the vessel. These images give an indication of the scale of the exercise and the large numbers of passengers involved.

Table 29 presents the overall population demographics broken down by gender of the passengers who responded to the alarm – approximately an even number of response times were collected for males (47%) and females (49%), with 4% of being unidentifiable.

Table 29 MS Jewel of the Seas demographics by gender.

Males	**Females**	**N/A**	**Total**
576	605	47	1228

(a) (b)

(c)

Figure 75 Passengers assembled in assembly stations on Jewel of the Seas (a) port side, external (looking forward); (b) starboard side, external (looking aft); (c) main theatre in bow area, internal.

Figure 76 Sample video still image showing passengers wearing IR tags and moving down main staircase toward assembly stations on Jewel of the Seas.

Table 30 presents the passenger age group demographics, which indicates that as with SS1, people between the ages of 20-39 and 40-59 formed the largest portion of the population onboard at 75% of the total population. The distribution of passengers in different regions of the ship is presented in Table 31, which suggests that most passengers were either in cabins (49%) or in restaurant areas (39%).

Table 30 MS Jewel of the Seas demographics by age group.

≤19 yrs	20-39 yrs	40-59 yrs	60+ yrs	N/A	Total
78	418	507	87	138	1228

Table 31 MS Jewel of the Seas demographics by region of ship.

Restaurants	Cabins*	Shops	Reception	Bars	Pool	Other	Total
479	595	31	41	60	18	4	1228

* Passengers that can be seen emerging from their cabin into adjacent corridor.

Table 32 shows that at the alarm, the activity of most passengers could not be directly observed as they were in cabin areas (47%), whereas the passenger activities that could be observed were mostly of those eating (23%) or sitting (15%). While it may appear that there is a discrepancy between some of the values presented in Table 31 and Table 32, the reader should understand that some passengers who were observed as being located in a cabin area may have been, for example eating when observed. Similarly, passengers who were observed as being physically located in a restaurant area may not have been actually eating at the time of the alarm. Group demographics are presented in Table 33, which clearly shows most passengers onboard (89%) appeared to be travelling as part of a group.

Table 32 MS Jewel of the Seas demographics by activity at alarm.

Eating	In Cabin	Sitting	Standing	Walking	Shopping	Sports	N/A	Total
283	582	184	43	27	41	15	53	1228

Table 33 MS Jewel of the Seas demographics by group type.

With Travelling Companions	With Family	Alone but near Strangers	Alone and Isolated	N/A	Total
974	122	72	31	29	1228

5.3.4 Ship 3 – Olympia Palace

Approximately 20 GB of video data (representing 9 hours of video footage) was collected during the first trial and 16 GB of video data (representing 7 hours of video footage) was collected on the second trial. It was found that passengers were less receptive to wearing IR tags during trials on this ship, however a large proportion of participating passengers agreed to complete a questionnaire (Figure 77). From analysis of video data, a total of 135 passenger response times were collected – 54 on day 1 and 81 on day 2. By comparison to trials on the preceding two ships, this is a much smaller dataset the can be used for analysis.

Figure 77 Passengers in the assembly station on Olympia Palace completing questionnaires after completion of the trial.

As can be seen from Table 34, the distribution of male to female passengers was approximately even on both days and most passengers onboard were under 19 years of age on day 1 (74%) while on day 2, only 26% of those onboard were under 19 (Table 35).

Table 34 MS Olympia Palace demographics by gender.

	Males	Females	N/A	Total
Day 1	30	24	0	**54**
Day 2	37	39	5	**81**
Total (Both Days)	**67**	**63**	**5**	**135**

Table 35 MS Olympia Palace demographics by age group.

	≤19 yrs	20-39 yrs	40-59 yrs	60+ yrs	N/A	Total
Day 1	40	7	7	0	0	**54**
Day 2	21	23	19	6	12	**81**
Total (Both Days)	**61**	**30**	**26**	**6**	**12**	**135**

Most of the passengers onboard were located in cabin areas (83% on day 1 and 62% on day 2), with 32% of those on day 2 being found in the bar area of the ship (Table 36). Analysis suggests that passenger activity at the alarm could not be directly observed, as 74% of passengers on day 1 and 62% on day 2 emerged from their cabin when the alarm sounded (Table 37). Table 38 shows, again that most passengers onboard appeared to be travelling with companions – 82% on day and 69% on day 2.

Table 36 MS Olympia Palace demographics by region of ship.

	Bar	Airline Seats	Cabins	Outdoor Lounge Area	Total
Day 1	4	0	45	5	**54**
Day 2	26	4	50	1	**81**
Total (Both Days)	**30**	**4**	**95**	**6**	**135**

Table 37 MS Olympia Palace demographics by activity at alarm.

	Eating	In Cabin	Sitting	Standing	Walking	N/A	Total
Day 1	0	40	7	0	7	0	**54**
Day 2	1	50	10	17	2	1	**81**
Total (Both Days)	**1**	**90**	**17**	**17**	**9**	**1**	**135**

Table 38 MS Olympia Palace demographics by group type.

	With Travelling Companions	With Family	Alone but near Strangers	Alone and Isolated	N/A	Total
Day 1	44	0	4	6	0	**54**
Day 2	53	3	3	1	21	**81**
Total (Both Days)	**97**	**3**	**7**	**7**	**21**	**135**

5.4 Potential Sources of Measurement Error

As noted in previous sections, considerable effort was made to understand and mitigate potential measurement errors in the data acquisition and analysis methods. In particular, the inter-rater reliability testing, analyst training and regular checks helped to ensure a consistent approach to the video analysis process. However, quantifying human behaviour is a complex task and it is important to recognise other potential sources of error in the analysis process. For example, given vessel complexity and size, it would be virtually impossible to track the movement of all passengers from their starting location to the assembly stations using video cameras. As such, when passengers move beyond the field of view of the cameras used for response time analysis, it was necessary to assume that they had responded to the alarm. However, it is possible that some passengers whose response time was recorded using a camera in one location may have gone to another location on the ship where a different camera was monitoring passenger response time. Thus, it is possible that a single passenger may have had more than one response time recorded. Similarly, a passenger's response time may have been recorded but he/she may not have actually gone to an assembly station (particularly for the case of SS1 and OP for which passengers were not required to participate in the assembly process). Given the complexity inherent in human behaviour and limitations of the technology available for measuring response time, it is not possible to determine if these errors occurred. It is, however, worth stating that none of the video analysts reported having detected such duplicates.

It is also possible for errors to have been made in the estimates of passenger characteristics during video analysis. While it is reasonable to assume a high level of accuracy in the video analysts' estimate of a passenger's gender, it is likely that there are errors in estimates of passenger age, since this a somewhat subjective assessment. For cases in which it was not possible to assess a passenger's characteristic, it was flagged as "unidentifiable". It is worth noting that the estimate of passenger age category was one of the terms assessed in the inter-rater reliability testing. Thus, since the raters passed the test after 4 attempts and no issues were detected during spot checks, it is reasonable to assume that the analysts' perception of age was well aligned.

Another potential source of error relates to the way passengers behaved during the trials, since they were told an exercise was planned for that day. While it is possible that some passengers may have behaved differently than they would in an actual emergency, it is encouraging that the results of this study show response time distributions, which have a lognormal shape and thus are in-line with what has been measured in other published research such as the FIRE EXIT project [103].

It is also noted that not all passengers chose to participate in the research by wearing a tag, however, it is known that a proportion of these individuals *did* choose to participate in the assembly process. As a result, errors are produced when attempting to accurately model the assembly process, since the passengers who chose not to wear a tag have an effect on the overall assembly process. This error is described in greater detail in Chapter 7.

Finally, it is worth noting that the camera and IR system synchronisation for the JoS trial was confirmed because the author, whose IR tag number was known, could be seen arriving at two external assembly areas, which were viewed by cameras at the same time and within a few seconds of the IR system time for each location. This provides us with confidence in the reliability of the methods used.

5.5 Chapter Summary

The data analysis methodology has been presented in this chapter for determining the response time from the video data, as well as the analysis methods for IR data collected.

Video analysis was undertaken using Adobe Premiere Pro software and the process of inter-rater reliability testing demonstrated that the three video analysts (including the author) required four rounds of testing before the level of results agreement met the 90% minimum threshold.

The IR dataset analysis method was also outlined and sample results used to demonstrate that the IR system provided high quality passenger assembly data, both in terms of the number of data points collected but also total assembly time of individual passengers for each assembly station. Detailed results also provide the starting locations onboard, including those who were located in each assembly station at the time of the alarm.

Demographic details for each trial are summarised in this chapter and show that the dataset collected is comprehensive and rich in detail. In all, 5,582 passengers were onboard during the trials and 3,680 chose to participate by wearing an IR tag (a 66% participation rate). The complete video dataset was 584GB in size and consisted of 186 hours of video. From this, 2,379 response times were collected, along with associated demographics information for each passenger. Questionnaires were completed (3,506 in total) by most passengers who participated, providing information about their location onboard, perception of the trial and level of familiarity with the vessel, however, the questionnaire dataset is not analysed in this dissertation.

A summary of the potential sources of measurement error has also been provided, for which the most significant issues identified relate to passenger behaviours, both in terms of whether their behaviour during the trials was realistic and whether the passengers assessed as having responded to the alarm actually went-on to the assembly stations. While these potential issues are difficult to quantify, it was noted that large numbers of passengers actually *did* assemble, and thus must have responded to the alarm. It was also noted that passenger response time distributions took a lognormal form which has been measured in other projects and is well documented in the literature.

Chapter 6 will provide a detailed analysis of passenger response times for the different demographics observed and locations onboard each ship and for each trial. Particular focus is put on comparing response time behaviour for the cabin and public areas on the different ships in order to determine if differences exist in response behaviour for similar spaces on different ship types. Repeatability of the response time behaviour is also examined for different trials on the same ship. Finally, response time distributions are proposed for updating the IMO passenger ship evacuation analysis guidelines, specifically as they relate to RO-PAX ferries and cruise ships.

6 Response Time Results and Analysis

6.1 General Overview

This chapter provides a detailed discussion of the response time data produced during the analysis of video discussed in Chapter 5. The analysis is provided in three main subsections – one for each ship tested and examines relationships that exist between passenger response time and passenger demographics, as well as location on the vessel. Where possible, the similarity of repeat trials is considered. The response time distributions developed in this chapter take a lognormal form according to Equation (6):

$$y = \frac{1}{\sqrt{2\pi} \cdot \sigma \cdot x} exp\left[-\frac{(\ln(x) - \mu)^2}{2 \cdot \sigma^2}\right] \quad (6)$$

Where:

μ = mean value parameter

σ = standard deviation parameter

x = independent variable (time (s) for the response time distributions presented)

y = probability density

A comparison is made of passenger response time distributions for analogous cases on the different ships tested, as well as data from trials on other vessels, in particular the FIRE EXIT project, which produced response time datasets used in IMO MSC.1/Circ.1238 [21]. The chapter concludes with recommendations for passenger response time datasets it is felt should be implemented in the updated version of IMO MSC.1/Circ.1238.

The work discussed in this chapter was presented by the author at the 5th International Human Behaviour in Fire Conference [224] and at the Royal Institution of Naval Architects (RINA) SAFEGUARD Passenger Evacuation Seminar [226]. It was also published in the peer reviewed International Journal of Maritime Engineering, which is produced by RINA [225], This publication received RINA's prestigious Medal of Distinction for 2013. An information (INF) paper was also prepared based on this chapter and submitted by the Canadian delegation to the IMO in 2013 [227].

6.2 Response Time Analysis for SuperSpeed 1

As presented in Chapter 5, passenger response time data from trials onboard the SuperSpeed 1 (SS1) was captured from analysis of video. The data was plotted as probability density functions - response time distributions (RTDs) - according to the different characteristics of the trials in order to determine what correlations exist in the data with respect to passenger response time. In particular, this included gender, age, pre-alarm activity, whether the passenger was part of a group, location on the ship and trial date. Commercially-available software package, Matlab (with the statistics toolbox) was used to generate all RTDs and to perform all statistical analyses presented in this chapter.

6.2.1 Trial 1 and Trial 2 Comparison

A summary of the response time data for trial 1 and trial 2 is provided in Table 39 and RTDs generated for each trial on SS1 are given in Figure 78. The data displays the typical lognormal distribution and so a lognormal curve was fitted to each of the datasets and the curves from both trials compared in Figure 79. It is observed that the curves from both trials are remarkably similar. A Mann-Whitney non-parametric U-Test [241][242] was performed at the 5% significance level with the null hypothesis that trial 1 and trial 2 results were independent samples from identical continuous distributions with equal medians. The Mann-Whitney z-value and p-value test statistics are examined to determine if the null hypothesis is retained or rejected. If the absolute value of z is less than the critical value of 1.96 the null hypothesis is retained, otherwise it is rejected. The p-value gives the probability that a decision to reject the null hypothesis is the result of random sampling error. Results show that, for the two distributions compared, the null hypothesis is not rejected, with a z-value = 1.7534 (i.e. less than 1.96) and a p-value = 0.0795.

Throughout the remainder of this chapter, comparisons are made between different distributions using the Mann-Whitney non-parametric U-Test at the 5% significance level. For all cases, the test is referred to simply as a *Mann-Whitney test*.

Table 39 Summary of response time data for SS1, by trial number.

Trial No.	Min (s)	Max (s)	Mean (s)	SD (s)	Median (s)	Mode (s)	n
1	0.6	469.2	47.2	60.0	30.2	14.1	533
2	2.1	402.4	58.5	68.0	33.7	9.4	470
Overall	0.6	469.2	52.5	64.1	32.0	9.4	1003

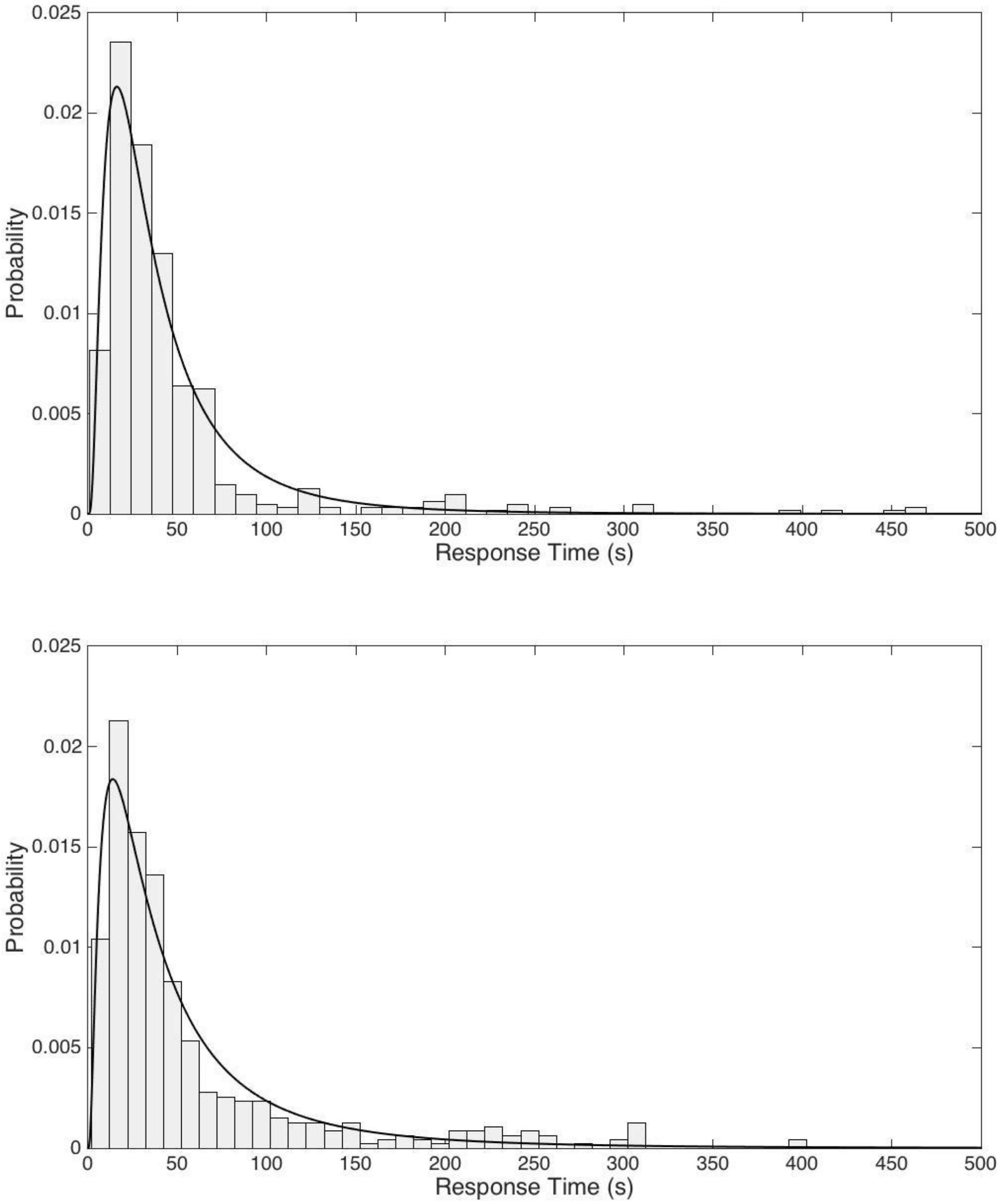


Figure 78 Response time distributions for SS1, (upper) Trial 1 and (lower) Trial 2.

This is an important finding, since it 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 an RTD that is statistically similar. Furthermore, this suggests that if the response times and demographics of a sufficient number of people are characterised for a given type of structure, then if the assembly exercise is repeated under similar notification conditions, a similar RTD would be generated. In other words, under these conditions the RTD is invariant.

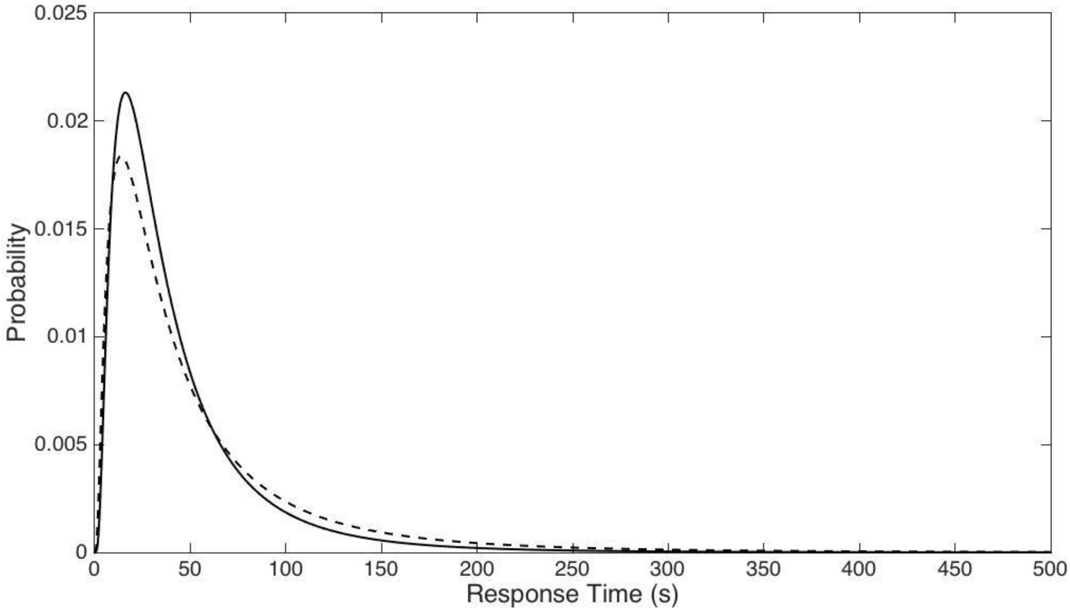


Figure 79 Comparison of response time distributions for trial 1 (solid) and trial 2 (dashed) on SS1

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 ship i.e. different ships of the same type. As there were also no significant differences between the distributions for male and female response times on both days, the results from both trials were combined to form a single dataset that can be considered representative of passenger response time behaviour on RO-PAX ferries that do not have cabins (Figure 80). The equation of the resulting lognormal distribution takes the form (Equation (7)):

$$y = \frac{1}{\sqrt{2\pi} \cdot 0.901x} exp\left[-\frac{(\ln(x) - 3.516)^2}{2 \cdot 0.901^2}\right] \tag{7}$$

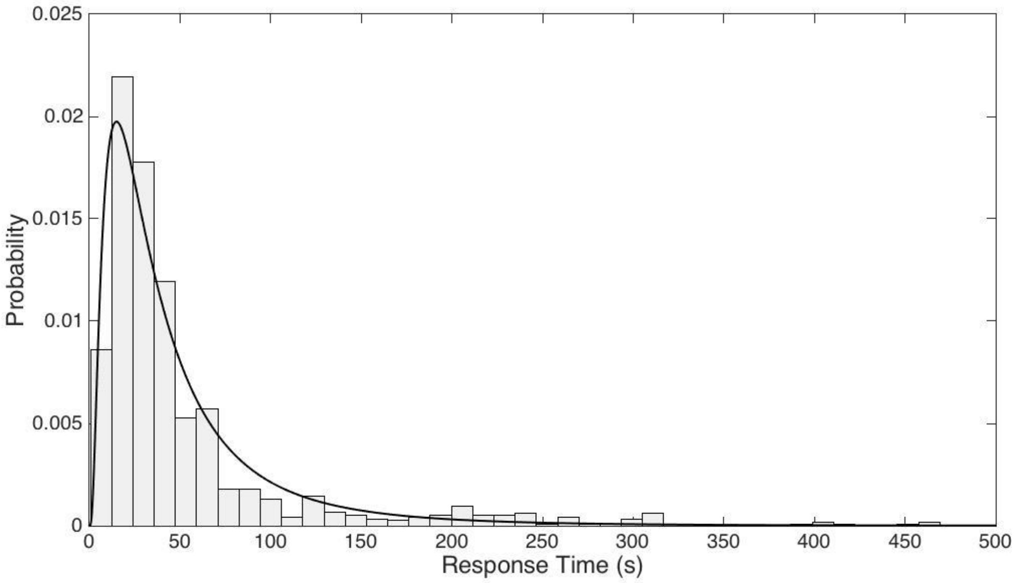


Figure 80 Overall response time distribution for SS1.

The minimum and maximum response times for the overall SS1 dataset are 0.6 s and 469 s, while the mean (μ) and standard deviation (σ) of the fitted distribution are 3.516 s and 0.901 s, respectively. Comparing the arithmetic mean and standard deviation of the fitted distribution to the dataset, using Equations (8) and (9):

$$\text{Arithmetic Mean} = e^{(\mu+\sigma^2/2)} \tag{8}$$

$$\text{Arithmetic Standard Deviation} = e^{(\mu+\sigma^2/2)}\sqrt{e^{\sigma^2}-1} \tag{9}$$

we see that the fitted distribution represents that dataset well with a 4% difference between the mean values and a 12% difference between the standard deviations, as presented in Table 40.

Table 40 Comparison of SS1 overall response time distribution arithmetic mean and standard deviation to that of the fitted distribution.

Arithmetic Value	**Mean**	**St. Dev.**
Fitted Distribution	50.5	56.5
Dataset	52.5	64.1

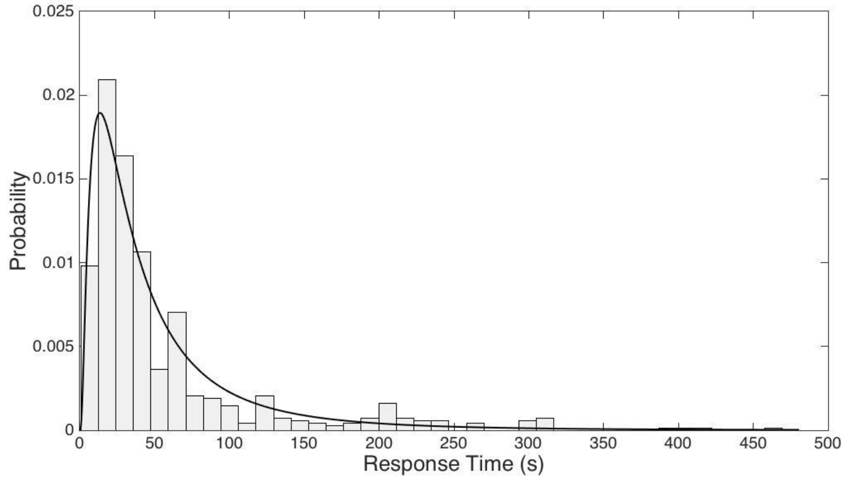
Further analysis of the dataset shows that 50%, 75% and 90% of the passengers had responded after 32 s, 56 s and 119 s respectively. By comparison, the assembly times collected (which will be outlined in detail in Chapter 7), it was found that 50%, 75% and 90% of the participating passengers had reached the assembly station after 23 s, 104 s, and 178 s respectively.

6.2.2 Male and Female Response Times

A summary of the response time data for male and female passengers is given in Table 41 and RTDs generated for male and female passengers are shown in Figure 81. The data displays a lognormal form, so a lognormal curve was fit to each. Plotting both curves on the same axes (Figure 82) suggested that the curves were very similar. A Mann-Whitney test [241][242] was performed with the null hypothesis that response times for male and female passengers were samples from the same distribution. Results from the test show that the null hypothesis is not rejected with a z-value = 1.2011 and p-value = 0.2297. This suggests that for the trials on SS1, males and females responded to the alarm in the same way and that it is reasonable to combine the two datasets to form a single response time distribution.

Table 41 Summary of response time data for SS1, by gender.

Gender	Min (s)	Max (s)	Mean (s)	SD (s)	Median (s)	Mode (s)	n
Male	0.6	469.2	56.8	68.2	32.6	9.4	584
Female	2.1	459.9	45.8	56.7	31.1	25.7	404



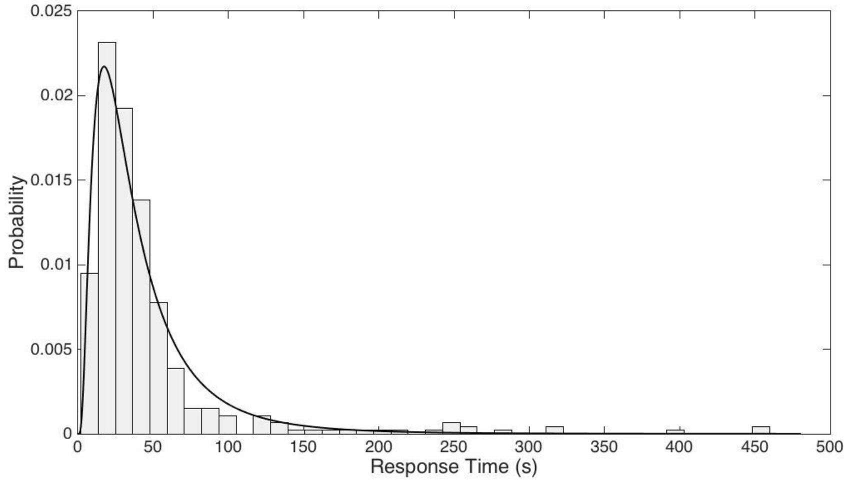


Figure 81 Response time distributions from SS1 trials (upper) males; (lower) females.

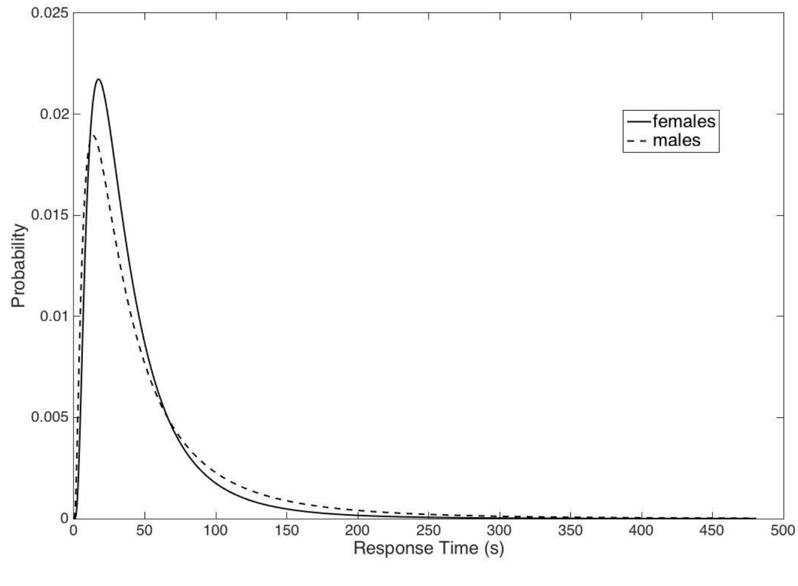


Figure 82 Comparison of fitted response time distributions for male and female passengers on SS1.

6.2.3 Age and Group Effects on Response Time

Mean response times were calculated for the different age groups observed. Results are shown in Table 42, which suggest that there are differences in how people of different ages responded to the alarm. Elderly people were slowest to respond to the alarm, while people in the youngest age group were fastest to respond, by a difference of 27.2 s on average. It is worth noting that both age groups also had the smallest proportion of the overall population examined, which may be the reason for the difference. Mean times for each age group were consistent between the two trials, suggesting that the data presented in Table 42 is reliable.

Table 42 Summary of response time data for SS1, by age category.

Age Group	Min (s)	Max (s)	Mean (s)	SD (s)	Median (s)	Mode (s)	n
Up to 19	2.1	246.0	36.6	55.0	19.1	14.3	69
20-39	0.6	469.2	57.8	71.3	33.8	21.8	473
40-59	2.8	402.4	47.5	54.3	31.1	9.4	410
Over 60	9.0	207.0	63.8	71.8	30.4	9.0	8

Similarly, mean response times were calculated for passengers based on whether or not they were part of a group. The results (presented in Table 43 and Figure 83) suggest that passengers who are travelling as part of a group tended to take 16 s longer, on average, to respond to the alarm than those who appeared to be travelling alone. The reasons for this observed difference may be related to the way in which people who know each other behave in such situations. For example, it was regularly observed that passengers travelling together would talk for a period of time before responding to the alarm. In addition, family groups often needed to collect belongings and provide instructions to younger members of the group.

Table 43 Summary of response time data for SS1, by group / no group.

	Min (s)	Max (s)	Mean (s)	SD (s)	Median (s)	Mode (s)	n
Group	0.6	469.2	54.3	64.3	33.1	9.4	843
No Group	2.1	413.6	38.3	60.6	22.4	15.8	123

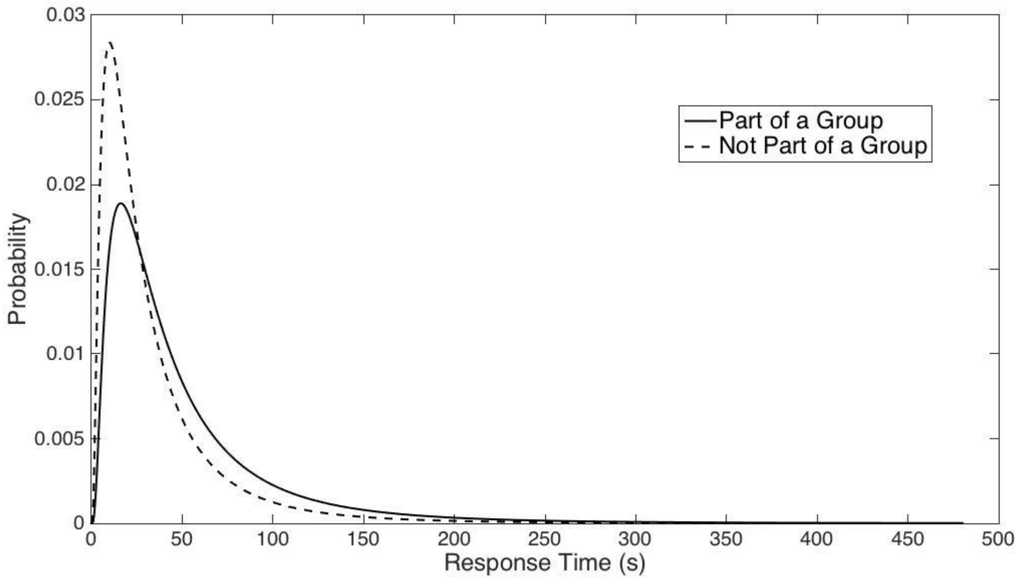


Figure 83 Comparison of SS1 passenger response time distribution for passengers who are and are not part of a group.

6.2.4 Comparing RTDs in Public Spaces for SS1 with Eurostar Roma

The RTDs shown in Figure 78 are for two different assembly trials on the same vessel. As discussed, these were found to be statistically similar, however it would be desirable to demonstrate that assembly trials on different vessels of the same type would produce a statistically 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 European Union Framework Program 5 project FIRE EXIT [103], described in Section 2.2.3. The ship used in this trial was a RO-PAX ferry named Eurostar Roma (ER). The ship had 11 decks, of which three could be utilised by passengers. The total passenger capacity of the ER was 1,400, with 208 passengers located in aircraft style seating, 626 accommodated in cabins and 566 deck passengers. The vessel had two restaurants, two bars and a casino area, as well as a reception area, shop and outdoor pool. The vessel is of a similar type 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. If we consider *only* data from the public spaces, in order to compare with that generated for SS1, a total of 67 response times are available. These data points were used to generate the day time RTD [21] used in the formulation of IMO MSC.1/Circ.1238. A lognormal distribution fitted to the ER dataset is presented on the same axes as the fitted distribution for the SS1 dataset in Figure 84. As can be seen from the Figure, the two distributions appear to be almost identical. A Mann-Whitney test [241][242] was performed with the null hypothesis that SS1 and ER results were samples from the same distribution. Results show that the null hypothesis is not rejected, with a z-value = -0.466 and p-value = 0.641. Using this result, it is argued that the RTD derived for SS1 can be considered representative of this vessel type – a RO-PAX ferry without cabins. Furthermore, the fact that the RTD derived from 1,003 individual response times during the SS1 trials is similar to that derived from 67 individual response times during the ER trials suggests that the fitted RTD is robust. Further recommendations regarding this RTD are provided below in Section 6.5.

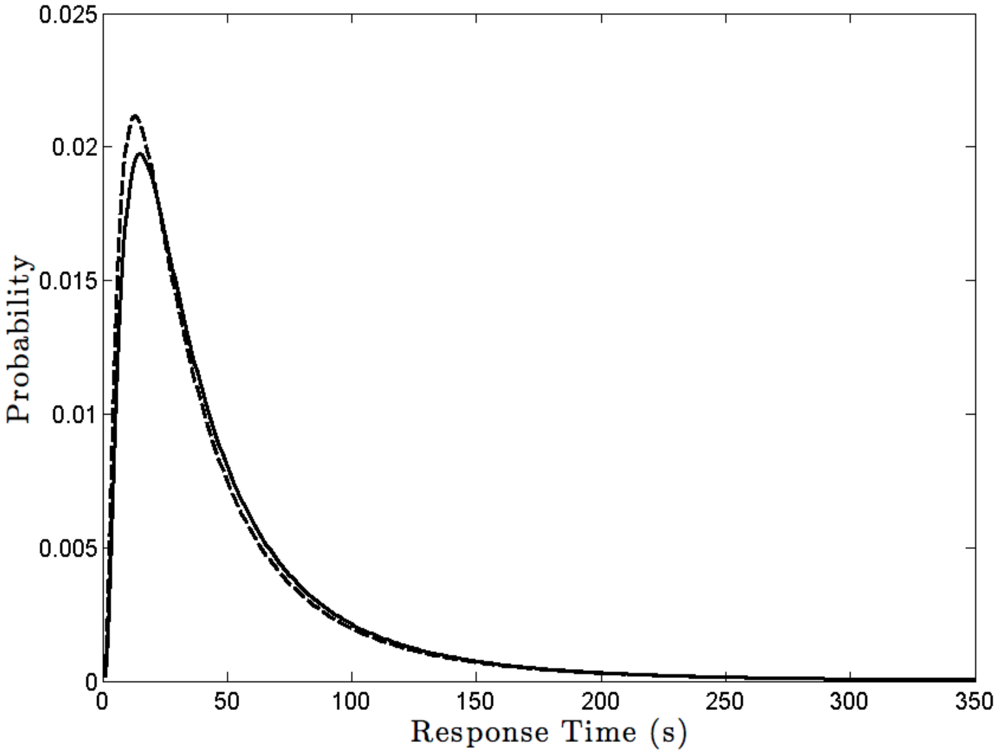


Figure 84 Comparison of RTDs for SS1 (solid) and ER (dashed)

6.3 Response Time Analysis for Jewel of the Seas

As presented in Chapter 5, passenger response times from the trial onboard the Jewel of the Seas (JoS) were captured from analysis of video. The data was plotted as probability density functions – response time distributions (RTDs) - according to the different characteristics of the trials in order to determine what correlations exist in the data with respect to passenger response time. In particular, this included gender, age, pre-alarm activity, whether the passenger was part of a group and location on the ship.

6.3.1 Male and Female Response Times

A summary of response time data for male and female passengers is given in Table 44 and RTDs generated are shown in Figure 85. The data displays a lognormal form, so a lognormal curve was fit to each. Plotting both curves on the same axes (Figure 86) suggested that the curves were very similar, as was seen onboard SS1. A Mann-Whitney test [241][242] was performed with the null hypothesis that response times for male and female passengers were samples from the same distribution. Results from the test show that the null hypothesis is not rejected, with a z-value = 1.3061 and p-value = 0.1915. This suggests that for the trials on JoS, males and females responded to the alarm in the same way and it is reasonable to combine the two datasets to form a single response time distribution.

Table 44 Summary of response time data for JoS, by gender.

Gender	Min (s)	Max (s)	Mean (s)	SD (s)	Median (s)	Mode (s)	n
Male	9.2	1269.0	232.5	228.4	154.7	31.0	576
Female	8.3	1378.7	222.6	228.5	138.0	53.9	605

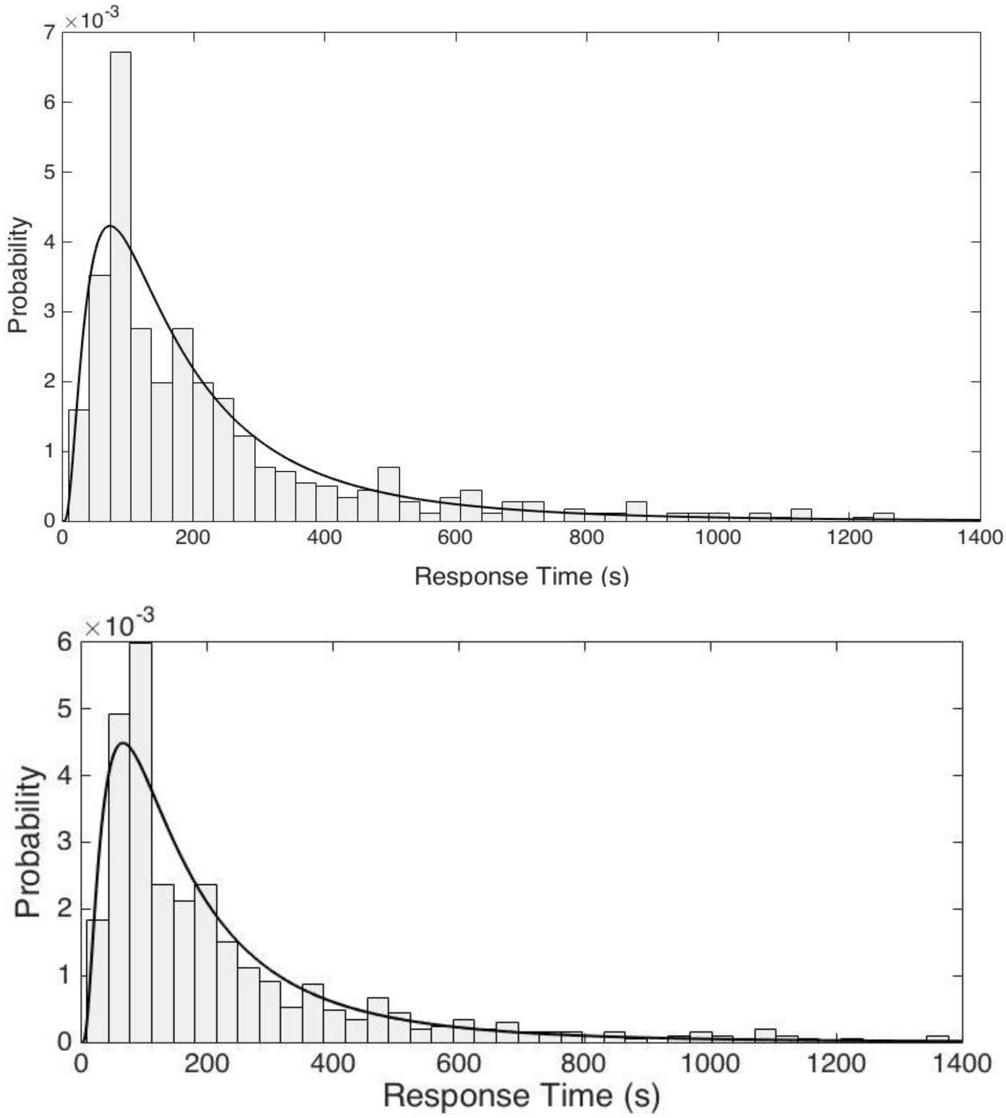


Figure 85 Response time distributions from JoS trial (upper) males; (lower) females.

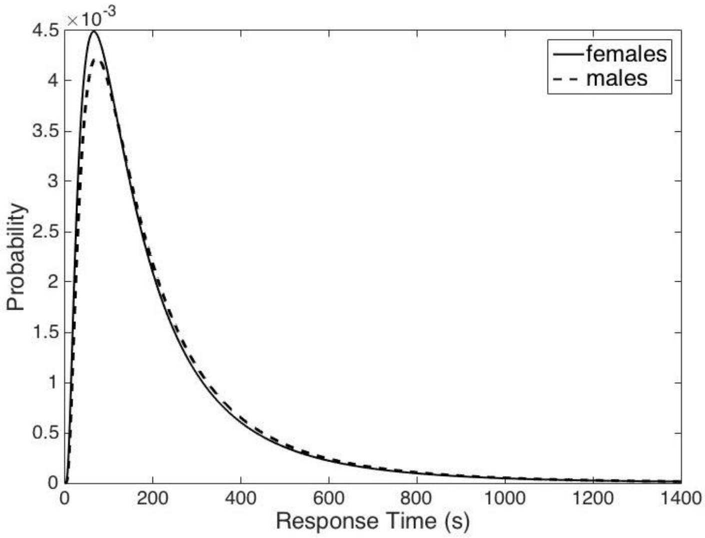


Figure 86 Comparison of response time distributions for male and female passengers on JoS.

6.3.2 Age and Group Effects on Response Time

Mean response times were calculated for the different age groups observed. Results are shown in Table 45, which suggest that, as with SS1, there are differences in how people of different ages responded to the alarm. Young adults (20-39 years old) were slowest to respond to the alarm, while people in the youngest age group (up to 19 years old) were fastest to respond, by a difference of 57.9 s on average.

Table 45 Summary of response time data by age category on JoS.

Age Group	Min (s)	Max (s)	Mean (s)	SD (s)	Median (s)	Mode (s)	n
Up to 19	14.9	712.8	186.2	149.6	136.4	23.8	78
20-39	8.3	1378.7	244.1	253.5	146.5	78.0	418
40-59	9.5	1260.2	229.5	230.7	146.6	293.2	507
Over 60	15.0	706.2	209.0	169.8	170.3	63.0	87

Similarly, mean response times were calculated for passengers based on whether or not they were part of a group and where they were located (cabins or not). These results are presented in Table 46 (part of a group) and Table 47 (not part of a group). For the overall case of whether passengers were in a group or not, the distributions are compared in Figure 83 which suggests that passengers who are travelling as part of a group tended to be 89.5 s faster, on average, to respond to the alarm than those who appear to be travelling alone.

Table 46 Summary of response time data for passengers who were part of a group and in cabins / not in cabins.

Response Time	Part of a Group						
	Min (s)	Max (s)	Mean (s)	SD (s)	Median (s)	Mode (s)	n
In Cabin	26.7	1378.7	330.3	263.8	233.4	66.0	505
Not in Cabin	8.3	448.8	122.0	83.4	89.0	78.0	592
Overall	8.3	1378.7	217.9	215.7	143.3	78.0	1097

Table 47 Summary of response time data for passengers who were not part of a group and in cabins / not in cabins.

Response Time	Not Part of a Group						
	Min (s)	**Max (s)**	**Mean (s)**	**SD (s)**	**Median (s)**	**Mode (s)**	**n**
In Cabin	24.0	1269.0	365.3	329.0	272.0	24.0	81
Not in Cabin	11.8	239.0	94.0	72.8	65.5	11.8	22
Overall	11.8	1269.0	307.4	313.8	189.2	98.4	103

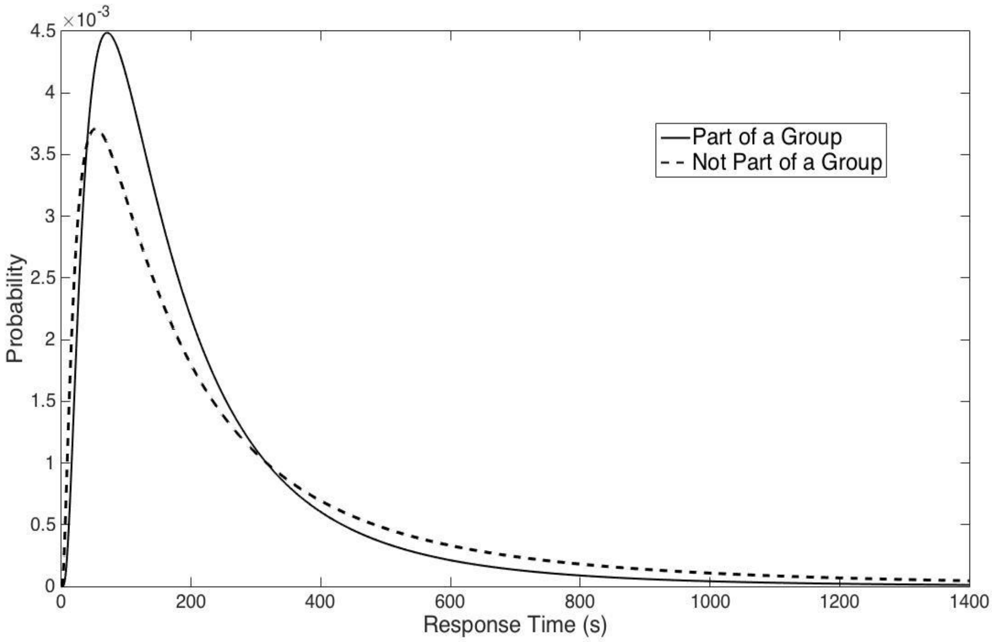


Figure 87 Comparison of JoS passenger response time distribution for passengers who are and are not part of a group.

This is the opposite of what was observed for passengers on SS1 so the dataset was further divided to determine if there were differences depending on where the passengers were located at the alarm – cabin areas or not. This data is also provided in Table 46 and shows that there is a large difference between passenger behaviour in groups, depending on where they are at the alarm. It can be seen that passengers not in cabin areas take much less time to respond than those in cabins. Interestingly, the observation on SS1 that passengers who appear to be alone respond more quickly to the alarm is also true for passengers on JoS in public spaces. In these cases, the passengers who appear to be part of a group at the alarm take 28 s longer, on average, to respond to the alarm. However, for passengers in cabin areas, those who do not appear to be part of a group tend to respond more slowly to the alarm by 35 s on average.

6.3.3 Overall RTD for JoS

A summary of the overall response time dataset for JoS is provided in Table 48 and the overall RTD is presented in Figure 88.

Table 48 Summary of the overall response time dataset for JoS.

Min (s)	Max (s)	Mean (s)	SD (s)	Median (s)	Mode (s)	n
8.3	1378.7	223.3	225.4	142.4	78.0	1228

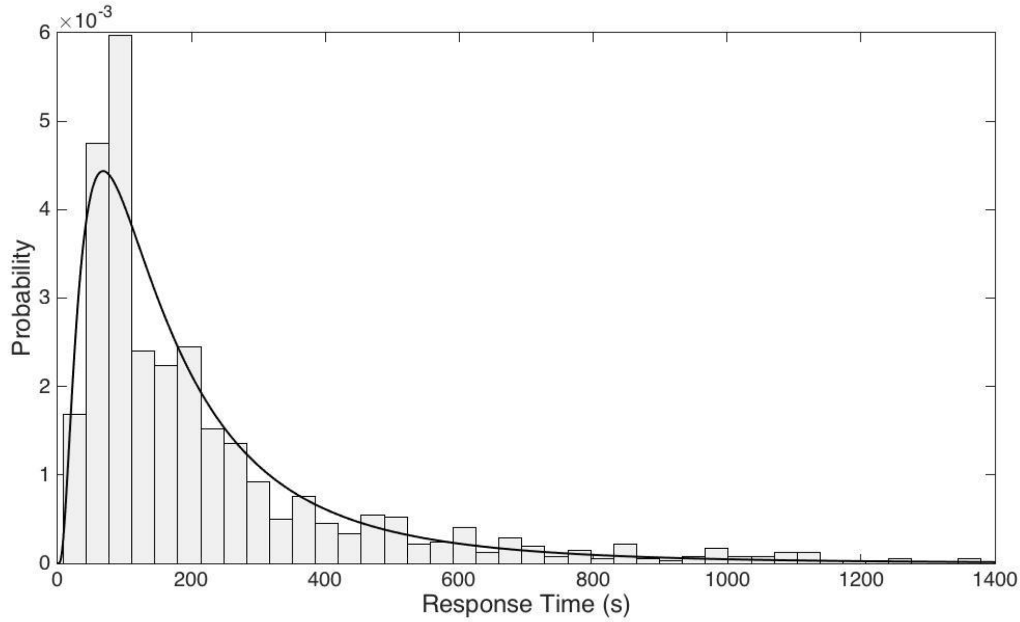


Figure 88 Overall response time distribution for JoS.

The data displays the typical lognormal distribution shape, so a lognormal curve was fitted as shown. The equation for the lognormal fit takes the form (Equation (10)):

$$y = \frac{1}{\sqrt{2\pi} \cdot 0.890x} exp\left[-\frac{(\ln(x) - 5.012)^2}{2 \cdot 0.890^2}\right] \tag{10}$$

The minimum and maximum response times were found to be 8.3 s and 1,379 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. Comparing the arithmetic mean and standard deviation of the fitted distribution to the dataset, using Equations (8) and (9), we see that the fitted distribution represents the dataset well with a 0.1% difference between the mean values and a 9% difference between the standard deviations, as presented in Table 49.

Table 49 Comparison of JoS overall response time distribution arithmetic mean and standard deviation to that of the fitted distribution.

Arithmetic Value	**Mean**	**St. Dev.**
Fitted Distribution	223.1	245.3
Dataset	223.3	225.4

6.3.4 Comparison of Cabin and Public Space RTDs

Since the assembly trial started at approximately 09:00 on the second day of the cruise, it was found that a significant number of passengers were still located in their cabins when the alarm sounded. It is considered valuable that passenger response times collected during this trial can be broadly divided into two main groups as noted above – passengers who were in cabins (595 passengers) and those who were in the public areas (633 passengers) of the ship. A summary of the response time data for passengers in cabins and public spaces is given as Table 50 and the RTDs generated are shown in Figure 89. For obvious reasons, the video record does not reveal passenger behaviour *within* cabins, thus the response time for passengers located in cabins was recorded as the point in time when the passenger had exited the cabin and started purposeful movement towards the assembly station.

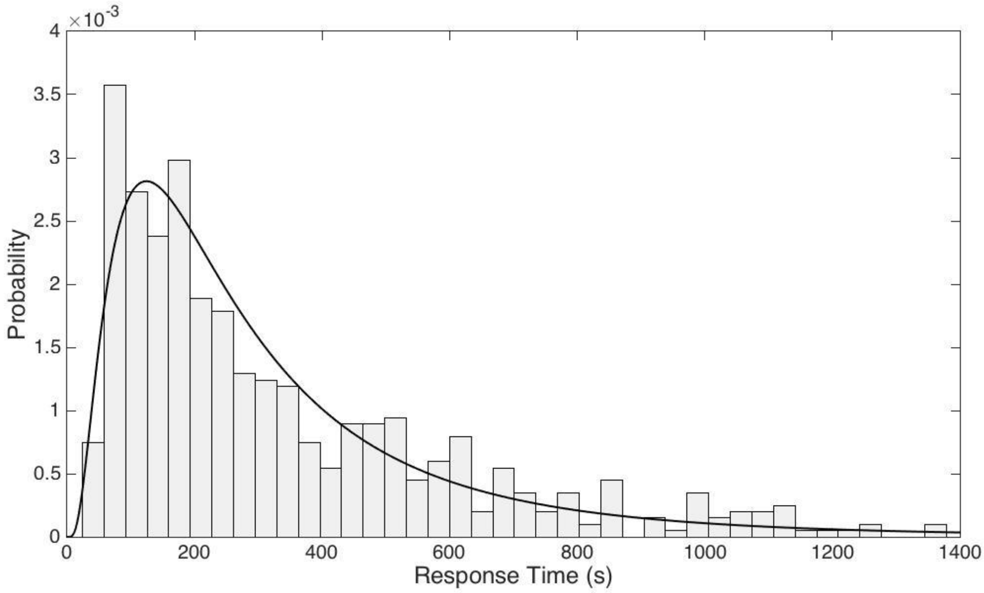
Table 50 Summary of response time data for JoS, by cabin and public areas.

Region	**Min (s)**	**Max (s)**	**Mean (s)**	**SD (s)**	**Median (s)**	**Mode (s)**	**n**
Cabin	24	1378.7	333.1	272.4	233.4	66.0	595
Public	8.3	448.8	120.1	82.6	88.4	78.0	633

The equations for the resulting RTDs for public spaces (Equation (11)) and cabins (Equation (12)) on JoS take the form:

$$y = \frac{1}{\sqrt{2\pi} \cdot 0.702x} exp\left[-\frac{(\ln(x) - 4.562)^2}{2 \cdot 0.702^2}\right] \tag{11}$$

$$y = \frac{1}{\sqrt{2\pi} \cdot 0.817x} exp\left[-\frac{(\ln(x) - 5.49)^2}{2 \cdot 0.817^2}\right] \tag{12}$$



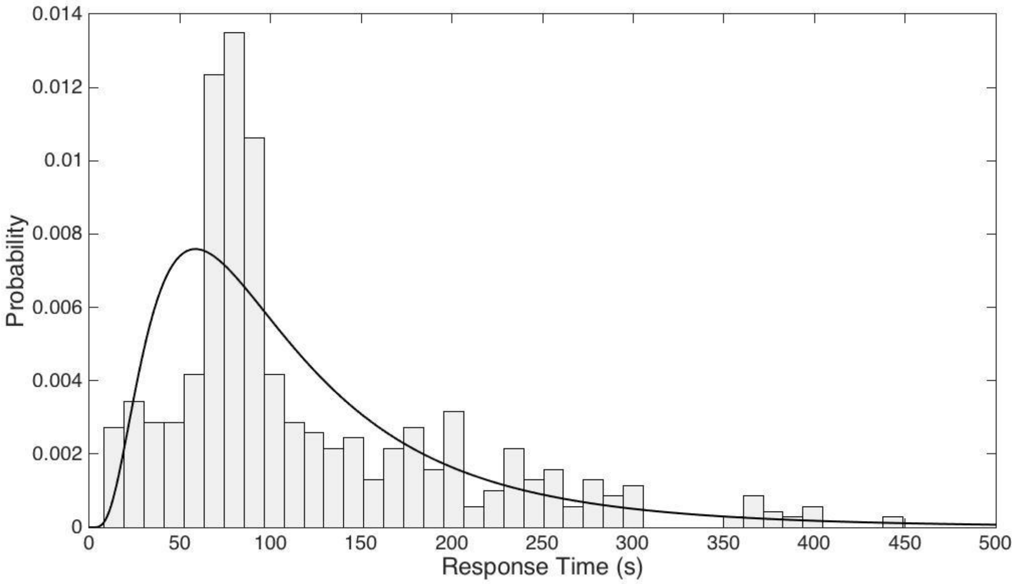


Figure 89 Response time distributions for JoS in (upper) cabins and (lower) public spaces.

Combining the two RTD on the same axes, we see that the response time distributions are quite different for passengers in cabins compared with passengers in public spaces on this ship (Figure 90). A Mann-Whitney test [241][242] was performed with the null hypothesis that results for passengers responding from cabins and results for passengers responding from public areas were samples from the same distribution. Results show that the null hypothesis *is* rejected, with a z-value = 18.230 and p-value = 0.000. Thus, passenger response times in each area are from statistically different distributions. This suggests that *different* RTDs should be used to represent passengers in cabins and public spaces on cruise ships. This observation is consistent with findings from the FIRE EXIT project onboard the Eurostar Roma [103].

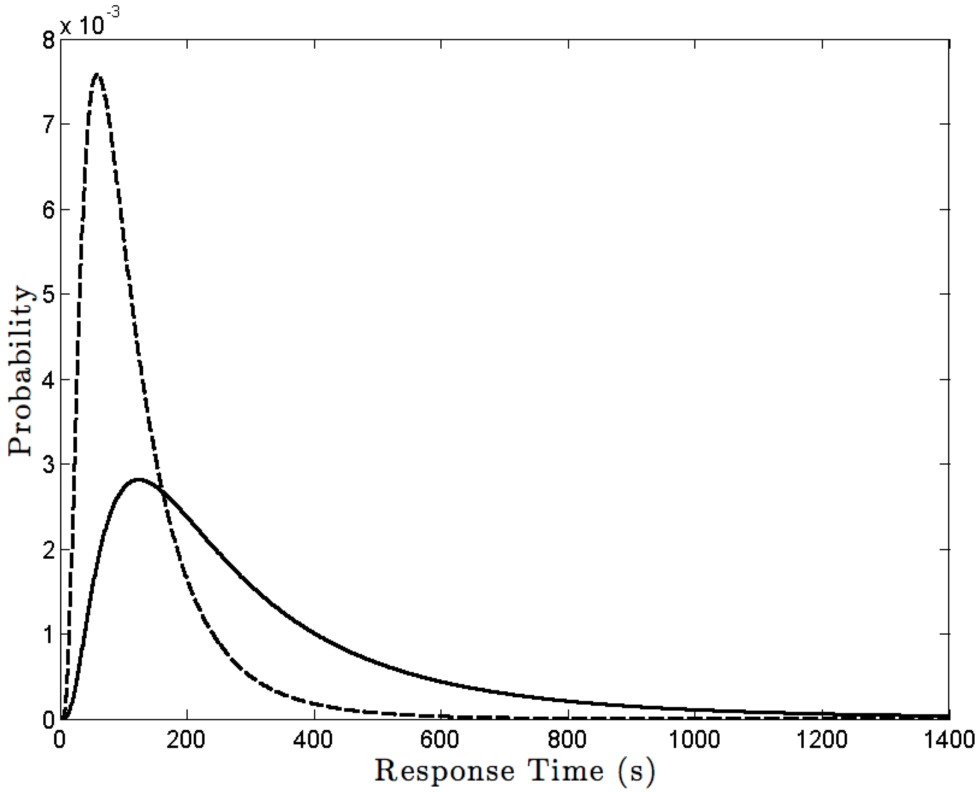


Figure 90 Comparison of RTDs for JoS in cabins (solid) and in public spaces (dashed)

It can be seen from Figure 90 that passengers in cabins tend to take considerably more time to respond to alarms than passengers in public areas. The arithmetic mean response time for passengers in cabins is 333 s while for passengers in public spaces it is considerably shorter at 120 s. A comparison of the arithmetic mean and standard deviation of the distributions fitted to the dataset, using Equations (8) and (9) is provided in Table 51.

From this, we see that for the cabin areas on JoS, the fitted distribution represents the dataset well with a 1.5% difference between the mean values and a 20.9% difference in the standard deviations. For the public areas on JoS, the fitted distribution also well represents the dataset, with a 2% difference between the mean values and an 18.2% difference between the standard deviations.

Table 51 Comparison of JoS response time distribution arithmetic mean and standard deviation to that of the fitted distribution, for cabin and public areas.

Arithmetic Value	**Cabin Areas**		**Public Areas**	
	Mean (s)	**St. Dev. (s)**	**Mean (s)**	**St. Dev. (s)**
Fitted Distribution	338.2	329.3	122.5	97.9
Dataset	333.1	272.4	120.1	82.6

Furthermore, for the cabins areas on JoS, 50%, 75% and 90% of passenger responded to the alarm after 233 s, 470 s and 704 s respectively, while in public spaces, the corresponding times are 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 (as depicted in Figure 6) and a different range of action and information tasks undertaken during the response phase [31]. For example, passengers in cabins may have been asleep, taking a shower or in the process of dressing, which would lead to longer notification times and a different range of action and information tasks compared to passengers in public spaces. This, in turn, could result in the different RTDs observed for each space.

6.3.5 Comparison of Public Spaces for JoS and SS1

As the JoS is a different vessel type than SS1, it is important to determine if the RTD generated for the SS1 (comprised of only public spaces) is similar to that for just the public spaces on JoS. Figure 91 presents the RTDs for passengers in public spaces for SS1, JoS and for the ER. It can be clearly seen that there is a difference between the RO-PAX ferry curves and JoS. A Mann-Whitney test [241][242] was performed with the null hypothesis that results for JoS passengers in public spaces and results for SS1 were samples from the same distribution. Results show that the null hypothesis *is* rejected, with a z-value = 22.456 and p-value = 0.000. Thus we can conclude that the distributions are statistically different. This is a significant result as it suggests that RTDs for public spaces generated for one vessel type cannot necessarily be applied to another vessel type.

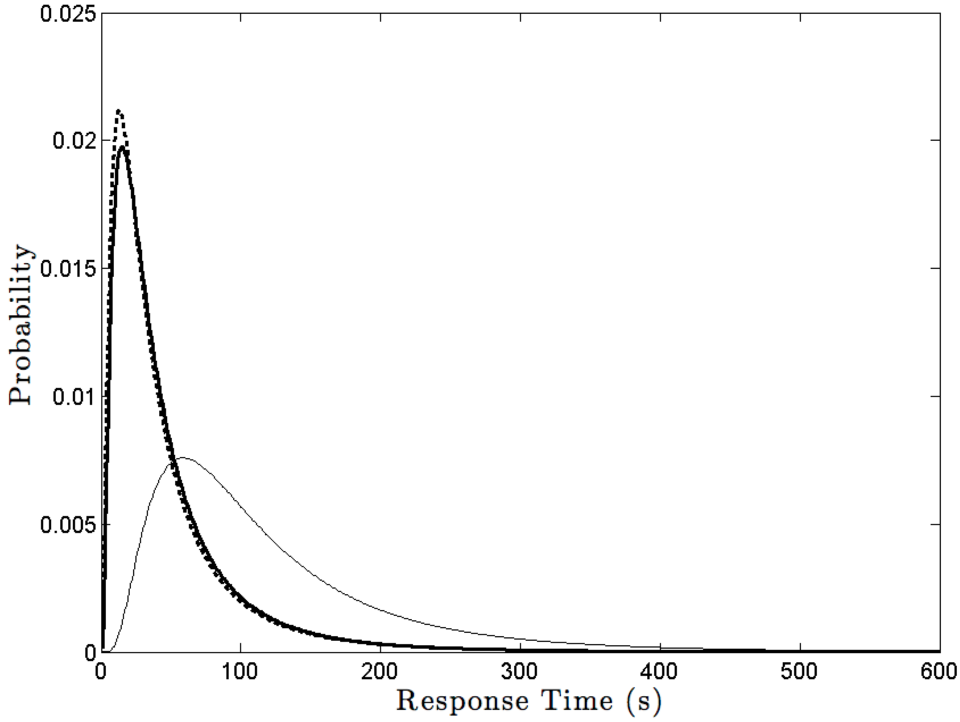


Figure 91 Comparison of RTD for public spaces on SS1 (thick solid), JoS (thin solid) and ER (dashed).

The difference in response behaviour between passengers on the RO-PAX ferries and cruise ships may be due to the differences in the *nature* of the voyage and the impact this may have on passenger perceptions of their connection to the vessel. RO-PAX ferries are normally used by people 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 ferries 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 port. In effect, the passengers are primed to leave. In contrast, since passengers on cruise ships tend to stay on the ship for several days, they effectively make the ship their home and have a greater expectation of permanency. This is hypothesised to be the reason for the differences in passenger response times presented here, with passengers taking longer to react in public spaces on the JoS compared to SS1 and ER.

If we compare the RTD for SS1 (and by implication the public spaces on ER) 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 passengers in public spaces on SS1 and JoS, the arithmetic mean response time is 52.5 s and 120 s respectively – a difference of 78%. Comparing public spaces for SS1/JoS we find that 50%, 75% and 90% of the population responded after 32 s/88 s (a 93% difference), 56 s/165 s (a 99% difference) and 119 s/242 s (a 68% difference) respectively. It is clear from this that passengers in public spaces on JoS tend to take considerably longer to respond to the alarm than passengers in public spaces on SS1. Furthermore, it is worth noting that these trials took place at approximately the same time of day, so this is not considered to be a contributory factor in the differences observed.

6.3.6 Comparison of Cabin Spaces for JoS and ER

A comparison was also made between the response time data for cabin spaces on JoS and ER as described in [103] for the FIRE EXIT project (Figure 92). A total of 126 response times were collected from passengers located in cabins onboard ER. These response times were used to generate the night time RTD presented in IMO MSC.1/Circ.1238 [21]. By comparison, a total of 595 response times (4.7 times more) were collected from the cabin area on JoS. From Figure 92, it appears that the RTDs generated for cabin spaces on JoS and ER are significantly different. A Mann-Whitney test [241][242] was performed with the null hypothesis that cabin area results for ER and JoS were samples from the same distribution. Results show that the null hypothesis *is* rejected, with a z-value = -12.5655 and p-value = 0.000.

While it seems reasonable for the passenger RTD in cabin areas on a cruise ship to be similar to that on a RO-PAX ferry, there are several reasons that may account for the differences observed here. The cabin spaces on the two types of vessel are significantly different and as has been already suggested above for public spaces, the *nature* of the voyage is different which could lead 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 JoS was an important part of the passengers' vacation experience. As such, the cabins on JoS were generally more luxurious and a more desirable place to stay than on ER. The cabin spaces on JoS were, in essence, temporary residences and passengers had "moved-in", unpacking their belongings and personal effects. In contrast, cabins on the ER were very small, simple spaces deigned to allow passengers to sleep for a few hours during the voyage and so passengers were less likely to 'move-in" on ER. It is hypothesised that this may have impacted the passengers' response to the alarm, with passengers taking longer to get ready to leave the cabin areas on JoS compared with ER.

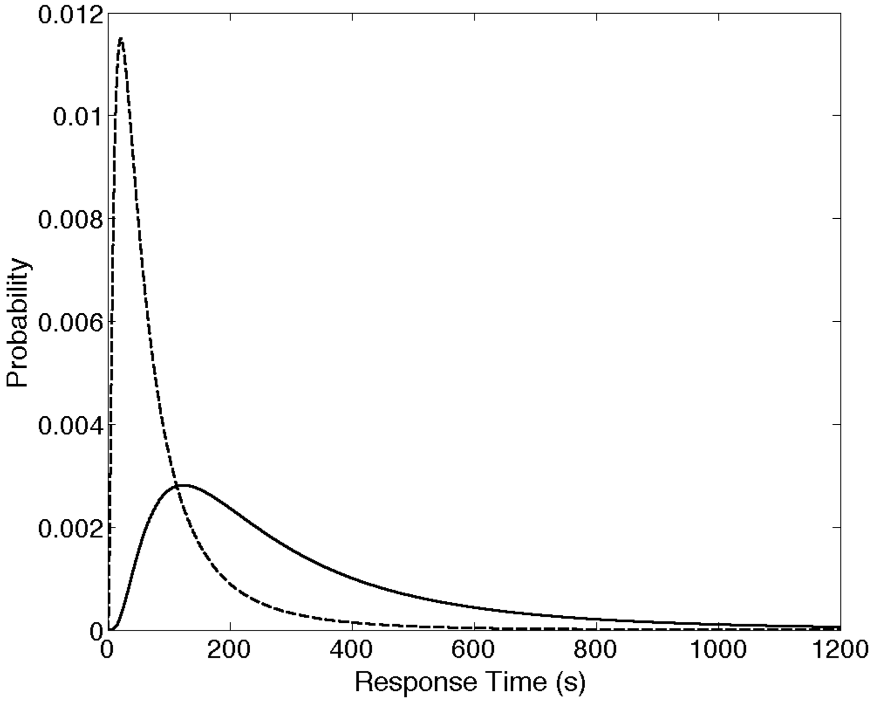


Figure 92 Comparison of RTDs for cabin areas on ER (dashed) and JoS (solid).

This, together with a similar observation concerning the public space RTD for JoS are significant results as they suggest that RTDs generated for one vessel type cannot necessarily be applied to another vessel type. Considering the RTDs presented, it is clear that passengers in both public spaces and cabins on JoS took considerably longer to respond to the alarm than passengers on the two RO-PAX vessels examined (SS1 and ER). The implications of this finding are that the RTDs currently used in IMO MSC.1/Circ.1238 [21], which were derived from assembly trials undertaken in the FIRE EXIT project onboard the ER [103] are not appropriate for *all* ship types. Thus, it is worth considering that different RTDs should be used for cruise ships and RO-PAX ferries when undertaking an evacuation analysis. This recommendation will be further discussed in Section 6.5.

6.4 Response Time Analysis for Olympia Palace

As presented in Chapter 5, passenger response time data from trials onboard the Olympia Palace (OP) were captured from analysis of video. The data was plotted as probability density functions – response time distributions (RTDs) - according to the different characteristics of the trials in order to determine what correlations exist in the data with respect to passenger response time. In particular, this included gender, age, pre-alarm activity, whether the passenger was part of a group, location on the ship and trial date.

6.4.1 Trial 1 and Trial 2 Comparison

A summary of the response time data for each trial on OP is provided in Table 52 and the RTDs generated are given in Figure 93. The distribution produced for trial 2 displays the typical lognormal shape, while the distribution for trial 1 does not appear to have a strong lognormal shape. Given that the datasets were quite small and with the understanding that response times are typically distributed in a lognormal fashion [103], a lognormal curve was fitted to each of the datasets and the curves from both trials compared on the same axes in Figure 94. The fitted curves from both trials are, again, very similar. A Mann-Whitney test [241][242] was performed with the null hypothesis that trial 1 and trial 2 results were samples from the same distribution. Results show that the null hypothesis is not rejected, with a z-value = 1.0824 and p-value = 0.2791. This suggests that both distributions can be combined to form a single, larger dataset for OP (a RO-PAX ferry with cabins) (see Figure 95). The equation of the resulting lognormal distribution takes the form (Equation (13)):

$$y = \frac{1}{\sqrt{2\pi} \cdot 1.308x} exp\left[-\frac{(\ln(x) - 4.259)^2}{2 \cdot 1.308^2}\right] \quad (13)$$

Table 52 Summary of response time data for OP, by trial number.

Trial No.	Min (s)	Max (s)	Mean (s)	SD (s)	Median (s)	Mode (s)	n
1	2.5	531.3	185.1	194.5	89.0	14.0	54
2	1.6	548.0	111.7	114.8	67.6	28.8	81
Overall	1.6	548.0	141.1	155.4	76.3	14.0	135

As with both trials on the SS1, this is an important finding that suggests if the trial were to be repeated again in the same environment with a different group of people with similar demographics, we would expect to generate an RTD that is statistically similar. As with the trials on SS1, this is a powerful result and suggests that if the response times and demographics of a sufficiently large number of people are characterised for a given type of structure, an assembly exercise repeated under similar notification conditions should result in a similar RTD. In other words, under these conditions the RTD is invariant, however, it is not clear that a similar RTD would be generated for passengers on different ships of the same type.

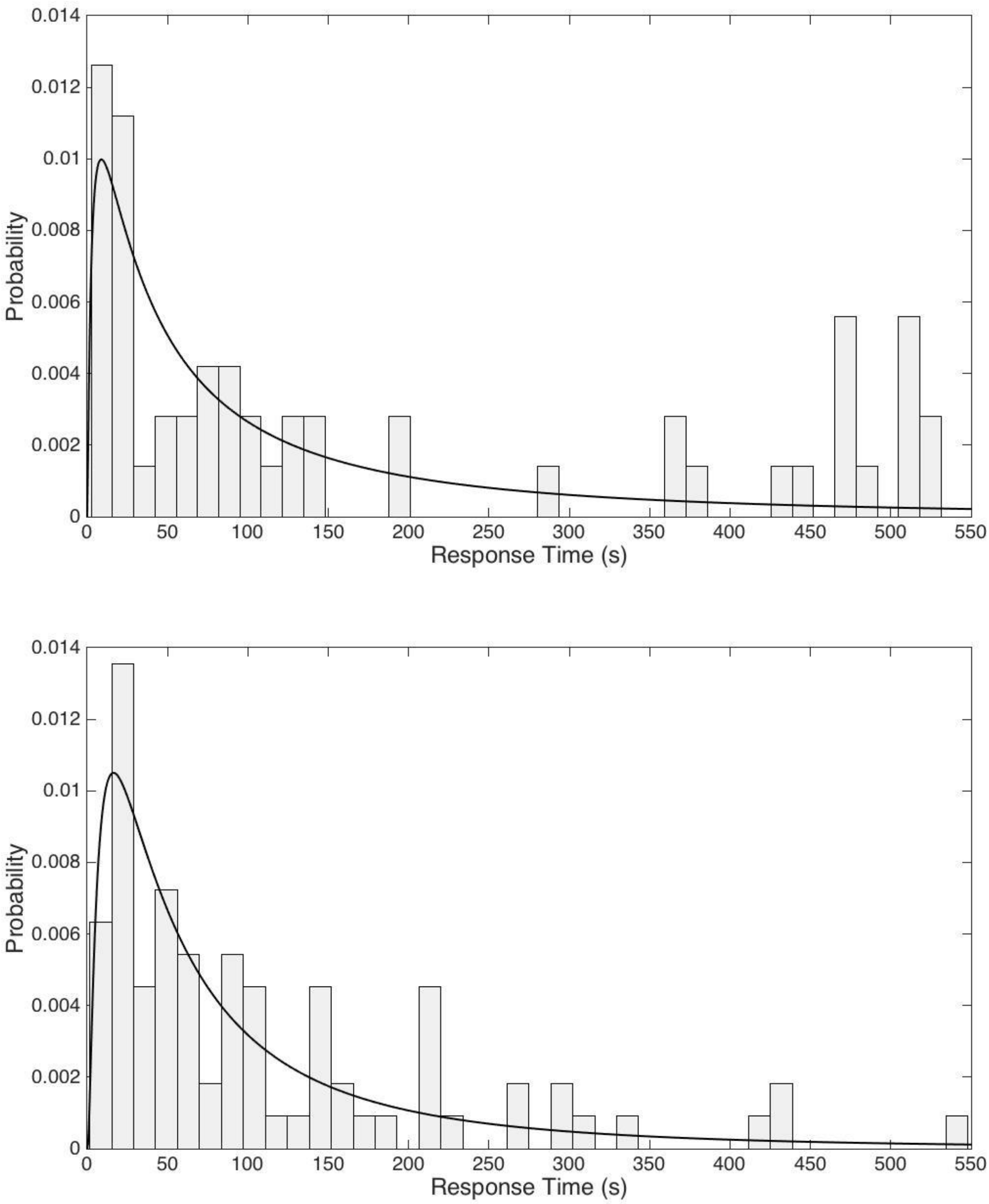


Figure 93 RTDs for OP, (upper) trial 1 and (lower) trial 2.

The minimum and maximum response times for the combined dataset are 1.6 s and 548 s, while the mean of the logarithm of response times is 4.259 s and the standard deviation of the logarithm of response times is 1.308 s. Analysis of the dataset shows that 50%, 75% and 90% of the passengers had responded after 76 s, 192 s and 432 s, respectively. Comparing the arithmetic mean and standard deviation of the fitted distribution to the dataset, using Equations (8) and (9), we see that the fitted distribution does not represent the dataset as well as for the other vessels, with a 17.9% difference in the mean values and a 127.9% difference in the standard deviations, as presented in Table 53. This provides further support that this RTD is not well represented by a lognormal model and caution should be exercised when using the dataset.

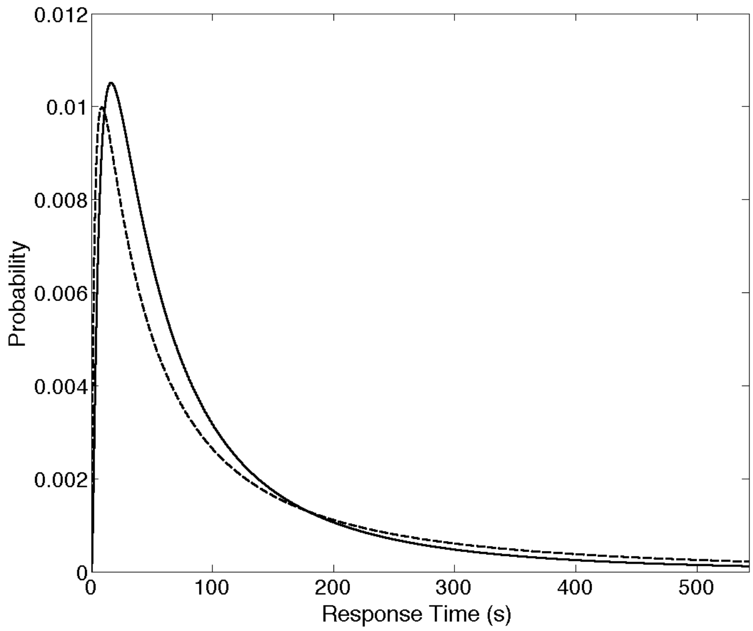


Figure 94 Comparison of RTDs for trials 1 (dashed) and 2 (solid) on OP.

Table 53 Comparison of OP overall response time distribution arithmetic mean and standard deviation to that of the fitted distribution.

Arithmetic Value	Mean (s)	St. Dev. (s)
Fitted Distribution	166.3	354.1
Dataset	141.1	155.4

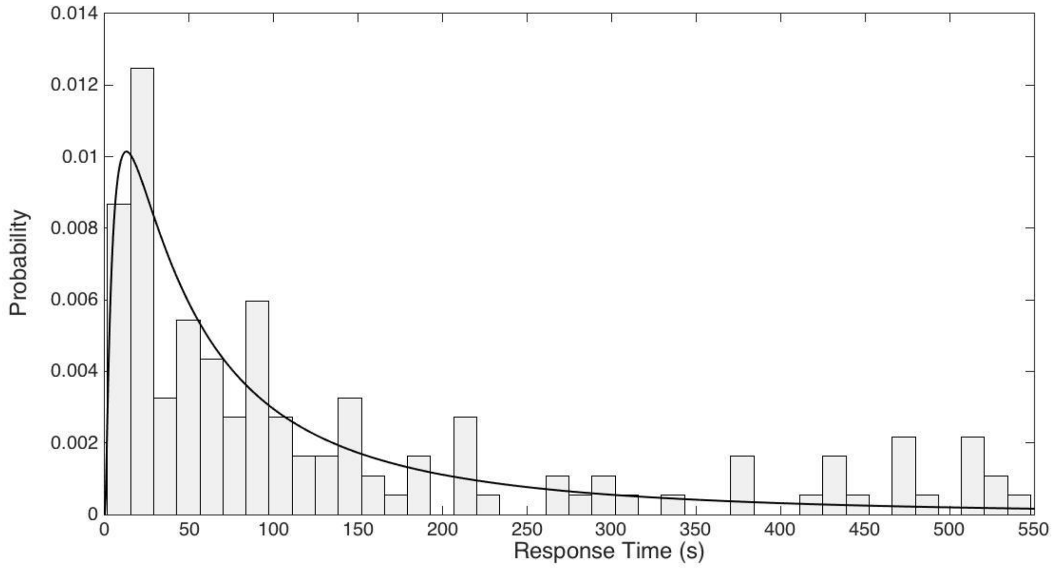


Figure 95 Overall RTD for OP (combining trials 1 and 2).

6.4.2 Male and Female Response Times

A summary of the response time data for male and female passengers is given in Table 54 and the RTDs generated are shown in Figure 96. The data displays an approximate lognormal form, so a lognormal curve was fit to each. Plotting both curves on the same axes (Figure 97) suggested that the curves were very similar. A Mann-Whitney test [241][242] was performed with the null hypothesis that response times for male and female passengers were samples from the same distribution. Results from the test show that the null hypothesis *is* rejected, with a z-value = 2.5715 and p-value = 0.0101. This suggests that for the trials on OP, males and females responded to the alarm differently – a different result than found for SS1 and JoS. While this may be an accurate finding, it is worth noting that the male and female datasets are both very small (67 and 63 passengers, respectively) and the lognormal form does not appear to be very strong.

Table 54 Summary of response time data for OP, by gender.

Gender	Min (s)	Max (s)	Mean (s)	SD (s)	Median (s)	Mode (s)	n
Male	2.5	548.0	178.0	171.4	123.2	2.5	67
Female	1.6	527.5	105.8	132.4	60.6	22.4	63

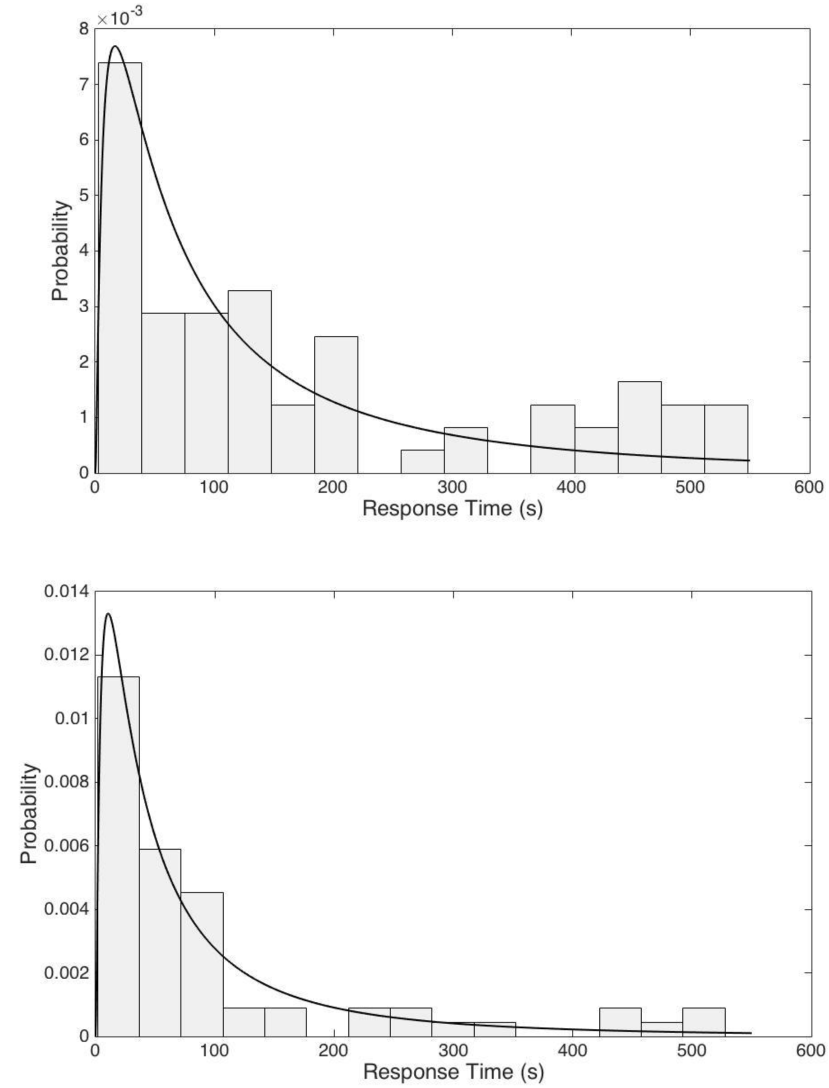


Figure 96 Response time distributions from OP trials (upper) males; (lower) females.

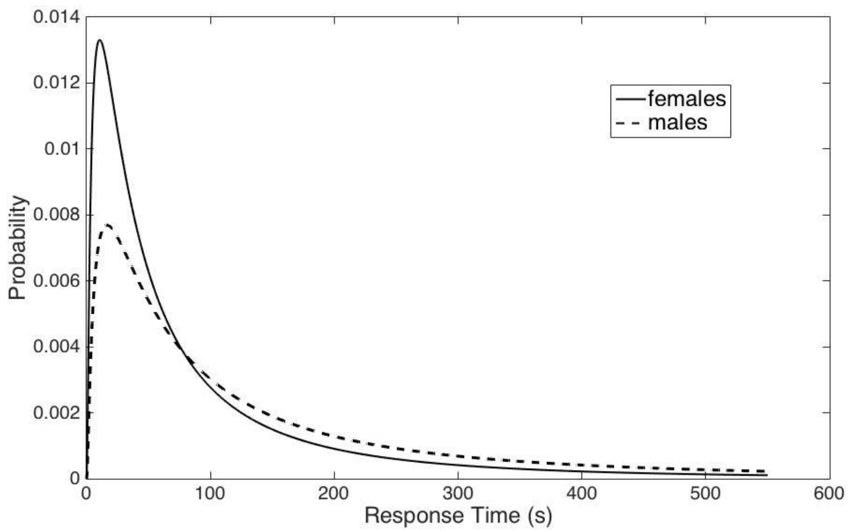


Figure 97 Comparison of fitted response time distributions for male and female passengers on OP.

6.4.3 *Age and Group Effects on Response Time*

Mean response times were calculated for the different age groups observed. Results are shown in Table 55, which suggest again that there are differences in how people of different ages responded to the alarm on OP. Elderly people were fastest to respond to the alarm, while people in the middle-aged group were slowest to respond, by a difference of 72.2 s on average. It is worth noting that because the overall sample size for these trials was quite small, these results may not be reliable.

Table 55 Mean response time by age category on OP.

Age Group	Min (s)	Max (s)	Mean (s)	SD (s)	Median (s)	Mode (s)	n
Up to 19	1.6	531.3	138.4	160.3	70.0	14.0	61
20-39	7.8	527.5	126.5	121.3	80.2	7.8	30
40-59	3.5	548.0	194.5	197.5	92.6	3.5	26
Over 60	25.5	298.2	122.3	136.6	41.5	25.5	6

Similarly, mean response times were calculated for passengers based on whether or not they were part of a group. These results are presented in Table 56, which also includes results for whether or not passengers were in cabins at the alarm. For the overall case of whether passengers were in a group or not, results suggest that passengers who are travelling as part of a group tended to be 102.3 s faster, on average, to respond to the alarm than those who appear to be travelling alone. This is the opposite to what was observed for passengers on SS1 but similar to that observed on JoS (which also had cabins). Thus, the OP dataset was further divided to determine if there were differences depending on where the passengers (in a group or not) were located at the alarm – cabin areas or not. This data is also provided in Table 56 (part of a group) and Table 57 (not part of a group) and shows that there is a large difference between passenger behaviour in groups, depending on where they were at the alarm. It can be seen that passengers not in cabin areas take much less time to respond than those in cabins. Interestingly, the observation on SS1 and JoS that passengers in public spaces who appear to be alone respond more quickly to the alarm is not true for passengers alone on OP in public spaces. In these cases, the passengers who appear to be alone at the alarm take 3.5 s longer, on average, to respond to the alarm. However, for passengers in cabin areas, those who do not appear to be part of a group tend to respond more slowly (as was found on JoS) to the alarm by 134.6 s on average. Again, these findings should be used with caution, given the datasets are very small and may not be reliable.

It is important to note that this dataset is quite small, due to low numbers of passengers travelling on the ship at the time of the trials. A total of 54 response times were captured from the first trial and 81 response times from the second trial. 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 datasets generated from these trials compared to the trials for the other two ships tested. The data is further complicated by the population demographics, which was found to be considerably different than the other trials.

Table 56 Mean response time for passengers who were part of a group and in cabins / not in cabins.

Response Time	**Part of a Group**						
	Min (s)	**Max (s)**	**Mean (s)**	**SD (s)**	**Median (s)**	**Mode (s)**	**n**
In Cabin	2.5	531.3	159.8	165.7	96.4	2.52	66
Not in Cabin	1.6	331.1	64.6	85.9	27.1	1.6	34
Overall	1.6	531.3	127.5	150.1	67.3	14.0	100

Table 57 Mean response time for passengers who were not part of a group and in cabins / not in cabins.

Response Time	**Not Part of a Group**						
	Min (s)	**Max (s)**	**Mean (s)**	**SD (s)**	**Median (s)**	**Mode (s)**	**n**
In Cabin	76.2	527.5	294.4	177.9	331.9	76.2	10
Not in Cabin	3.5	209.5	68.1	95.3	29.6	3.5	4
Overall	3.5	527.5	229.8	187.8	171.0	3.5	14

6.4.4 Comparison of Cabin and Public Space RTDs

The combined dataset was then separated into public spaces (40 data points) and cabins (95 data points). A summary of this response time data is provided as Table 58 and the RTDs generated are shown in Figure 98 (public spaces) and Figure 99 (cabins) generally follow a lognormal form and so lognormal curves were fitted to the two distributions using Equations (14) and (15) respectively:

$$y = \frac{1}{\sqrt{2\pi} \cdot 1.18x} exp\left[-\frac{(\ln(x) - 3.485)^2}{2 \cdot 1.18^2}\right] \tag{14}$$

$$y = \frac{1}{\sqrt{2\pi} \cdot 1.224x} exp\left[-\frac{(\ln(x) - 4.584)^2}{2 \cdot 1.224^2}\right] \tag{15}$$

It is, however, noted that the public spaces distribution is a small dataset (approximately 40% fewer response times than the dataset derived from trials on ER) and so there is considerably less confidence in the OP public space dataset compared to the other two trials on SS1.

Table 58 Summary of response time data for OP, by cabin and public areas.

Region	Min (s)	Max (s)	Mean (s)	SD (s)	Median (s)	Mode (s)	n
Cabin	2.5	548.0	173.8	166.9	99.0	2.5	95
Public	1.6	331.1	63.3	83.7	28.6	1.6	40

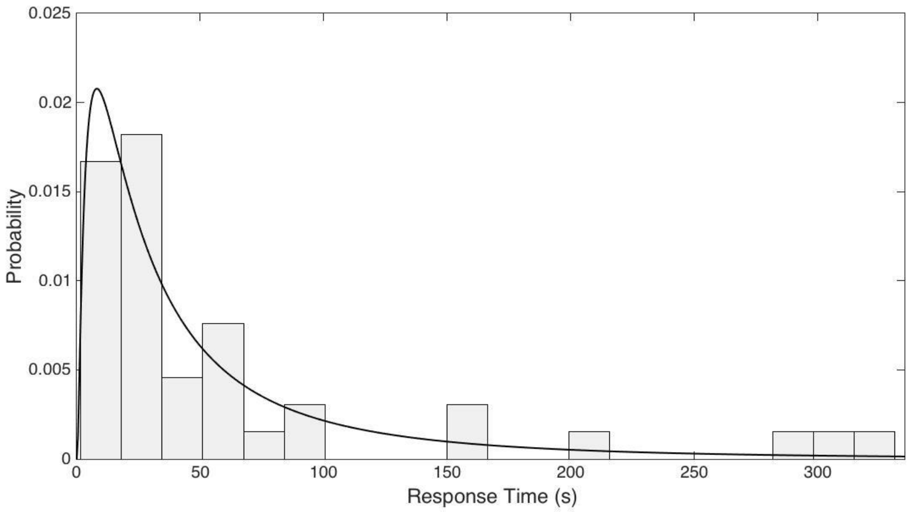


Figure 98 Response time distribution for public spaces on OP

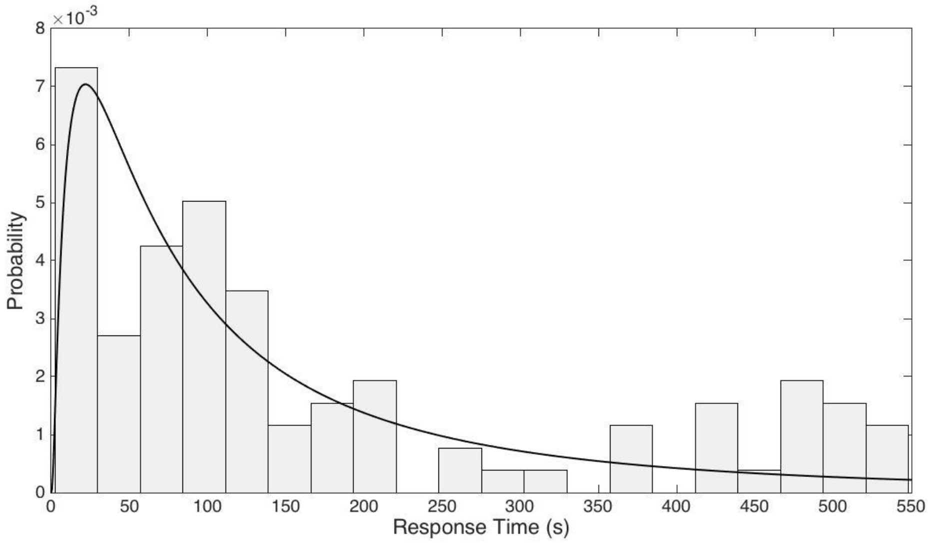


Figure 99 Response time distribution for cabin areas on OP.

Comparing the RTDs developed for cabins and public spaces on OP (Figure 100), it is clear that they are not statistically similar. A Mann-Whitney test [241][242] was performed with the null hypothesis that cabin and public area results were samples from the same distribution. Results show that the null hypothesis *is* rejected, with a z-value = -4.5874 and p-value = 0.000. Thus, for OP, the RTDs for cabins areas and public spaces are different.

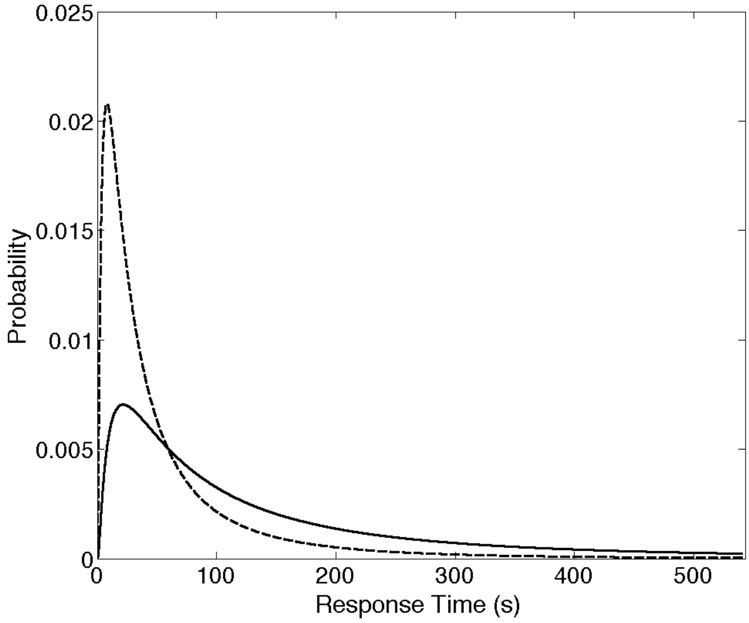


Figure 100 Comparison of response time distributions for cabin areas (solid) and public spaces (dashed) on OP (both trials combined).

A comparison of the arithmetic mean and standard deviation for the distribution fitted to the dataset, using Equations (8) and (9) is presented in Table 59. From this, we see that the fitted distribution in cabin areas does not represent the cabin area dataset very well, with a 19.3% difference between mean values and a 131.6% difference between the standard deviations. However, comparing the values for public areas on the vessel, we see that the mean values differ by only 3.5%, while there is a 36.0% difference between the standard deviations for this area.

Table 59 Comparison of OP response time distribution arithmetic mean and standard deviation to that of the fitted distribution, for cabin and public areas.

Arithmetic Value	**Cabin Areas**		**Public Areas**	
	Mean (s)	**St. Dev. (s)**	**Mean (s)**	**St. Dev. (s)**
Fitted Distribution	207.3	386.5	65.5	113.8
Dataset	173.8	166.9	63.3	83.7

6.4.5 Comparison of Public Space RTDs for OP and SS1

A comparison was made between the response time data for SS1 (public spaces - Equation (7)) and OP public spaces (Equation (14)). Both distributions are shown in Figure 101 on the same axes and appear to be very similar. A Mann-Whitney test [241][242] was performed with the null hypothesis that the SS1 data and the OP public space data were samples from the same distribution. Results show that the null hypothesis is not rejected, with a z-value = -0.2369 and p-value = 0.8128. This suggests that both datasets are statistically similar. While this is a promising result and consistent with findings presented above (see Section 6.2.4), it is not recommended that the two datasets be combined. The concern here relates to the significant differences in the population demographics on each ship during the trials (see Table 60). From the table, it can be seen that 47.5% of the population on OP was under 19 years of age compared with just 6.9% on SS1. Furthermore, 41.7% of the population on SS1 was over 40 years of age compared to 0% on OP. It is expected that these differences in population demographics had a significant impact on the RTD and so until further data has been collected, we should be cautious about combining the results.

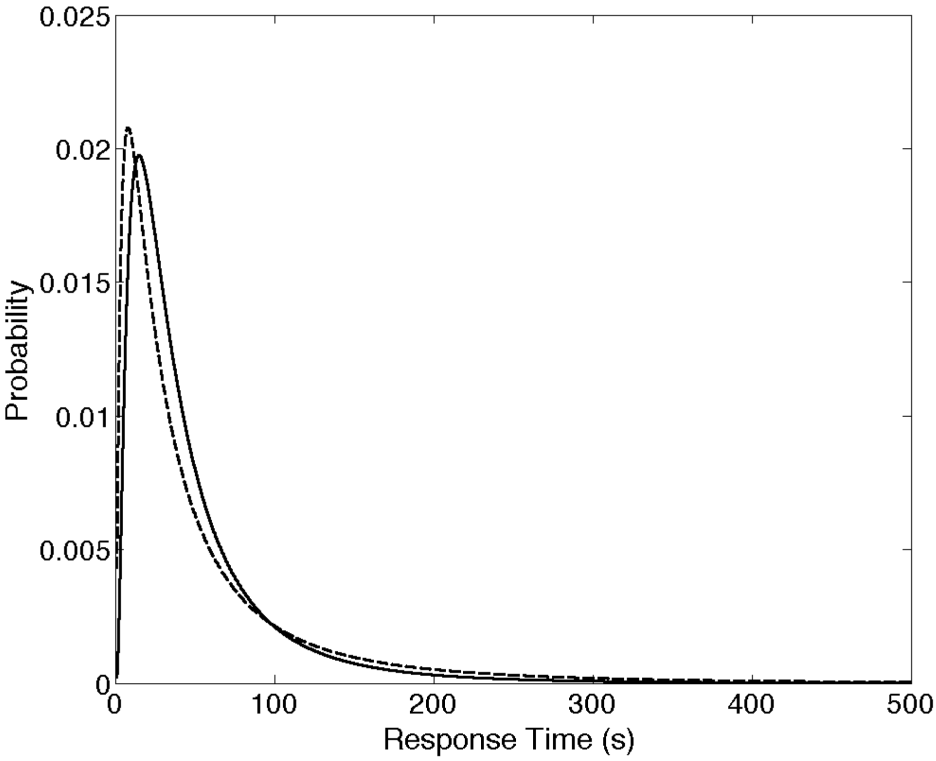


Figure 101 Comparison of RTDs for SS1 (solid) and public spaces on OP (dashed)

Table 60 Population demographics on SS1 compared OP public spaces

Age Group	SS1		OP – 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**

6.4.6 Comparison of Cabin Spaces for OP and JoS

A comparison was made between the RTD for cabin spaces on JoS (Equation (12)) and OP (Equation (15)) (see Figure 102). It is clear from the figure that the RTD for each vessel is different. To confirm the difference, a Mann-Whitney test [241][242] was performed with the null hypothesis that cabin RTDs for JoS and OP were samples from the same distribution. Results show that the null hypothesis *is* rejected, with a z-value = -6.8096 and p-value = 0.000. This result is significant and supports the earlier result discussed in Section 6.3.5 that different types of vessel may require different RTDs. It should be noted, however, that differences in population demographics onboard the vessels for the trials 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 (Table 61). From the table, we see that 44.2% of the population in cabins on OP was less than 19 years of age compared to 7.7% on JoS. Furthermore, 48.7% of the population in cabins on JoS was over 40 years of age compared to 33.7% on OP. 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 JoS compared with OP, however, further testing would be required to confirm this.

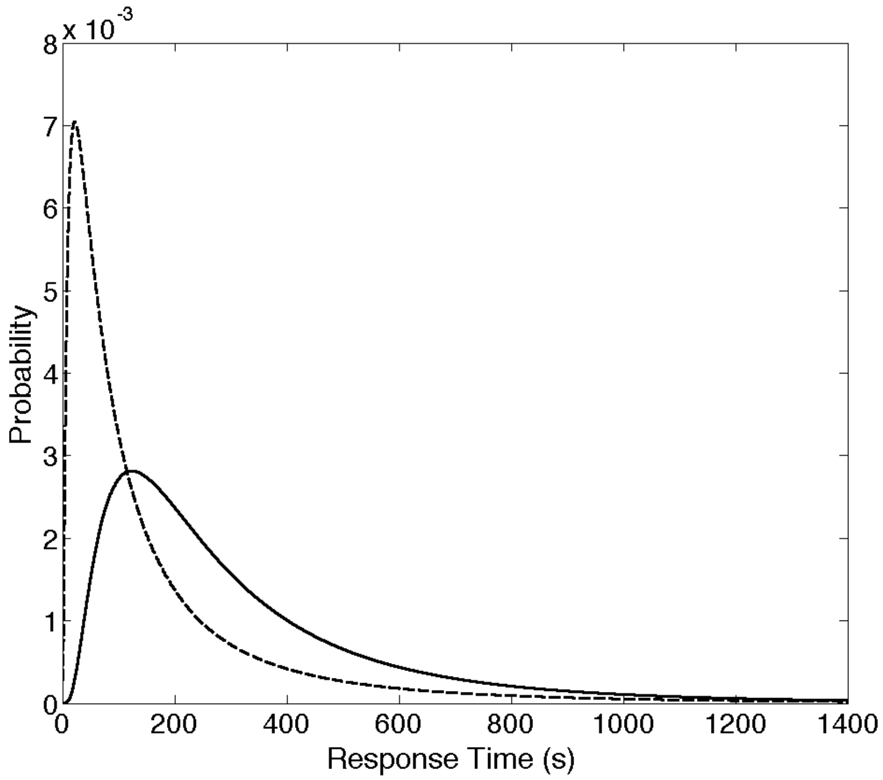


Figure 102	Comparison of RTDs for cabin areas on JoS (solid) and OP (dashed)

Table 61 Population demographics in cabins on JoS compared cabins on OP

Age Group	**JoS - Cabins**		**OP – 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**

6.4.7 Comparison of Cabin Spaces for OP and ER

A comparison was made between the response time data for cabin spaces on ER and OP (Figure 103). Once again, it is clear from the figure that the RTD for each vessel is different. To confirm the difference, a Mann-Whitney test [241][242] was performed with the null hypothesis that cabin space results for ER and OP were samples from the same distribution. Results show that the null hypothesis *is* rejected, with a z-value = 3.7360 and p-value = 0.000, thus supporting the observation that the two distributions are statistically different.

It is reasonable expect that the RTDs produced in cabin areas on OP and ER to be similar, given that both vessels RO-PAX ferries with cabins, the cabin spaces are similar and the nature and duration of the voyages was similar. The difference between the two RTDs is believed to be the result of the differences in population demographics already noted - the population in cabins on OP was predominately young (see Table 61) with almost half (44.2%) of the population being under 19 years of age. While the detailed population demographics for ER are not available, the information that is available suggests that passenger demographics in the cabin areas for this vessel may have been comprised primarily of adults. This is based on details published in [103] which indicated that of the two trials, 508 passengers were involved in the first for which “the majority of which were unaccompanied teenage school children”. For the second trial, 236 passengers were involved, which consisted of a “mixture of adults and unaccompanied school aged children”. According to [103], a total of 124 questionnaires (25% of those onboard) were completed by passengers during the first trial on ER and 80 (34% of those on board) were completed during the second trial. From the questionnaires returned, 42% from the first trial indicated that they were under 21 years of age, while from the second trial 21% were under the age of 21. Thus, 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 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 generated from the ER trials comes from the second trial. It follows from this that the majority of passengers in cabins were likely adults and, while we cannot be certain, it is likely that there was a greater proportion of adults in cabin spaces during the ER trials than for the OP trials. 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 generated.

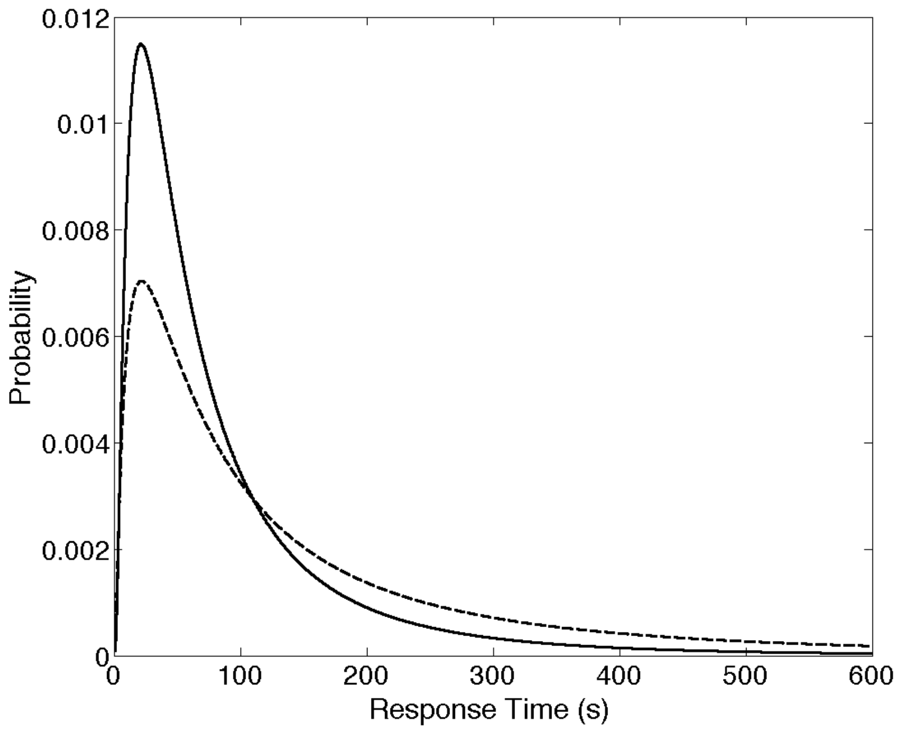


Figure 103 Comparison of RTDs for cabin areas on ER (solid) and OP (dashed).

6.5 Recommendations to the IMO Regarding Response Time

Currently, the RTDs found in the IMO guidelines for passenger ship evacuation analysis – IMO MSC.1/Circ.1238 [21] are used for all types of passenger ships (i.e. all RO-PAX ferries and cruise ships). The current regulations provide two RTDs – one for day case simulations and one for the night case. As described in the preceding sections, these RTDs were based on two assembly trials conducted the RO-PAX ferry with cabins - Eurostar Roma (ER). A total of 194 unique response time data points were collected during the two trials on ER from which two RTDs were generated, with the day case distribution being derived from public areas of the ship, and the night case being derived from cabin areas.

Following the analysis of passenger response times presented in this chapter, it is clear that RTDs for RO-PAX ferries are different than RTDs for cruise ships. The University of Greenwich team for the SAFEGUARD project, which included significant contributions from the author, prepared an information paper to the IMO regarding the nature of passenger response time. The distributions were prepared in a manner similar to those currently in the regulations; i.e. shifted to the right by 400s for the night case, truncated to a maximum value and scaled to ensure the area under the probability density function was equal to one (to account for the truncated amount).

The recommendations presented here suggest that day and night case RTDs for cruise ships should be added to the regulations to differentiate these vessels from RO-PAX ferries.

6.5.1 Proposed RTDs for RO-PAX Ferries

Given that the public space RTDs derived from trials on SS1 and ER were found to be statistically similar (see Section 6.2.4), they can be combined to produce a single RTD for the day case on RO-PAX ferries. The combined curve consists of 1,070 response time data points - 1,003 collected from the two SAFEGUARD trials and 67 that comprise the RTD currently used within the IMO evacuation analysis guidelines. Thus, the combined RTD recommended here is based on significantly more data (15 times more) than is currently used and is based on data from four trials on 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. Truncating the distribution in this manner represents 99.2% of the overall distribution, thus a small scale factor must be applied so that the area under the curve equals 1.0.

The new recommended day case RTD is presented in Figure 104 and is described using Equation (16). Given the similarity of this RTD to that currently used in the IMO guidelines, the new curve will not significantly impact evacuation analysis for RO-PAX ferries but is considered to be a more representative, robust and reliable representation of passenger response behaviour for this case.

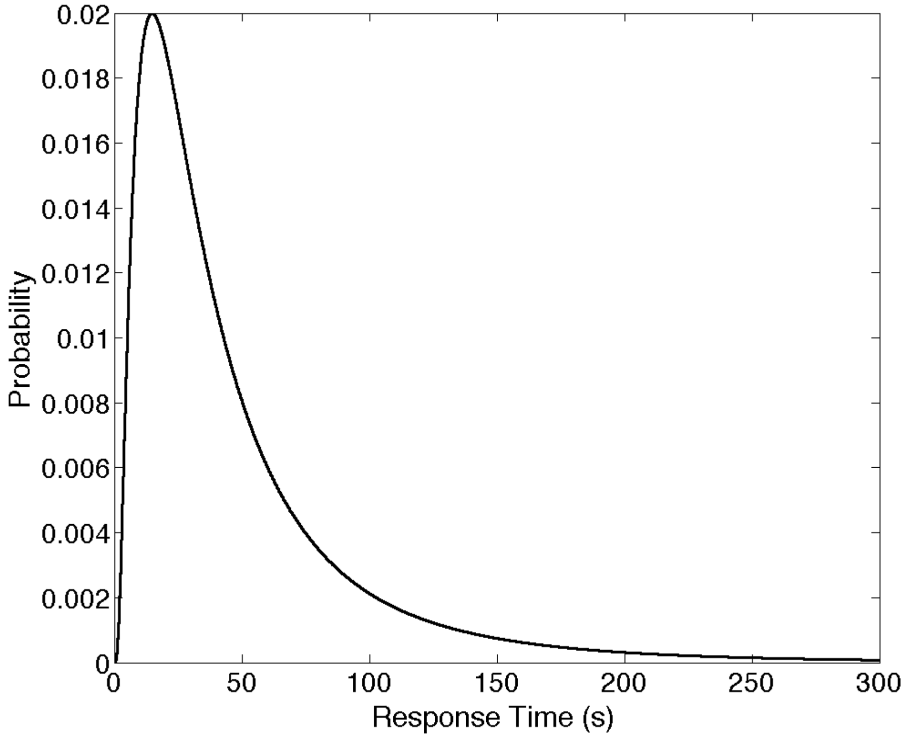


Figure 104 Recommended new IMO Day Case RTD for RO-PAX ferries

$$y = \frac{1.0076}{\sqrt{2\pi} \cdot 0.903x} exp\left[-\frac{(\ln(x) - 3.511)^2}{2 \cdot 0.903^2}\right] \tag{16}$$

Due to significant differences in population demographics, the public space response time data generated from trials on OP is not included in the suggested day case RTD for RO-PAX vessels (refer to Section 6.4.5). Furthermore, the cabin space response time data generated from trials on OP is not considered suitable for the same reasons (see Sections 6.4.6 and 6.4.7) and so is not recommended for defining the night case RTD. For this reason, it is recommended that the night case RTD currently used within the IMO evacuation guidelines remain the unaltered until a more reliable dataset has been collected.

6.5.2 Proposed RTDs for Cruise Ships

Given that there is currently no distinction between cruise ships and ferries in the IMO evacuation analysis guidelines, it is recommended that the RTD derived from trials on JoS for public spaces (Figure 89) should be used to represent the new day case RTD for cruise ships. To keep a similar form as used currently by the IMO, 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 105 and is described using Equation (17). This distribution is statistically different compared to the existing RTD in the IMO evacuation analysis guidelines. This newly recommended day case RTD is based on 633 data points, considerably more than the 67 data points used in the existing IMO day case, but should be used only for cruise ship evacuation analysis.

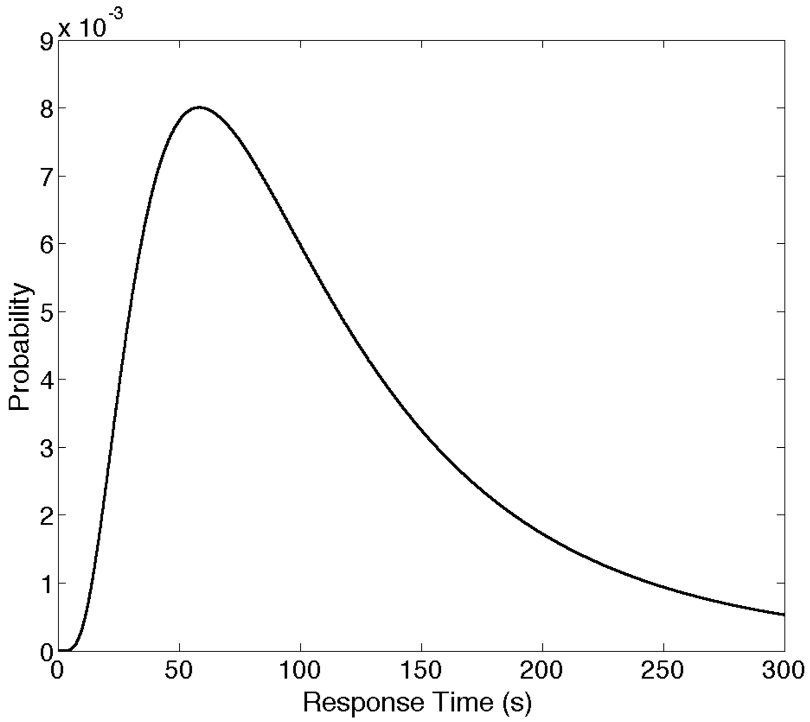


Figure 105 Recommended new IMO Day Case RTD for Cruise Ships.

$$y = \frac{1.0548}{\sqrt{2\pi} \cdot 0.702x} exp\left[-\frac{(\ln(x) - 4.562)^2}{2 \cdot 0.702^2}\right] \qquad (17)$$

Considering the analysis of passenger response time in cabin areas of JoS, it is suggested that the RTD derived (Figure 89) should be used as a basis for representing the night case RTD for cruise ships. Truncating this RTD at 300 s as is done in the current IMO evacuation guidelines, results in only 60.3% of the dataset being included, thus requiring a large scale factor to adjust the area under the curve to be equivalent to 1.0. Since a significant proportion of the data is represented in the tail of this distribution, it is felt that truncating the RTD at 300 s would not adequately characterise the broader range of response times observed in the cabin areas (i.e. night case) on cruise ships. It is suggested that the truncation point should be extended to 700 s, which would result in a greater proportion (90.3%) of the original dataset being included 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 to the right by 400 s to account for the fact that passengers may likely be sleeping (which was typically not the case for the trials conducted). While somewhat arbitrary in nature, using this approach to represent response time behaviour for the night case on cruise ships is in keeping with the current approach at the IMO for evacuation analysis guidelines. This truncated, shifted and scaled curve is presented in Figure 106 and described using Equation (18). This distribution is statistically different when compared to the existing RTD in the IMO evacuation analysis guidelines. 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, but should be used only for cruise ship evacuation analysis.

The chapter that follows provides a detailed discussion of the assembly time data collected using the IR system and presents a method for validating evacuation models using results from the data collected. Chapter 8 then provides details on evacuation modelling carried-out using a hypothetical ship model to demonstrate the impact of the new RTDs on the overall assembly time predicted.

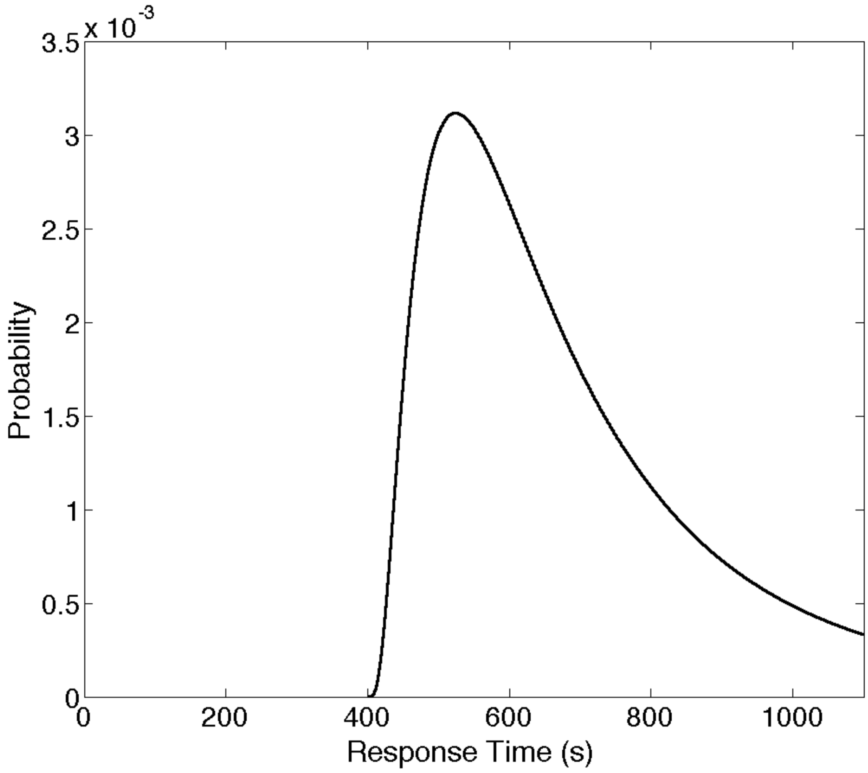


Figure 106 Suggested new IMO Night Case RTD for Cruise Ships.

$$y = \frac{1.1074}{\sqrt{2\pi} \cdot 0.817(x-400)} exp\left[-\frac{(\ln(x-400)-5.49)^2}{2 \cdot 0.817^2}\right] \quad (18)$$

6.6 Chapter Summary

This chapter has presented the results of a detailed analysis of passenger response times for the three vessels tested. The analysis presented helps to address the shortage of response time data for large passenger ships, in particular for cruise ships and RO-PAX ferries. As described in the preceding chapters, this data was generated from analysis of video recordings made during semi-unannounced assembly trials using real, paying passengers on three different large passenger ships at sea. This dataset of passenger response time is relevant, credible, realistic, and represents a significant improvement in the state of knowledge in this field. The key findings from this analysis include:

- Passenger RTDs generated for RO-PAX ferries and cruise ships were generally found to fit a lognormal model, which is consistent with response time data generated for the built environment [103] and suggests that passenger behaviour when responding to evacuation alarms on large passenger ships is similar to that in the built environment;

- If assembly trials are repeated with a sufficient number of different people in the same physical environment who are exposed to the same notification conditions, the RTD generated is likely to be statistically similar.
- The response of passengers both in public spaces and cabin spaces is dependent on the type of vessel:
    - RTDs for cruise ships generally have longer and more significant distribution tails compared to RTDs for RO-PAX ferries.
    - When conducting an evacuation analysis, it is not appropriate to use the same RTD for cruise ships and RO-PAX ferries.
- Passenger demographics may have a significant impact on the response time distribution, however, further research is required before this can be stated definitively.

Although the response time data presented here represents a comprehensive improvement in our understanding of passenger behaviour onboard ships during the assembly process, additional data is required to:

- Quantify the RTD for passengers in cabins on RO-PAX ferries.
- Better quantify the response of passengers during different times of the day, particularly night time when passengers may be sleeping. A more reliable data set based on actual experimental data is required, rather than current assumptions in the international regulations that suggest simply shifting the daytime response curve to the right by 400s.
- Explore the dependence of the RTD on population demographics. Passenger vessels may have very different populations onboard, depending 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.
- Explore the impact of vessel motions, sea sickness and intoxication on passenger response time.
- Determine if passengers with experience onboard ships, or those who are familiar with the particular ship in question has an impact on response time.

- Quantify the effect of crew assertiveness and general crew intervention on passengers response time. This could also include exploring the impact of crew training effectiveness.
- Finally, for improving the mathematical modelling of passengers' response phase behaviour on ships, it would be of crucial importance to understand the influence of visual, auditory and olfactory cues on the notification stage of passenger response behaviour.

The results presented in this chapter characterise passenger response time - the first phase of evacuation behaviour as outlined the framework shown in Chapter 1, Figure 6. Chapter 7 will provide a detailed analysis of passenger evacuation movement – the second phase of evacuation behaviour. Data is provided for the first two ships tested; SS1 and JoS as two ship evacuation model validation datasets. The validation datasets provide details for each of the two ship geometries, the initial population distribution, response times and the assembly time for each passenger. The maritimeEXODUS evacuation model was used to predict the assembly process onboard both ships, based on the data from the trials and requirements of the IMO guidelines and then a validation metric is presented that can be used to compare the modelling results to the experimental results. Chapter 7 ends with recommendations to the IMO regarding validation data.

7 Validation Data – Results and Analysis

7.1 Overview

As with mathematical modelling of any complex process, it is important that models predicting ship evacuation behaviour undergo a validation process to ensure model predictions are realistic and reliable. Given the impact that evacuation modelling may have on ship design construction costs and the life-safety of passengers, validation of ship evacuation models should be considered particularly important. It was stated in Chapter 1 that a goal of this research was to develop a method for validating ship evacuation models. It is important to understand that a validation method need not demonstrate that the model can replicate a real emergency case, unless such data of a sufficient quality were available. To be validated, the model must be able to demonstrate that, for a given set of input conditions and ship geometry, it is capable of predicting the outcome of passenger movement for a given scenario with a reasonable degree of accuracy. To meet this goal, it is necessary for the dataset of passenger movement onboard the vessel to include, at a minimum:

Passenger response times to be able to accurately represent when passengers started moving after the alarm. Using representative response times enables a more realistic development of passenger congestion throughout the assembly process. This data was collected from video recordings are discussed in earlier chapters.

Number of passengers onboard that participated in the assembly exercise. It was possible to determine this quantity from the IR system dataset as the number of passengers who had assembled, since those who did not assemble did not complete the process.

Passenger location at the alarm and when assembled to set-up the simulations with representative starting conditions. It was possible to use IR system data from the trials to determine the zones where passengers were located at the alarm and which assembly station was used.

Passenger assembly time to identify when individuals arrived at the different assembly stations onboard. This was determined using the IR system, knowing the beacon IDs at the assembly station entry points.

In addition, it is necessary to have detailed, up-to-date ***CAD drawings for the vessel*** being tested. Finally, a ***metric*** must be used to objectively quantify how well the experimentally produced curves compare with those resulting from the model. The metric chosen should be capable of determining how well the shape and magnitude of the curves compare.

With validation data in-hand, the modeller should be able to set-up and run simulations in an analogous way so that modelling results may be compared with data obtained experimentally. For such a task, the experimental data need not be represented exactly for all individuals observed on the ship, since the process of ship evacuation tends to be stochastic in nature and thus should not be exactly the same each time. The results of modelling should, however, be capable of representing the process well as a whole, particularly in terms of the overall assembly time of the passengers.

As described in Section 5.2, detailed, high quality datasets were generated using the IR tracking system for large numbers of passengers during this project. Given the technical challenges with one important IR beacon in trial 1 on SS1 (as described in Section 4.8.3) and the small number of passengers involved in trials 4 and 5 on OP, only the data from trials 2 and 3 (ferry without cabins and cruise ship respectively) were useable for validation purposes. Thus, two validation data sets are presented in this chapter, which are unique for a number of reasons. Unlike most evacuation model validation data sets, these datasets incorporate regional information relating to the approximate starting locations of the population at the alarm, as well as the end locations chosen by each passenger. Thus, it is also possible to utilise the data set to evaluate the capabilities of route planning and way finding algorithms in evacuation models. In addition, the actual response time distributions for the population were available for the specific locations on the ship where the passengers were located. Most evacuation validation data sets lack these essential details that allow modellers to fine-tune their algorithms in order to obtain the best fit to experimental results [202][203][204]. Furthermore, the trials were conducted on real ships, at sea, involving real, paying passengers and the notification alarms were semi-unannounced making the results relevant, credible and realistic.

Data from trial 2 (from SuperSpeed 1, trial 2) forms what is referred to here as validation data set #1, while data from trial 3 (from Jewel of the Seas) forms validation data set #2. Aspects of the work presented in this Chapter was carried-out by other team members of the SAFEGUARD project at UoG (namely the evacuation modelling for both ships and summary of the passenger route data derived from the IR tags). The author contributed significantly in all areas of this work and any efforts of other team members will be identified and referenced where appropriate.

The work described in this chapter was presented by Prof. Galea at the 6th International Conference on Pedestrian and Evacuation Dynamics [204], 11th Symposium on Fire Safety Science [203], the SAFEGUARD Passenger Evacuation Seminar [229] and in the peer review Journal of Ship Research published in the United States by the Society of Naval Architects and Marine Engineers (SNAME) [202]. In addition, an information (INF) paper was also prepared based on this chapter and submitted by the Canadian delegation to the IMO in 2013 [228].

7.2 Validation Dataset #1

This section describes the details of validation dataset #1, which was developed from trial 2 onboard SuperSpeed 1. The ship geometry is presented, along with the initial population distribution, response times, passenger routes and assembled locations. The modelling procedure is then explained and the method for comparing model results to experimental.

7.2.1 Ship Geometry

While the details of SS1 have been provided in the preceding chapters, a summary of the ship is provided here which is relevant for the validation dataset development. The ship contains a mixture of spaces spread over three decks, which are accessible to passengers, as depicted in Figure 107. The uppermost deck (deck 9) contains airline-style seating at the aft end of the vessel, as well as cabins that were accessible only to crew and truck drivers during the trial. Deck 8 contains a large restaurant at the forward end of the ship, general and cafeteria-style seating near midships, which also served as assembly station D (accessible by two routes at the aft and forward ends of the area), general seating areas, business-class airline-style seating and the upper level of a bar in the aft end of the vessel.

The lowest passenger deck (deck 7) contains three assembly stations – one internal at midships (assembly station A, accessible by two routes on deck 7 and one stairway from the deck above) and two external in the aft region of the port and starboard sides (assembly station C and D respectively), each of which have two entrances. The external assembly stations also serve as the lifeboat embarkation areas during abandonment (not a part of these trials). Deck 7 also contains a general external seating area at the aft end of the vessel, the lower deck of the bar area at the aft end of the ship, general seating, lockers and small gambling area. A small shopping area is located on the starboard side at midships (adjacent to assembly station A) and a large retail shopping area in the forward end of the ship. The shaded areas of Figure 107 were not accessible by passengers during this trial.

The vessel has four sets of primary stairs for passenger use, as shown in Figure 107. Stair #1 is the furthest aft in the vessel and measures 1m wide. It is located in the bar and extends from deck 7 to deck 8. Stair #2 is located just outside the bar on deck 7 and extends to deck 9. The stair consists of two lanes (each measuring 1.35m wide) separated by a banister with landings located between each deck. Stair #3 is located just aft of midships and also extends between decks 7 and 9. From deck 7 to deck 8 the stair consists of two lanes (each measuring 1.35m wide) separated by a banister with a landing between the decks. From deck 8 to deck 9, there is a single stair lane (measuring 1.35m wide) with a landing located between the decks. Stair #4 is the forward-most stair, located just forward of assembly stations A and D and extends from deck 7 to deck 8. The stair consists of two lanes (each measuring 1.35m wide) separated by a banister with a landing located between the decks.

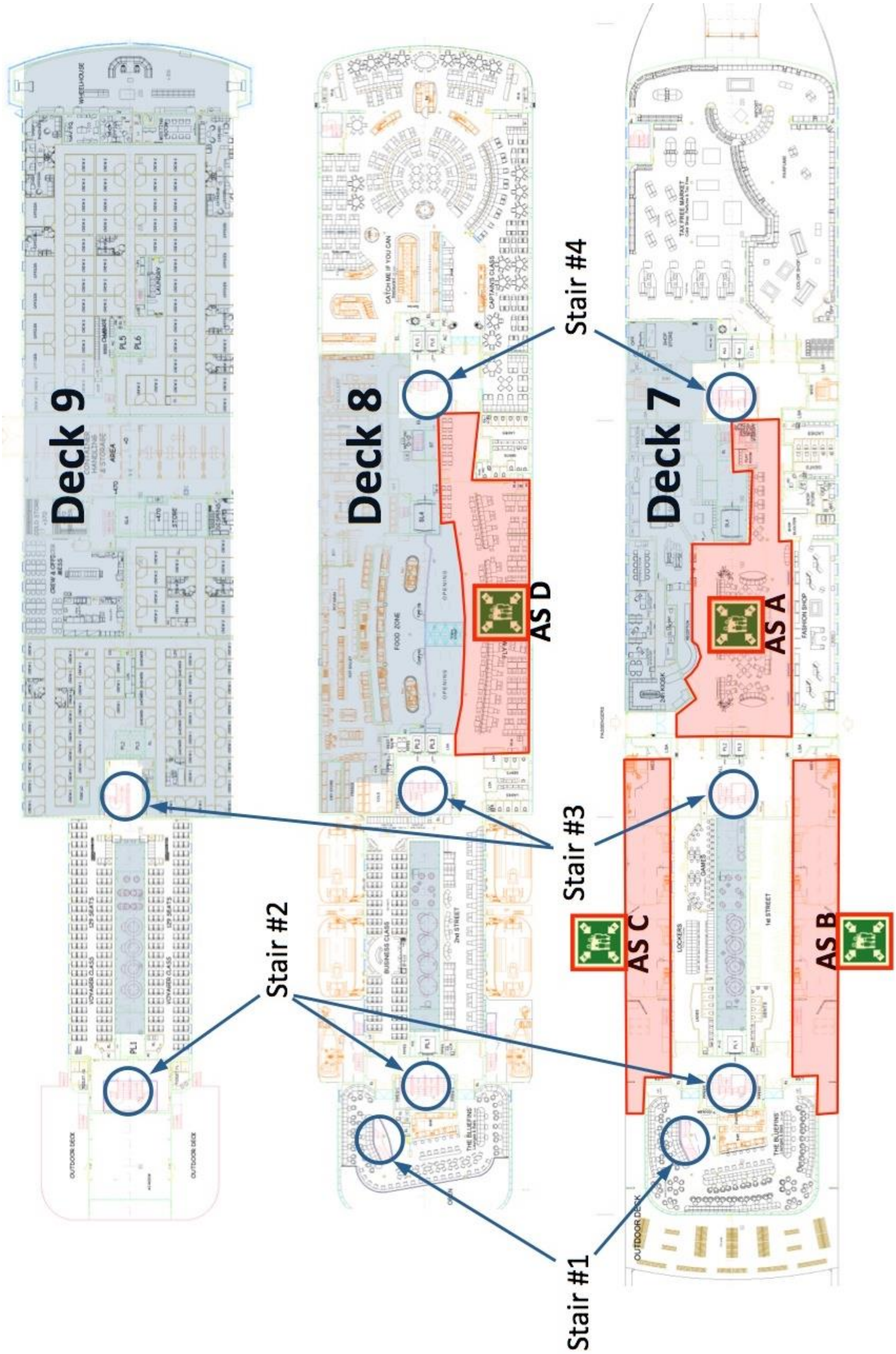


Figure 107 Layout of SuperSpeed 1, showing assembly stations, stairways and passenger areas.

7.2.2 Initial Population Distribution

For SuperSpeed 1, the starting locations for 764 tagged passengers were determined from the IR dataset (described in Section 3.3.4). As shown in Figure 108, it was determined that 77 tagged passengers started on deck 9, 413 tagged passengers started on deck 8 and 274 tagged passengers started on deck 7. The breakdown of passenger starting locations on each deck is shown in Figure 108 with the type of space defined by the labels provided in Table 62.

The number of passengers shown in the figure required some interpretation of the dataset, since a significant proportion of passengers wearing tags (320 out of 764 participating, or 42%) were located in one of the four assembly stations at the time of the alarm. The two internal assembly stations (A and D) held about 244 (76%) of these passengers, while the two external assembly stations (B and C) held the remaining 76 (24%). Some of these passengers remained in the same assembly station throughout the exercise, while some moved to another assembly station and remained there until the exercise was complete.

Table 62 Key for labels and initial distribution shown in Figure 108.

ID	**Definition**	**Deck**			**Total**
		7	**8**	**9**	
A	Airline-style seating	-	4	77	81
B	Bar	41	39	-	80
G	General seating	226	35	-	261
R	Restaurant	-	335	-	335
S	Shopping	7	-	-	7
	Total	274	413	77	764

These passengers must be accounted for, as well as the potential impact that passengers who participated in the assembly but chose *not* to wear an IR tag. While we have no data for these passengers, it is important to include an estimate of the number involved, since they may have an impact on the assembly process by increasing congestion in different locations. This will be described further in the sections that follow.

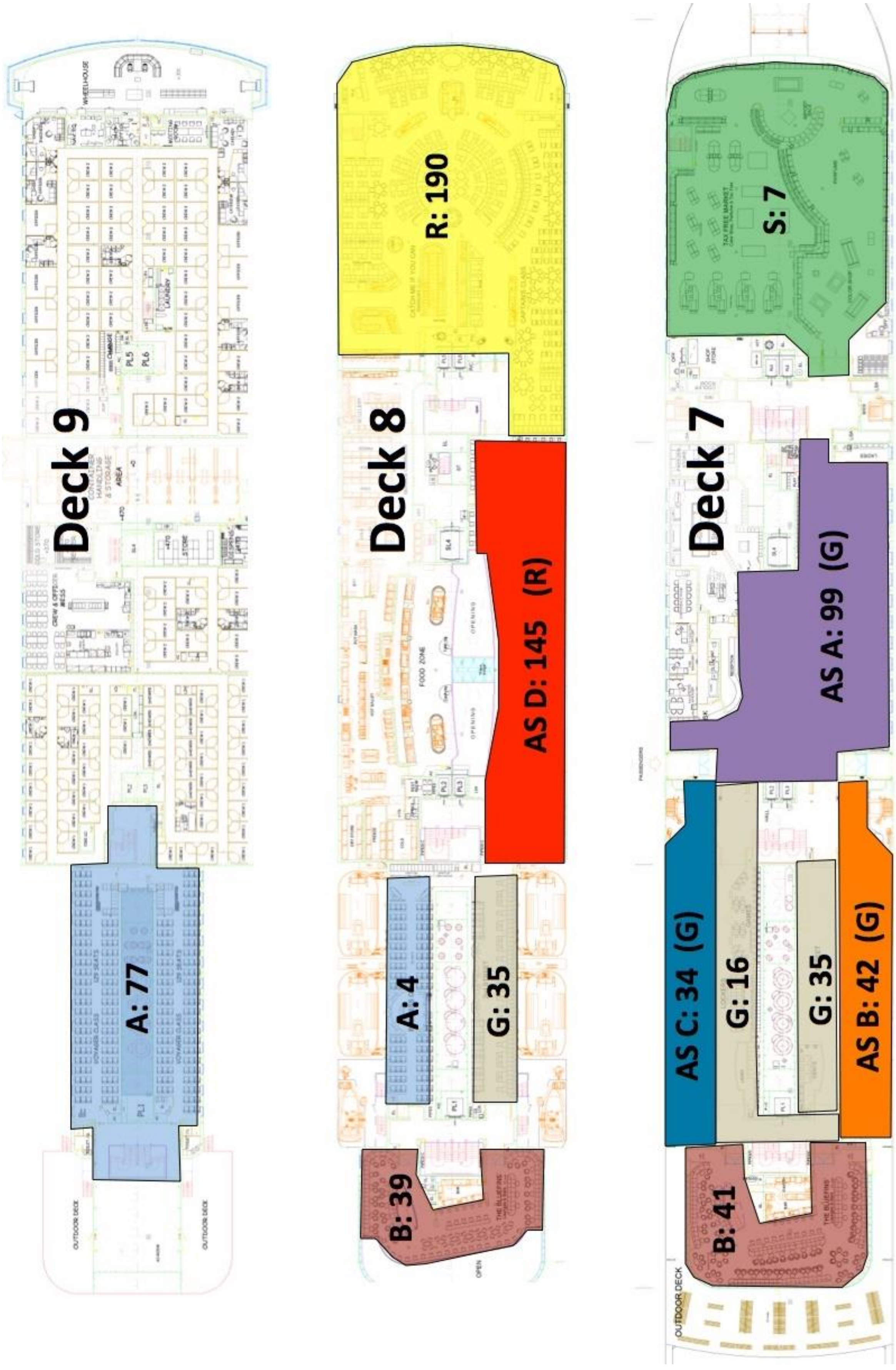


Figure 108 Initial distribution of tagged passengers on SuperSpeed 1.

7.2.3 Response Times

Five different response time distributions were used for validation dataset #1, chosen to represent the main areas on the ship where passengers were located at the alarm. The RTDs presented here were not developed in the preceding chapter, since they were taken from trial 2 onboard SS1 in order to match the IR path data used. The five areas chosen as the primary starting locations were: airline-style seating, bar, restaurant, shopping and general. A summary of the trial 2 response time data for these different areas onboard is provided in Table 63. The response time distributions for each area are provided below, along with the equation of the lognormal distribution fit to each.

Table 63 Summary of response time data for trial 2, different areas of SS1.

Location	**Min (s)**	**Max (s)**	**Mean (s)**	**SD (s)**	**Median (s)**	**Mode (s)**	**n**
Airline-style Seating	9.4	145.6	37.1	28.3	28.9	17.8	71
Bar	7.6	402.4	52.0	71.5	26.0	9.4	105
General	6.7	311.0	92.0	93.4	48.3	34.6	100
Restaurant	3.9	259.6	63.2	56.7	41.2	25.4	149
Shopping	2.1	104.8	17.5	18.0	12.5	2.1	45

Area "A": Airline-style seating contained 71 passengers for whom response times were collected up to a maximum of 145.6 s. The response time distribution resulting from this region is shown in Figure 109 and the resulting equation of the distribution is given as Equation (19), with mean, μ = 3.413 and standard deviation, σ = 0.608.

$$y = \frac{1}{\sqrt{2\pi} \cdot 0.608x} exp\left[-\frac{(\ln(x) - 3.413)^2}{2 \cdot 0.608^2}\right] \qquad (19)$$

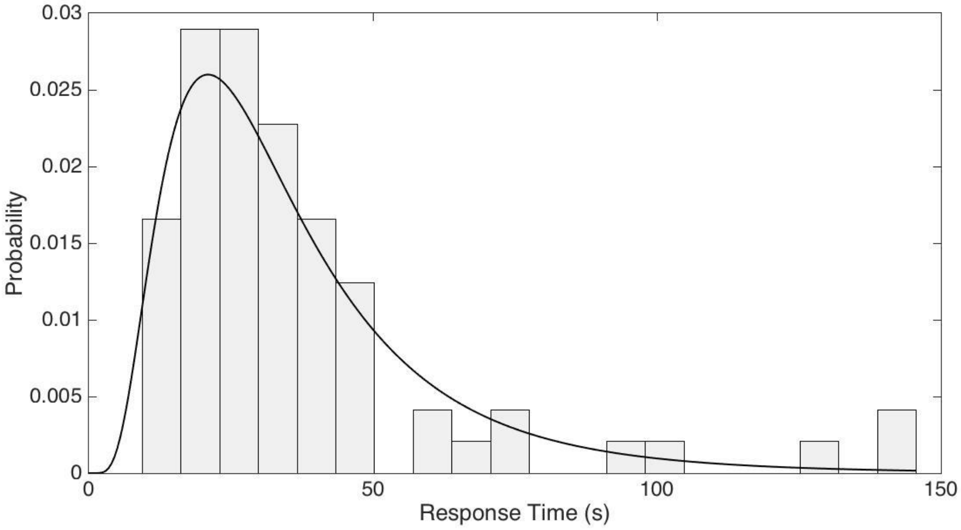


Figure 109 RTD for SS1, trial 2, airline-style seating area.

Area "B": Bar contained 105 passengers for whom response times were collected up to a maximum of 402.4 s. The response time distribution resulting from this region is shown in Figure 116 and the resulting equation of the distribution is given as Equation (20), with mean, μ = 3.432 and standard deviation, σ = 0.924.

$$y = \frac{1}{\sqrt{2\pi} \cdot 0.924x} exp\left[-\frac{(\ln(x) - 3.432)^2}{2 \cdot 0.924^2}\right] \quad (20)$$

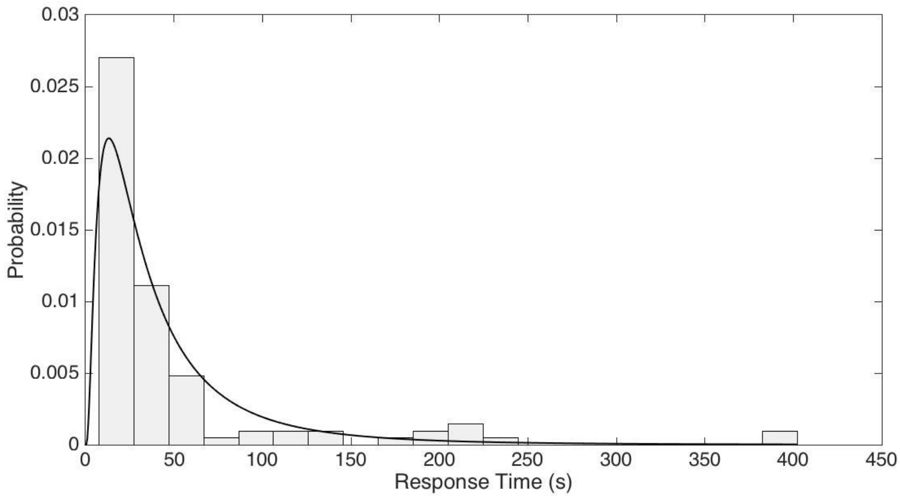


Figure 110 RTD for SS1, trial 2, bar area.

Area "G": General consisted of cafeteria-style seating, children's play areas and outer deck areas and contained 100 passengers for whom response times were collected up to a maximum of 311.0 s. The response time distribution resulting from this region is shown in Figure 111 and the resulting equation of the distribution is given as Equation (21), with mean, μ = 4.019 and standard deviation, σ = 1.032.

$$y = \frac{1}{\sqrt{2\pi} \cdot 1.032x} exp\left[-\frac{(\ln(x) - 4.019)^2}{2 \cdot 1.032^2}\right] \tag{21}$$

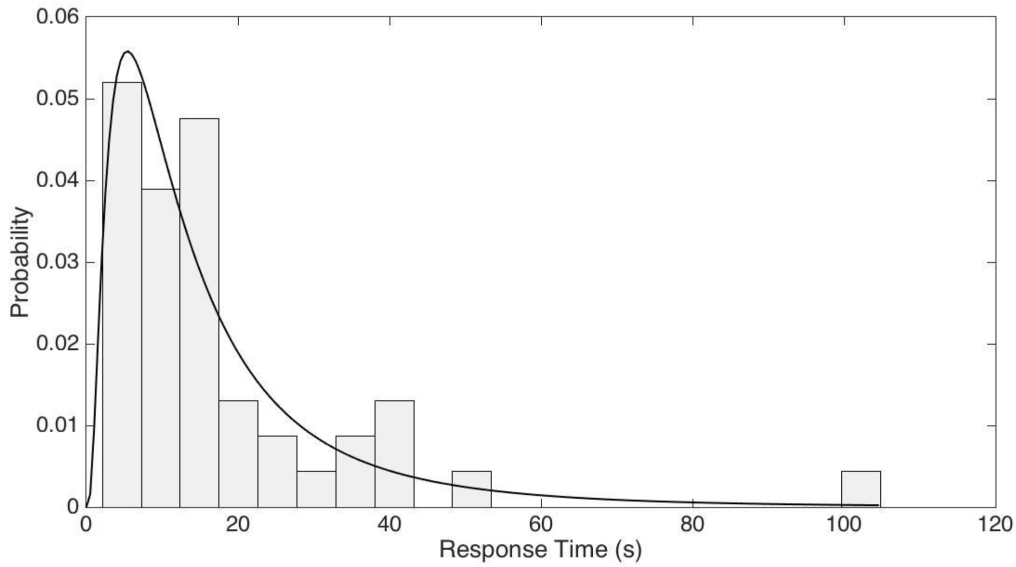


Figure 111 RTD for SS1, trial 2, general areas.

Area "R": Restaurant contained 149 passengers for whom response times were collected up to a maximum of 259.6 s. The response time distribution resulting from this region is shown in Figure 112 and the resulting equation of the distribution is given as Equation (22), with mean, μ = 3.796 and standard deviation, σ = 0.847.

$$y = \frac{1}{\sqrt{2\pi} \cdot 0.847x} exp\left[-\frac{(\ln(x) - 3.796)^2}{2 \cdot 0.847^2}\right] \tag{22}$$

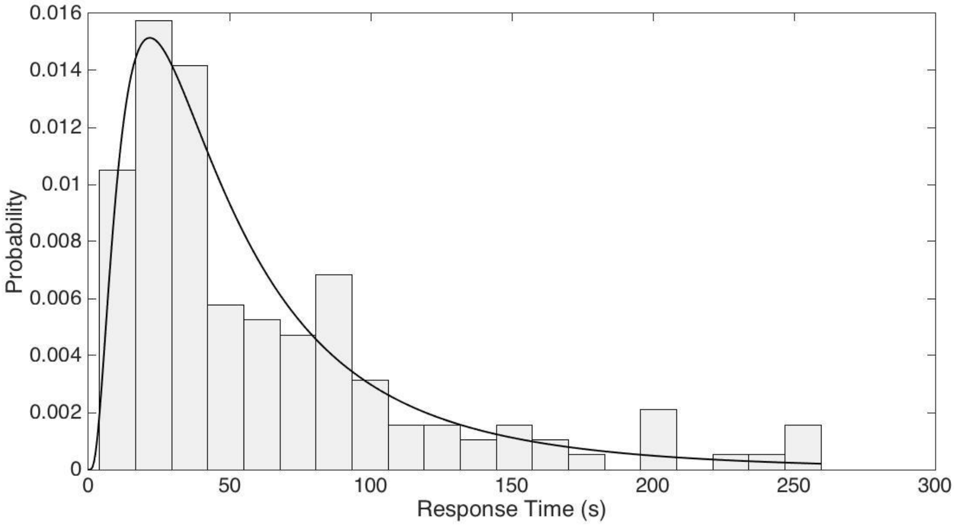


Figure 112 RTD for SS1, trial 2, restaurant area.

Area "S": Shopping contained 45 passengers for whom response times were collected up to a maximum of 104.8 s. The response time distribution resulting from this region is shown in Figure 113 and the resulting equation of the distribution is given as Equation (23), with mean, μ = 2.479 and standard deviation, σ = 0.890.

$$y = \frac{1}{\sqrt{2\pi} \cdot 0.890x} exp\left[-\frac{(\ln(x) - 2.479)^2}{2 \cdot 0.890^2}\right] \quad (23)$$

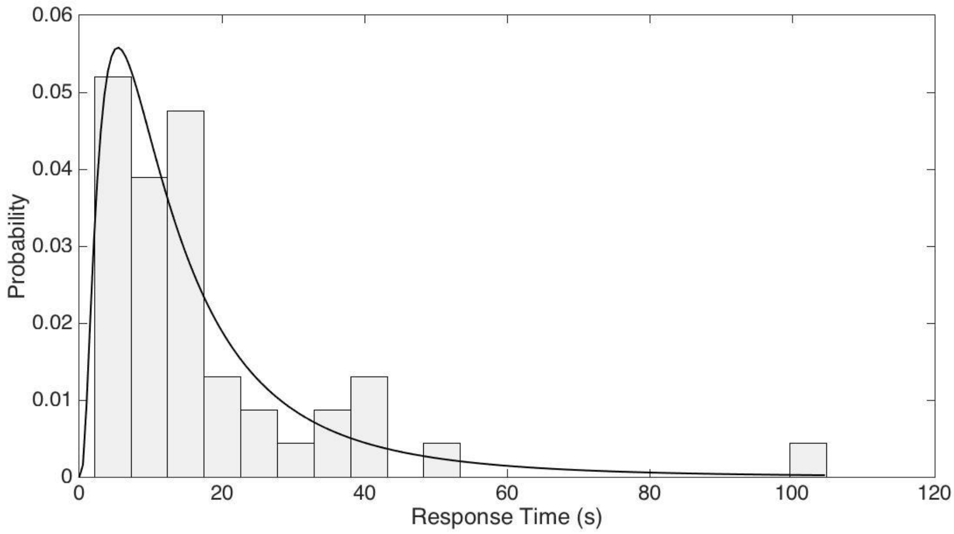


Figure 113 RTD for SS1, trial 2, shopping area.

7.2.4 Passenger Routes and Assembly Time

Detailed routes for passengers are not presented here since these are not prescribed by the validation analysis. Assembly time curves are presented for each assembly station, as well as the overall vessel. In addition, given that we know passenger starting locations, this section also presents the assembly station to which passengers went during the trial. Of the 1,349 passengers on board SS1 for trial 2, a total of 764 passengers wore tags and were tracked throughout the trial. In addition to identifying the starting location of the tagged passengers, the IR tracking system enabled the determination of the route taken by each tagged passenger and to which assembly station they went. On *completion* of the exercise, the distribution of passengers was as follows (Figure 114):

> **AS A:** 157 passengers, with 80 of these having been in the assembly station since the start of the exercise and 77 moving from other areas of the ship.
>
> **AS B:** 179 passengers, with 37 of these having been in the assembly station since the start of the exercise and 142 moving from other areas of the ship.
>
> **AS C:** 102 passengers, with 28 of these having been in the assembly station since the start of the exercise and 74 moving from other areas of the ship.
>
> **AS D:** 326 passengers, with 139 of these having been in the assembly station since the start of the exercise and 187 moving from other areas of the ship.

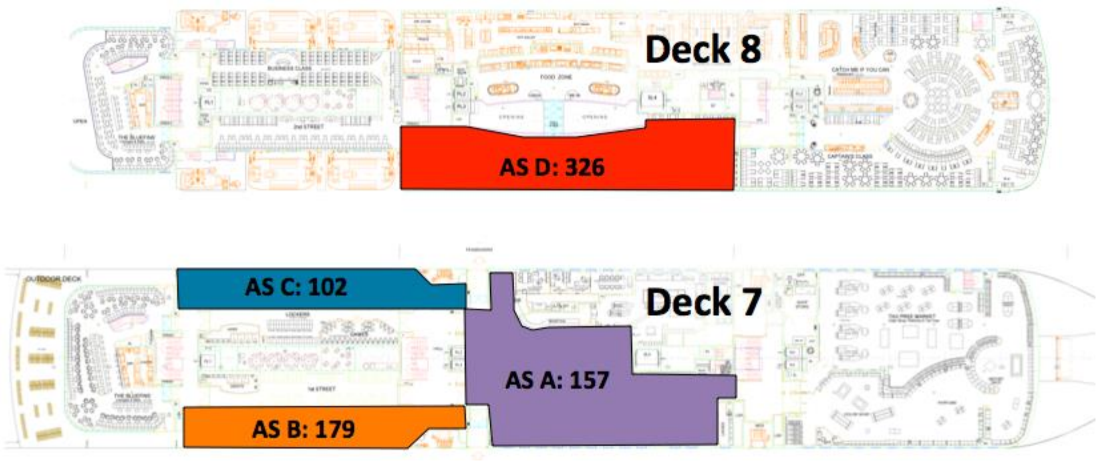


Figure 114 Number of passengers assembled in each assembly station.

Figure 115 presents the assembly time curves for each of the four assembly stations on the ship (one on deck 8 and three on deck 7). Figure 116 presents additional detail derived from the IR data, indicating the assembly station to which passengers from different locations on the ship assembled. It can be seen that, as one might expect, the majority of passengers moved to the assembly station nearest where they were located at the alarm, except for the general area on deck 8. For this area, the majority of passengers moved to assembly station B on the deck below rather than directly into the adjacent assembly station D on deck 8. It is difficult say with certainty the reason for this difference; however, it may be related to the fact that the nearest assembly station (D) was also the most crowded. Thus, passengers may have chosen to avoid congestion and move to a less crowded area.

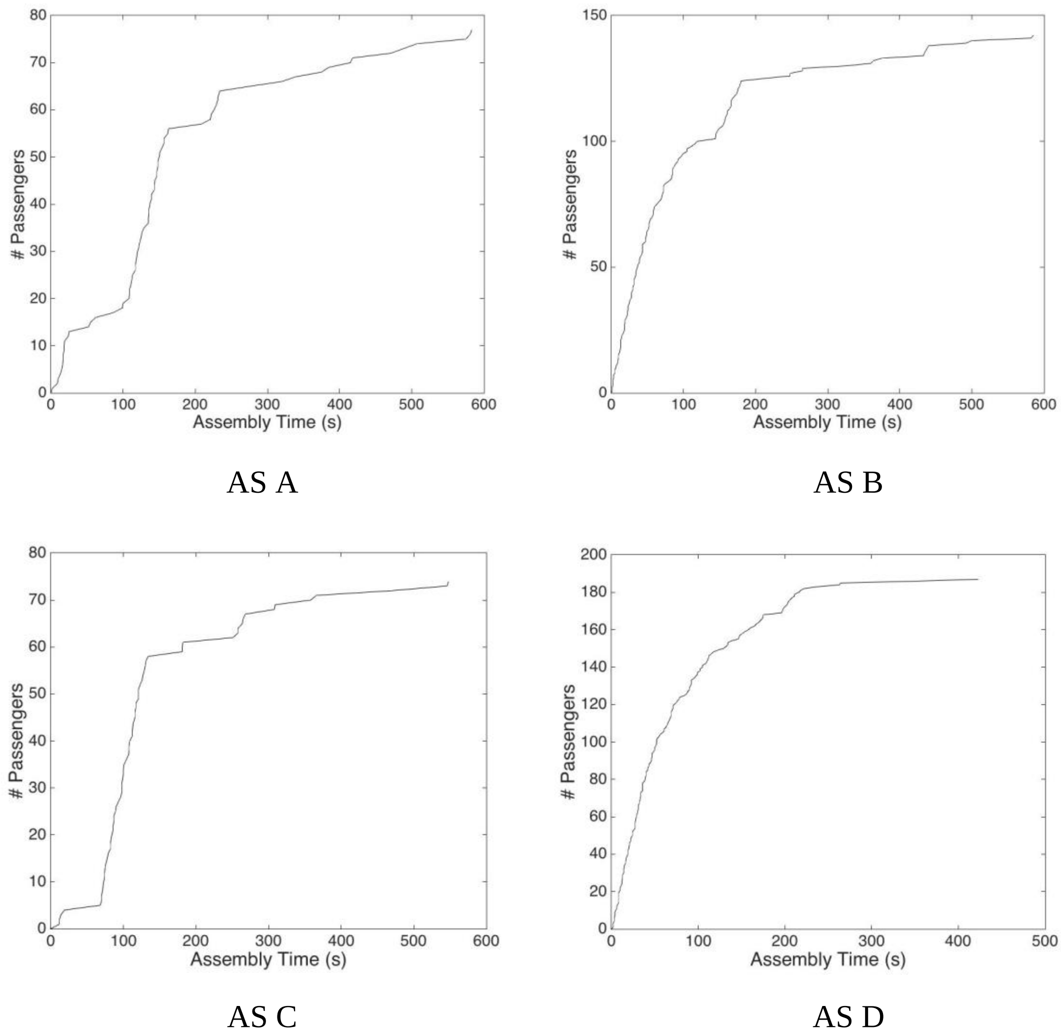


Figure 115 Assembly time curves for the four assembly stations onboard SS1, with passengers in the assembly station removed.

Figure 116 also outlines movement between assembly stations, including the number of passengers who remained in each assembly for the entire exercise. It can be seen that only a small number of passengers moved from one assembly station to another – 4.7% of the total population participating, compared with 37.2% who stayed in the same assembly station throughout the exercise.

The Captain used the public address system to officially end the assembly exercise 10 minutes after its start. The IR tracking system recorded the time that each tagged passenger entered an assembly station, thus providing a good indication of the overall assembly time.

The IR data suggests that the last tagged passenger arrived in AS A after 585 s (9 min 45 s). In addition to the assembly curves presented in Figure 115, the overall arrival curve is shown in Figure 117. As such, this validation dataset provides a means of not only determining how well an evacuation model can predict the overall assembly time, but more importantly, how well the evacuation model can predict the overall assembly *process* and hence the overall assembly time.

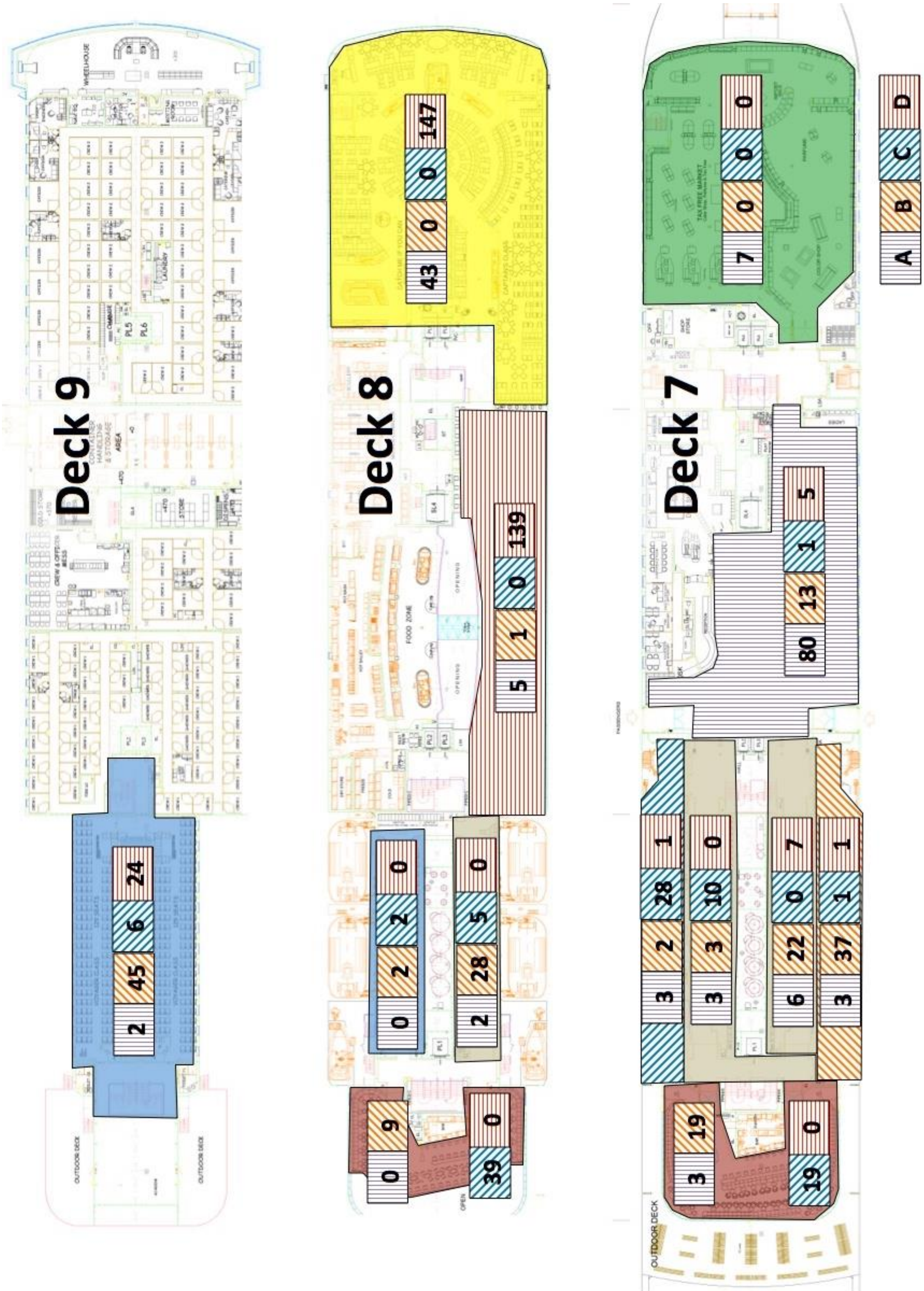


Figure 116 Starting and assembled locations for passengers in different areas of SuperSpeed 1 (boxes with numbers and cross hatch pattern indicates number from this region that go to the AS with the same hatch pattern).

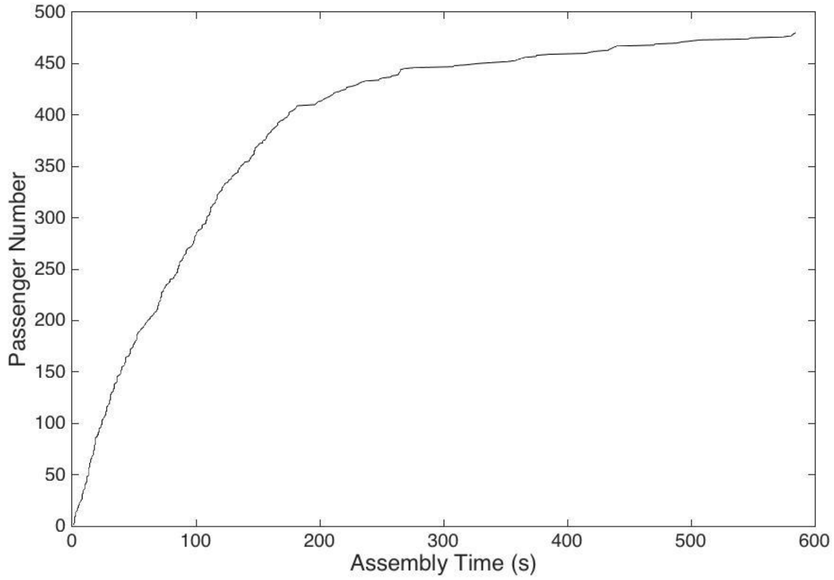


Figure 117 Overall measured assembly curve for the SS1 trial (removing all passengers who remained in an assembly station throughout the process and thus had an assembly time of zero).

7.3 Validation Dataset #2

This section describes the details of validation dataset #2, which was developed from the trial onboard Jewel of the Seas. The ship geometry is presented, along with the initial population distribution, response times, passenger routes and assembled locations. The modelling procedure is then explained and the method for comparing model results to experimental.

7.3.1 Ship Geometry

As with SuperSpeed 1, details of JoS have been provided in the preceding chapters, however, a summary of the ship geometry is provided here that has relevance for the validation dataset development. The vessel has 12 decks (of 14 total) that are accessible to passengers (see Figure 118). Seven decks consist primarily of passenger cabins – decks 7-10 are all passenger cabins while decks 2-4 are mostly passenger cabins. The other five decks consist of general circulation and entertainment spaces such as; restaurants (decks 4, 5, 6, and 11), bars (decks 6, 12 and 13), disco (deck 13), swimming pools (deck 11), casino (deck 6), theatre (decks 4-6), cinema (deck 5), spa/health centre (decks 11 and 12), business centre (decks 7 and 12), leisure pursuits (such as gymnasium, climbing wall, crazy golf, cards room – decks 12 and 13) and retail areas (deck 5). In all, the vessel has 18 uniquely identified assembly stations, however, many of these were located adjacent to each other on the port and starboard exterior lifeboat embarkation areas on Deck 5. To help simplify the analysis, it was decided that these external assembly stations would be grouped together as single assembly "zones" on each side of the vessel (AS B and AS C), thus making a total of four distinct assembly zones onboard – two inside the vessel (AS A and AS D) and two outside (AS B and AS C).

Assembly station B, on the starboard side of the vessel, has three entrances – the aft-most being located near the atrium at midships, one located forward of this area near the shopping space and the third located just outside the theatre at the forward end of the vessel. Assembly station C on the port side of the vessel has two entrances – the aft-most located near the atrium amidships and the other located just outside the theatre in the forward end of the vessel.

For the two internal assembly stations, AS A (the main theatre in the forward end of the ship which spans decks 4-6) has four entrances – two on each of deck 5 and deck 6 located at the entrance to the theatre. Assembly station D has two entrances – one located at the forward end of the assembly station in the atrium (amidships) and the other at the aft end of the assembly station from the bar area located in the aft end of the vessel.

The vessel has seven main vertical fire zones however only three main vertical passenger staircases were made available in the trial. The first staircase is located within the restaurant in the aft section of the vessel, and spans deck 4 and deck 5. This stair is curved with a landing. The second staircase is located amidships in the ship's atrium and extends from deck 2 to deck 13 with a varying geometry. The other main staircase is located in the forward part of the vessel, just aft of the theatre, and extends from deck 3 to deck 12. All of the stair runs for this staircase are 1.2 m wide and 1.9 m long, with two double lane runs leading to a landing that measures 5.2 m by 1.5 m. From the landing there are two more double lane stair runs leading up to the next deck. Finally, several staircases of varying geometries run between decks 11/12 and decks 12/13 to connect the multi-use spaces in that area. These staircases were all measured during ship visits in order to accurately represent the geometry of each in maritimeEXODUS.

Figure 118 Layout of Jewel of the Seas, Deck 11-13, showing stairways (circled) and non-passenger areas (shaded, no outline).

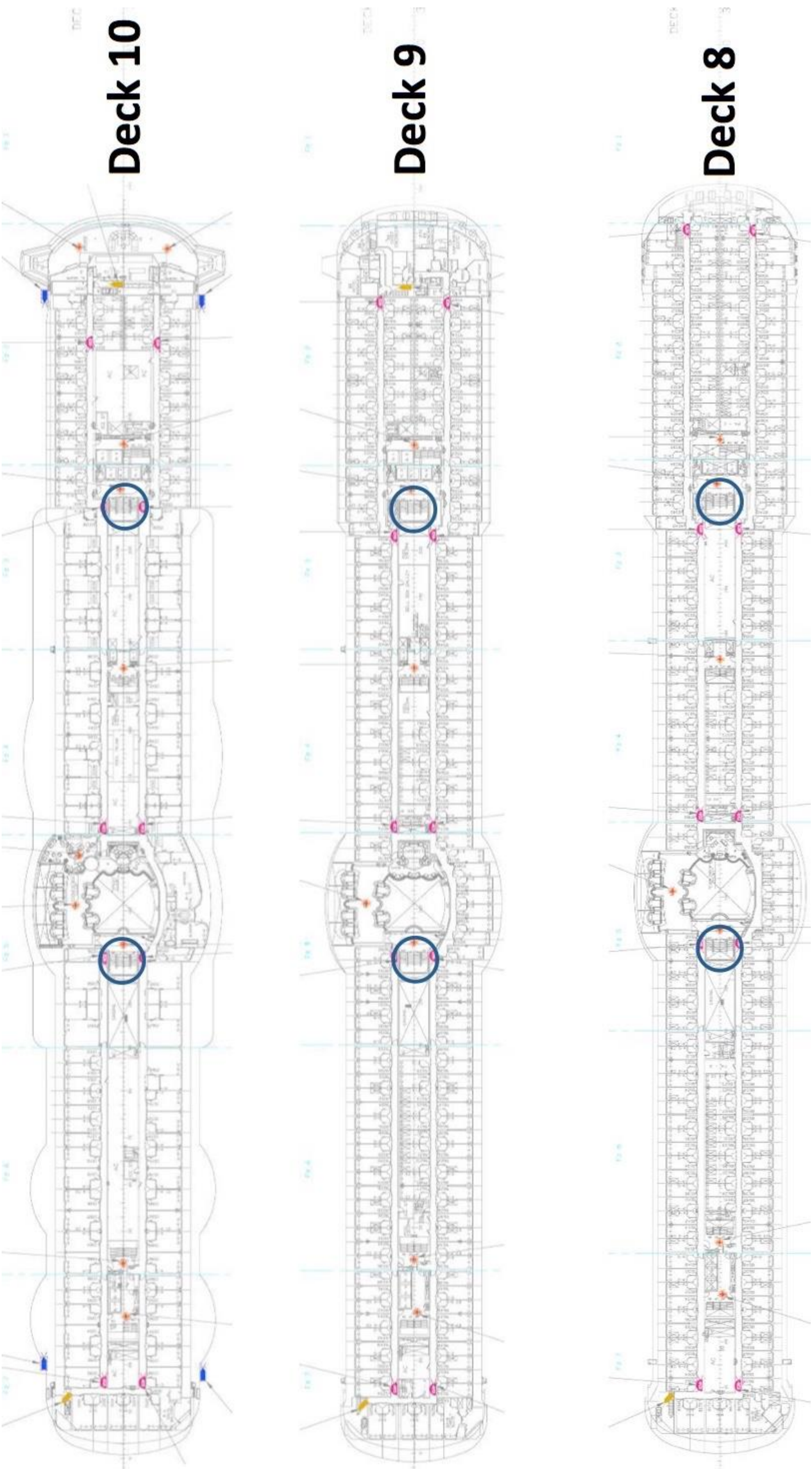


Figure 119 Layout of Jewel of the Seas, Deck 8-10, showing stairways (circled).

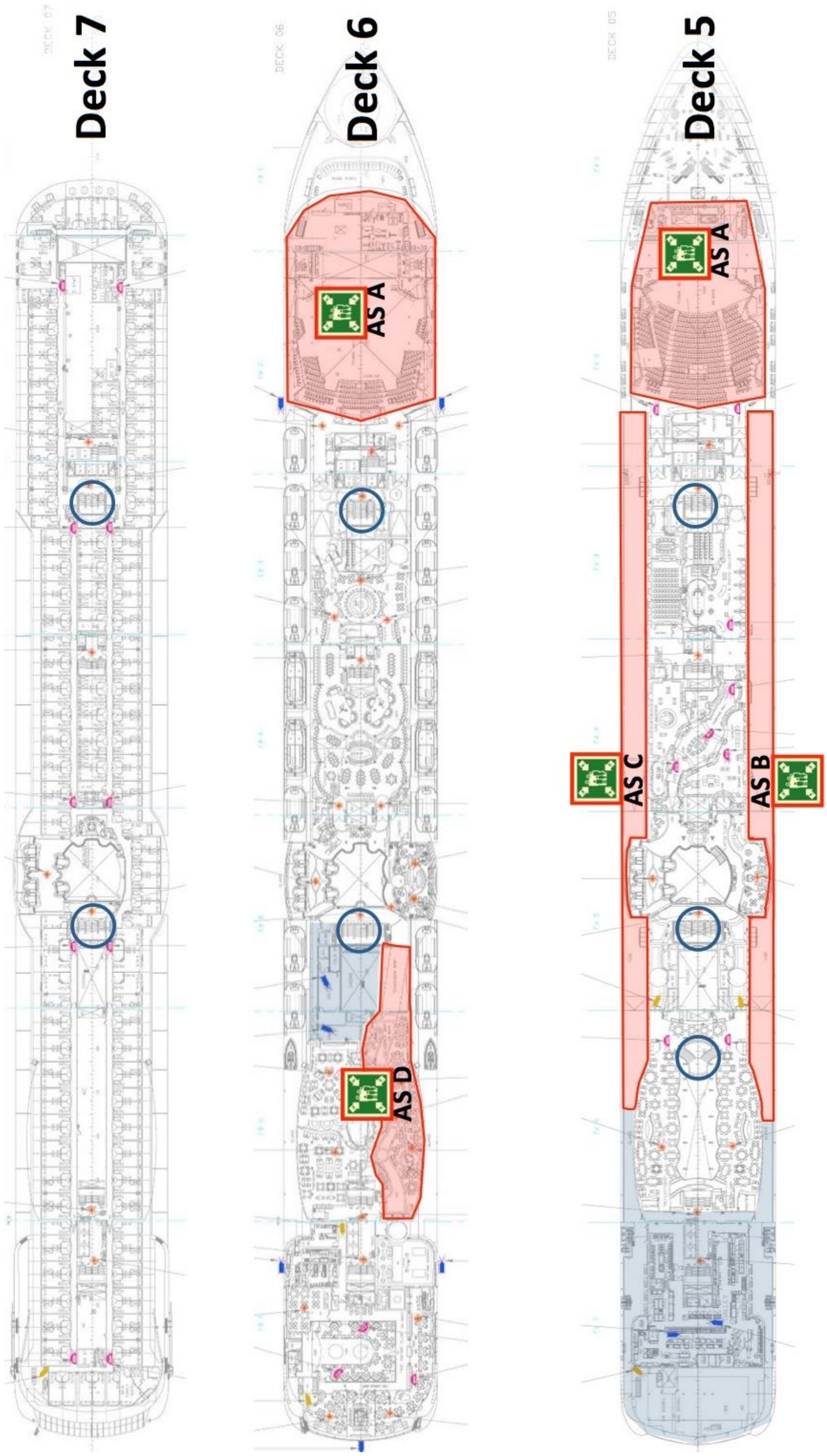


Figure 120 Layout of Jewel of the Seas, Deck 5-7, showing assembly stations (shaded with thick outline), stairways (circled) and non-passenger areas (shaded, no outline).

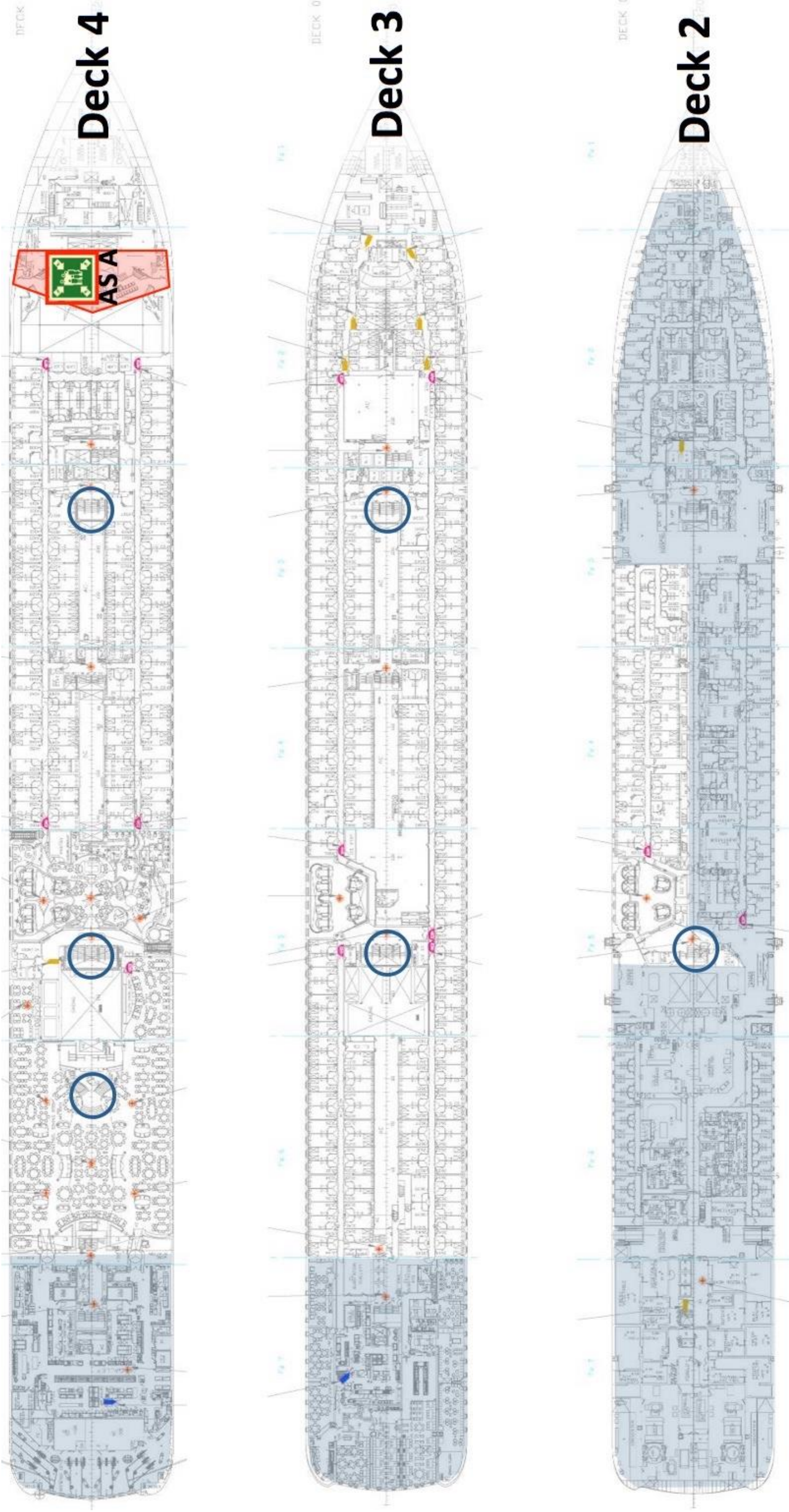


Figure 121 Layout of Jewel of the Seas, Deck 2-4, showing assembly stations (shaded with thick outline), stairways (circled) and non-passenger areas (shaded, no outline).

7.3.2 Initial Population Distribution

For Jewel of the Seas, the starting locations for 1,779 tagged passengers were determined from the IR dataset (described in Section 3.3.4). As shown in Figure 122, it was found that most passengers were either in cabins (760) or restaurants (620). Almost one third of passengers (545) were located on deck 11 at the time of the alarm, with very few passengers located on deck 2 (19) and deck 13 (8). The breakdown of passenger starting locations is shown in Figure 122 and the type of space defined by the labels as shown in Table 64.

Unlike SuperSpeed 1, very few passengers wearing tags (52 out of 1,779 participating, or 2.9%) were located in one of the four assembly stations at the time of the alarm. More than half of these passengers (27) were located in AS D. Some of these passengers remained in the same assembly station throughout the exercise (14), while the remainder moved to the other three assembly stations and stayed there until the exercise was complete. All 5 passengers in AS A at the alarm remained there until the exercise was complete, as did 14 out of 15 in AS B and 3 out of 5 in AS C.

Table 64 Key for labels and initial passenger distribution shown in Figure 122.

ID	**Area**	**Deck**												**Tot.**
		2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	
B	Bar	-	-	-	-	27	-	-	-	-	-	-	8	35
C	Cabins	19	133	86	-	-	139	126	153	104	-	-	-	760
G	General	-	-	-	122	25	-	-	-	-	-	-	-	147
L	Leisure Activities	-	-	-	-	-	-	-	-	-	122	56	-	178
R	Restaurant	-	-	197	-	-	-	-	-	-	423	-	-	620
T	Theatre	-	-	-	5	-	-	-	-	-	-	-	-	5
Y	Youth Activities	-	-	-	-	-	-	-	-	-	-	34	-	34
Total		19	133	283	127	52	139	126	153	104	545	90	8	1,779

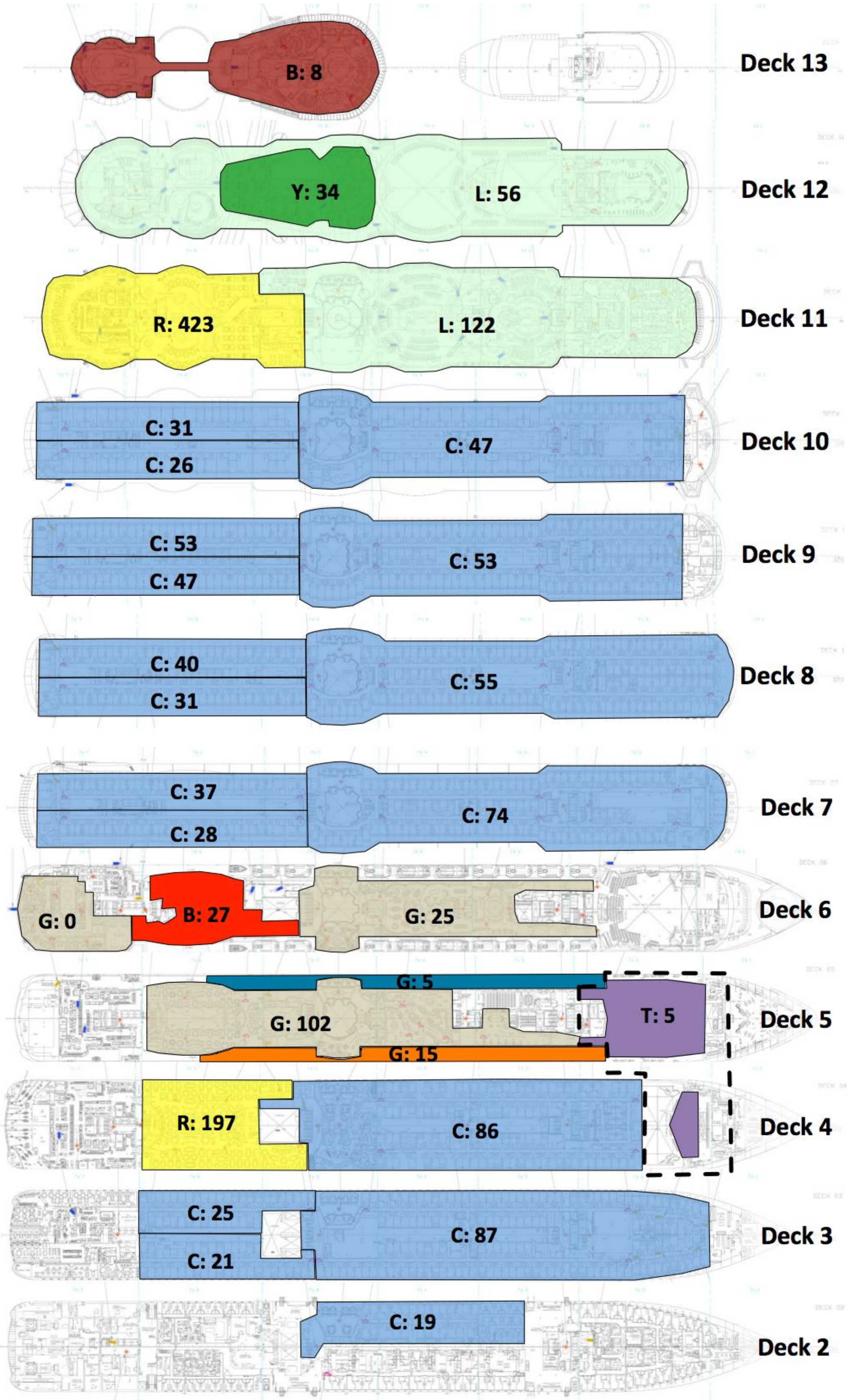


Figure 122 Initial distribution of tagged passengers on Jewel of the Seas (see Table 64 for a reference key explaining each region).

7.3.3 Response Times

Since it was not possible to collect response times for all passengers in all the various regions of the ship (due to its size and large number of decks), the overall RTD was used for modelling response time on Jewel of the Seas. This response time distribution was given in Figure 88 and is, again, provided here as Figure 123 for convenience. It is based on response times collected from 1,228 passengers and fitted with a log normal curve, with the following key parameters; the minimum and maximum response times are 0 s and 1379 s, respectively, while the mean, μ =5.012 and the log of the standard deviation, σ = 0.89.

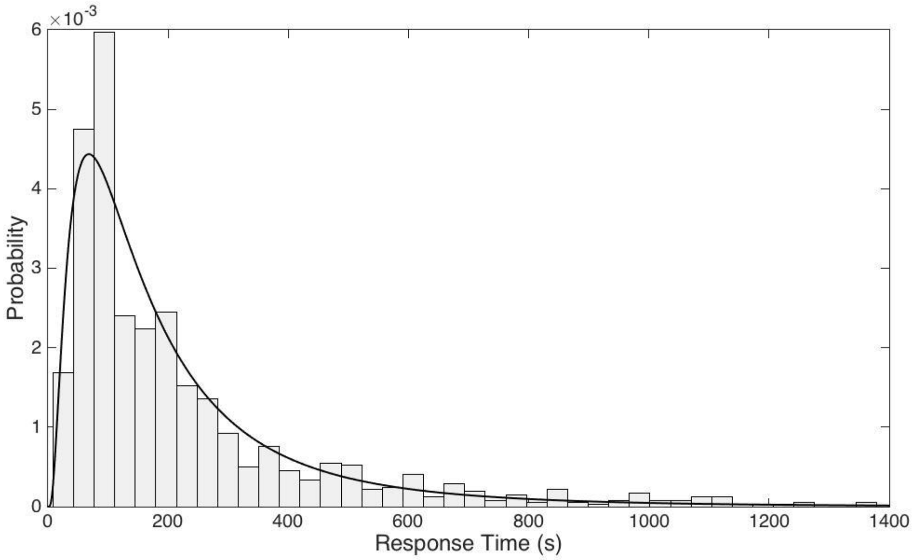


Figure 123 Overall response time distribution for Jewel of the Seas.

7.3.4 Passenger Routes and Assembly Time

Detailed routes for passengers are not presented here since these are not prescribed by the validation analysis. Assembly time curves are presented for each assembly station, as well as the overall vessel. In addition, given that we know passenger starting locations, this section also presents the assembly station to which passengers went during the trial. Of the 2,292 passengers on board JoS for trial 2, a total of 1,779 passengers (78%) wore tags and were tracked throughout the trial. In addition to identifying the starting location of the tagged passengers, the IR tracking system enabled the determination of the route taken by each tagged passenger and to which assembly station they went. On completion of the exercise, the distribution of passengers was as follows (Figure 124):

AS A: 402 passengers, with 5 of these having been in the assembly station since the start of the exercise and 397 moving from other areas of the ship.

AS B: 575 passengers, with 14 of these having been in the assembly station since the start of the exercise and 561 moving from other areas of the ship.

AS C: 437 passengers, with 3 of these having been in the assembly station since the start of the exercise and 434 moving from other areas of the ship.

AS D: 365 passengers, with 14 of these having been in the assembly station since the start of the exercise and 351 moving from other areas of the ship.

Figure 125 shows the assembly time curves for each of the four assembly stations on the ship. Figure 126 presents additional detail derived from the IR data collected on Jewel of the Seas, indicating the assembly station to which passengers from different locations on the ship assembled. Since all passengers onboard were assigned to specific assembly stations, there are no obvious trends in this dataset regarding whether passengers moved to the closest assembly station or not – passengers appeared to have moved to the assembly station indicated on their key card. There was little movement between assembly stations, again, for the same reason and the number of passengers located in assembly stations at the alarm was minimal.

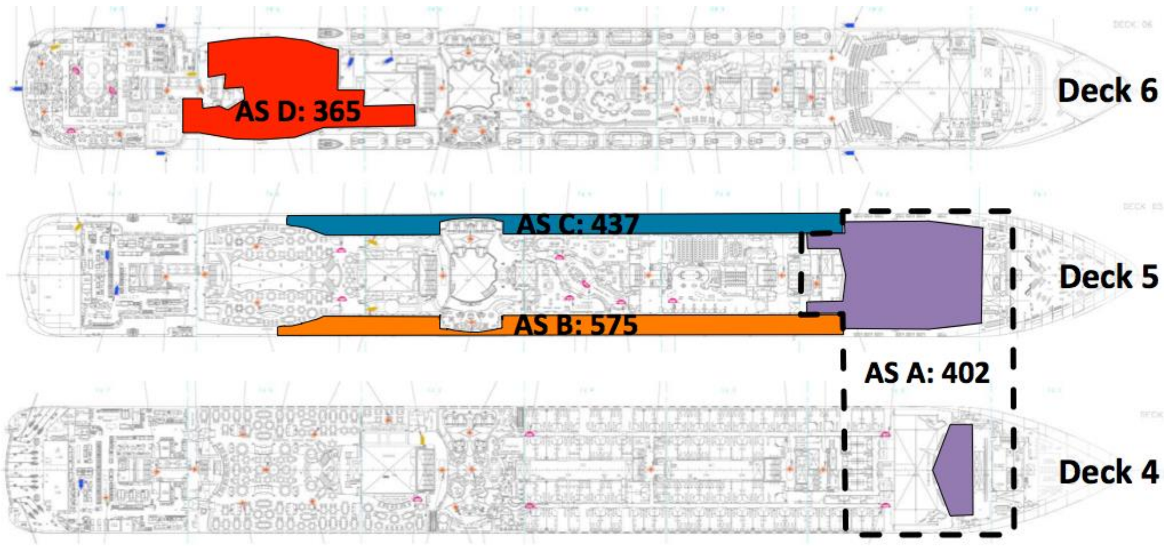
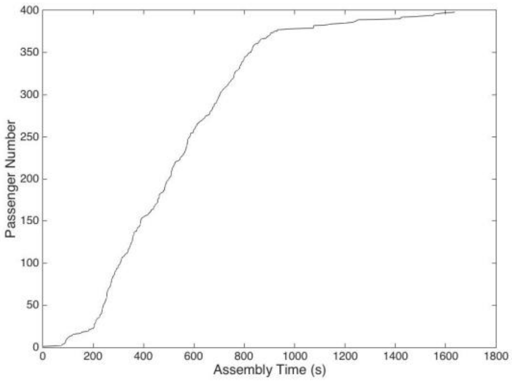
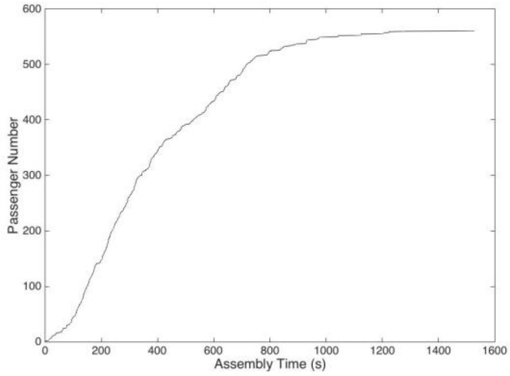


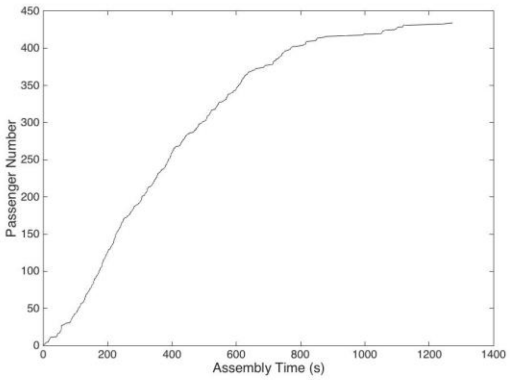
Figure 124 Number of passengers assembled in each assembly station.



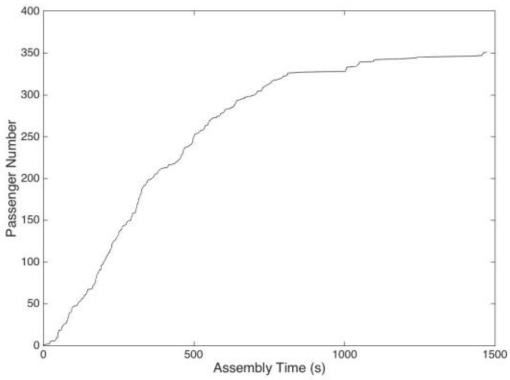
AS A



AS B



AS C



AS D

Figure 125 Assembly time curves for the four assembly stations onboard JoS, with passengers already in the assembly station removed.

The Captain officially ended the assembly exercise 29 minutes after its start. The IR system recorded the time that the last tagged passenger arrived in AS A as 1637 s (27 min 17 s), thus providing a good indication of the overall assembly time. In addition to the assembly curves presented in Figure 125, the overall arrival curve is presented in Figure 130. As with the SS1 dataset, this validation dataset provides a means of not only determining how well an evacuation model can predict the overall assembly time, but more importantly, how well the evacuation model can predict the overall assembly *process* and hence the overall assembly time.

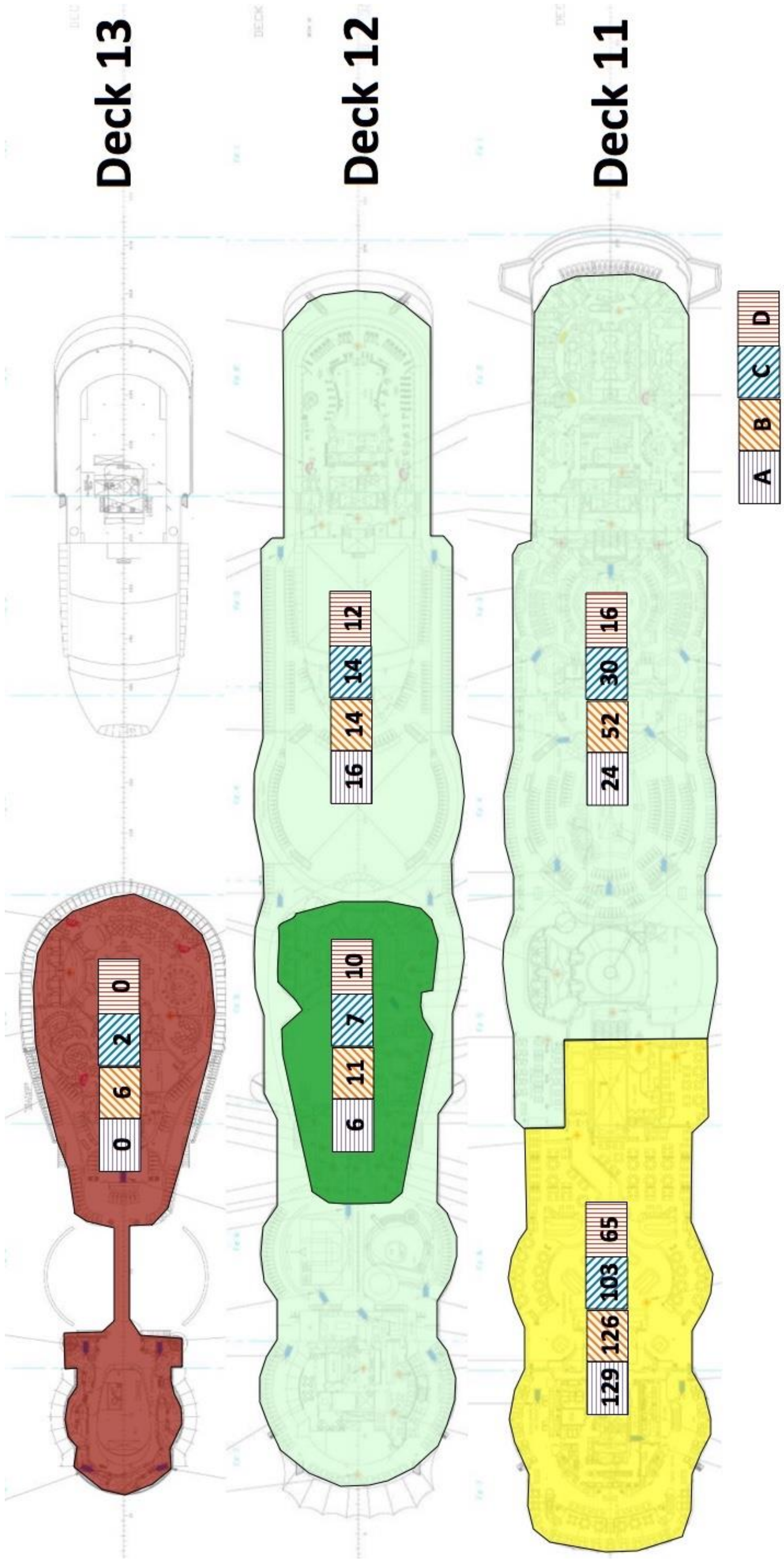


Figure 126 Starting and assembled locations for passengers in different areas of Jewel of the Seas, Deck 11-13 (boxes with numbers and cross hatch pattern indicates number from this region that go to the AS with the same hatch pattern, shown in the key).

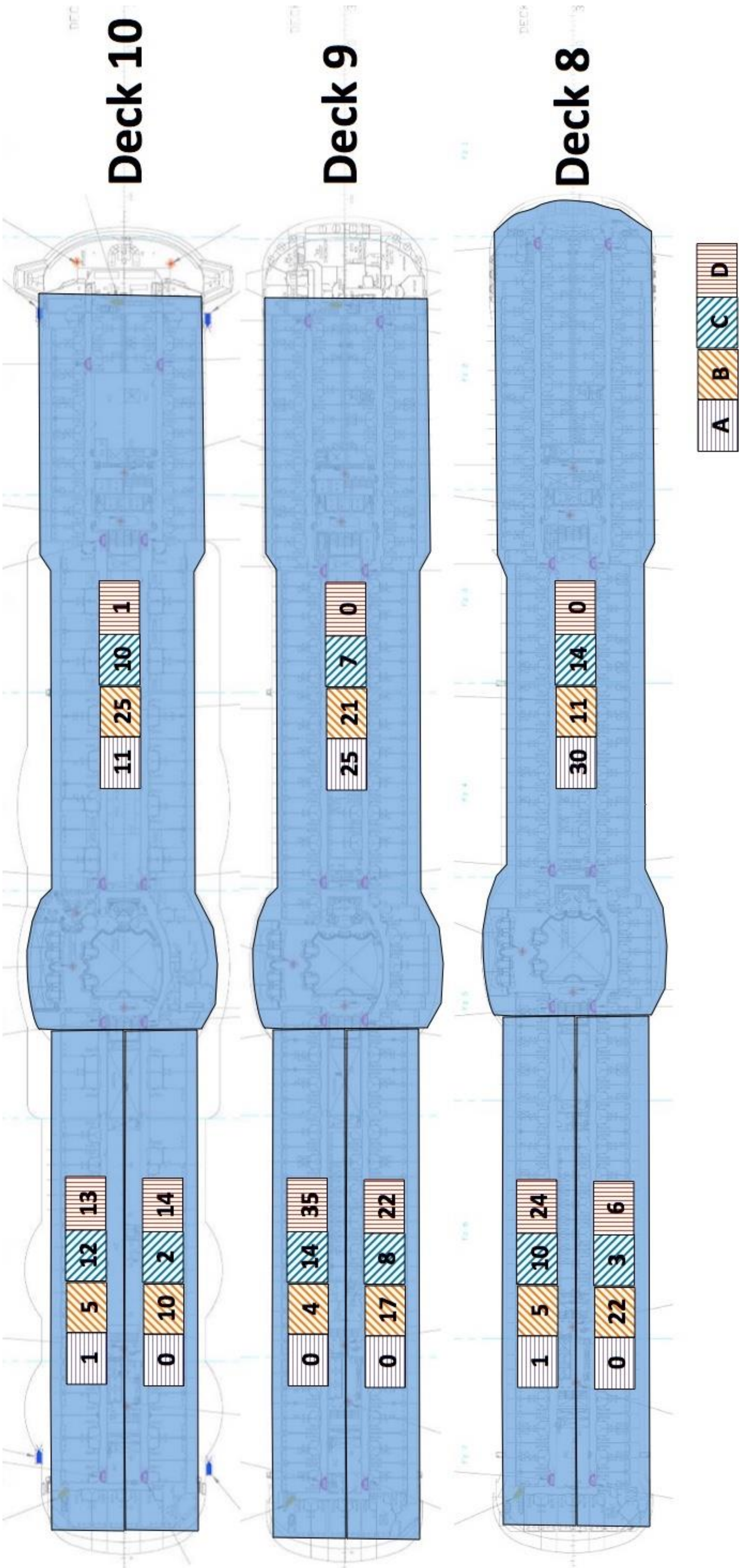


Figure 127 Starting and assembled locations for passengers in different areas of Jewel of the Seas, Deck 8-10 (boxes with numbers and cross hatch pattern indicates number from this region that go to the AS with the same hatch pattern, shown in the key).

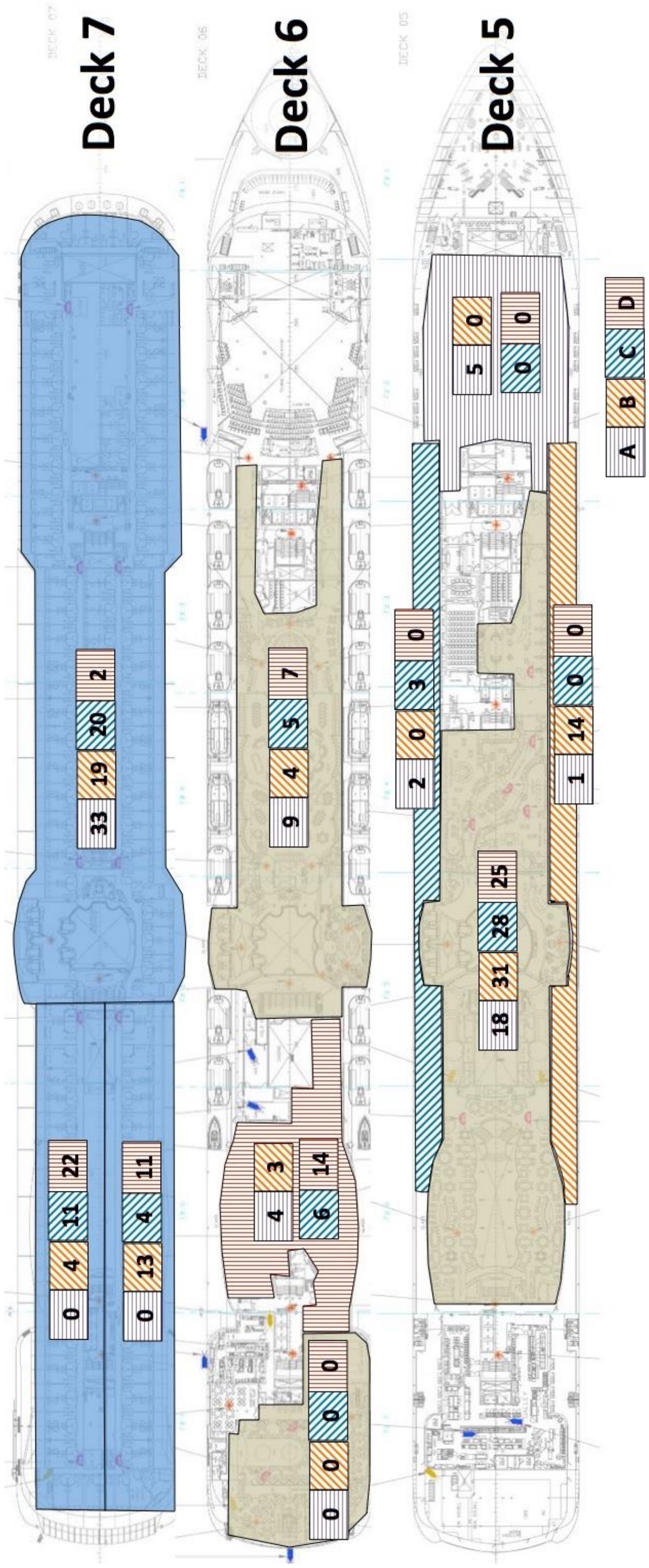


Figure 128 Starting and assembled locations for passengers in different areas of Jewel of the Seas, Deck 5-7 (boxes with numbers and cross hatch pattern indicates number from this region that go to the AS with the same hatch pattern, shown in the key).

Figure 129 Starting and assembled locations for passengers in different areas of Jewel of the Seas, Deck 2-4 (boxes with numbers and cross hatch pattern indicates number from this region that go to the AS with the same hatch pattern, shown in the key).

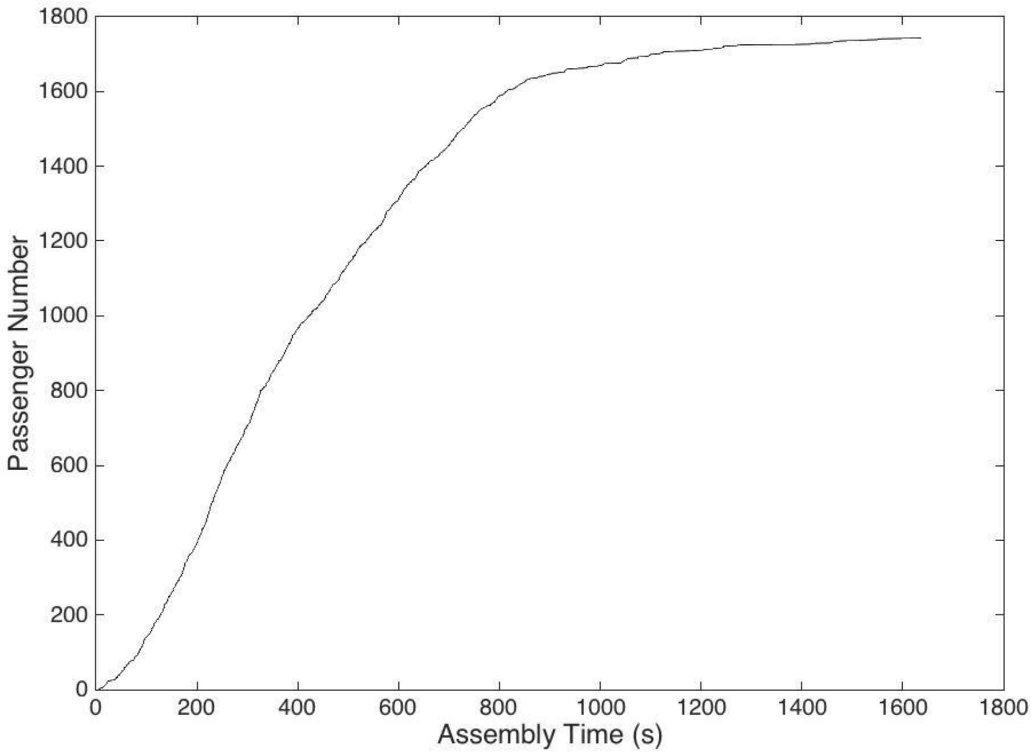


Figure 130 Overall measured assembly curve for the JoS trial (removing all passengers who remained in an assembly station throughout the process and thus had an assembly time of zero).

7.4 Modelling Procedure

7.4.1 Overview

This section outlines the methods used to model SS1 and JoS using maritimeEXODUS software. The IMO evacuation analysis guidelines MSC.1/Circ.1238 [21] provide specific parameters that must be used when performing an evacuation analysis for regulatory approval. These parameters are grouped into four categories and are outlined below:

- **Geometrical:**
    - Layout of escape routes – passengers and crew are expected to proceed along primary escape routes and know how to reach the assembly stations
    - Initial passenger and crew distribution – based on Chapter 13 of the FSS Code [118]

- **Population:**
    - Demographics – should be based on the details provided in Table 65
    - Response time – should be truncated lognormal distributions, according to (where *x* is response time in seconds and *y* is probability density at time *x*):

For Night Cases (*400 < x < 700*):

$$y = \frac{1.01875}{\sqrt{2\pi} \cdot 0.84(x - 400)} exp\left[-\frac{(\ln(x - 400) - 3.95)^2}{2 \cdot 0.84^2}\right] \tag{24}$$

For Day Cases (*0 < x < 300*):

$$y = \frac{1.00808}{\sqrt{2\pi} \cdot 0.94x} exp\left[-\frac{(\ln(x) - 3.44)^2}{2 \cdot 0.94^2}\right] \tag{25}$$

    - Unhindered travel speed in corridors – are based on the formulations presented in Table 66 and should be modelled as uniform random distributions with minimum and maximum values as presented in Table 65 for corridors, according to the age and gender of each agent.
    - Unhindered travel speed on stairs – should be modelled as uniform random distributions with minimum and maximum values as presented in Table 65 for stairs, according to the age and gender of each agent and whether moving in an up stairs or down stairs direction.
    - Door exit flow rates – should not exceed more than 1.33 persons per unit time (seconds) per unit width (m) of the exit.
- **Environmental:**
    - Static and dynamic condition of the ship – these conditions would affect the movement speeds of people onboard but currently no reliable data is available so this is not accounted for.
- **Procedural:**
    - Special crew procedures – modelling of special crew procedures is not required.

Table 65 Population composition for passengers (age and gender) with associated walking speed ranges for corridors and stairs [21]. Note that "Mobility 1" refers to individuals with the first type of mobility impairment.

	Age range	% of PAX	Walking Speed (m/s)					
			Corridor		Stairs (Down)		Stairs (Up)	
			Min	Max	Min	Max	Min	Max
Females	< 30 yrs	7	0.93	1.55	0.56	0.94	0.47	0.79
	30-50 yrs	7	0.71	1.19	0.49	0.81	0.44	0.74
	> 50 yrs	16	0.56	0.94	0.45	0.75	0.37	0.61
	>50, Mobility 1	10	0.43	0.71	0.34	0.56	0.28	0.46
	>50, Mobility 2	10	0.37	0.61	0.29	0.49	0.23	0.39
Males	< 30 yrs	7	1.11	1.85	0.76	1.26	0.50	0.84
	30-50 yrs	7	0.97	1.62	0.64	1.07	0.47	0.79
	> 50 yrs	16	0.84	1.4	0.50	0.84	0.38	0.64
	>50, Mobility 1	10	0.64	1.06	0.38	0.64	0.29	0.49
	>50, Mobility 2	10	0.55	0.91	0.33	0.55	0.25	0.41

Table 66 Formulation of mean travel speeds by age group and gender [21].

Gender	Age (yrs)	Speed Equation (m/s)
Female	2 – 8.3	0.06 x Age + 0.5
	8.3 – 13.3	0.04 x Age + 0.67
	13.3 – 22.25	0.02 x Age + 0.94
	22.25 – 37.5	-0.018 x Age + 1.78
	37.5 - 70	-0.01 x Age + 1.45
Male	2 – 5	0.16 x Age + 0.3
	5 – 12.5	0.06 x Age + 0.8
	12.5 – 18.8	0.008 x Age + 1.45
	18.8 – 39.2	-0.01 x Age + 1.78
	39.2 – 70	-0.009 x Age + 1.75

All parameters used for the simulations performed were compliant with those specified above (IMO MSC.1/Circ.1238 [21]) with the exception of the response time distribution and the starting and ending location of passengers, which were based on trial data. The validation simulations presented here do not examine the route finding or way finding capabilities of the model, since the agent goes to a target assembly station defined by the trial results. However, the *route taken* by each model agent to reach the assigned assembly station was not prescribed. It should also be explicitly stated that population demographics used are those specified in IMO MSC.1/Circ.1238 [21] and not for passengers involved in the experiment.

The results presented in this chapter were generated from blind simulations using the maritimeEXODUS V4.1 software ([39][40][41][42][43] and as described in Section 2.6.3.10). While the simulations presented here were carried-out by a member of the UoG project team rather than the author, the results are presented here to show the method for performing a validation assessment of the model used. This is work that the author was intimately involved in, particularly the use of the metrics to compare simulation results to experimental data.

7.4.2 SuperSpeed 1 – Trial 2

For the simulations presented here, the regional response time data was used (Section 7.2.3) and the first known (i.e. regional starting) locations of the passengers, as defined in Section 7.2.2, were used. There were several issues with the data set collected onboard SuperSpeed 1 that reduce its quality. These are outlined in the paragraphs that follow.

Firstly, of the 1,349 passengers on board, 780 wore the IR tags and participated in the assembly trial. Of these, 16 people (2.1% of people with tags) appeared in the AS after the trial ended, so were not included in the analysis, which gives a total of 764 tagged passengers. The majority of the 569 passengers who did not wear the tags indicated that they did not want to participate in the assembly exercise – which was not compulsory for passengers, given the duration of the voyage. A small number indicated that they did not want to wear a tag. However, of the 569 passengers who chose not to wear a tag, a significant number did eventually decide to participate in the exercise. This was determined during analysis of video footage, reviewing completed questionnaires and observations made by project team members who were positioned in the assembly stations to collect tags from the participants after the exercise was complete. The presence of untagged passengers mixed with tagged passengers during evacuation process would naturally be expected to impact on the overall evacuation time and process, especially in highly congested areas. However, the assembly time for these passengers was not recorded by the IR system.

Secondly, while the IR system logged the first beacon passed after the alarm, this did not represent the *exact* starting location of the tagged participants. Examination of the ship's general arrangement drawings showed that passenger starting areas ranged in size from 24-48m in length; thus not knowing the precise starting location of an individual may increase/decrease their arrival time by 25-50 seconds, assuming a mean walking speed of 0.96 m/s.

Finally, the response times used are not associated with individual passengers but to the regions in which they were located. Thus the precise response time of each unique individual modelled is not known. All of these factors must be taken into consideration when determining how well the evacuation model predicts the assembly exercise.

As already noted, of the 569 passengers that did not wear IR tags, an unknown number actually participated in the trial and so had an effect on the movement of those passengers wearing the IR tags during the assembly exercise. In order to take this into account, it was assumed that 250 of these passengers, approximately half, did actually participate in the assembly exercise. These passengers were included in the evacuation simulation as moving passengers, but were not included in the analysis of the assembly station arrival curves and total assembly times. These 250 agents were distributed throughout the vessel in the same proportion as the population distribution of the known 764 passengers. As required by IMO MSC.1/Circ.1238 [21] a total of 50 repeat simulations were carried-out in which the starting locations of the passengers within the different regions were randomised and the total assembly time was derived from the 95th percentile time selected to represent the prediction of the assembly process. The procedure outlined in [21] assumes that evacuation models will under-predict the total assembly time so requires that a safety factor of 1.25 be applied to the predicted total assembly time.

7.4.3 Jewel of the Seas

As described in the previous section for SS1, several complications with the validation dataset for JoS introduced a degree of uncertainty in the trial results. Firstly, of the 2,292 passengers on board, 1,950 wore the IR tags and participated in the assembly trial. Of these, 171 tagged participants were excluded from the data-set for various reasons e.g. a number of participants arrived at the AS after the trial was declared over, several participants had response times considerably longer than that measured using the video camera data, another participant took a unusually circuitous route to the AS, such as going up stairs for several decks when he/she should have been moving towards the AS. The 342 passengers that did not have tags were: (1) children under the age of 12 who were not permitted to take part in the study, (2) passengers who chose not take part in the trial and (3) a number of passengers who decided not to wear the IR tag or forgot to do so but still participated in the trial. The number in the latter category is believed to be small (from analysis of video footage from the entrance to several assembly stations) and estimated to be less than 10% of the number participating who wore tags. Unlike in the case of the SS1 trial, the impact of these passengers on the overall results is expected to be small and is ignored.

Secondly, as with SS1, the exact starting location of the tagged participants was not known, but the region in which they were located was known. Spatial regions were calculated by another member of the UoG project team to be between 50m and 95m long; thus not knowing the precise starting location of an individual may increase/decrease their arrival time by 48-91 seconds.

Thirdly, the response time distribution used is not associated with a unique individual but represents the overall response time distribution for the entire vessel. Thus, unlike the analysis undertaken for SS1, the zonal response time distributions on JoS are not known to sufficient resolution to be meaningful. The impact that this could have on an evacuation analysis is difficult to estimate as each time the simulation is run, a different random allocation of response times is made for all agents. Thus an agent may be allocated a very long response time in one simulation and in the next simulation may be allocated a very short response time. The error associated with the random allocation of the global response time may be minimised if the mean predicted assembly time distribution is considered. However, IMO MSC.1/Circ.1238 [21] requires that the 95th percentile case be used to represent the vessel assembly performance. All of these factors must be taken into consideration when determining how well the evacuation model predicts the assembly exercise.

7.5 Comparison of Model Results to Trial Results

7.5.1 Validation dataset #1

A comparison of maritimeEXODUS 95th percentile case simulation results to trial results for each assembly station – A through D is presented in Figure 131. The overall assembly time curve is presented in Figure 132.

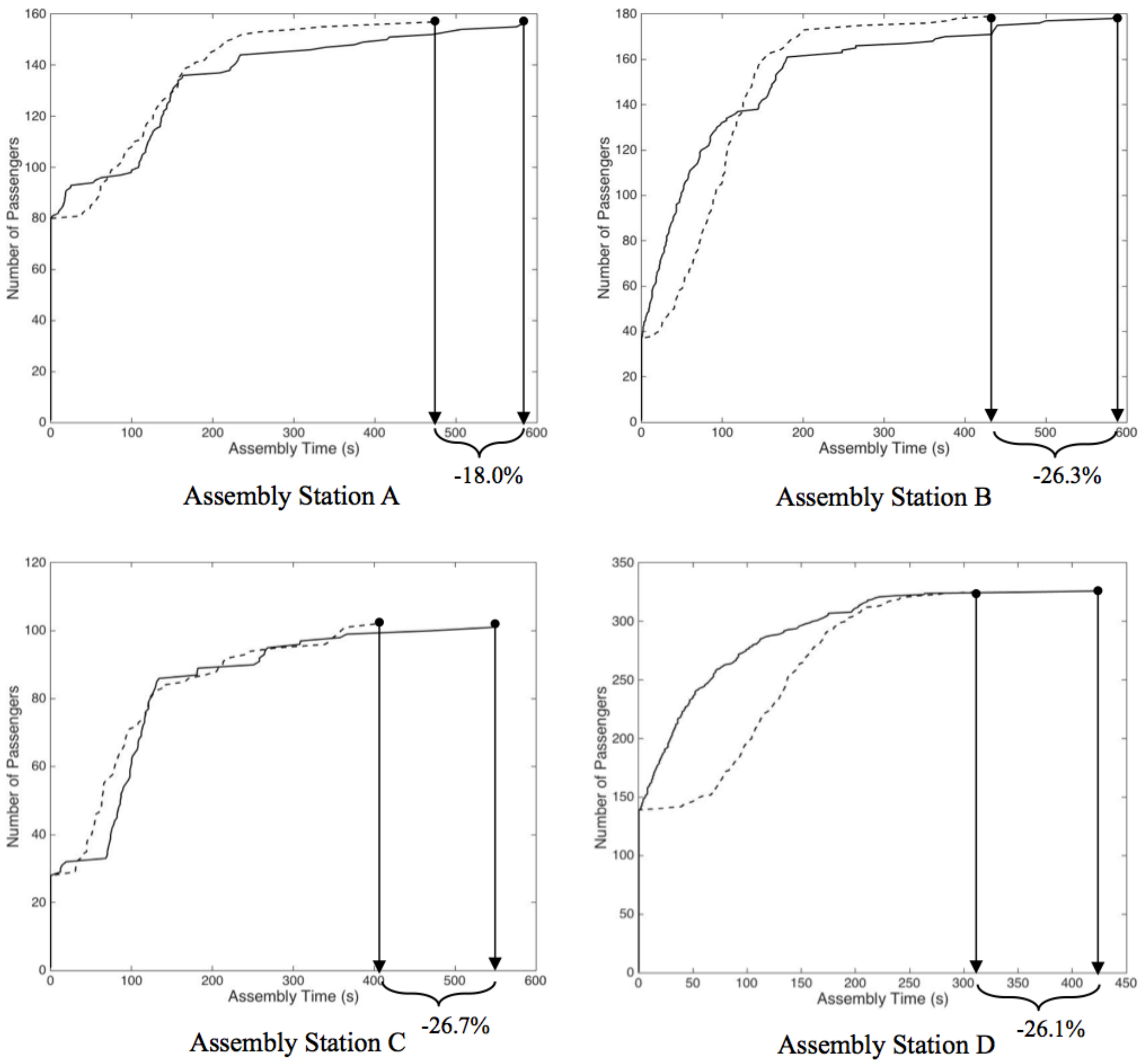


Figure 131 Graphical comparison of model predictions with experimental results by assembly station on SS1; showing difference between model and actual total assembly times (dashed lines: maritimeEXODUS results; solid lines: experimental results).

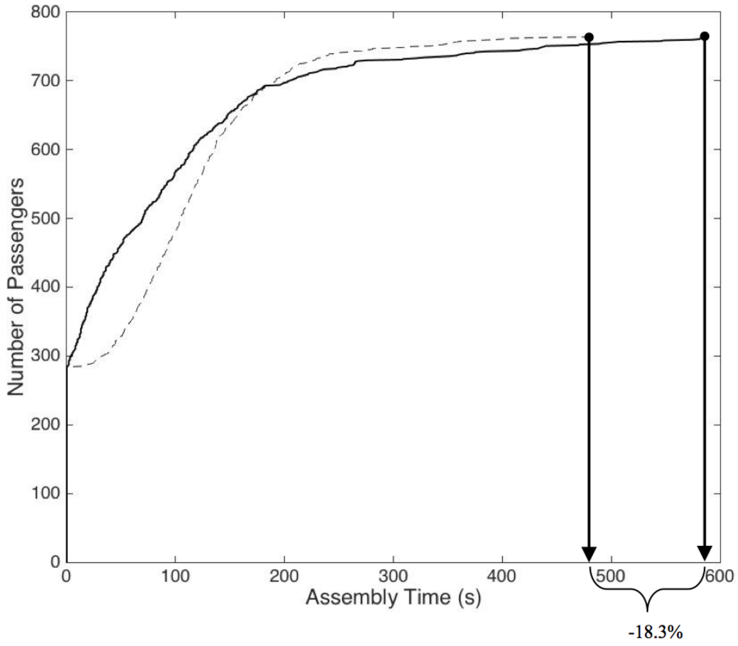


Figure 132 Comparison of model predictions to experimental results for the overall assembly process on SS1; showing difference between model and actual total assembly times (dashed lines: maritimeEXODUS results; solid lines: experimental results).

Section 7.4.2 provides a detailed explanation for differences observed between modelled and experimental results shown in Figure 131 and Figure 132. In summary: a proportion of passengers not wearing tags participated in the assembly exercise which impacted the assembly times measured and predicted; there may be a delay of up to 50 s before passengers in the experiment were logged by the IR system since it was not precisely known where passengers were located within each zone at the time of the alarm; and individual response time for tagged passengers is not known, which may affect the model results.

As noted above, the total assembly time (TAT) – the time at which the final passenger reached the assembly station – is the primary measure of interest for regulatory authorities when interpreting evacuation analysis of a ship design. It can be seen from Figure 131 and Figure 132 that the model under-predicts the TAT for each assembly station and the overall assembly process. The simulations under-predict the TAT for each AS by: 18.0%, 26.3%, 26.7% and 26.1% for assembly stations A, B, C and D respectively and the overall TAT is under-predicted by 18.3%. It can also be seen from Figure 131 and Figure 132 that the number of passengers involved in this difference (i.e. the portion that is under-predicted) is relatively small and possibly caused by a few late-comers to the AS (A: 5 PAX or 3.2% of the population at this AS; B: 9 PAX or 5.0% of the population at this AS; C: 3 PAX or 2.9% of the population at this AS; D: 2 PAX or 0.6% of the population at this AS and overall: 11 PAX or 1.4% of the total population assembling).

In addition, as noted earlier, there are several uncertainties associated with representing the experimental conditions in the modelling activity. The uncertainty in the exact starting location of the passengers can introduce an error of about 25 s to 50 s in the prediction of assembly times. This uncertainty alone introduces a possible error of as much as 10.5% in the overall TAT and an error of 10.5%, 11.6%, 12.5% and 16.0% in the prediction of the TAT for the individual assembly stations A, B, C and D respectively. The error associated with the assembly of the non-tagged passengers is difficult to estimate. While the analysis has attempted to take this into account by introducing approximately half the population of untagged passengers into the simulation, it is not clear if this is sufficient. Taking this uncertainty into consideration, the errors in the predicted assembly times appear reasonable.

It is also noted that the simulations in maritimeEXODUS correctly identified that the last AS to be assembled was AS A. This is an important result, as IMO MSC.1/Circ.1238 [21] requires that the simulations identify which is the last AS to assemble and makes use of this information to formulate additional scenarios to be investigated.

7.5.2 Validation Dataset #2

A comparison of maritimeEXODUS 95th percentile case simulation results for JoS to trial results for each assembly station – A through D and results is presented in Figure 133 and the overall arrival curve is presented in Figure 134.

It can been seen from Figure 134 that the maritimeEXODUS simulations for JoS over-predict the TAT for the overall assembly process and either under-predict (negative values) or over-predict (positive values) the assembly time for each AS. The error for TAT between simulation and experimental results for each AS 8.1%, -10.1%, 10.1% and -5.0% for assembly stations A, B, C and D respectively and the overall TAT, which is over-predicted by 8.1%.

When compared with model predictions for SuperSpeed 1, we see that the Jewel of the Seas simulation results are significantly closer to the experimental data. It can be seen from the figures that the number of passengers involved in this difference (i.e. the portion that is under/over-predicted) is quite small and possibly caused by a few late-comers to the assembly station, in either the trial or the simulation (A: 1 PAX or 0.2% of the population at this AS; B: 2 PAX or 0.3% of the population at this AS; C: 1 PAX or 0.2% of the population at this AS; D: 6 PAX or 1.6% of the population at this AS and overall: 1 PAX or 0.06% of the total population assembling).

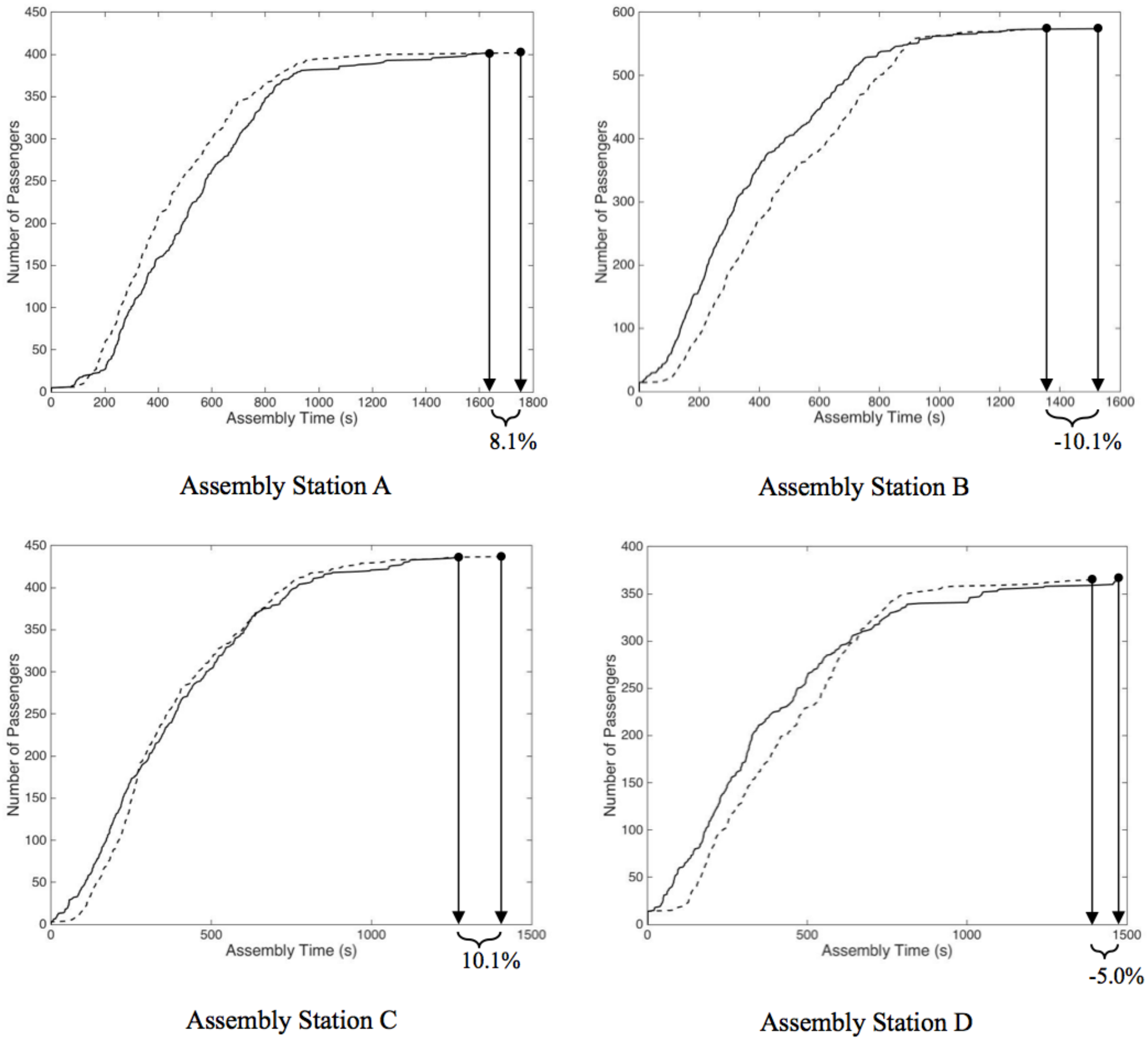


Figure 133 Graphical comparison of model predictions with experimental results by assembly station on JoS; showing difference between model and actual total assembly times (dashed lines: maritimeEXODUS results; solid lines: experimental results).

As noted for the SS1 dataset, there are several uncertainties introduced into the experimental data which should be considered when assessing the level of agreement between model predictions and experimental data. The uncertainty in the exact starting location of the passengers can introduce an error of 48s to 91s in the prediction of assembly time. This uncertainty alone introduces a possible error of up to 5.4% in the overall TAT and an error of up to 7% in the prediction of the TAT for each AS. The error associated with using the global response time distribution rather than the actual response time for an agent is difficult to estimate but may be appreciable.

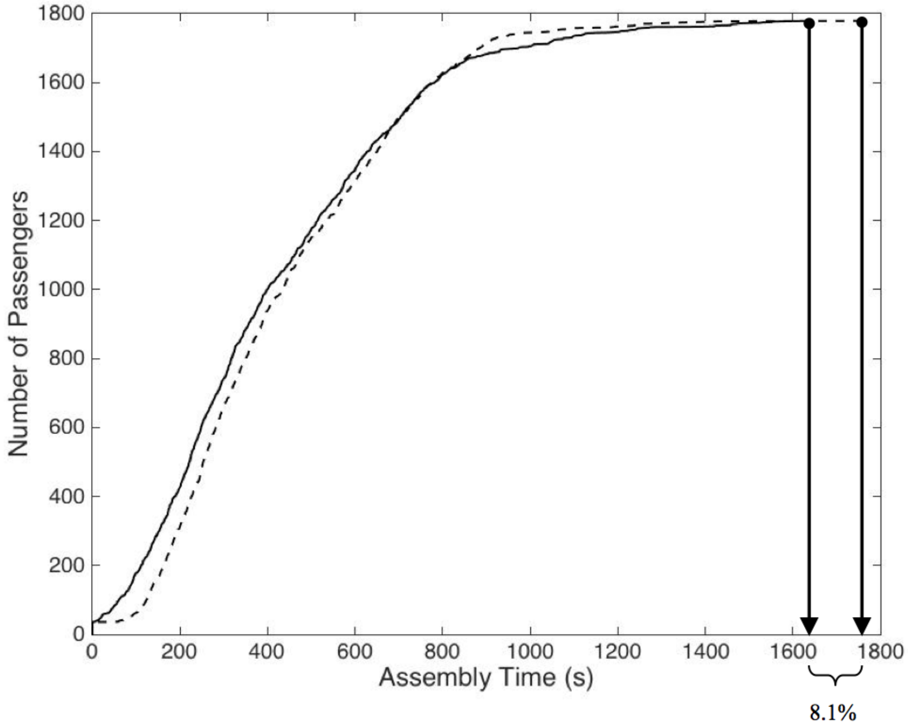


Figure 134 Comparison of model predictions to experimental results for the overall assembly process on JoS; showing difference between model and actual total assembly times (dashed lines: maritimeEXODUS results; solid lines: experimental results).

Finally, the error associated with the untagged passengers is expected to be small, and the approximate 5 s measurement error in the arrival times associated with using the IR system (explained in Section 3.3.7) is considered insignificant for this trial (0.3% for the overall TAT). Taking these uncertainties into consideration, the errors in the predicted assembly times appear reasonable.

It is also noted that, as with the SS1 dataset, the numerical simulations for the 95th percentile case (those presented) correctly identify that the last AS to assemble is AS A. By visual inspection, the shape of the predicted and measured assembly curves is in very good agreement for the overall assembly (Figure 134), as are the curves for each individual AS (Figure 133). This suggests that the evacuation model is doing a good job of predicting the overall assembly process. Furthermore, the level of agreement for the JoS dataset appears to be significantly better than that of the SS1 dataset.

7.6 Validation Metric

7.6.1 Overview

While the prediction of TAT is a useful measure of simulation performance, it is not sufficient alone for determining whether or not the simulation provides an accurate representation of the assembly *process*. It may be possible for a reasonable prediction of TAT but with the evacuation dynamics misrepresented by the simulation model. Thus, to determine if the evacuation simulation is a good representation of the evacuation dynamics it is important to determine how well the predicted assembly time curves match the experimental curves.

By visual inspection, the predicted and measured assembly curves presented for the overall assembly appear to be in reasonable agreement (Figure 132 and Figure 134 for SS1 and JoS respectively). Similarly, this is the case for the individual assembly stations (presented in Figure 131 and Figure 133 for SS1 and JoS respectively), with the exception of AS D on SS1. This suggests that the evacuation model does a reasonable job of predicting the overall assembly process. However, it is desirable to have an *objective* measure of the level of agreement between the predicted and experimental results, rather than relying on subjective assessments. This is particularly important if the validation analysis is to be used by regulatory authorities to determine the suitability of evacuation modelling tools. Thus it is necessary to quantify the level of agreement between predicted and measured performance; in particular shape and magnitude differences between the curves.

Peacock et al. [243] provided several metrics for quantifying the level of agreement between predicted and measured values. However, the mathematical formulations presented in [243] were found to have a number of typographical errors, which meant that the formulations as provided could not be used. After some testing of what was thought to be the correct formulations and communication [244] with the lead author of [243], the correct versions were confirmed and these are presented here as Equations (26) to (29).

The equations are based on functional analysis – a generalisation of linear algebra, analysis and geometry [243] – to geometrically represent the central features of the problem. As explained by Peacock et al. [243], functional analysis makes use of vector notation to describe the mathematical problems. Operations on these vectors allows for quantitative analysis of the underlying system properties. For the work presented here, the vector operations of interest are the *norm* (a measure of a vector's length) and the *inner product* (a measure of the angle between two vectors). It is recognised that while there are other methods available for comparing two curves, the metrics provided in [243] allow for comparison of several qualities that are important for comparison of model predictions with experimentally obtained data.

Before presenting the formulation of the metrics it is necessary to introduce some terminology explained in [243]. The series of measured experimental data is represented by the *n*-dimensional vector $E = (E_1, E_2, \ldots, E_n)$, where each element, E_i represents the measured assembly time for the i^{th} passenger. Similarly, the series of predicted model data is represented by the *n*-dimensional vector $m = (m_1, m_2, \ldots, m_n)$, where each element, m_i represents the predicted assembly time for the i^{th} model agent. The metric used to quantify the level of agreement between predicted and measured values consists of three measures. The first measure is the *Euclidean Relative Difference* (*ERD*), defined by Equation (26). This metric is used to assess the distance between the experimental data, *E* and the model data, *m*. The calculation of *ERD* approaches a value of zero as the magnitude difference between the two curves is reduced. Smaller values for the *ERD* mean better overall agreement than larger values. An *ERD=0.2* suggests that the average difference between the model and experimental results, taken over all the data points is 20%.

$$ERD = \frac{\|E - m\|}{\|E\|} = \frac{\sqrt{\sum_{i=1}^{n}(E_i - m_i)^2}}{\sqrt{\sum_{i=1}^{n} E_i^2}} \tag{26}$$

The second measure is the *Euclidean Projection Coefficient* (*EPC*), defined by Equation (27). This metric provides a factor which, when multiplied by each modelled data point (m_i), reduces the distance between the model (*m*) and experimental (*E*) vectors to its minimum. Thus, the *EPC* provides a measure of the best possible level of agreement between the model (*m*) and experimental (*E*) curves. An *EPC=1.0* suggests that the difference between the model (*m*) and experimental (*E*) vectors is as small as possible.

$$EPC = \frac{\langle E, m \rangle}{\|m\|^2} = \frac{\sum_{i=1}^{n} E_i m_i}{\sum_{i=1}^{n} m_i^2} \tag{27}$$

The third measure is the *Secant Cosine* (*SC*) defined by Equation (28). Unlike the other two measures, *SC* provides a measure of how well the shape of the model (*m*) curve matches that of the experimental (*E*) curve. It uses a numerical calculation of the first derivative of both curves at each element in the series. An *SC=1.0* suggests that the shape of the model (*m*) curve is identical to that of the experimental (*E*) curve.

$$SC = \frac{\langle E, m \rangle}{\|E\|\|m\|} = \frac{\sum_{i=s+1}^{n} \left[\frac{(E_i - E_{i-s})(m_i - m_{i-s})}{s^2(t_i - t_{i-1})}\right]}{\sqrt{\sum_{i=s+1}^{n} \left[\frac{(E_i - E_{i-s})^2}{s^2(t_i - t_{i-1})}\right] \sum_{i=s+1}^{n} \left[\frac{(m_i - m_{i-s})^2}{s^2(t_i - t_{i-1})}\right]}} \tag{28}$$

The term, *t* in Equation (28) is a measure of the spacing of the data. For the assembly data presented in Figure 131 and Figure 132, the spacing of the data is always 1 (i.e. there is a data point for each passenger/agent that enters an AS). Thus, the difference in *t* consecutive values in Equation (28) is always 1, which simplifies the equation to

$$SC(\Delta t = 1) = \frac{\langle E, m \rangle}{\|E\|\|m\|} = \frac{\sum_{i=s+1}^{n} \left[\frac{(E_i - E_{i-s})(m_i - m_{i-s})}{s^2}\right]}{\sqrt{\sum_{i=s+1}^{n} \left[\frac{(E_i - E_{i-s})^2}{s^2}\right] \sum_{i=s+1}^{n} \left[\frac{(m_i - m_{i-s})^2}{s^2}\right]}} \tag{29}$$

The term, *s* in Equation (29) is a factor that represents the period of noise in the data, or variations in the experimental data resulting from microscopic behaviour that cannot be reproduced in the model. Selecting a value of *s* greater than the period of noise in the data provides a means to smooth the effect of the noise. However, care must be taken in selecting the value of *s*; if the chosen value of *s* is too large, the natural variation in the data may be lost, while if *s* is too small, the variation in the data created by noise may dominate the analysis. Selecting an appropriate value of *s* is dependent on the number of data points in the data set, given by the number of elements, *n*. Thus it is desirable to keep the ratio *s/n* as low as practical.

To illustrate how these metrics can provide a quantitative comparison of two curves, a set of hypothetical curves was generated that have varying degrees of similarity to the experimental data. These are shown in Figure 135, where the experimental data is compared to the following curves: maritimeEXODUS modelled data, a stepped curve, a low stepped curve and a simple XY curve (*y=x*). Comparison of the different curves to the experimental curve using the metrics defined in Equations (26) to (29) produce the results shown in Table 67. By inspection, we see that the maritimeEXODUS modelled data produces the best fit to the experimental curve and this is supported by the results in the table for which *EPC* is closest to 1.0, *ERD* is closest to 0.0 and *SC* is closest to 1.0. Figure 135 also shows the range size for s/n=0.05 so that the reader can better understand the impact of choosing a value for *s* that is too large.

Table 67 Results of hypothetical curve comparison to the experimental data.

Curve	**EPC (ideal 1.0)**	**ERD (ideal 0.0)**	**SC (ideal 1.0)**			
			s=5	***s=10***	***s=15***	***s=20***
mEX	1.05	0.30	0.76	0.88	0.92	0.93
Stepped	0.33	1.82	0.02	0.03	0.04	0.05
XY	0.43	1.26	0.44	0.47	0.49	0.50
Low Step	2.57	0.90	0.12	0.18	0.20	0.18

To further illustrate the influence of *s* on the resulting calculation of *SC*, Figure 136 shows *SC* as a function of *s* between 1 and 480 (the size of the data set). In this instance, *s=24* represents *s/n=0.05* (i.e. smoothing over 5% of the dataset). From this, we see that for the case presented, there is generally a point after which choosing a larger value for *s* would be smoothing too large a portion of the data set and causing unpredictable calculations of *SC*.

For instance, the fact that all curves end with the same values means that choosing *s=479* gives *SC=1* for all curves, which is clearly a misleading result. As such, it is difficult to recommend what value of *s* (or *s/n*) should be used in the calculation of *SC* (Equation (29)), since the noise and natural variability in the datasets should be considered when making this choice. It is recommended that *s* (or *s/n*) should be as small as possible so that the natural variability in a given dataset is not smoothed-over.

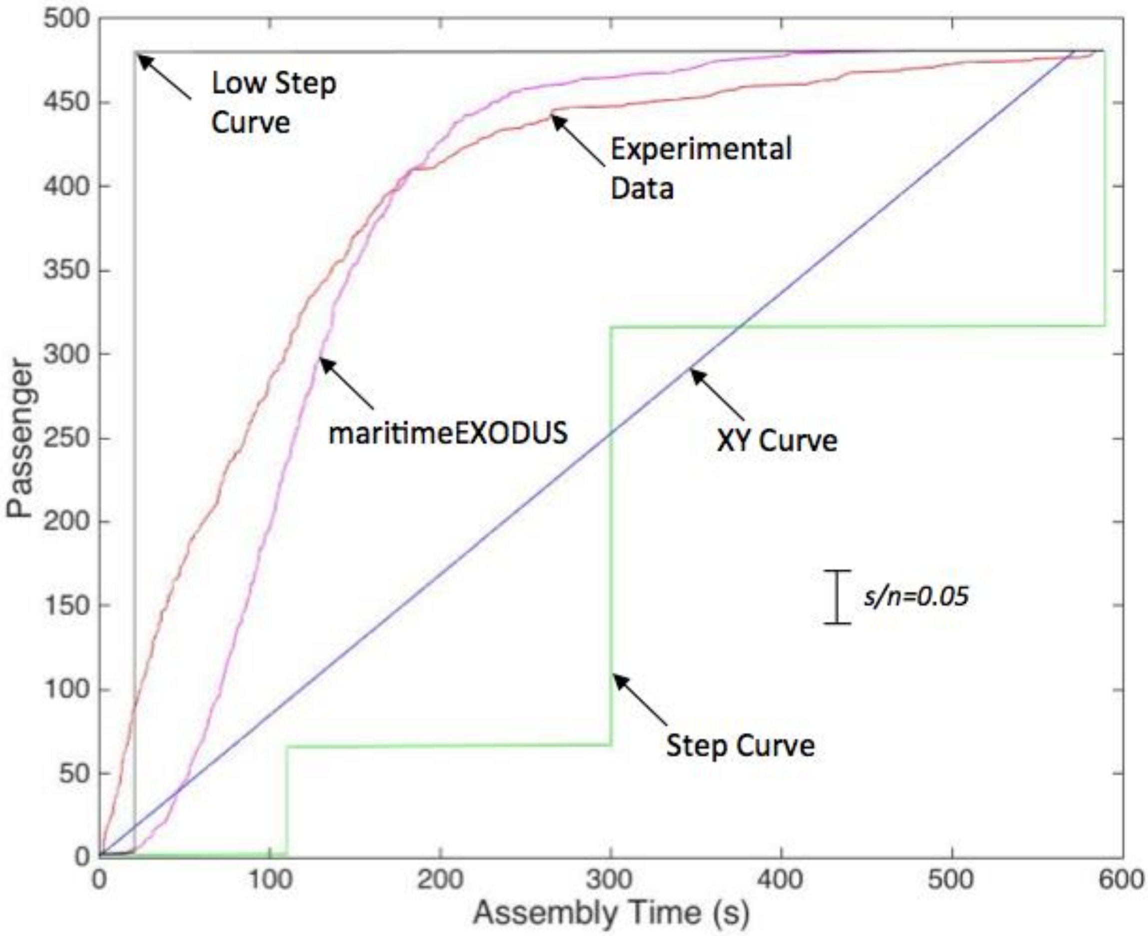


Figure 135 Example curves created to demonstrate influence of S-Value on calculation of Secant Cosine in Equation (29), with experimental curve shown as dashed.

A few additional considerations are presented here to help understand the meaning of the terms *ERD*, *EPC* and *SC*. For data sets in which an experimental and model data points are available for each element, if *ERD = 0.0* then it would not be necessary to consider other measures, since the two data sets would be identical. In all other cases it is necessary to consider the three measures together in order to quantify how well the two data sets match each other. Since it is possible for a model data curve to *cross* an experimental data curve one or more times, *EPC* can return a value close to 1.0 while there is a difference between the two curves. Similarly, *SC* can return a value of 1.0 even though the model and experimental data curves are offset by a constant value. In general, for the model and experimental curves to be considered a perfect match, it is necessary to have all three measures at their optimal values i.e. *ERD = 0.0*, *EPC = 1.0* and *SC =1.0*.

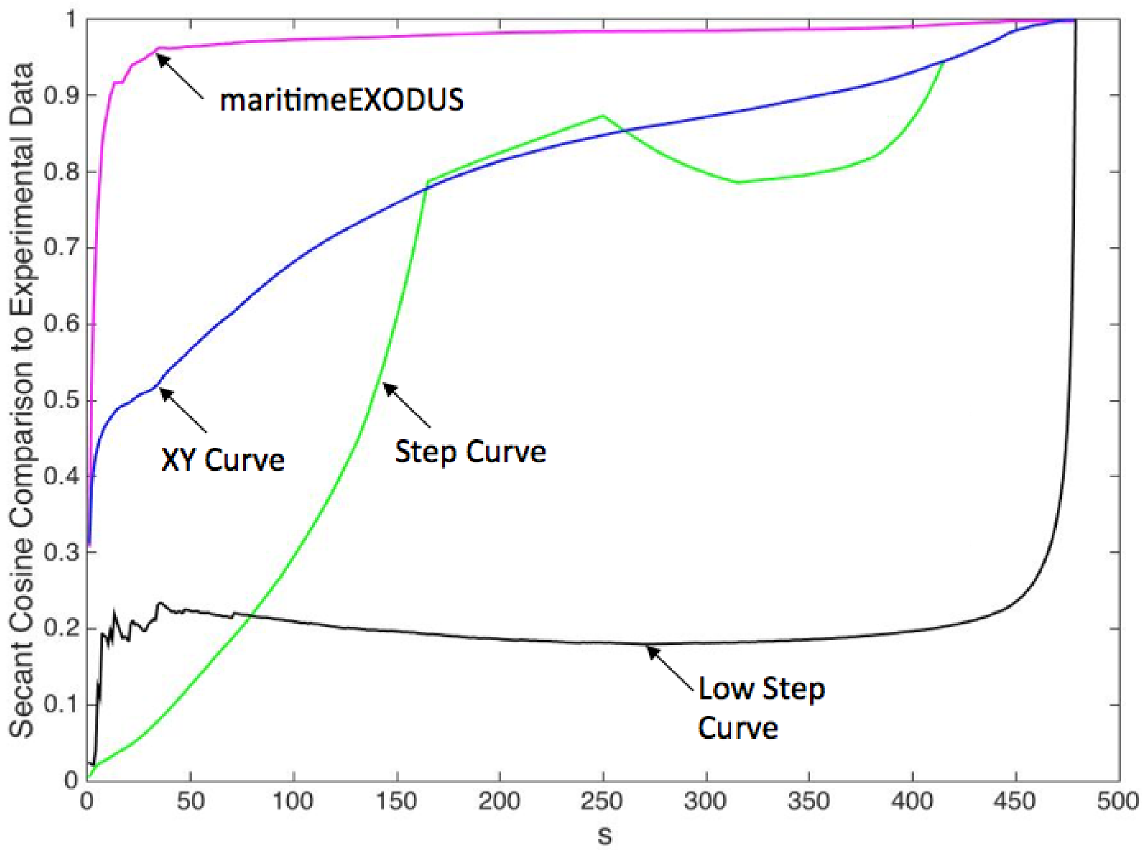


Figure 136 Secant Cosine as a function of *s* (Equation (29)) for curves shown in Figure 135 compared with experimental data (*s=24* is equivalent to *s/n=0.05*).

7.6.2 Applying the Metric to Validation Dataset #1

Applying the metrics to the assembly time data shown for SS1 in Figure 131 and Figure 132 produces the values shown in Table 68. If we consider first the data relating to the overall assembly curve (Figure 132), the values for *SC* suggest that the shape of the overall curve closely resembles that of the experimental data, even with *s/n* as low as 0.01. This is consistent with the conclusion drawn from a visual inspection of this figure. Note that for this case, an *s/n=0.01* represents smoothing over 1% of the data set and implies *s=5* in

Equation (29) and the gradients used in the evaluation of the equation are spread over 5 data points, which is considered reasonable. Furthermore, the *ERD* result for the overall assembly is low (0.3) and *EPC* is close to 1.0, suggesting that the overall predicted assembly curve is quite close to the measured curve.

If we then consider the individual assembly stations, we find that for *s/n=0.05*, *SC* values for all assembly stations are close to 1.0 suggesting that the shapes of the predicted curves are in good agreement with the measured curves. This *s/n* value, which represents smoothing over 5% of the data set, is larger than that discussed above for the overall assembly curve, but is still considered to be small. For the smallest of the assembly station data sets (AS C), this represents an *s=4*, while for the largest of the assembly station data sets (AS D), this represents an *s=9*.

With the exception of AS D, *ERD* values are reasonably low, and *EPC* values are reasonably close to 1.0 with the exception of that for AS A and AS D. These values suggest that, with the exception of AS D, the predicted values are reasonably close to the measured values, which again is consistent with a visual inspection of Figure 131.

Table 68 Metric values for maritimeEXODUS prediction of validation set 1.

	SC					**n**	**ERD**	**EPC**	**% diff TAT**
s/n →	**0.01**	**0.03**	**0.05**	**0.07**	**0.09**				
AS A	**0.4**	**0.7**	**0.7**	**0.7**	**0.8**	**77**	**0.4**	**1.4**	**-18.0**
AS B	**0.6**	**0.7**	**0.7**	**0.8**	**0.9**	**142**	**0.4**	**1.2**	**-26.3**
AS C	**0.3**	**0.4**	**0.6**	**0.7**	**0.9**	**74**	**0.2**	**1.1**	**-26.7**
AS D	**0.7**	**0.8**	**0.8**	**0.9**	**0.9**	**187**	**0.6**	**0.7**	**-26.1**
Overall	**0.8**	**0.9**	**0.9**	**1.0**	**1.0**	**480**	**0.3**	**1.1**	**-18.3**

Based on this analysis, a set of acceptance criteria can be suggested for this validation data set that considers the uncertainties in experimental data and that model predictions are a reasonable match, based upon a visual inspection of the data. A general two-step validation method was developed and published by members of the UoG project team, including the author [202][203][204]. The method is based in part on the philosophy of

IMO MSC.1/Circ.1238 [21], which focuses on the overall assembly process (i.e. for all passengers across the entire ship), but also requires that the user demonstrate reliable model predictions for the individual assembly stations.

For the first step of the validation protocol, the acceptance criteria are applied to the model predictions of the overall assembly of all passengers on the ship. To be deemed to be acceptable, the model predictions must satisfy *all* elements of the acceptance criteria and only if this is the case does the user move to the second step. For the second step, the acceptance criteria are applied to *each individual* assembly station. Applying the three metrics *SC*, *ERD* and *EPC* to the four assembly stations, gives a total of 12 values to consider (i.e. *SC*, *ERD* and *EPC* values for each of the four assembly stations → 3 metrics x 4 AS = 12). To provide an objective means for assessing the curves, the following set of acceptance criteria is suggested:

(i) Predicted TAT for the overall assembly to be within 45% of the measured value (this criterion is only applied to step 1 of the acceptance process)

(ii) $ERD \leq 0.45$

(iii) $0.6 \leq EPC \leq 1.4$

(iv) $SC \geq 0.6$ with $s/n \leq 0.05$

These values are suggested based on what seems reasonable and acceptable for the maritimeEXODUS modelling conducted and from visual inspection of the curves being compared. The cut-off values were chosen so as to be not too restrictive as to make it impossible for other models to pass the validation test. In addition, the quality of this dataset was considered and the fact that there were some issues with dataset quality. Therefore, it is further suggested that 2 fails out of 12 would be acceptable, as long as these do not occur in any one assembly station. While the cut-off values are somewhat arbitrarily chosen, they represent the first step in establishing a validation method for ship evacuation models and provide a basis for discussion and debate on how best to tackle the problem of model validation.

Applying the suggested protocol to the maritimeEXODUS data presented in Table 68, we note that for step 1, the model predictions of TAT are always within 45% difference, hence step 2 of the validation protocol is considered. In the second step, AS D fails to meet criteria (ii) (*ERD*=0.6 → thus *ERD*>0.45) but all other criteria are satisfied. As the model predictions have satisfied all four criteria in step 1 and 11 of the 12 criteria in step 2, the model is considered to have satisfied the acceptance criteria.

7.6.3 Applying the Metric to Validation Dataset #2

Applying the metrics to the data shown in Figure 133 and Figure 134 produces the values shown in Table 69. If we first consider the data for the overall assembly curve (Figure 134), the values for *SC* suggest that the shape of the overall assembly curve very closely (SC ≥ 0.9) resembles that of the experimental data, even with *s/n* as low as 0.01. This is consistent with the conclusion drawn from a visual inspection to compare the curves. Note that for this case, *s/n=0.01* represents smoothing over 1% of the dataset and implies *s=17* in Equation (29) and the gradients used in the evaluation of the equation are spread over 17 data points, which is considered reasonable. In addition, the *ERD* result for the overall assembly is very low (*ERD=0.1*) and *EPC=1.0,* suggesting that the overall predicted assembly curve is very close to the measured curve, again consistent with a visual inspection of Figure 134. It is also noted that the overall TAT is within 8.1% of the experimental value.

Table 69 Metric values for maritimeEXODUS prediction of validation set 2.

	SC					**n**	**ERD**	**EPC**	**% diff TAT**
s/n →	**0.01**	**0.02**	**0.03**	**0.04**	**0.05**				
AS A	**0.5**	**0.7**	**0.8**	**0.8**	**0.9**	**397**	**0.2**	**1.2**	**8.1**
AS B	**0.9**	**0.9**	**0.9**	**0.9**	**0.9**	**561**	**0.2**	**0.9**	**-10.1**
AS C	**0.8**	**0.8**	**0.9**	**0.9**	**1.0**	**434**	**0.1**	**1.0**	**10.1**
AS D	**0.7**	**0.8**	**0.9**	**0.9**	**0.9**	**351**	**0.2**	**1.0**	**-5.0**
Overall	**0.9**	**0.9**	**0.9**	**1.0**	**1.0**	**1743**	**0.1**	**1.0**	**8.1**

If we then consider the individual assembly stations, we find very good agreement between the modeled and experimental data. For an *s/n=0.02*, the *SC* values for each assembly station range from 0.7 to 1.0. This suggests that the shape of the predicted assembly curves is in good agreement with the measured curves, again supporting the conclusions of visual inspection of the curves. This *s/n* value, representing 2% of the dataset, is larger than that considered above for the overall assembly curve, but is still considered small.

For the smallest of the assembly station datasets (AS D), this represents *s=7*, while for the largest of the AS data-sets (AS B), this represents *s=11*. The ERD values for each assembly station were also found to be quite low (≤ 0.20). Finally, each of the three cases produce good values of *EPC*, with all values being close to 1.0.

Based on this analysis, a set of acceptance criteria can be defined for this validation data set that considers the uncertainties in experimental data and that model predictions are a reasonable match for the experimental data based on a visual inspection of the data. As for the validation dataset for SS1, a general two-step validation method was developed by members of the UoG project team, including the author [202][203][204]. The method is based in part on the philosophy of IMO MSC.1/Circ.1238 [21, which focuses on the overall assembly process (i.e. for all passengers across the entire ship), but also requires that the user demonstrate reliable model predictions for the individual assembly stations.

For the first step of the validation protocol, the acceptance criteria are applied to the model predictions of the overall assembly. To be deemed to be acceptable, the model predictions must satisfy *all* elements of the acceptance criteria and only if this is the case does the user move to the second step. For the second step, the acceptance criteria are applied to *each individual* assembly station. Applying the three metrics *SC*, *ERD* and *EPC* to the four assembly stations, gives a total of 12 values to consider. To provide an objective means for assessing the curves, the following set of acceptance criteria was developed, which is stricter than the criteria developed for SS1 due to the lower uncertainty in the measured values:

(i) Predicted TAT for the overall assembly to be within 15% of the measured value (this criterion is only applied to step 1 of the acceptance process)
(ii) ERD ≤ 0.25
(iii) 0.8 ≤ EPC ≤ 1.2
(iv) SC ≥ 0.8 with s/n = 0.02

As with validation dataset #1, these values are suggested based on what seems reasonable and acceptable for the maritimeEXODUS modelling conducted and from visual inspection of the curves being compared. In addition, the fact that the data was of higher quality than validation dataset #1, the cut-off values were chosen to be more restrictive. It is again suggested that 2 fails out of 12 would be acceptable, as long as these do not occur in any one assembly station. While the cut-off values are somewhat arbitrarily chosen, they represent the first step in establishing a validation method for ship evacuation models and provide a basis for discussion and debate on how best to tackle the problem of model validation.

Applying the suggested validation protocol to the maritimeEXODUS data presented in Table 69, we note that for step 1, the model predictions of TAT are always below 15% difference, hence step 2 of the validation protocol is considered. In the second step, AS A fails to meet criteria (iv) (*SC (s/n=0.02)* = 0.7 → thus *SC (s/n=0.02)* < 0.8) but all other criteria are satisfied. As the model predictions have satisfied all four criteria in step 1 and 11 of the 12 criteria in step 2, the model is considered to have satisfied the acceptance criteria.

7.7 Recommendations to the IMO Regarding Validation Data

Two validation data sets are recommended for inclusion into the IMO evacuation analysis guidelines to meet the requirement identified in IMO MSC.1/Circ.1238, Annex 3, Paragraph 18 – Quantitative Verification which states: "At this stage of development there is insufficient reliable experimental data to allow a thorough quantitative verification of egress models" [21]. Given the validation results presented in this chapter, particularly those for the cruise ship Jewel of the Seas, it is felt that sufficient and reliable data are now available to meet the needs of quantitative validation and to enable validation testing of ship evacuation simulation software.

It is recommended that before an evacuation simulation tool is considered appropriate for use in ship evacuation certification analysis, it should demonstrate that it satisfies the requirements of the proposed validation protocol.

As part of the validation protocol developed by the UoG team, including the author, all information required to setup the evacuation analysis is made freely available from the UoG website. This includes: CAD layout of vessel (.DXF file format), starting location of passengers, end location of passengers, passenger response time distribution, assembly curves for each individual assembly station and the overall assembly curve. All other parameters required to perform the simulations should be extracted from IMO MSC.1/Circ.1238 [21]. Based on the analysis presented in this chapter, the suggested validation protocol is as follows:

- Perform 50 simulations of the validation scenario.
- Rank each simulation according to the total assembly time (TAT) determined for the total assembly.
- Select the simulation producing the 95th percentile TAT, which will be the basis of the validation comparison.
- For the selected simulation case go through the two phase assessment process which consists of the following phases:
    - **Phase 1**: For the predicted total assembly curve, determine the percentage difference between the predicted and measured TAT. Determine if the predicted parameters satisfy the acceptance criteria (Table 70) for all assembly stations and the overall assembly data. If so, the user should move on to Phase 2. If not, the software has failed the assessment.
    - **Phase 2**: For the predicted assembly curve for each of the four assembly stations, determine *ERD*, *EPC* and *SC* (Equations (26), (27) and (28), respectively). Determine which of the 12 predicted parameters (three values for four assembly station) satisfy the acceptance criteria (Table 70). At least 9 out of 12 criteria must be met for validation data set #1 and 10 out of 12 criteria must be met for validation data set #2 to satisfy the criteria. It is further recommended that it would not be acceptable to have two or more failed criteria in any one assembly station.
- The process should be carried-out for both validation data sets.

Table 70 Summary of the acceptance criteria for validation data sets #1 and #2.

Validation Dataset #1	**Validation Dataset #2**
Phase 1: % TAT < 45%	Phase 1: % TAT < 15%
Phase 2 (minimum 9 of 12): ERD ≤ 0.45 0.6 ≤ EPC ≤ 1.4 SC ≥ 0.6 with s/n = 0.05	Phase 2 (minimum 10 of 12): ERD ≤ 0.25 0.8 ≤ EPC ≤ 1.2 SC ≥ 0.8 with s/n = 0.02

7.8 Chapter Summary

Data from two of the five semi-unannounced assembly trials performed – trial #2 on the SuperSpeed 1 ferry and the trial on the cruise ship Jewel of the Seas were used to define two unique datasets for validating ship evacuation models. The datasets are unique for a number of reasons, primarily because unlike most validation datasets, they contain details on passenger response times, starting locations, end locations and final arrival times. Furthermore, the trials were conducted on real ships, at sea and were semi-unannounced making the results relevant, credible and realistic.

The validation protocol and acceptance criteria proposed here enable an objective but clear means by which evacuation modelling tools can be assessed alongside the experimental data collected during this research. The three measures used - Euclidean Relative Difference (*ERD*), Euclidean Projection Coefficient (*EPC*) and Secant Cosine (SC) compute the magnitude of the distance between the predicted and experimental data and the similarity of the shapes of the predicted and experimental arrival time curves. The proposed acceptance criteria take into consideration uncertainties associated with the measured data in each of the datasets.

It is proposed that the suggested validation protocol and the acceptance criteria should be used by IMO as part of a validation suite to determine acceptability of maritime evacuation models in a future enhancement to its ship evacuation assessment regulations. To this end, the validation datasets are both made freely available from the UoG website for the Fire Safety Engineering Group, as provided through [245].

The validation datasets produced were used independently by members of the SAFEGUARD project (University of Greenwich, University of Strathclyde and Principia Engineering) to perform a validation analysis for three leading ship evacuation models developed within their respective organisations, namely maritimeEXODUS, EVI and ODIGO. It was found that, while all three models performed better in different areas, *all* were capable of meeting the validation criteria set forth in this chapter. It is worth noting here also, that since public release of the validation datasets produced as part of this research, two ship evacuation simulation models, SIMPEV and CityFlow-M are known to have been successfully validated independently using the two validation datasets [200][201].

With a comprehensive set of response time distributions now produced (Chapter 6), a means for validating evacuation models established and used to validate five different commercially available models (Chapter 7), it would be useful to understand the implications on total assembly time of using the different response time distributions developed. This is done in the next chapter (Chapter 8) using a hypothetical passenger ship model and maritimeEXODUS which has passed the validation tests presented here. Day and night case scenarios are modelled using the IMO MSC.1/Circ.1238 [21] parameters to provide baseline measures for comparison with repeat modelling using the different relevant response time distributions presented in Chapter 6.

8 Comparative Modelling with New Response Time Data

8.1 Overview

Changing the response time distributions used within the IMO guidelines (MSC.1/Circ.1238 [21]), as suggested in Section 6.5, may have a significant impact on the outcome of evacuation analysis for new and existing passenger ships. This was described in [32] and [103] which showed that using a lognormal response time distribution rather than a uniform random distribution tends to generate greater levels of congestion, but can actually shorten the total assembly time predicted. Representative response time distributions are also more likely to give more reliable insight into the strengths and weaknesses of a given ship design [32][103].

This chapter explores the impact that suggested changes to response time have on total assembly time. This is accomplished by using the different response time distributions developed in Chapter 6 and applying them to a hypothetical ship layout to simulate the assembly process using the maritimeEXODUS software (described in Section 2.6.3.10). The predicted assembly times are compared with times derived using the current response time distributions specified within the IMO evacuation analysis guideline MSC.1/Circ.1238 [21]. Only a single ship layout is used in the analysis, however, the layout contains a variety of public spaces, as well as a large number of cabins and thus is considered relevant for both cruise ships and ferries. As suggested in Chapter 6, and through the INF paper [227] submitted to the IMO, this is the first time it has been suggested that two different ship types should be considered (RO-PAX ferries and cruise ships) for evacuation analysis protocols.

8.2 Hypothetical Ship Model

A set of general arrangement drawings for a hypothetical ship was produced at UoG and is described in [246]. This model was provided for the author to use in performing the simulations outlined in this chapter. Thus, while it was necessary for the author to make adjustments to the ship model, it was not necessary to develop a .DXF file from a CAD drawing and then prepare the geometry for simulation within maritimeEXODUS.

The hypothetical ship (shown in Figure 137) is a large RO-PAX ferry with a length overall of 150m, breadth of 28m and 10 decks, 5 of which are accessible by passengers (Decks 6 – 10).

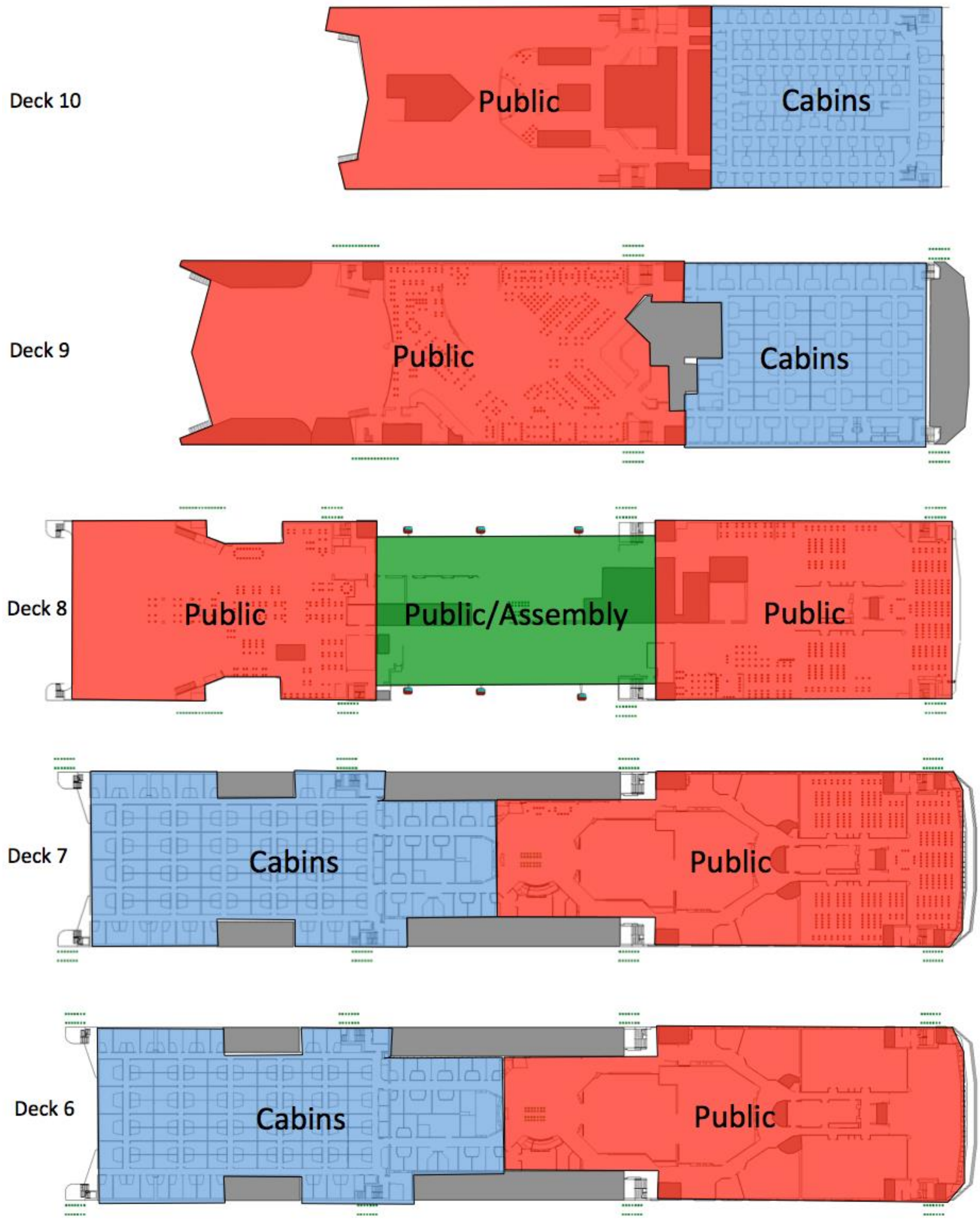


Figure 137 Five decks of the hypothetical ship model, as depicted in maritimeEXODUS software.

The decks are connected by stairways and the vessel is subdivided into 3 main vertical fire zones. The vessel has a total of 8 assembly stations, all located on deck 8 – four on each of the port and starboard sides of the vessel. For each side, there is one at the midships location where the lifesaving appliances (lifeboats) are located, plus one adjacent at the forward and aft ends of this location. In addition, a large, internal assembly station is located at the aft end of the vessel. All stairways on the vessel are similar in construction – narrow and capable of having only a single lane of passengers use the stairs. One exception is a dual lane staircase, which is located in the midships area and runs from deck 6 to deck 9.

8.3 Passenger Population

As described in detail in Section 7.4.1, the IMO evacuation analysis guidelines MSC.1/Circ.1238 [21] provide specific parameters that must be used when performing an evacuation analysis for regulatory approval. These parameters are grouped into four categories; geometrical, environmental, procedural and population, which were outlined in Section 7.4.1. The population parameters are defined in this section.

A population of 650 passengers was randomly generated according to the proportions required by MSC.1/Circ.1238 [21] and as shown in Table 65 (Chapter 7) for gender and age ranges. Mean walking speed for passengers was derived from the formulations presented in Table 66 (Chapter 7) and the walking speed for each gender and age group was modelled as a uniform random distribution with the minimum and maximum values specified in Table 65. Flow rate through exits (given as the number of persons past a point in the escape route per unit time per unit width for the route) did not exceed 1.33 persons/(m s).

Ten different populations were randomly generated and positioned randomly in either cabin areas or public areas, depending on whether the scenario being modelling was a night or day case. Each of the 10 populations was used for 5 simulation runs, with the individual agent positions randomised for each run. Thus, for each test case, 50 simulations were run. To allow for a more consistent comparison between the results for each test case, when the populations had been generated and positioned, only the response time distribution was changed for each test scenario. Thus, the population characteristics and starting locations for the daytime base case were the same as those used for each of the other comparison cases and the same was true for the night case.

8.4 Scenarios Examined

MSC.1/Circ.1238 [21] requires completion of four simulation cases. The first two cases are the primary night and day cases in which all evacuation routes are available. The last two cases are secondary night and day cases in which the main vertical zone producing the longest assembly time is further examined to determine the impact of two alternatives:

1. The largest capacity staircase in the zone being unavailable, and
2. 50% of the passengers in one of the main vertical zones (the one with the largest population) adjacent to the zone identified are required to move into the zone to proceed to the relevant assembly station.

For the analysis provided here, only the primary day and night cases were simulated as the goal was to determine the impact of using different response time distributions on the total assembly time predicted.

A total of ten scenarios were simulated using maritimeEXODUS – four night cases and six day cases:

a. Scenario 1: Baseline case using IMO night RTD
b. Scenario 2: Night case using RTD derived from cabin areas on JoS
c. Scenario 3: Night case using RTD derived from cabin areas on OP
d. Scenario 4: Night case using new recommended cruise ship RTD derived from cabin areas on JoS (truncated, scaled and shifted)

e. Scenario 5: Baseline case using IMO day RTD
f. Scenario 6: Day case using RTD derived from public areas on JoS
g. Scenario 7: Day case using RTD derived from public areas on OP
h. Scenario 8: Day case using RTD derived from public area on SS1

i. Scenario 9: Day case using new recommended RO-PAX day RTD derived from public areas on SS1 and ER (truncated & scaled)
j. Scenario: 10: Day case using new recommended cruise ship day RTD derived from public areas on JoS (truncated & scaled)

For the night case simulations, all passengers were positioned in cabin areas, while for the day case they were positioned in public areas of the ship (up to 75% of maximum capacity). The scenarios are described above are presented in the section that follows.

8.5 Total Assembly Time - Night Case

8.5.1 Scenario 1: Baseline Case using IMO Night RTD

The response time distribution provided in the IMO MSC.1/Circ.1238 [21] night case was used as the baseline night case and a total of 50 simulations run. The resulting assembly curves (shown in Figure 138) were sorted by total assembly time (TAT) and the 95th percentile case chosen to represent the assembly process. Results from the night case simulations are presented in Table 71. We can see that for the representative base case it took 16 minutes and 49 seconds for all 650 passengers to assemble. The difference between the slowest and fastest assemblies was 3 minutes and 16 seconds (20.2% difference). These results compare well with those presented by Galea et al. 2003 [246] using the same hypothetical ship model with the IMO night case distribution which predicts the 95th percentile TAT as 15 min 57 sec (a 5% difference).

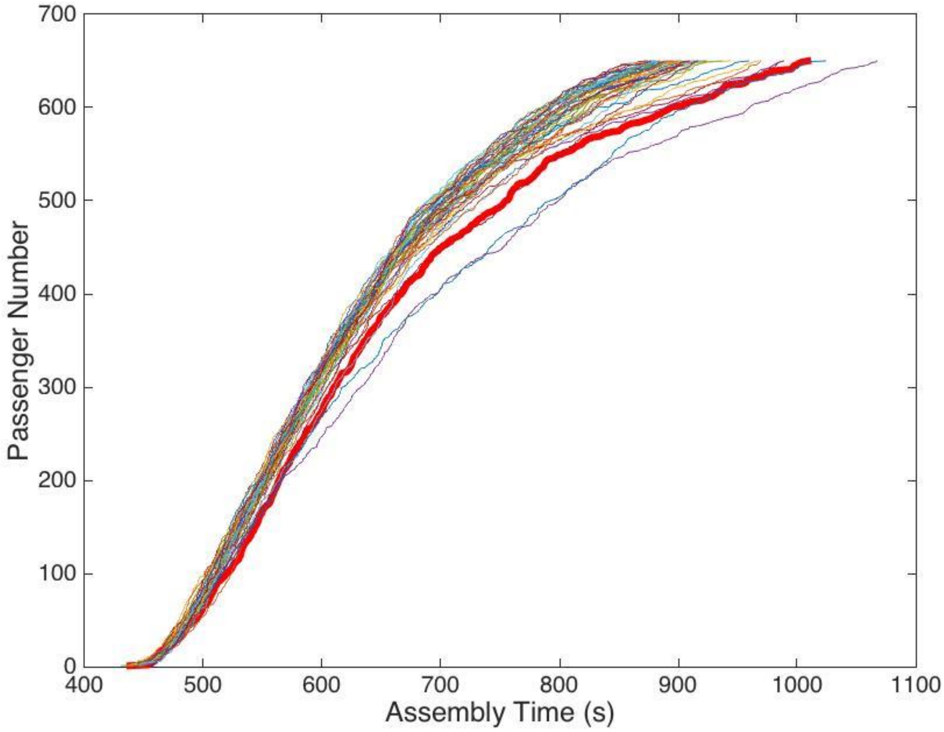


Figure 138 Baseline results for all 50 simulations for the night case, with 95th percentile shown as the thick red curve.

8.5.2 Scenario 2: Night Case using RTD Derived from Cabin Areas on Jewel of the Seas

The cabin area response time distribution for the Jewel of the Seas was used for comparison to the baseline case and a total of 50 simulations run. The RTD was utilised in the same form as presented in Section 6.3, Equation (12) – not truncated and not shifted to account for passengers who may be sleeping. The resulting predicted assembly curves (shown in Figure 139) were sorted by total assembly time (TAT) and the 95th percentile case chosen to represent the assembly process. It can be seen from the figure that this RTD produces a greater spread in the range of predicted assembly curves when compared with the baseline case. Thus, this RTD produces greater variability in the resulting assembly times. Results from the JoS cabin area RTD simulations are presented in Table 71 and we can see that for this RTD it took just over 13 minutes for all 650 passengers to assemble. The difference between the slowest and fastest assemblies was 2 minutes and 48 seconds (23.7% difference). Using this RTD predicts a TAT that is 4 minutes and 12 seconds *less* than that predicted for the baseline case (-25.5% difference).

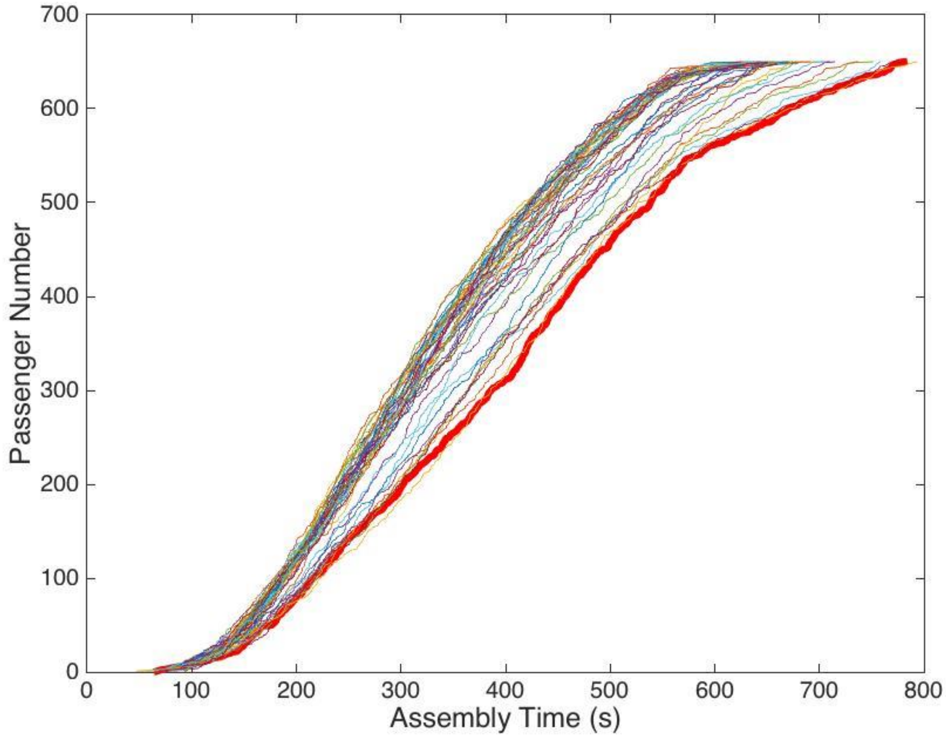


Figure 139 Results for all 50 simulations using the cabin area RTD for Jewel of the Seas, with 95th percentile shown as the thick red curve.

8.5.3 Scenario 3: Night Case using RTD Derived from Cabin Areas on Olympia Palace

The response time distribution measured in cabin areas of Olympia Palace was used for comparison to the baseline case and a total of 50 simulations run. The RTD was utilised in the same form as presented in Section 6.4, Equation (15) – not truncated and not shifted to account for passengers who may be sleeping. The resulting assembly curves (shown in Figure 140) were sorted by total assembly time (TAT) and the 95th percentile case chosen to represent the assembly process. It can be seen from the figure that this RTD also produces a greater spread in the range of assembly curves when compared with the baseline case. Thus, this RTD produces greater variability in the resulting assembly times. It is interesting to note that the 95th percentile curve for this simulation case tends to predict shorter assembly times throughout the assembly process but the last few passengers arrive at the assembly station late. This helps illustrate why one should be cautious when describing a given assembly process using only TAT, since it may not be very representative of the overall process. Results from the OP cabin area RTD simulations are presented in Table 71 and we can see that for this RTD it took just over 12 minutes for all

650 passengers to assemble. The difference between the slowest and fastest assemblies was 3 minutes and 6 seconds (25.6% difference). Using this RTD predicts a TAT that is 5 minutes and 17 seconds *less* than that predicted for the baseline case (-32.6% difference).

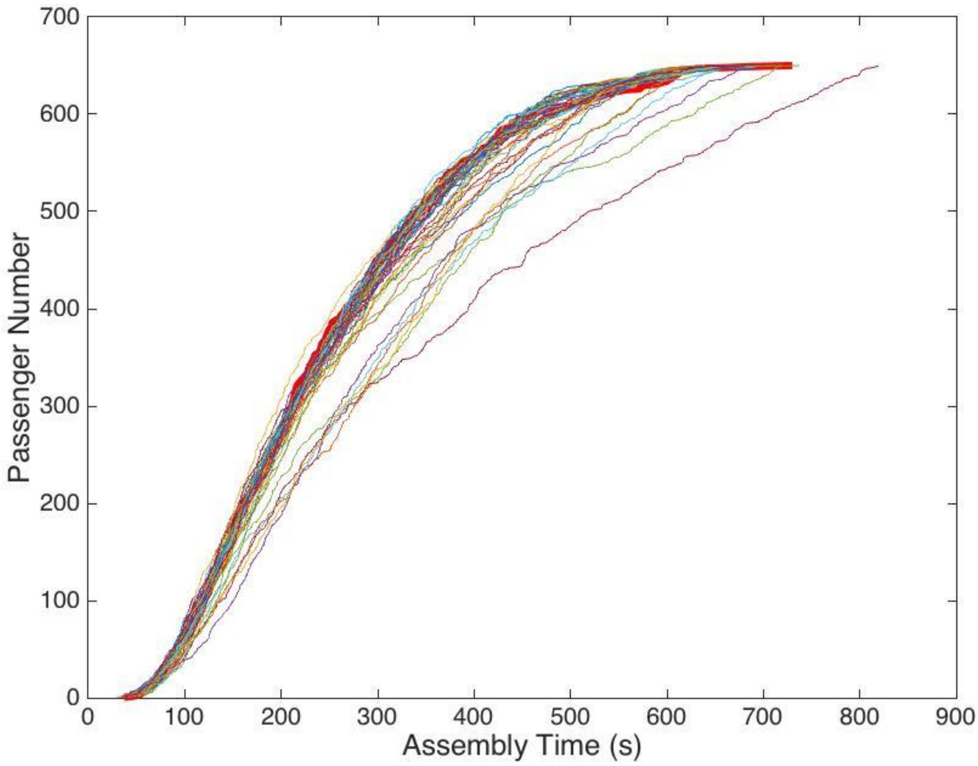


Figure 140 Results for all 50 simulations using the cabin area RTD for Olympia Palace, with 95th percentile shown as the thick red curve.

8.5.4 Scenario 4: Night Case using New Recommended Cruise Ship RTD Derived from Cabin Areas on JoS (Truncated, Scaled and Shifted)

The night case response time distribution recommended in Section 6.4 to update the IMO regulations was measured in cabin areas of Jewel of the Seas but shifted to the right by 400 seconds and truncated at 1,100 seconds. This RTD was used for comparison to the baseline case and a total of 50 simulations run. The resulting assembly curves (shown in Figure 141) were sorted by total assembly time (TAT) and the 95th percentile case chosen to represent the assembly process. As with the other RTD comparison cases, it can be seen from the figure that this RTD also produces a greater spread in the range of predicted assembly curves when compared with the baseline case. Thus, this RTD produces greater variability in the resulting assembly times. Results from these simulations are presented in Table 71 and we can see that for this RTD that it took about 21.5 minutes for all 650 passengers to assemble. The difference between the slowest and fastest assemblies was 4 minutes and 38 seconds (21.6% difference). Using this RTD predicts a TAT that is 4 minutes and 46 seconds *more* than that predicted for the baseline case (+24.8% difference).

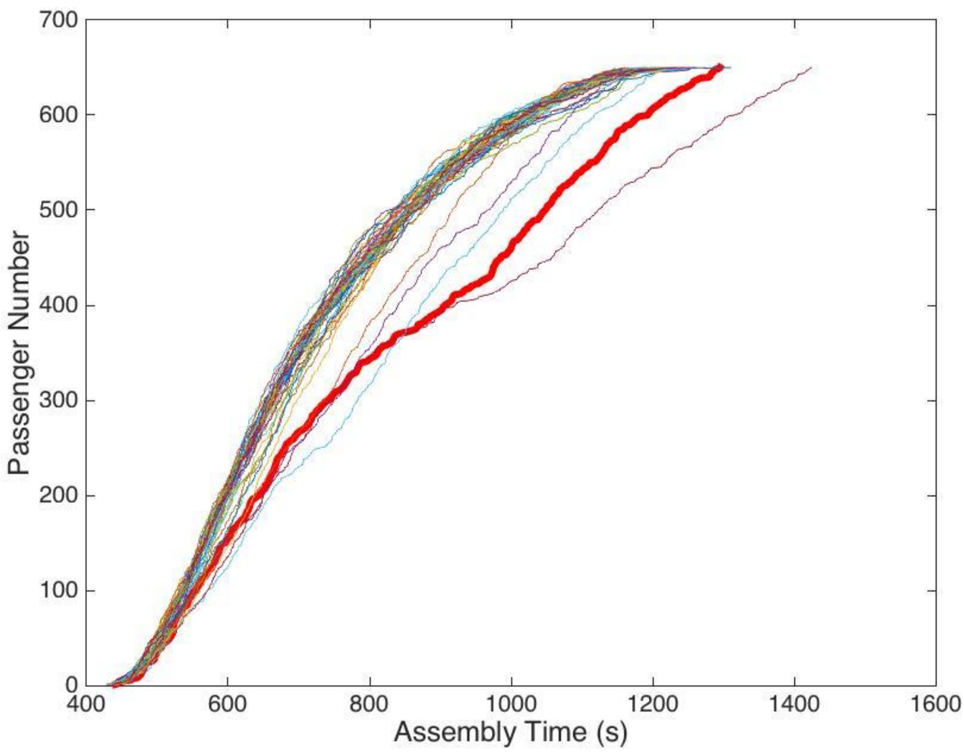


Figure 141 Results for all 50 simulations using the recommended cruise ship night case RTD, with 95th percentile shown as the thick red curve.

8.6 Total Assembly Time - Day Case

8.6.1 Scenario 5: Baseline Case using IMO Day RTD

The response time distribution for the day case identified by IMO MSC.1/Circ.1238 [21] was used for the baseline case and a total of 50 simulations run. The resulting predicted assembly curves (shown in Figure 142) were sorted by total assembly time (TAT) and the 95th percentile case chosen to represent the assembly process. Results from the day case simulations are presented in Table 72. We can see that for the base case it took 7 minutes and 16 seconds for all 650 passengers to assemble. The difference between the slowest and fastest assemblies was 2 minutes and 35 seconds (40.2% difference). Despite this difference in TAT, it can be seen from the figure that the individual assembly curves tend to be grouped tightly together when compared with the night case baseline results. It is interesting to note that for all cases, most passengers had completed the assembly process by approximately 275 s, despite the fact that the overall TAT is significantly longer. Again, this difference is mainly due to the difference between RTD used for each case – the night case distributions tend to be spread across a broader time range than those measured for the day case. In addition, for the day case simulations, passengers tend to be located more often in open areas when compared with cabin areas which tend to have passageways that are more narrow and restricted.

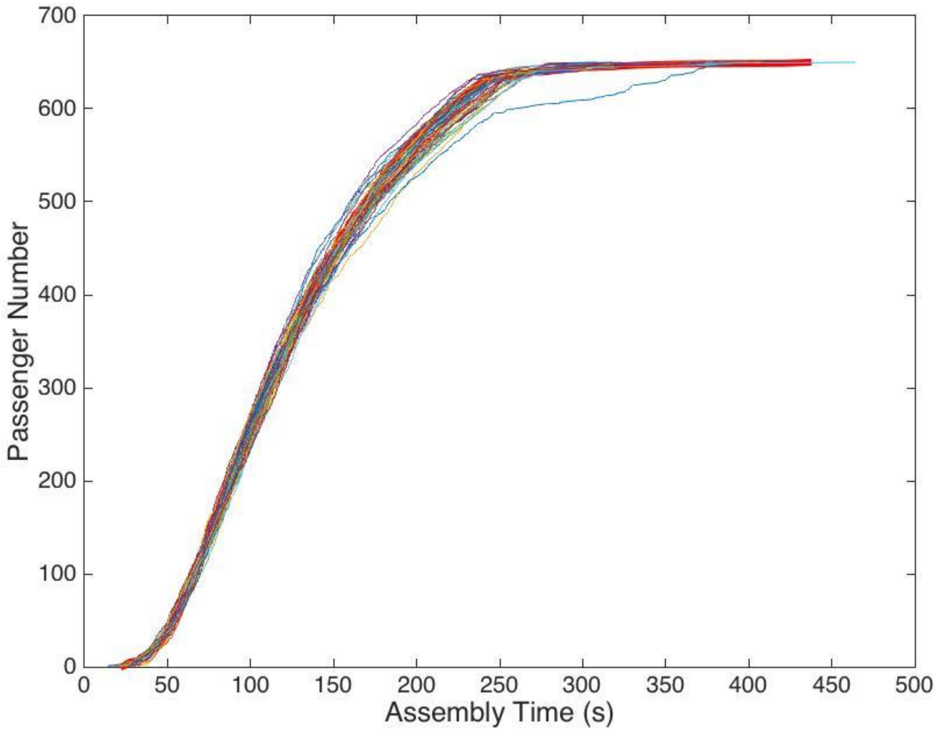


Figure 142 Baseline results for all 50 simulations for the day case, with 95th percentile shown as the thick red curve.

8.6.2 Scenario 6: Day Case using RTD Derived from Public Areas on Jewel of the Seas

The response time distribution for the Jewel of the Seas, measured in public areas of the ship was used for comparison to the baseline case and a total of 50 simulations run. The RTD was utilised in the same form as presented in Section 6.3, Equation (11) – not truncated. The resulting predicted assembly curves (shown in Figure 143) were sorted by total assembly time (TAT) and the 95th percentile case chosen to represent the assembly process. It can be seen from the figure that this RTD also produces a very tightly grouped set of assembly curves, as observed for the baseline case. For this case, it is interesting to note that most passengers had assembled by about 500 s. Results from the JoS public area RTD simulations are presented in Table 72 and we can see that for this RTD it took just over 20 minutes for all 650 passengers to assemble. The difference between the slowest and fastest assemblies was 10 minutes and 6 seconds (65.7% difference). Using this RTD predicts a TAT that is 12 minutes and 39 seconds *greater* than that predicted for the baseline case (+93.8% difference). This significantly longer TAT and greater spread on TAT for the 50 cases run can be attributed to the fact that this RTD, in the non-truncated form, would be expected to have a few individuals that are very late responding to the alarm and thus extend the TAT.

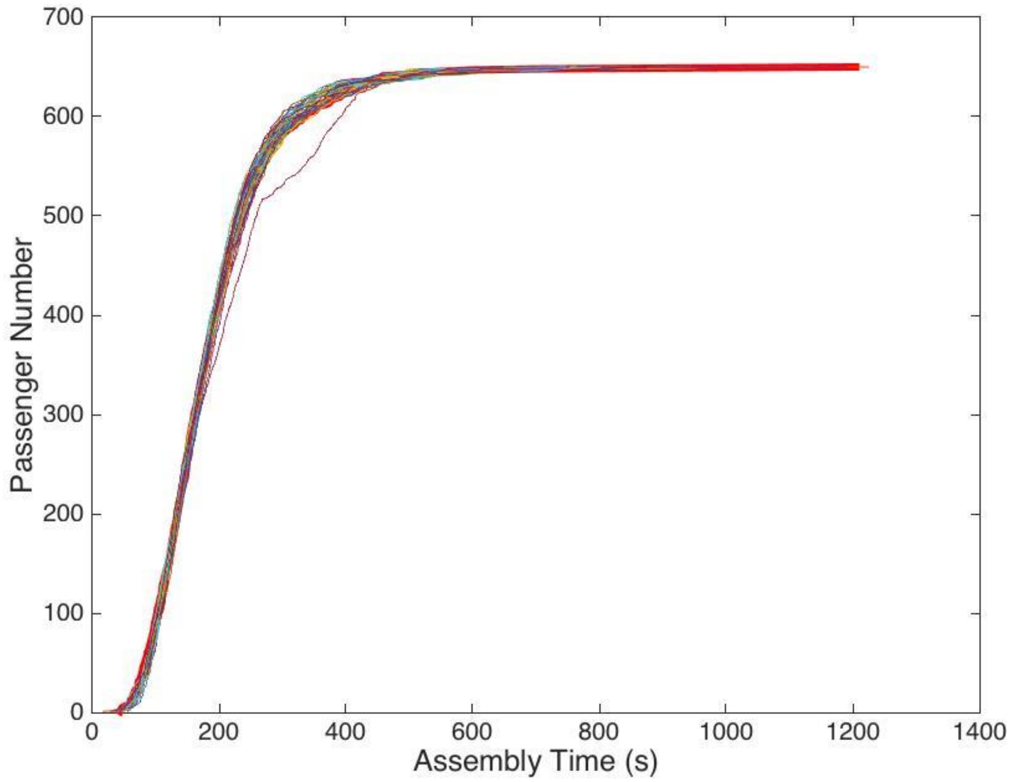


Figure 143 Results for all 50 simulations using the public area RTD for Jewel of the Seas, with 95th percentile shown as the thick red curve.

8.6.3 Scenario 7: Day case using RTD Derived from Public Areas on Olympia Palace

The response time distribution measured in public areas of Olympia Palace was used for comparison to the baseline case and a total of 50 simulations run. The RTD was utilised in the same form as presented in Section 6.4, Equation (14) – not truncated. The resulting predicted assembly curves (shown in Figure 144) were sorted by total assembly time

(TAT) and the 95th percentile case chosen to represent the assembly process. It can be seen from the figure that this RTD also produces a tightly grouped set of assembly curves for which most passengers have assembled by about 300 s. Results from the OP public area RTD simulations are presented in Table 72 and we can see that for this RTD it took just under 8 minutes for all 650 passengers to assemble. The difference between the slowest and fastest assemblies was 2 minutes and 5 seconds (28.7% difference). Using this RTD predicts a TAT that is just 28 seconds *greater* than that predicted for the baseline case (+6.3% difference).

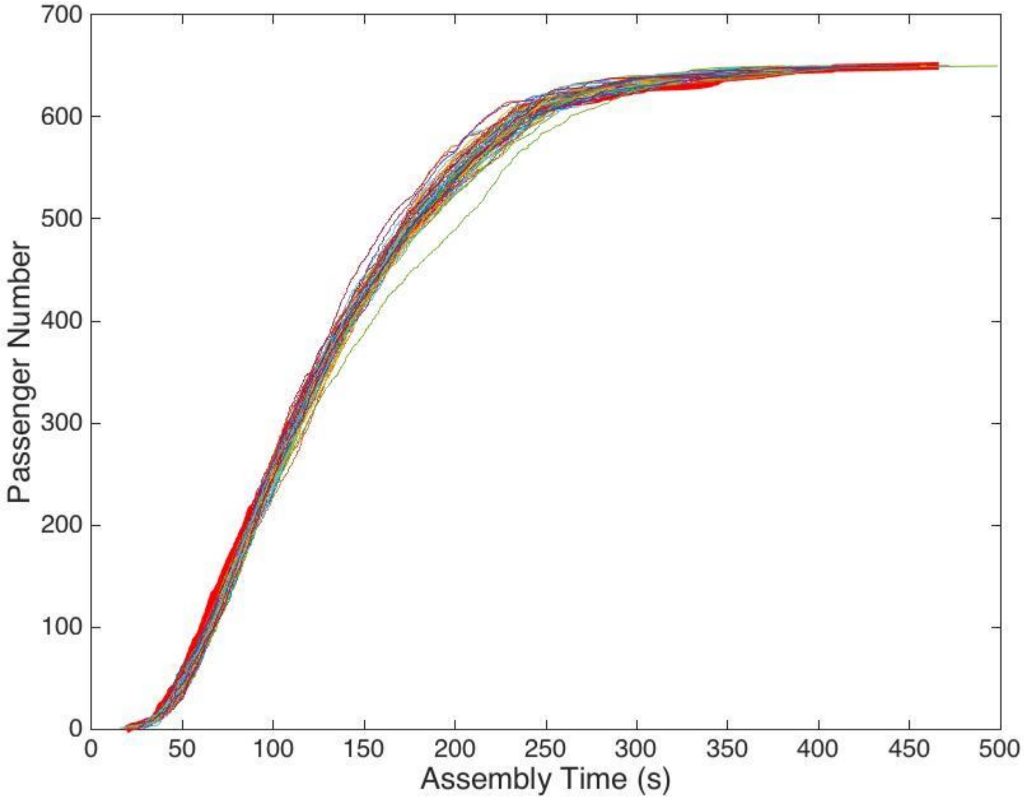


Figure 144 Results for all 50 simulations using the public area RTD for Olympia Palace, with 95th percentile shown as the thick red curve.

8.6.4 Scenario 8: Day Case using RTD Derived from Public Areas on SuperSpeed 1

The response time distribution for SuperSpeed 1, measured in public areas of the ship was used for comparison to the baseline case and a total of 50 simulations run. The RTD was utilised in the same form as presented in Section 6.2, Equation (7) – not truncated. The resulting assembly curves (shown in Figure 145) were sorted by total assembly time (TAT) and the 95th percentile case chosen to represent the assembly process. It can be seen from the figure that this RTD also produces a very tightly grouped set of predicted assembly curves, as observed for the baseline case. For this case, it is interesting to note that most passengers had assembled by about 300 s. Results from the SS1 public area RTD simulations are presented in Table 72 and we can see that for this RTD it took just over 9 minutes for all 650 passengers to assemble. The difference between the slowest and fastest assemblies was 3 minutes and 25 seconds (39.3% difference). Using this RTD predicts a TAT that is 1 minute and 53 seconds *greater* than that predicted for the baseline case (+22.9% difference).

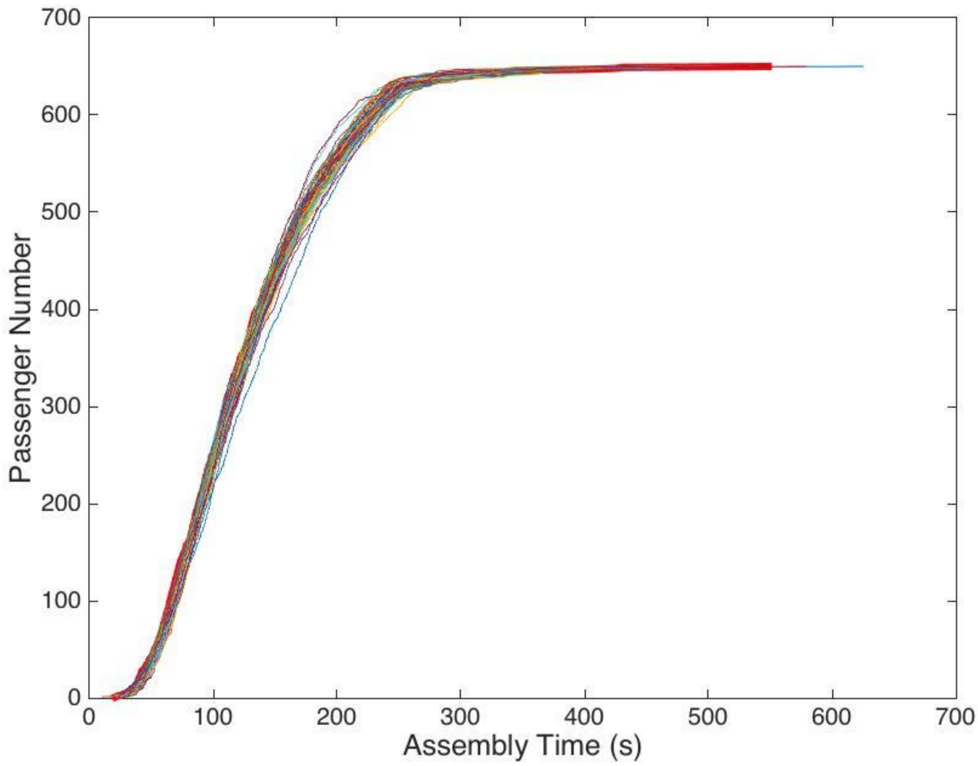


Figure 145 Results for all 50 simulations using the public area RTD for SuperSpeed 1, with 95th percentile shown as the thick red curve.

8.6.5 Scenario 9: Day Case using New Recommended RO-PAX RTD Derived from Public Areas on SuperSpeed 1 and Eurostar Roma (Truncated and Scaled)

The RO-PAX ferry day case response time distribution recommended in Section 6.5, Equation (16) to update the IMO regulations measured in public areas of SuperSpeed 1 and the Eurostar Roma, combined and truncated at 300 seconds was used for comparison to the baseline case and a total of 50 simulations run. The resulting assembly curves (shown in Figure 146) were sorted by total assembly time (TAT) and the 95th percentile case chosen to represent the assembly process. As with the other day case RTD comparison cases, it can be seen from the figure that this RTD also produces a tightly grouped set of predicted assembly curves for which most passengers had assembled by about 275 seconds. Results from these simulations are presented in Table 72 and we can see that for this RTD it took about 7.5 minutes for all 650 passengers to assemble. The difference between the slowest and fastest assemblies was 2 minutes and 22 seconds (37.2% difference). Using this RTD predicts a TAT that is just 2 seconds *more* than that predicted for the baseline case (+0.4% difference). This result is to be expected, since the RTD used is essentially the same provided in the IMO guidelines and is truncated at the same value.

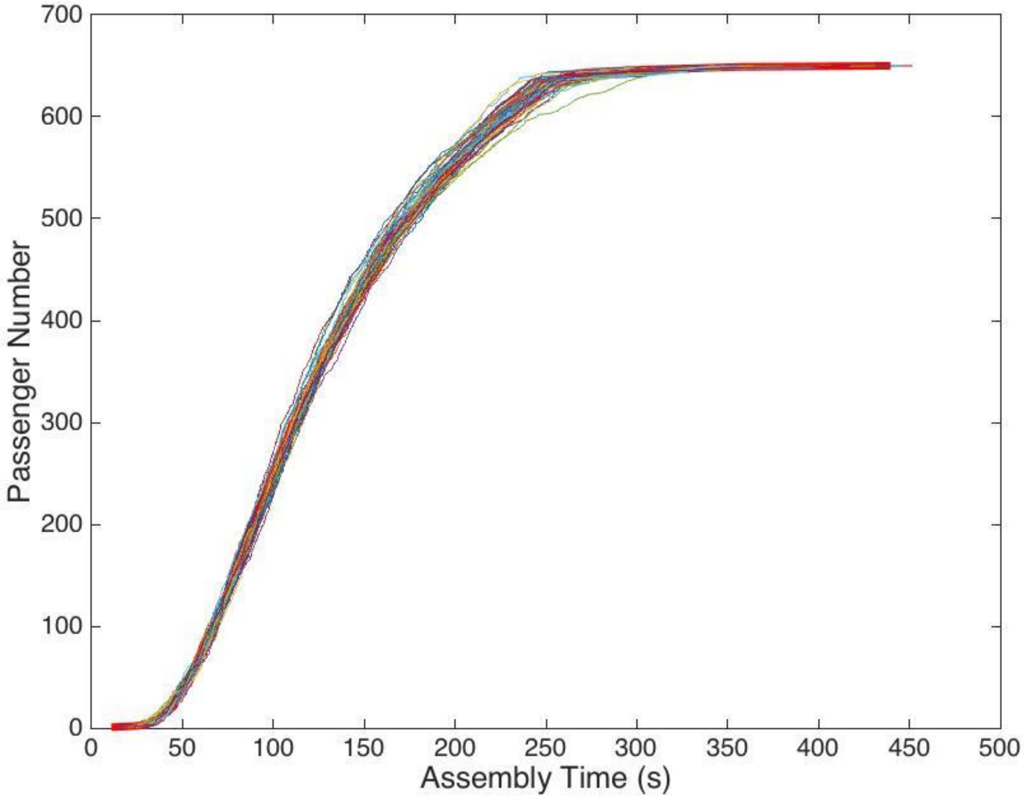


Figure 146 Results for all 50 simulations using the recommended RO-PAX ferry day case RTD, with 95th percentile shown as the thick red curve.

8.6.6 Scenario 10: Day Case using New Recommended Cruise Ship RTD Derived from Public Areas on Jewel of the Seas (Truncated and Scaled)

The cruise ship day case response time distribution recommended in Section 6.5, Equation (17) to update the IMO regulations measured in public areas of Jewel of the Seas and truncated at 300 seconds was used for comparison to the baseline case and a total of 50 simulations run. The resulting predicted assembly curves (shown in Figure 146) were sorted by total assembly time (TAT) and the 95th percentile case chosen to represent the assembly process. As with the other day case RTD comparison cases, it can be seen from the figure that this RTD also produces a tightly grouped set of assembly curves for which most passengers had assembled by about 350 seconds. Results from these simulations are presented in Table 72 and we can see that for this RTD, as with the recommended RO-PAX curve, it took about 7.5 minutes for all 650 passengers to assemble. The difference between the slowest and fastest assemblies was 1 minutes and 54 seconds (27.5% difference). Using this RTD predicts a TAT that is just 21 seconds *greater* than that predicted for the baseline case (+4.7% difference).

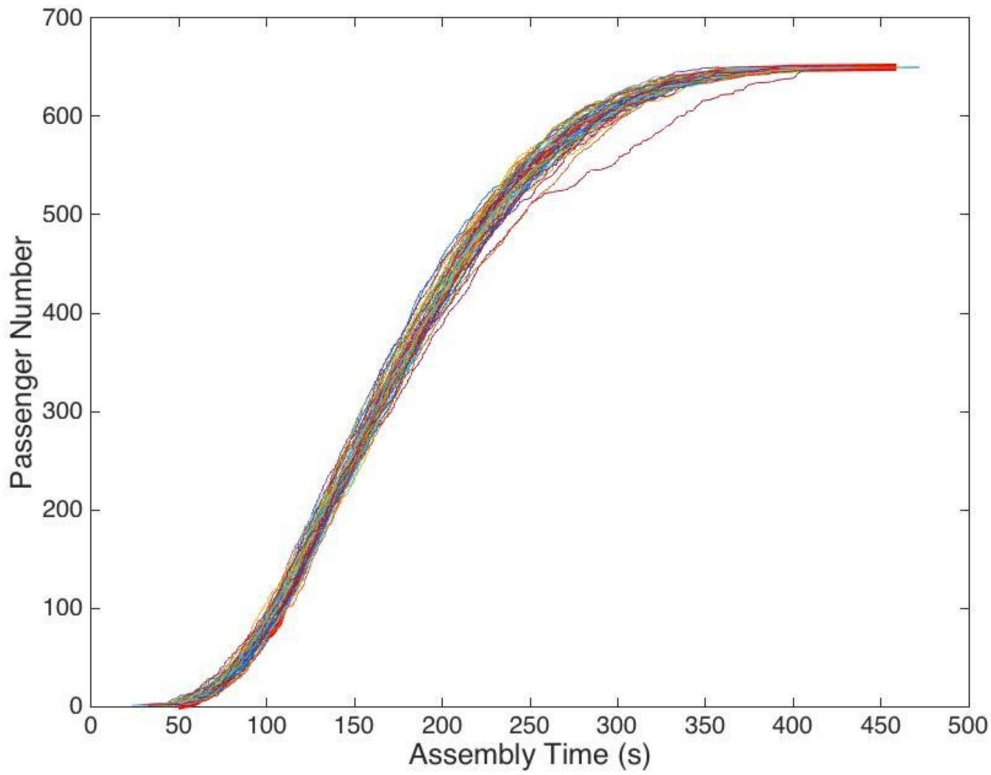


Figure 147 Results for all 50 simulations using the recommended cruise ship day case RTD, with 95th percentile shown as the thick red curve.

8.7 Discussion of Modelling Results

We can see from the preceding that the response time distribution used in passenger ship evacuation modelling can have a significant impact on the total assembly time predicted. In addition, the *nature* of the assembly time curve, particularly when we consider the variability in the range, is also impacted by the RTD used. This section provides a discussion of modelling results in terms of the variability within each scenario and also the differences observed between the 95th percentile curve for each scenario, broken down by night and day case.

8.7.1 Night Case Results

Table 71 shows that a similar level of variability is produced for all RTDs between the minimum and maximum TAT values calculated for 50 simulations (ranging from 20.2% to 25.6%). The RTD that produced the greatest absolute TAT range difference was the newly recommended night case distribution. It is also interesting to note that this RTD predicts a TAT that is 24.8% greater than that predicted when using the current IMO baseline case.

Table 71 Results for night case simulations with hypothetical ship.

RTD used	95th Percentile TAT	Difference between min and max (50 runs)	% Difference from Baseline IMO Night Case
Baseline IMO Night	16min 49sec	3min 16sec (20.2%)	--
JoS (cabin spaces), not shifted	13min 1sec	2min 48sec (23.7%)	- 4min 12sec (-25.5%)
OP (cabin spaces), not shifted	12min 6sec	3min 6sec (25.6%)	- 5min 17sec (-32.6%)
New recommended cruise	21min 35sec	4min 38sec (21.6%)	+ 4min 46sec (+24.8%)

The 95th percentile results for each night case RTD scenario used are shown in Figure 148. From this figure we see that the RTDs that are shifted by 400 s (current IMO base case and new recommended cruise case) also produce the longest assembly times. This is an intuitive result, since these passengers do not bgin responding to the alarm until 400 s has passed, thus passengers responding between 0-400 s would be expected to complete the assembly process first.

The assembly time curves for the JoS cabin area RTD (not shifted) and the new recommended cruise RTD (shifted) take a similar shape and the difference in TAT between these curves is 515 s. This is an interesting result because the new recommended cruise ship RTD is a version of the JoS cabin area RTD (but shifted right by 400 s, truncated and scaled to account for the area truncated in the distribution tail). Thus, the adjustments made to create the new recommended cruise ship RTD result in a TAT that is 115 s more than the 400 s shift between the RTDs (a difference of 25.1%) which is close to the range specified in Table 71 for JoS cabin areas.

The OP cabin area RTD produced an assembly curve most similar in shape to the IMO baseline, though the TAT was 282.9 s less than the baseline result. It is interesting to note the similarity in shape for these two curves, since both were derived from trials onboard RO-PAX ferries with cabins. This supports the recommendation made to the IMO (Section 6.5) that cruise ships should be added as a new category in the guidelines for passenger ship evacuation analysis. However, it is important to remember that the response time dataset collected onboard OP may have issues of reliability and further data is required before a new RO-PAX ferry RTD can be recommended.

Comparing the assembly curves produced using the current IMO baseline RTD and the new recommended cruise ship RTD, we see that the assembly curve shapes are noticeably different. The cruise ship RTD produces an assembly curve that is approximately linear to the end of the process, after the assembly of the first 50 or so passengers, with the TAT not being measurably affected by latecomers to the assembly station, as is the case for the OP night curve and, to a lesser degree, the IMO baseline curve. This is an important result since it suggests that the RTD used can have an impact on the shape of the predicted assembly curve. The recommended cruise ship RTD is more widely distributed over a greater time range than the RO-PAX RTD and this affects the way in which crowd congestion develops in spaces with reduced area onboard. Thus, it demonstrates that differences in the response behaviour have an effect on the *nature* of the assembly process predicted by the model.

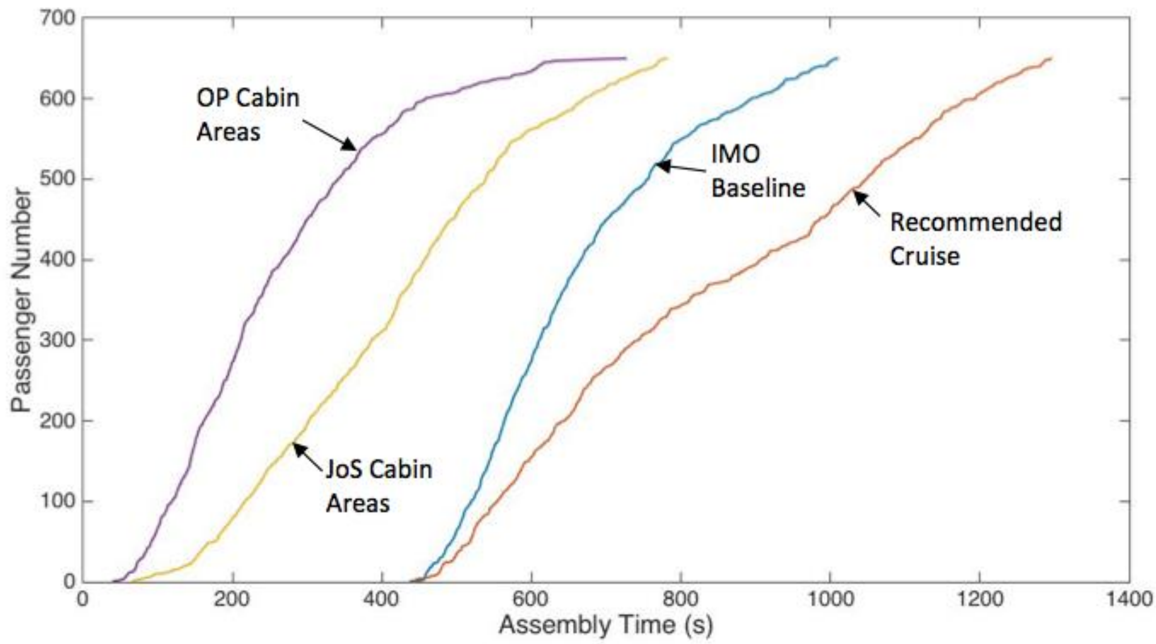


Figure 148 95th percentile assembly time curves for the night case RTD scenarios (scenario 1 to 4).

These differences are important to consider in the context of real-world application to design of cruise ships since the RTD is based on data collected from actual passengers on a cruise ship at sea. Therefore evacuation modelling results for cruise ships should be considered more reliable than would be the case if using an RTD which was derived from a RO-PAX ship at sea, as is currently the case in the IMO guidelines. Using an RTD for cruise ship evacuation modelling which represents passenger behaviour onboard a RO-PAX ferry may result in vessel design modifications that are not relevant for cruise ships, given that RO-PAX passengers tend to respond more quickly, on average, than cruise ship passengers.

Finally, it should be noted that despite the increased TAT associated with using the new recommended cruise ship RTD, this design still meets the IMO requirement for all passengers to be assembled with 30 minutes of the alarm. However, for ships with a TAT that is closer to the accepted performance requirement threshold, using a cruise ship night case RTD that increases the predicted TAT by 24.8% may make it more challenging for a given design to be certified. Given that the IMO guidelines currently require the addition of a safety factor (to account for uncertainty in the evacuation modelling process), it may be worth considering a reduction in the factor since the new recommended RTD is more realistic than what is currently being used.

8.7.2 Day Case Results

We see from Table 72 for the day case simulations that the range of variability between the minimum and maximum predicted TAT is more significant than for the night case (ranging from 27.5% to 65.7%). The RTD that produces the greatest range in 50 simulations was from the JoS dataset for public spaces. It is should be noted that this RTD also predicts a TAT that is 93.8% greater than that predicted when using the current IMO baseline case. As discussed above, the reason for this large difference is the result of a few passengers who were slow responding to the alarm (due to the significantly greater spread in the JoS RTD compared with the other distributions) and therefore late arriving at the assembly station. When this RTD is truncated and scaled (i.e. the new recommended cruise ship day case RTD), the difference in TAT with the baseline case dramatically reduces from 93.8% to 4.7%.

Table 72 Results for day case simulations with hypothetical ship.

RTD used	95th Percentile TAT	Difference between min and max (50 runs)	% Difference from Baseline IMO Day Case
Baseline IMO Day	7min 16sec	2min 35sec (40.2%)	--
JoS (public spaces)	20min 5sec	10min 6sec (65.7%)	+ 12min 39sec (93.8%)
OP (public spaces)	7min 44sec	2min 5sec (28.7%)	+ 28sec (6.3%)
SS1 (public spaces)	9min 8sec	3min 25sec (39.3%)	+ 1min 53sec (22.9%)
New truncated ROPAX	7min 18sec	2min 22sec (37.2%)	+ 2sec (0.4%)
New truncated Cruise	7min 37sec	1min 54sec (27.5%)	+ 21sec (4.7%)

The 95th percentile results for each day case RTD scenario examined are shown in Figure 149. From this figure we see that the shape of all assembly curves is similar but that results using the RTDs based on JoS public areas result in assembly curves that are typically 50 s slower than for RO-PAX RTDs. This value is approximately equivalent to the difference between mean response time for SS1 and JoS, as presented in Section 6.3.5. We also see that the assembly curves produced using the IMO baseline, SS1, OP and new recommended RO-PAX RTDs are virtually the same. This is an expected result, given that the RTDs are all very similar. The greatest difference is seen for the SS1 RTD derived from public spaces which, while similar in shape, produces a TAT that is almost 23% longer than that predicted using the IMO baseline RTD. This is largely due to a few latecomers to the assembly station and is likely the result of the fact that this RTD has not been truncated or scaled. Unlike the night case assembly curves, we do not see a significant difference in the nature of the assembly curves for the cruise ship RTDs as compared with the RO-PAX results, aside from the shift noted.

It is obvious from what has been presented for RO-PAX ships that the new recommended RO-PAX RTD does not have a significant negative impact on the vessel's ability to meet the required evacuation performance when compared with results for the current IMO baseline RTD. This is not a surprising result, given that the recommended RTD is very similar to the current baseline RTD. As noted in Section 6.5.1, it is recommended that the new RTD be used because it is based on a significantly larger dataset of passenger response time behaviour.

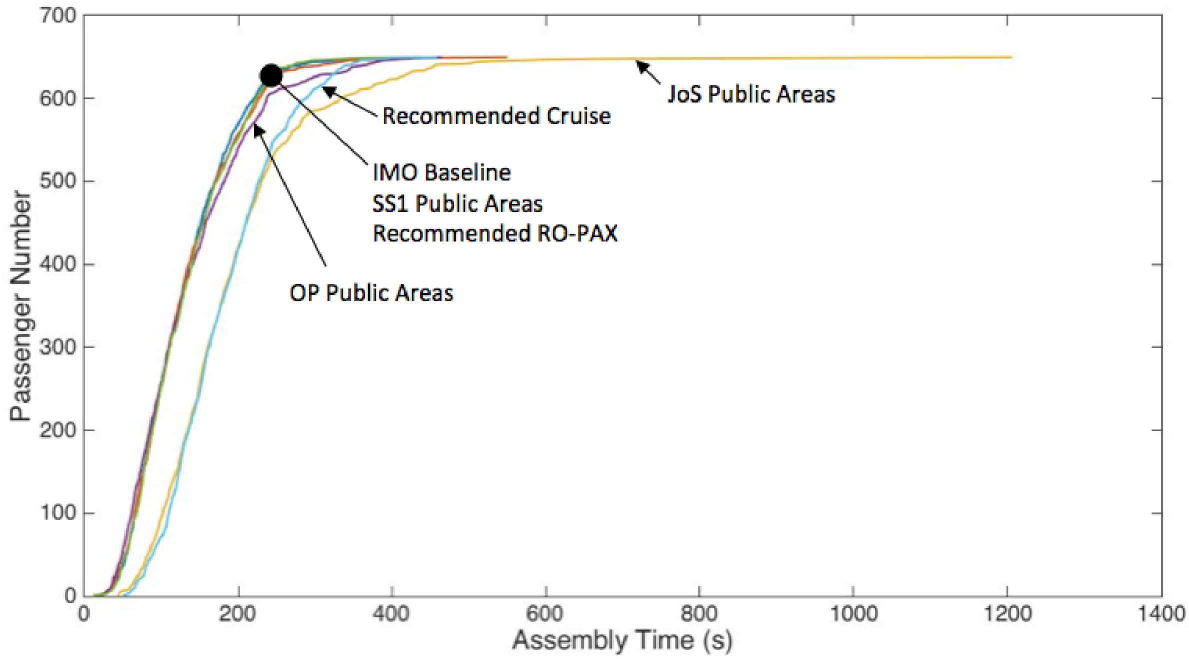


Figure 149 95th percentile assembly time curves for the day case RTD scenarios (scenario 5 to 10).

Results for cruise ships suggest that that increases in total assembly time can be expected when using the new recommended cruise RTD as compared with using the current IMO baseline case RTD. For the ship tested here, the increase in TAT is small in comparison to the overall assembly time, however given that the resulting assembly curve for the new recommended cruise RTD is offset to the right of the curve produced using the current baseline RTD, it may be reasonable to expect differences in TAT would be greater if a few agents are late arriving at the assembly station. Even still, assuming that the 95th percentile model results presented are representative of the evacuation process, it seems likely that the new cruise RTD would not produce unreasonably pessimistic results.

8.8 Chapter Summary

For ship evacuation modelling, the choice of response time distribution has a direct impact in on the prediction of the assembly process. The effect has been demonstrated in this chapter using maritimeEXODUS and a hypothetical ship model comprised of 5 passenger decks with a mixture of public and cabin areas throughout. A population of 650 passengers was positioned in either cabin areas or public areas, depending on whether a night or day case simulation was being undertaken. The population demographics and randomised locations were identical between all different day and night scenarios tested. As required by the IMO evacuation analysis guidelines, 50 simulations were performed for each scenario and the 95th percentile case was chosen as the representative assembly curve.

A total of ten different scenarios were examined for which a different RTD was used in each – four night cases and six day cases. The current IMO day and night response time distributions were used to generate baselines for comparison. From the results presented, it is obvious that choice of RTD can have a significant impact on the predicted total assembly time, particularly for RTDs with greater spread and long tails. It was noted that the variability between results for the 50 simulations performed in each scenario was similar among night cases and among day cases.

For the night cases examined, the new recommended cruise ship RTD (based on the JoS trial results for cabins areas, truncated, scaled and shifted by 400 s) produced a TAT that was 24.8% longer than when using the current IMO night case RTD with the same vessel design. Although this increase in TAT is significant, the vessel would still meet the required performance criteria for certification, however, this may not be the case for all vessel designs being certified. It is important to remember that the baseline RTD was derived from a RO-PAX ship and may not be broadly representative of passenger response behaviour on cruise ships, thus it is recommended that the cruise ship RTD be used as presented. Since the RO-PAX cabin RTD (night case) data collected through this research was not considered reliable, an analysis of its impact on RO-PAX assembly time was not presented here and changes are not recommended for this case and ship type.

Results for the day cases examined show that the baseline day RTD and new recommended RO-PAX RTD produce assembly curves that are almost identical. This is an expected result from the modelling, since the baseline and new RTD are almost identical. Thus, using the new recommended RTD does not pose an additional certification challenge, however, the new RTD is based on a much more reliable dataset and should be used in the regulations. Results using the new recommended cruise ship RTD produced a slight increase in TAT over the baseline case but should not pose a significant additional certification challenge, except in marginal designs. Given this result and that the RTD was derived from public areas on JoS (truncated and scaled), it represents a more reliable, representative dataset and should be used in the regulations.

The results presented in this chapter provide an indication of the impact that using more representative response time behaviour data is expected to have on results of evacuation simulation used in certification of passenger ships. These are important findings which, if adopted, will have a direct and positive effect on the design of passenger ships and the safety of the travelling public. Chapter 9 will summarise the work presented in this dissertation, referencing the research questions posed in Chapter 1 and identifying the main findings and results.

9 Conclusions

The research described in this dissertation focusses on the emergency assembly of passengers on large cruise ships and ferries; in particular, the response phase and the evacuation movement phase. As identified in Chapters 1 and 2, there are gaps both in our understanding of behaviour during the passenger assembly process on cruise ships and ferries, as well as the international regulations that govern passenger ship evacuation analysis. Thus, the main objective of this dissertation has been to collect realistic passenger response and assembly time data through large-scale experiments on different passenger ships and to disseminate results so that ship evacuation modellers and the International Maritime Organization can improve upon the current state of passenger ship evacuation analysis. In particular, the current IMO passenger ship evacuation analysis guidelines (MSC.1/Circ.1238) lack a proper definition of passenger response time, and the circular identifies in its third Annex, Paragraph 18 the need for proper quantitative validation of models used to simulate the assembly process on passenger ships. Furthermore, as discussed in Section 2.3.4, in the publication of MSC.1/Circ.1238, the IMO specifically requested its member governments to provide "…information and data resulting from research and development activities, full-scale tests and findings on human behaviour, which may be relevant for the necessary future upgrading of the present Guidelines". This dissertation has provided such data for the regulator to use in updating the guidelines.

To this end, the novel aspects of the work described in this dissertation have been identified as; (1) the first time that human alarm response time has been characterised with significant numbers of paying passengers onboard different types of passenger ships at sea; (2) the first time a method for accurately collecting individual passenger routes during the assembly process has been provided and demonstrated; and (3) the first time a detailed method for validating passenger ship evacuation analysis models has been proposed which includes two detailed datasets as well as a metric that allows for *objective* assessment of model performance. These are important aspects of the work carried-out which, it is hoped, will have a direct impact on future passenger ship designs through recommended improvements to the governing regulations at the IMO.

Methods for data acquisition have been described in detail in Chapter 3, including the use of video cameras for collection of response time data but with a particular focus on tests undertaken with RFID and IR technologies to determine the best method for collecting passenger movement data. The IR system employed was a novel approach to the collection of passenger movement data and produced a high-quality, reliable dataset for *individual* passengers involved in the trials.

Experimental methods were described in detail in Chapter 4 for each of the three ships tested – a RO-PAX ferry without cabins, a cruise ship and a RO-PAX ferry with cabins. This included the development of a detailed test protocol for each vessel to ensure the safety of passengers involved and to prevent unforeseen problems from arising, where possible. This was a complex and logistically challenging process which took several months to complete for each vessel. In the end, a total of five trials were completed safely, involving 5,582 passengers in total and producing the largest datasets collected to date for passenger response time and movement on cruise ships and ferries during assembly trials at sea.

The arduous process of data analysis is described in Chapter 5, including video analysis (584 GB of video collected) methods for generating the response time dataset (2,379 response times in all), inter-rater reliability testing to ensure consistency between analysts in producing the response time dataset, and passenger movement data collected from the IR tracking system, which provided details of the start and end locations for each individual participating in the trials (3,680 passengers in all) and the associated assembly time.

Using the response time dataset collected, Chapter 6 provided a detailed analysis of the statistical distribution of passenger response times for each of the three ships tested. *The dataset of passenger response time is relevant, credible, realistic, and represents a significant improvement in the state of knowledge in this field.* From the analysis presented in this chapter, recommendations were made to the IMO through an information paper, with details of new response time distributions that should be used for evacuation analysis of passenger ships.

Despite technical failure of part of the IR system during the first trial and low numbers of passengers on the last two trials, results from the two remaining trials were used to produce two different ship evacuation model validation datasets. This work is described in Chapter 7 and is unique for a number of reasons, primarily because unlike most validation datasets, these contain details on passenger response times, starting locations, end locations and final arrival times. Furthermore, the trials were conducted on real ships, at sea and were semi-unannounced making the results *relevant, credible and realistic*. Using the response time data, recommendations were made to the IMO through a second information paper, with details of the two validation datasets that were recommended for inclusion in updated regulations in an effort ensure that models used for evacuation analysis meet the validation performance tests.

Sime [84] stated that the time taken by people in responding to information concerning fires is as important as actions taken after this response. The impact of response time distribution used in evacuation modelling was demonstrated in Chapter 8, using a hypothetical ship model, it was shown that the new recommended cruise ship RTDs (day and night) produced longer total evacuation times than when using the existing IMO RTDs (day and night). For the new recommended RO-PAX day case RTD, results were almost identical to those for the current IMO day case RTD, which is an expected result, given that the new recommended RO-PAX day case RTD was almost identical to the currently used day case RTD. The results provide an indication of the impact that using more representative response time behaviour data is expected to have on results of evacuation simulation used in certification of passenger ships. These are important findings which, if adopted by the IMO, will have a *direct and positive effect on the design of passenger ships and the safety of the travelling public*.

Considering the four main research questions introduced in Chapter 1, the paragraphs that follow provide detailed evidence of what was achieved in this dissertation.

1. ***How do we collect realistic passenger ship evacuation data while ensuring the safety of passengers and balancing the responsibility and requirements of the Captain and crew, research team, ship owner and regulatory authority?***

1a) *What are the regulatory requirements for conducting an evacuation assessment of a passenger ship and what knowledge gaps exist in these requirements?*

IMO MSC.1/Circ.1238 outlines the regulatory requirements for conducting an evacuation assessment of a passenger ship. A detailed discussion of this circular was provided in Section 2.3, which outlined that there are gaps in how the regulations represent passenger response time and that, to date, sufficient data for validation of evacuation analysis models does not exist. It is these two gaps in the governing regulations that have guided much of the research in this dissertation.

1b) *What are the key components of people's evacuation behaviour and how can we measure it on passenger ships?*

The key components of people's evacuation behaviour were identified and discussed in Section 1.2 and Section 2.2. It was shown that evacuation behaviour of people can be divided into two main phases – response and evacuation movement, each of which were further subdivided within the text. This definition of evacuation behaviour is well-aligned with the gaps identified in the regulations.

Data collection methods used by other researchers in the built and maritime environments were reviewed and discussed in Sections 2.4.1 and 2.4.2. This information was assessed to determine the best way forward for measuring response time data (video cameras, further detailed in Section 3.2) and passenger movement data (RFID). Further investigation of RFID was provided in Section 3.3, in which RFID technology was tested alongside IR technology. It was found that the IR system performed significantly better than RFID and was less challenging to use from a logistical point of view. Ultimately, IR technology was chosen for the trials and the project team worked with the system manufacturer to tailor the features to the needs of the project. Additional detailed testing with the IR system was discussed in Sections 3.3.6 and 3.3.7 which gave a measure of system's accuracy and demonstrated that the technology may be capable to automatic measurement of crowd density.

1c) *Can an experiment be designed and executed that will allow us to fill the knowledge gaps noted in (a) and measure behaviour identified in (b)?*

A detailed trial protocol and methodology were developed and are presented in Chapter 4 which helped ensure the success of the data collection activities and the safety of those involved. This included obtaining ethics approval for the study (Section 4.2), the information passengers required and how it was provided (Section 4.3), and trials team make-up and tasks (Section 4.6). Pre-trial planning activities (outlined for each ship in Sections 4.8.2, 4.9.2 and 4.10.2) were carried-out involving the ship owner, Captain and crew for each vessel in order to ensure all requirements were met. Part of the pre-trial planning activities included developing a data acquisition equipment setup plan for each ship. This is provided for each ship in Sections 4.8.3, 4.9.3 and 4.10.3. While there were a few unexpected challenges with the execution of each trial (discussed for each ship in Sections 4.8.4, 4.9.4 and 4.10.4), the experimental design and plan were successful in enabling the collection of a large corpus of passenger response time data and detailed passenger movement data for all three ships.

1d) *Are the data collection methods noted in (c) reliable, feasible and safe to use with large numbers of passengers?*

It was shown in Section 5.3 that the use of video cameras provides a very reliable method for collection of passenger response on ships. This is evidenced by the fact that large numbers of portable digital video cameras were successfully used, as well as pre-existing shipboard CCTV cameras to capture passenger response behaviour throughout the different ships tested. At no time was there a problem with camera use or operation and video was recorded in all areas planned.

Similarly, the IR tracking system produced a detailed passenger movement dataset with accuracy demonstrated in Section 3.3.7 for shipboard environments, using video as a comparison. As discussed in Section 4.8.4, one IR system beacon was unknowingly damaged by a member of the ship's crew before the start of the trial. This issue was corrected and no further problems were experienced in the use of this system.

Finally, all trials were undertaken in a safe manner with no injuries reported by passengers, crew or members of the research team. From the level effort given to the detailed planning process, it was no accident that this is the case and it shows that it should be possible to carry-out future trials in the same manner.

1e) *Are there any significant ethical concerns for conducting such full-scale experiments and, if so, how are they addressed?*

Conducting research with human participants *always* requires due consideration of ethics. It must be determined if the benefits of the research outweigh the risks to participants and it must be understood that risks to participants does not only mean risk of harm or injury but includes the security of personal information. For the trials conducted, approval was received from the Research Ethics Board at the University of Greenwich and no major concerns were identified. Details of the ethics approval process have been provided in Section 4.2.

2. Can we collect representative and detailed response time data for passengers responding to alarms on passenger ships?

2a) *Given the arduous task of assessing passenger behaviour from video methods, how do we ensure reliability of the data capture methods?*

A total of three video data analysts were used to collect response time data from the video collected on each ship. Section 5.1.4 provides a detail discussion of the analysis procedure developed, along with the method and results from inter-rater reliability testing that ensured reliability of the dataset produced. Following four stages of in-rater testing, the analysists had reached a level of 92% agreement on the measures taken. Video analysis produced a large database of response times, as presented in Table 20, which is reproduced below for convenience:

Vessel	Trial	Hours of footage	Storage space (GB)	No. Response times Captured
SuperSpeed 1	1	49	115	533
	2	45	106	470
Jewel of the Seas	1	76	328	1,241
Olympia Palace	1	9	20	54
	2	7	15	81

2b) *What mathematical form do passenger response times take when developed as statistical distributions and how well does this form match the data sets collected?*

As discussed at length throughout Chapter 6, the response time distributions were generally found to fit a lognormal form, which is in agreement with what has been presented in Section 2.2 from previous research in both the building an maritime environments. One exception was found for the trials on Olympia Palace (Section 6.4) in which the lognormal fit was not seen to be as strong as observed for trials on the other ships. It was hypothesised that the reason for this poor fit was related to the population size, which was small, and the demographics of passengers onboard (comprised mostly of teen-aged children). As a result, these datasets were *not* recommended as part of the response time dataset and further research is required in order to fill this gap for ferries with cabins.

2c) *Is response behaviour different on different ships or in different regions of the same ship?*

It was demonstrated in Chapter 6 that the response behaviour for passengers on SuperSpeed 1 was remarkably similar to what was published from the FIRE EXIT project for the Eurostar Roma – also RO-PAX ferry (Figure 84). However, it was also demonstrated that passengers' response behaviour on the RO-PAX vessels was different than that for passengers in similar areas of the cruise ship Jewel of the Seas (Figure 91). In addition, it was demonstrated that response behaviour in different areas of the same ship was different. These two findings are significant as they suggest that the same response time distribution should *not* be used for all ship types and that different response time distributions may be required for *different* areas of the *same* ship (i.e. cabin areas and public areas). It was hypothesised that the reason for the observed differences may be related to the passengers' mindset onboard each vessel, since ferry passengers are generally using the ship as part of their voyage, while cruise passengers "move-in" and are on vacation. This hypothesis has not been proven and should be further investigated.

2d) *Do population demographics significantly influence passenger response behaviour (e.g. males vs. females, age, presence of travelling companions or family members)?*
It was observed that response behaviour for males and females was the same onboard SuperSpeed 1 (Section 6.2.2, Figure 82) and on Jewel of the Seas (Section 6.3.1, Figure 86), however for the trials on Olympia Palace, there were differences in the male and female response times produced (Section 6.4.2, Figure 97). It was hypothesised that the reason for the differences observed on Olympia Palace were related to the small sample size and the fact that the overall population demographics were different than for the other two ships. It was also noted in Section 6.4 that, despite SuperSpeed 1 and Olympia Palace being similar ship types (both RO-PAX), the response time distributions produced for public areas on both ships were not the same, as might be expected. Differences were also observed between response time in cabin areas on Olympia Palace and cabin areas on Jewel of the Seas, as well as between response time in cabin areas on Olympia Palace and cabin areas on Eurostar Roma. It is hypothesized that these differences might be related to the significant differences in passenger demographics between the different trials compared, however, additional research is required to prove the hypothesis.

2e) *Can we expect response behaviour on a given ship to be the same with a different population of passengers?*
Two trials were conducted on SuperSpeed 1, as well as on Olympia Palace, as described in Sections 6.2.1 and 6.4.1 respectively. It was observed that repeat trials for both ships were statistically similar. *This is a powerful result* which suggests that if the response times and demographics of a sufficiently large number of people are characterised for a given type of structure, an assembly exercise repeated under similar notification conditions should result in a similar RTD. Because only one trial was carried-out onboard Jewel of the Seas, it is not known if this result applies to cruise ships, thus further research is required.

2f) Do different response time distributions produce significantly different results when used to model evacuation behaviour?

As discussed in Chapter 8, a hypothetical ship model was used to carry-out evacuation modelling with the maritimeEXODUS software for 4 night case scenarios and 6 day cases. Response time distribution was the only factor varied from scenario to scenario. It was observed that the new recommended night case RTD for cruise ships produced a total assembly time that was almost 25% longer than when using the current IMO RTD. While this is a significant increase in TAT, it was found that this result would still meet the IMO performance requirement for certification, however, this may not be the case for all vessel designs tested. The new recommended day case RTD for RO-PAX ships produced almost exactly the same TAT as when using the current IMO day case RTD. This was not a surprising result, given that the RTDs are almost identical. Furthermore, a marginal increase in TAT was observed for simulations using the new recommended cruise ship day case RTD when compared with results for the current IMO day case RTD.

3. How do we objectively determine the degree of agreement between ship evacuation model predictions and experimental data?

3a) What quantities or variables provide the best indication of how well model predictions compare with experimentally obtained data?

It has been established that ship evacuation modelling (and indeed ship evacuation) is a complex process involving the interaction of many variables. Given the stochastic nature of the evacuation process, it is not reasonable to expect models to predict individual passenger paths during evacuation. Therefore, more broad methods for comparison were required. One method (presented in Section 7.5) to compare model results to experiments would be to determine the difference between total assembly time for each case. This measure, however, only provides a single point of comparison between modelling and experimental results and is not considered robust. To provide a better estimate of model performance, the *nature* of the evacuation process was considered, which involved comparing both the shape of the curves and the magnitude difference between them. A detailed discussion of the measures is provided in Section 7.6.

3b) Do numerical methods exist to quantify how well the overall shape of two curves compare with each other?

A numerical method, from Peacock et al. [243] and discussed in Section 7.6 was used to quantify how well the overall shape of the two assembly arrival time curves compared for each dataset. The method was based on functional analysis and a quantity known as the *secant cosine* which is defined by Equation (28) in Section 7.6.1. The secant cosine uses a numerical calculation of the first derivative of both curves at each element in the series. A value of 1.0 suggests that the shape of the model curve is identical to that of the experimental curve. This metric is discussed in detail in Section 7.6.1 and its use presented in Sections 7.6.2 and 7.6.3.

3c) Do numerical methods exist that enable us to quantify how proximate two curves are to each other, in a global sense?

Using the method from Peacock et al. [243] and discussed in Section 7.6 it was possible to quantify how proximate the experimental and modelled assembly curves were to each other. The method is also based on functional analysis and provides two measures - the *Euclidean Relative Difference*, defined by Equation (26) in Section 7.6.1 and the *Euclidean Projection Coefficient,* defined by Equation (27), also in Section 7.6.1. The Euclidean relative difference was used to assess the distance between the experimental data and the model data and returns a value of zero if the two curves are identical in magnitude. Smaller values for the *Euclidean relative difference* mean better overall agreement between the two curves than larger values. The Euclidean projection coefficient provides a factor which, when multiplied by each modelled data point, reduces the distance between the model and experimental vectors to its minimum amount. Thus, the *Euclidean projection coefficient* provides a measure of the best possible level of agreement between the model and experimental curves where a value of 1.0 would suggest that the difference between the curves is as small as possible. These metrics are discussed in detail in Section 7.6.1 and their use presented in Sections 7.6.2 and 7.6.3.

4. Can we collect a dataset for use in validating ship evacuation models?

4a) What datasets are required for model validation?

Validating a ship evacuation model requires that the starting conditions in the simulation are set as closely as possible to the start time in the experiment. It was shown in Chapter 7 that if the ship geometry is known, the total number of passengers involved in the experiment and initial passenger distribution are known (from IR tracking), the distribution of response times is known for the experiment (from video analysis), and the assembly time and location for each passenger in the experiment is known (from IR tracking), then using the population demographics specified in IMO MSC.1/Circ.1238, it should be possible to simulate the experiment in the model and compare results to what was measured in the experiment. Using this approach, two model validation datasets were developed and presented in Sections 7.2 and 7.3 for SuperSpeed 1 and Jewel of the Seas, respectively. Given uncertainties with the validation dataset developed for SuperSpeed 1 (as discussed in Section 7.2), it may be necessary to exclude this dataset, particularly since validation dataset #2 developed for Jewel of the Seas (as discussed in Section 7.3) is considered to be reliable and should be included in an updated version of MSC.1/Circ.1238.

4b) What ship types should be tested so that the validation data sets are most representative?

The IMO defines a passenger ship as any vessel that carries 12 passengers or more (Section 2.3.1). While there is bound to be a difference in the nature of the evacuation process on large ships compared with smaller ships, it was decided that this dissertation would focus on large ships. The reason for this is that large passenger ships carry a greater risk of death or injury in an emergency and the evacuation process on large ships is expected to be more complex and more difficult to characterise than smaller passenger ships. Thus, the assumption was that if we could develop a validation method for large ships, it should also be relevant for small ships. With this in mind, three different ship types were tested in this research – a RO-PAX ferry without cabins (described in Section 4.8.1), a cruise ship (described in Section 4.9.1) and a RO-PAX ferry with cabins (described in Section 4.10.1). It was felt that these ships represent a wide cross section of passenger ship types in use today.

4c) *What level of accuracy is required in the dataset?*

The validation dataset should be of sufficient accuracy to characterise the experimental conditions. This means the number of people involved in the experiment should be accurately known, otherwise it will be difficult to compare with the model predictions. This issue arose with the second trial on SuperSpeed 1 (discussed in Section 7.2 and Section 7.4.2) and is the reason we have less confidence in this validation dataset. The starting locations of people must also be known to a reasonable degree of accuracy. The IR system provided a measure of the individuals located within different zones at the time of the alarm. An estimate (described in Sections 7.4.2 and 7.4.3) was made for each ship of the error associated with where passenger may have been located with each zone. This was assessed as being about 40 s on average for SuperSpeed 1 and 60 s on average for Jewel of the Seas, both of which were considered acceptable for the validation datasets produced. The assembled locations must be known with certainty and the assembly times within a reasonable degree of accuracy. The IR system was validated onboard the Jewel of the Seas and found to lag the actual assembly time by an average of about 4 s (up to a maximum of 10 s), as discussed in Section 3.3.7. This level of accuracy was deemed acceptable. From the inter-rater reliability process, response time data was found to be accurate to within a maximum of 1 s between raters, an accuracy deemed acceptable for validation purposes.

4d) *What pass/fail criteria should be suggested in the method?*

Two levels acceptance criteria were proposed (described in Section 7.7) for evacuation model validation. These criteria for both validation datasets were presented in Table 70, which is reproduced below for convenience:

Validation Dataset #1	**Validation Dataset #2**
Phase 1: % TAT < 45%	Phase 1: % TAT < 15%
Phase 2 (minimum 9 of 12): ERD ≤ 0.45 0.6 ≤ EPC ≤ 1.4 SC ≥ 0.6 with s/n = 0.05	Phase 2 (minimum 10 of 12): ERD ≤ 0.25 0.8 ≤ EPC ≤ 1.2 SC ≥ 0.8 with s/n = 0.02

For phase 1 of the acceptance criteria, the percentage difference between the modelled and experimental total assembly time for the entire ship must be less than 45% for dataset #1 and 15% for dataset #2. The difference between the acceptable difference in TAT relates to the overall quality of the validation datasets produced. If the criteria is satisfied, the user moves to phase 2. For this phase of the acceptance criteria, the Euclidian relative difference (ERD), Euclidian projection coefficient (EPC) and secant cosine (SC) (provided in Section 7.6.1) are computed for the assembly curve at each assembly station on the ship and results checked to ensure they meet the criteria ranges identified in the table. A total of 12 measures were produced for each dataset and it was determined that for validation dataset #1, three fails would be permitted, while for validation dataset #2, 2 fails would be permitted. For each of these cases, it was decided that the only one fail should be permitted per assembly station. These criteria have been established somewhat arbitrarily while still providing a rational means by which ship evacuation model validation can be accomplished.

4e) Are the dataset and validation method relatively easy for software manufacturers to understand and use for validating their software and will models have difficulty meeting the required performance?

It is impossible to state with certainty whether or not any model developers will have difficulty understanding how to use the validation datasets proposed, or if models will be able to meet the required performance for these validation datasets. However, it has been shown through this research (Sections 7.6.2 and 7.6.3) that the maritimeEXODUS, EVi and ODIGO models have successfully met the validation requirements. In addition, as discussed in Section 7.8, the validation datasets (made freely available on the University of Greenwich website) have been downloaded and used independently to validate two additional ship evacuation models, with results published in peer-reviewed journals by the model developers. This suggests that the validation datasets produced are not unnecessarily restrictive in their requirements but still provide a real, quantitative validation method for assessing ship evacuation models.

4f) Will it be possible for software developers to "fudge" validation results?

It is unlikely that the ill-intentions of unscrupulous individuals can always be prevented. However, given the level of detail provided in the validation datasets recommended in Section 7.7 and the effort required to produce the simulation results, it would be a challenging task for software developers to falsify results. It is hoped that developers of ship evacuation software would use poor validation results as an incentive to improve upon their models so that predictions can be made better and safety onboard passenger ships improved.

In conclusion, the work presented in this dissertation has produced a large corpus of data relating to human response behaviour and movement on passenger ships during assembly exercises at sea. The data has been disseminated widely in the form of peer-reviewed journal and conference papers, as well as through presentations to relevant stakeholders. The datasets have been submitted to the IMO in the form of two INF papers but, as yet, have not been incorporated in an updated version of the evacuation analysis guidelines.

Currently, there is no accepted method for validation of ship evacuation models. The implications of this fact are significant for the passenger ship industry since it means that at the present time, *any* ship evacuation model can be used for the certification of passenger ships, including those models that are unfit for this specific purpose. Prior to the research described in this dissertation, the modelling and regulatory community had no choice but to use models that were not validated as the dataset simply did not exist. However, as part of this research, a total of five ship evacuation models have been validated successfully using the recommended protocols. While the data produced and recommended is by no means complete in characterising human behaviour during evacuation on passenger ships, it is greatly superior to what is currently used in the governing regulations and should be included in a revised version of IMO MSC.1/Circ.1238 to help ensure the safety of those who work, travel and vacation at sea.

10 Future Work

The research presented in this dissertation has added substantially to our understanding of passenger response time and the nature of the assembly process on different types of passenger ships. However, additional research must be carried-out if we are to characterise and more accurately model the broad range of scenarios and evacuation performance for passengers on ships at sea. Many factors may impact the ability of passengers to assemble during an emergency and future research must first identify what the most important factors are and then characterise their impact on the assembly process. This chapter identifies some important areas for future research, so that we may have a better understanding of the assembly process onboard passenger ships and be able to improve upon current levels of passenger ship safety.

Response to alarms at different times of the day, particularly for nighttime, must be better understood and quantified if we are to move beyond the current model of night response time distributions which are based on data collected during the day but shifted arbitrarily to account for the process of passengers awaking, becoming aware of the alarm, understanding its meaning and starting to assemble. Such data will be very difficult to collect since ship owners will likely be reluctant to permit such an inconvenience to paying passengers. Furthermore, it may be unethical to plan and execute such experiments due to the risk to passenger safety. Despite this it is important that we gain a better understanding of the nighttime response behaviour so that regulations governing vessel design can be made more realistic and reliable. The research presented in this dissertation has provided a response time distribution for cruise ships, which was based on passenger response in cabin areas on the ship tested. In keeping with the current IMO RTD for night cases, the RTD collected here was shifted by 400 s to account for the fact that most passengers would be sleeping in the night. However, it is not known if this approach accurately represents passenger response behaviour when asleep. Furthermore, given the challenges outlined in Section 6.4, the night case RTD presented for RO-PAX ferries is not considered to be reliable. Thus, future research should also characterise the night case RTD for this vessel type.

Additional validation data should be collected for RO-PAX ferries in order to improve upon the validation dataset presented in Section 7.5.1, which was made less reliable by a relatively significant proportion of the passengers who chose not to wear am IR tag but decided to participate in the exercise. In addition to developing a more reliable validation dataset for RO-PAX ships, it would be useful to have additional data from repeat trials in order to give greater confidence in the validation datasets produced.

The dependence of response time on population demographics should be further explored in order to determine if demographic factors significantly affect response behaviour. Based on our experience in the trails described in this dissertation, it was hypothesised that demographics can have an impact on response behaviour. This is an important factor to consider, given the wide variety of demographics possible on passenger ships. Findings could benefit the evacuation modelling community and potentially ship operations on any given voyage in which the Captain and crew could be provided a better expectation of evacuation performance for the passengers, in the event of an emergency.

The impact of sea state and vessel motions on passenger behaviour during emergencies is not well understood and requires additional research in order to characterise. Vessel motion is known to cause seasickness for a certain proportion of the travelling public but yet, we do not have an understanding of how seasickness affects a passenger's ability to evacuate. Furthermore, significant vessel motions in different sea states will have an effect on passengers' walking speeds in passageways but also on stairs. Future research should quantify the impact of a broad range of vessel motions on all aspects of passengers' evacuation performance.

Repeat data should be collected on different ships, in different conditions and in a variety of regions with different passengers in order to more provide greater confidence in the results presented here. What has been presented is promising in its reliability but until we have collected similar datasets on a wide range of different ships, we will not know for certain if it representative for *most* ships and ship types.

Effectiveness of training for evacuation scenarios on passengers ships should be further investigated, both as it pertains to passengers and crew. Passengers should know *how* to recognise the cues that an evacuation may be required and *what* to do when cues have been recognised. Training for passengers is generally provided in the form of drills, short briefings or videos once onboard but there is some suggestion within the survival training community that passengers who travel regular routes should be provided with more in-depth knowledge so they can be better prepared in the event of an emergency. Better understanding the impact of passenger training on the evacuation process should be studied further so that evacuation modelling can be accurate and the best option can be provided for passengers.   Research should also attempt to better understand the impact of crew training on managing the evacuation process onboard passenger ships. Currently, crew training is mandated by the IMO through the Convention on Standards of Training, Certification and Watchkeeping (STCW). Whether or not crew training is effective for such rare situations as emergency evacuation remains largely unknown, however, it is hypothesised that well-trained crews would be better equipped to manage emergency evacuation than those who are not.

The impact of the lifejacket donning process should be characterised onboard different passenger ships to give a better understanding of the time for this activity, space requirements onboard and whether or not wearing a lifejacket adversely affects a passenger's ability to move freely throughout the vessel (particularly if donned in advance of arriving at the assembly station). Furthermore, the impact of different onboard procedures regarding lifejacket donning should be better characterised so that the most effective procedures can be recommended. For example, on some ships, the lifejackets are stored in cabins and must be retrieved and donned prior to arriving at the assembly stations, while on other ships the passengers are provided lifejackets at the assembly stations when they arrive. What is the impact for passengers who are familiar with procedures on one ship if they are faced with different procedures in an emergency on another ship?

Consumption of intoxicating agents (such as alcohol) is common onboard passenger ships. While alcohol impairment and effectiveness of alarms has been considered for evacuation situations in buildings [247][248], the same has not been done for passenger ships. Currently, the effectiveness of intoxicated passengers during emergency situations and their impact on the assembly process for passenger ships should be characterised.

A detailed analysis of questionnaire responses collected in SAFEGUARD has not yet been carried-out. This dataset represents a unique opportunity to further develop correlations between passenger characteristics provided in the questionnaires and the routes and assembly time performance for the associated IR tag data. This dataset is very unique because it connects assembly performance to personal data and should be analysed in detail to determine what correlations exist. The results from such investigation should be made publicly available to regulators, designers and modellers.

It is hoped that the result of additional research in the areas identified would be enhanced evacuation models, updated regulations, improved procedures and better training for passengers and crew.

11 Publications Arising from this Research

11.1 Journal Papers

E. Galea, S. Deere, **R. Brown** & L.Filippidis (2013). *An Experimental Validation of an Evacuation Model Using Data-Sets Generated from Two Large Passenger Ships*. Society of Naval Architects and Marine Engineers (SNAME) Journal of Ship Research, Vol. 57, No. 3, ISSN 0022-4502, pp. 155-170.

Brown, R., E. Galea, S. Deere, L.Filippidis (2013). *Response Time Data-Sets for Large Passenger Ferries and Cruise Ships Derived from Sea Trials*. Transactions Royal Institution of Naval Architects (RINA) International Journal of Maritime Engineering, Vol 155, Part A1, ISSN 1479-8751, pp. 33-48.

11.2 Conference Papers

Brown, R., Galea, E.R., Deere, S. & Filippidis, L. (2015). Using Infra-Red Technology to Track People Moving in the Built Environment – Accuracy of Automatically Measuring Walking Speed and Crowd Congestion. Proceedings of the 6th International Symposium on Human Behaviour in Fire, Cambridge, UK, Sept 28-30, 2015.

Galea, E.R., S. Deere, **R. Brown**, & L. Filippidis (2014). *An Evacuation Validation Data Set for Large Passenger Ships*, Pedestrian and Evacuation Dynamics 2012. 6th International Conference. Proceedings. June 6-8, 2012, Springer, New York, NY, ISBN 978-3-319-02446-2, pp. 109 -124.

E. Galea, S. Deere, **R. Brown** & L.Filippidis (2014). A Validation Data-Set and Suggested Validation Protocol for Ship Evacuation Models. To Appear in the Proceedings of the 11th Symposium on Fire Safety Science, Christchurch, New Zealand, 10-14 February, 2014.

Brown, R., Galea, E.R., Deere, S., Filippidis, L. (2012). “Response Time Data for Large Passenger Ferries and Cruise Ships”, Proceedings of the 5th International Symposium, Human Behaviour in Fire, Cambridge, UK, 2012, Interscience Communications Ltd, ISBN 978-0-9556548-8-6, pp. 460-71.

Galea, E.R., **Brown, R.C.**, Filippidis, L, Deere, S. (2010). “The SAFEGUARD Project: Collection and Preliminary Analysis of Assembly Data for Large Passenger Vessels at Sea”, 9th International Conference on Computer and IT Applications in the Maritime Industries:, Gubbio, 12-14 April 2010, Hamburg, Technische Universitat Hamburg-Harburg, ISBN 978-3-89220-649-1, pp. 424-433.

Galea, E.R., **Brown, R.C.**, Filippidis, L, Deere, S. (2011). “Collection of Evacuation Data for Large Passenger Vessels at Sea”, Presented at the 5th International Conference on Pedestrian and Evacuation Dynamics, Maryland, USA, March 8-10, 2010, Springer Science, ISBN 978-1-4419-9724-1, pp. 163-72.

11.3 Seminars with Proceedings

Deere, S., **Brown, R.**, Galea, E.R., Filippidis, L., “Data Collection Methodologies Used in the SAFEGUARD Project”, Proceedings of the SAFEGUARD Passenger Ship Evacuation Seminar, Published by the Royal Institution of Naval Architects, London, 30 November, 2012, ISBN No: 978-1-909024-08-3, pp. 16-26.

Brown, R., Galea, E.R., Filippidis, L., Deere, S., “The SAFEGUARD Response Time Data-Set and Recommendations to IMO to Update MSC Circ 1238”, Proceedings of the SAFEGUARD Passenger Ship Evacuation Seminar, Published by the Royal Institution of Naval Architects, London, 30 November, 2012, ISBN No: 978-1-909024-08-3, pp. 27-42.

Galea, E.R., Deere, S., Filippidis, L., **Brown, R.**, Nicholls, I., Hifi, Y., Besnard, N., “The SAFEGUARD Validation Data-Set and Recommendations to IMO to Update MSC Circ 1238”, Proceedings of the SAFEGUARD Passenger Ship Evacuation Seminar, Published by the Royal Institution of Naval Architects, London, 30 November, 2012, ISBN No: 978-1-909024-08-3, pp. 43-62.

11.4 INF Papers to IMO

IMO FP 56/INF.12, Review of the Recommendations on Evacuation Analysis for New and Existing Passenger Ships: Response Time Data for Large Passenger Ferries and Cruise Ships, Submitted by Canada for Agenda Item 6, 56th Session of the Subcommittee on Fire Protection, 14 November, 2012.

IMO FP 56/INF.13, Review of the Recommendations on Evacuation Analysis for New and Existing Passenger Ships: The SAFEGUARD Validation Data Set and Recommendations for Updating MSC.1/Circ. 1238, Submitted by Canada for Agenda Item 6, 56th Session of the Subcommittee on Fire Protection, 14 November, 2012.

11.5 Essays in Magazines

James Parsons, **Robert Brown** & Edwin Galea (2015). “Analysing Passenger Ship Evacuation”, Seaways; International Journal of the Nautical Institute, June 2015, ISSN 01 44 1019, pp. 21-22.

Galea, E.R., Lohrmann, P., **Brown, R.**, S. Deere, L.Filippidis (2012). “Understanding Human Behaviour in Ship Evacuation”, Journal of Ocean Technology, Vol. 7, No. 3, October 2012, ISSN 1718-3200.

11.6 Presentations Made

Brown, R. & R. Rutherford (2011). “Measuring Passenger Mustering Time during Assembly Trials on Passenger Ships”, Presentation at the 2011 AGM of the Canadian Ferry Operators Association, Owen Sound, Ontario, Sept. 12 & 13, 2011.

Brown R. (2011). “Project SAFEGUARD: Measuring Passenger Assembly Time during Trials on Passenger Ships”, Presentation to the managers, officers and crew of the Newfoundland Provincial Ferries Department, Port Blandford, NL, Canada, 21 Oct. 2011.

Brown, R., Galea, E.R., Deere, S. and Filippidis, L. (2009). “Project SAFEGUARD: Acquiring Realistic Passenger Ship Mustering Data during Full-Scale Trials at Sea”. Presentation at the 8th International Conference of the International Association for Safety & Survival Training (IASST), Alexandria, Egypt, Oct. 19-20, 2009.

12 Awards Received for this Research

1) Engineers Canada – TD Meloche Monnex Scholarship, October 2009.

2) Royal Institution of Naval Architects, 2013 Medal of Distinction for the paper:

Brown, R., E. Galea, S. Deere, L.Filippidis (2013). *Response Time Data-Sets for Large Passenger Ferries and Cruise Ships Derived from Sea Trials*. Transactions Royal Institution of Naval Architects (RINA) International Journal of Maritime Engineering, Vol 155, Part A1, ISSN 1479-8751, pp. 33-48.

3) Society of Fire Protection Engineers - First Annual Dr. Guylène Proulx, OC, Scholarship, May 2015.

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Appendix A:

Approval Letter from University Research Ethics Committee the UNIVERSITY of GREENWICH

Lazaros Filippidis
School of Computing and Mathematical Sciences
Fire Safety Engineering Group
Queen Mary Court
Greenwich Campus

Direct Line 020 8331 8842
Direct Fax 020 8331 8824
Email research_ethics@gre.ac.uk
Our Ref UREC/08/09/6.5.6
Date 23rd July 2009

Dear Lazaros

University Research Ethics Committee – Minute 08/09.6.5.6 – Application for ethical approval

I am writing to confirm that the above application has been **approved** by the Committee and that you have permission to proceed.

I am advised by the Committee to remind you of the following points:

- You must notify the Committee immediately of any information received by you, or of which you become aware, which would cast doubt upon, or alter, any information contained in the original application, or a later amendment, submitted to the Committee and/or which would raise questions about the safety and/or continued conduct of the research;
- You must comply with the Data Protection Act 1998;
- You must refer proposed amendments to the protocol to the Committee for further review and obtain the Committee's approval thereto prior to implementation (except only in cases of emergency when the welfare of the subject is paramount).
- You are authorised to present this University of Greenwich Research Ethics Committee letter of approval to outside bodies in support of any application for further research clearance.

On behalf of the Committee may I wish you success in your project.

Yours sincerely

[redacted]

John Wallace
Secretary, University Research Ethics Committee

cc. Prof. Ed Galea

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Appendix B:

Trial Details – Equipment Shipping, Information for Passengers, Passenger Incentives and Questionnaires

B1.0 Shipping of Trials Equipment

An overview of the equipment shipping requirements for the project were described in Section 4.5. Figures B1 and B2 show the camera equipment prior to being packed and packed, respectively. Figure B3 shows the IR equipment cases packed and ready for shipping.

Figure B1 "Exploded" view of contents for a typical case of video camera equipment for six cameras, stopwatches, two-way radios and all necessary camera accessories.

Figure B2 Camera equipment packed and ready for shipping.

Figure B3 IR equipment cases packed and ready for shipping.

B2.0 Detailed Planning for SuperSpeed 1 Trials

B2.1 Trial Team

The team size was determined following careful consideration of the team skill requirements identified above in Section 4.6, along with detailed discussions within the project team and with the vessel's Captain and officers. It was determined that a team of 26 people would be required in order to ensure smooth running of the trials. Most team members had prior experience in assisting with large-scale egress trials, though not necessarily at sea. The team of 26 was subdivided into smaller groups with clear, predefined roles summarised in Table B1.

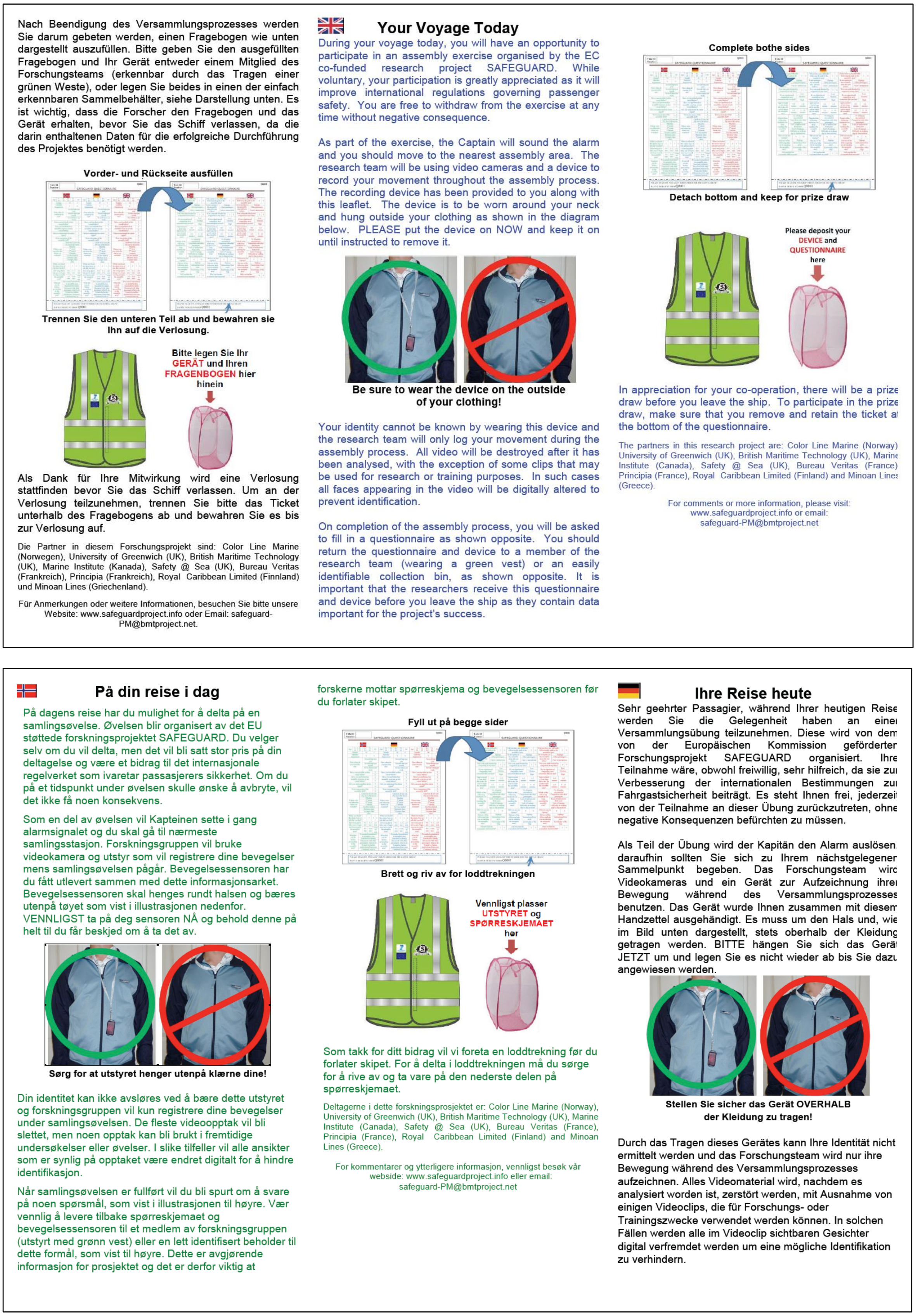
In total, there are 4 assembly stations on board SS1, namely A with 3 entry points, B with 3 entry points (two were close together and regarded as one), C with 3 entry points (again, two were close together and regarded as one) and D with 3 entry points. During the trials, each entry point into the *internal* assembly stations (A and D) had 1 person with a stopwatch timing when the last person entered that assembly station (thus, 6 people in total). In addition, 3 people were located within each internal assembly station collecting tags and distributing questionnaires (6 people in total). For the external assembly stations, 1 team member was positioned next to each exit (2 in total) and 1 team member was placed within each assembly station. Therefore the total number of people required for the assembly stations during the trial was 18.

Table B1 Trials team sub-groups

Team #	Group	Number of people	Team recycling
1	Setup team	6	
2	Entry team	10	
3	Controller + Ship liaison	2	
4	Assembly team	18	Team 2 plus 8 others
5	Equipment collection team	6	Team 1
6	Data transfer team	6	Team 5
7	Exit team	11	Team 2 plus 1 from Team 1

B2.2 Information for Passengers

As noted in Section 4.3 above, detailed wording about the trial was prepared for the different information sources. A printed information leaflet is shown in Figure B4, which provides details about the trials as described in Section 4.3.



Nach Beendigung des Versammlungsprozesses werden Sie darum gebeten werden, einen Fragebogen wie unten dargestellt auszufüllen. Bitte geben Sie den ausgefüllten Fragebogen und Ihr Gerät entweder einem Mitglied des Forschungsteams (erkennbar durch das Tragen einer grünen Weste), oder legen Sie beides in einen der einfach erkennbaren Sammelbehälter, siehe Darstellung unten. Es ist wichtig, dass die Forscher den Fragebogen und das Gerät erhalten, bevor Sie das Schiff verlassen, da die darin enthaltenen Daten für die erfolgreiche Durchführung des Projektes benötigt werden.

Vorder- und Rückseite ausfüllen

Trennen Sie den unteren Teil ab und bewahren sie Ihn auf die Verlosung.

Bitte legen Sie Ihr GERÄT und Ihren FRAGENBOGEN hier hinein

Als Dank für Ihre Mitwirkung wird eine Verlosung stattfinden bevor Sie das Schiff verlassen. Um an der Verlosung teilzunehmen, trennen Sie bitte das Ticket unterhalb des Fragebogens ab und bewahren Sie es bis zur Verlosung auf.

Die Partner in diesem Forschungsprojekt sind: Color Line Marine (Norwegen), University of Greenwich (UK), British Maritime Technology (UK), Marine Institute (Kanada), Safety @ Sea (UK), Bureau Veritas (Frankreich), Principia (Frankreich), Royal Caribbean Limited (Finnland) und Minoan Lines (Griechenland).

Für Anmerkungen oder weitere Informationen, besuchen Sie bitte unsere Website: www.safeguardproject.info oder Email: safeguard-PM@bmtproject.net.

Your Voyage Today

During your voyage today, you will have an opportunity to participate in an assembly exercise organised by the EC co-funded research project SAFEGUARD. While voluntary, your participation is greatly appreciated as it will improve international regulations governing passenger safety. You are free to withdraw from the exercise at any time without negative consequence.

As part of the exercise, the Captain will sound the alarm and you should move to the nearest assembly area. The research team will be using video cameras and a device to record your movement throughout the assembly process. The recording device has been provided to you along with this leaflet. The device is to be worn around your neck and hung outside your clothing as shown in the diagram below. PLEASE put the device on NOW and keep it on until instructed to remove it.

Be sure to wear the device on the outside of your clothing!

Your identity cannot be known by wearing this device and the research team will only log your movement during the assembly process. All video will be destroyed after it has been analysed, with the exception of some clips that may be used for research or training purposes. In such cases all faces appearing in the video will be digitally altered to prevent identification.

On completion of the assembly process, you will be asked to fill in a questionnaire as shown opposite. You should return the questionnaire and device to a member of the research team (wearing a green vest) or an easily identifiable collection bin, as shown opposite. It is important that the researchers receive this questionnaire and device before you leave the ship as they contain data important for the project's success.

Complete bothe sides

Detach bottom and keep for prize draw

Please deposit your DEVICE and QUESTIONNAIRE here

In appreciation for your co-operation, there will be a prize draw before you leave the ship. To participate in the prize draw, make sure that you remove and retain the ticket at the bottom of the questionnaire.

The partners in this research project are: Color Line Marine (Norway) University of Greenwich (UK), British Maritime Technology (UK), Marine Institute (Canada), Safety @ Sea (UK), Bureau Veritas (France) Principia (France), Royal Caribbean Limited (Finland) and Minoan Lines (Greece).

For comments or more information, please visit: www.safeguardproject.info or email: safeguard-PM@bmtproject.net

På din reise i dag

På dagens reise har du mulighet for å delta på en samlingsøvelse. Øvelsen blir organisert av det EU støttede forskningsprosjektet SAFEGUARD. Du velger selv om du vil delta, men det vil bli satt stor pris på din deltagelse og være et bidrag til det internasjonale regelverket som ivaretar passasjerers sikkerhet. Om du på et tidspunkt under øvelsen skulle ønske å avbryte, vil det ikke få noen konsekvens.

Som en del av øvelsen vil Kapteinen sette i gang alarmsignalet og du skal gå til nærmeste samlingsstasjon. Forskningsgruppen vil bruke videokamera og utstyr som vil registrere dine bevegelser mens samlingsøvelsen pågår. Bevegelsessensoren har du fått utlevert sammen med dette informasjonsarket. Bevegelsessensoren skal henges rundt halsen og bæres utenpå tøyet som vist i illustrasjonen nedenfor. VENNLIGST ta på deg sensoren NÅ og behold denne på helt til du får beskjed om å ta det av.

Sørg for at utstyret henger utenpå klærne dine!

Din identitet kan ikke avsløres ved å bære dette utstyret og forskningsgruppen vil kun registrere dine bevegelser under samlingsøvelsen. De fleste videoopptak vil bli slettet, men noen opptak kan bli brukt i fremtidige undersøkelser eller øvelser. I slike tilfeller vil alle ansikter som er synlig på opptaket være endret digitalt for å hindre identifikasjon.

Når samlingsøvelsen er fullført vil du bli spurt om å svare på noen spørsmål, som vist i illustrasjonen til høyre. Vær vennlig å levere tilbake spørreskjemaet og bevegelsessensoren til et medlem av forskningsgruppen (utstyrt med grønn vest) eller en lett identifisert beholder til dette formål, som vist til høyre. Dette er avgjørende informasjon for prosjektet og det er derfor viktig at forskerne mottar spørreskjema og bevegelsessensoren før du forlater skipet.

Fyll ut på begge sider

Brett og riv av for loddtrekningen

Vennligst plasser UTSTYRET og SPØRRESKJEMAET her

Som takk for ditt bidrag vil vi foreta en loddtrekning før du forlater skipet. For å delta i loddtrekningen må du sørge for å rive av og ta vare på den nederste delen på spørreskjemaet.

Deltagerne i dette forskningsprosjektet er: Color Line Marine (Norway), University of Greenwich (UK), British Maritime Technology (UK), Marine Institute (Canada), Safety @ Sea (UK), Bureau Veritas (France), Principia (France), Royal Caribbean Limited (Finland) and Minoan Lines (Greece).

For kommentarer og ytterligere informasjon, vennligst besøk vår website: www.safeguardproject.info eller email: safeguard-PM@bmtproject.net

Ihre Reise heute

Sehr geehrter Passagier, während Ihrer heutigen Reise werden Sie die Gelegenheit haben an einer Versammlungsübung teilzunehmen. Diese wird von dem von der Europäischen Kommission geförderten Forschungsprojekt SAFEGUARD organisiert. Ihre Teilnahme wäre, obwohl freiwillig, sehr hilfreich, da sie zur Verbesserung der internationalen Bestimmungen zur Fahrgastsicherheit beiträgt. Es steht Ihnen frei, jederzeit von der Teilnahme an dieser Übung zurückzutreten, ohne negative Konsequenzen befürchten zu müssen.

Als Teil der Übung wird der Kapitän den Alarm auslösen daraufhin sollten Sie sich zu Ihrem nächstgelegenen Sammelpunkt begeben. Das Forschungsteam wird Videokameras und ein Gerät zur Aufzeichnung ihrer Bewegung während des Versammlungsprozesses benutzen. Das Gerät wurde Ihnen zusammen mit diesem Handzettel ausgehändigt. Es muss um den Hals und, wie im Bild unten dargestellt, stets oberhalb der Kleidung getragen werden. BITTE hängen Sie sich das Gerät JETZT um und legen Sie es nicht wieder ab bis Sie dazu angewiesen werden.

Stellen Sie sicher das Gerät OVERHALB der Kleidung zu tragen!

Durch das Tragen dieses Gerätes kann Ihre Identität nicht ermittelt werden und das Forschungsteam wird nur ihre Bewegung während des Versammlungsprozesses aufzeichnen. Alles Videomaterial wird, nachdem es analysiert worden ist, zerstört werden, mit Ausnahme von einigen Videoclips, die für Forschungs- oder Trainingszwecke verwendet werden können. In solchen Fällen werden alle im Videoclip sichtbaren Gesichter digital verfremdet werden um eine mögliche Identifikation zu verhindern.

Figure B4 Printed pamphlet conveying trials information (in Norwegian, English and German) to passengers onboard SS1.

Color Line personnel and the Captain of the vessel approved the scripts before they were translated into three languages recommended (based on typical passenger demographics) – English, Norwegian and German. The various scripts are shown below.

Captain Announcement 1A (read shortly after leaving port and only once):

"Ladies and Gentlemen, as explained in the information sheet you were given at check-in, at some time during this crossing we will be holding an assembly exercise. As part of this exercise it is essential that you all wear the small red device given to you during check-in. So, I ask you to please make sure that you are all wearing this device now.

The assembly exercise will start with the sounding of an alarm. When you hear the alarm please proceed to your nearest assembly station. Your participation in the exercise is completely voluntary but would be greatly appreciated, as it will help improve international regulations governing passenger safety on ships. If you do not wish to participate in the exercise, please do not discard the red device, as this will be collected from you later.

At the end of the exercise, you will be given a questionnaire, which we would like you to complete and return along with the red device. Please remember to keep the prize ticket located at the end of your questionnaire, as a prize draw will be held before we arrive in Hirtshals. As a mark of our appreciation for your participation, three prize winners will be announced. Please now make sure that you are all wearing the small device and continue doing what you normally had planned to do at this time. Thank-you"

Captain Announcement 2 (thanking passengers after the trial is complete):

"Ladies and Gentlemen, the assembly exercise is now completed. Thank-you very much for your time and cooperation. We would ask that you now please hand-in your red device to the research staff wearing the green vests and take a few moments to complete the questionnaire being handed-out. Remember, when you return your questionnaire, remove and keep the prize ticket located at the end of the questionnaire in order to be eligible for one of the three prizes that will be announced before we arrive in Hirtshals."

Captain Announcement 3 (announcing the winners of the prize draw):

"Ladies and Gentlemen, once again, thank-you for your participation in the assembly exercise today. You should be proud to know that by participating you will help improve passenger ship safety. You may be interested to know that the assembly time was [TIME] minutes, [well within the time required by international regulations].

We have held the prize draw and the following ticket holders should come to [LOCATION] to collect their prizes: Ticket number [X] has won the first prize of [PRIZE 1], Ticket number [Y] has won the second prize of [PRIZE 2] and Ticket number [Z] has won the third prize of [PRIZE 3]. Please remember to bring your ticket with you when you come to claim your prize.

If you have not already done so, please remember to return your red devices to the research staff wearing the green vests. Thank-you and enjoy the rest of your voyage."

Color Line Tag Distribution Personnel Script (providing the tag and information leaflet at check-in):

"Please note that on your voyage today, we will be holding an assembly exercise. As part of the exercise we are providing you with a small device that we would like everyone over the age of 11 to wear around their neck. Once the exercise is over you will be asked to return this device. Also, here is an information leaflet about the exercise, which you should read through. Please don't forget to wear your test device as there will be three prize draws onboard the ship for all participants!"

B2.3 Passenger Incentives

Three prizes (Figure B5) were given away during the raffle onboard SuperSpeed 1:

1. A free ticket for a return trip with vehicle onboard a Color Line vessel
2. A tax free shop voucher that could be used onboard Color Line vessel
3. An "iPod Shuffle" MP3 player

Figure B5 The three prizes awarded to the Color Line passengers

The winners were invited to the ship's bridge where the Captain gave them the raffle prizes while in the presence of several project members. The rate of passenger participation in questionnaires for both trials was high so it was felt that the incentives offered were particularly useful.

B2.4 Questionnaire

Questionnaire used onboard SuperSpeed 1 was printed in the same three languages as the information leaflet – Norwegian, English and German (Figure B6 and Figure B7). The questions were printed on both sides of a single A4 sheet of paper with the bottom portion perforated to act as a raffle ticket. A total of 2,300 questionnaires were printed for the first two trials – 1,150 for each. Questionnaire data, while not presented in this dissertation, provides an interesting dataset in this research, particularly since the passenger's personal information can be associated with his/her location on the ship at the alarm, route chosen and total assembly time.

Vennligst skriv inn nummeret på sensoren her:	Please write your device number here		**Q0001**
Bitte tragen Sie Ihre Geräte-Nr. hier ein	:		

SAFEGUARD QUESTIONNAIRE

Vennligst plasser en sirkel rundt et av svarene om ikke annet er beskrevet.

1) Age	11-20	21-35	36-50	51-65	66+
2) Hva slags kjønn er du?	M	F			
3) Er du bevegelseshemmet?	Y	N			
4) Hvis du reiser med en gruppe, hvor mange personer inkludert deg er det i gruppen?					
5) Gjennomsnittelig, hvor mange ganger i året reiser på sjøen?					
6) Hvor mange ganger tidligere har du vært på dette skipet?					
7) Har du noen gang tidligere deltatt ved en samlingsøvelse på et skip?	Y	N			
8) Når du hørte alarmen, hva trodde du det var?	En øvelse	En virkelig hendelse			
9) Hva følte du når du hørte alarmen?	1) Ubekymret	2) Bekymret, men trygg	3) Urolig for at jeg eller en i gruppen min skulle bli skadet.	4) Urolig for at jeg eller en i min gruppe skulle bli alvorlig skadet.	
10) Hvor var du da du ble oppmerksom på alarmen?	Buffet Restauranten	Kafeteria	Bar	Dekk 7 Sitteområdet	Dekk 8 Sitteområdet
	Handleområdet	Tax Free Market	Business Class	Voyager Class	Other
11) Hva gjorde du rett føre alarmen gikk?	Spiste / drakk	Sov	Var sosial	Handlet	Annen aktivitet f.eks leste
12) Hvor langt tid tok det før du begynte å bevege deg mot samlings-stasjonen?	0-1 min	1–2 min	2-3 min	3-5 min	5-10 min
	Over 10 min				

Bitte kreisen Sie eine Antwort pro Frage ein, falls nicht anders angebenen.

1) Alter	11-20	21-35	36-50	51-65	66+
2) Ihr Geschlecht?	M	W			
3) Ist Ihre Mobilität beeinträchtigt	J	N			
4) Falls Sie in einer Gruppe reisen, wieviele Personen gehören zu Ihrer Gruppe (inkl. Ihnen)?					
5) Wie oft reisen Sie im Durchschnitt pro Jahr auf See?					
6) Wie oft sind Sie bisher mit diesem Schiff gereist?					
7) Haben Sie vorher schon einmal an einer Versammlungsübung auf einem Schiff teilgenommen?	J	N			
8) Als Sie den Alarm gehört haben, dachten Sie es war	Eine Übung	Ein wirklicher Notfall			
9) Wie haben Sie sich gefühlt als Sie den Alarm hörten?	1) Gleichgültig	2) Nicht gleichgültig, aber sicher	3) Besorgt, dass ich oder ein Mitglied meiner Gruppe verletzt sein könnte.	4) Besorgt, dass ich oder ein Mitglied meiner Gruppe ernsthaft verletzt sein könnte.	
10) Wo waren Sie als Sie den Alarm realisiert haben?	Buffetrestaurant.	Cafeteria	Bar	Deck 7 Flur Sitzgelegenheit	Deck 8 Flur Sitzgelegenheit
	Einkaufspassage	Tax-Free Markt	Business Class	Voyager Class	andere
11) Womit waren Sie beschäftigt, bevor Sie den Alarm bemerkten?	Essen / Trinken	Schlafen	Gruppenaktivität, z.B Small Talk	Einkaufen	Einzelbeschäftigung, z.B. Lesen
12) Wie lange hat es gedauert, bis Sie zum Sammelpunkt aufgebrochen sind?	0-1 Min	1–2 Min	2-3 Min	3-5 Min	5-10 Min
	Mehr als 10 Min				

Please circle a single answer for each question unless instructed otherwise

1) Age	11-20	21-35	36-50	51-65	66+
2) What is your Gender	M	F			
3) Do you have a Mobility Impairment	Y	N			
4) If you are travelling in a group, how many people are in your group including yourself?					
5) On average, how many times do you travel by sea in a year?					
6) How many times have you travelled on this ship before?					
7) Have you been involved in an assembly exercise on any ship before?	Y	N			
8) When you heard the alarm, did you think it was	An exercise	A real emergency			
9) When the alarm sounded, how did you feel?	1) Unconcerned	2) Concerned but safe	3) Worried I or a member of my group may be injured	4) Worried I or a member of my group may be seriously injured	
10) Where were you when you became aware of the alarm	Buffet Restaurant.	Cafeteria	Bar	Deck 7 Corridor seating	Deck 8 Corridor seating
	Shopping Area	Tax Free Market	Business Class	Voyager Class	Other
11) What were you doing just before you became aware of the alarm?	Eating / drinking	Sleeping	Socialising	Shopping	Individual activity e.g. reading
12) How long did it take you to start moving towards the assembly area?	0-1 min	1–2 min	2-3 min	3-5 min	5-10 min
	Over 10 min				

VENNLIGST RIV HER OG TA VARE PÅ NUMMERET FREM TIL LODDTREKNINGEN! BITTE ABREISSEN UND NUMMER FÜR VERLOSUNG AUFBEWAHREN! PLEASE TEAR OFF AND KEEP THIS NUMBER FOR THE PRIZE DRAW! Q0001

Figure B6 Questionnaire issued to passengers after the SS1 trials (page 1).

13) Etter at du ble oppmerksom på alarmen, gjorde du...	Gikk rett til samlingsstasjonen
	Fortsatte min aktivitet
	Ventet på instruksjoner
	Diskuterte hva man skulle gjøre
	Letet etter gruppen min
14) Hvis du reiste sammen med en gruppe, hvor mange av dem var sammen med deg da du gikk til samlingsstasjonen?	
15) Hadde du noen vanskeligheter med å finne veien til samlingsstasjonen?	Y N
16) Hva var du mest avhengig av for å finne samlingsstasjonen:	Skilt
	Fulgte andre passasjerer
	Instruksjoner fra Mannskap
	Tidligere kunnskap
17) Hvor nyttig var skiltingen som ledet til samlingstasjonen?	1) Ikke nyttig
	2) Lite nyttig
	3) Litt nyttig
	4) Nyttig
	5) Veldig nyttig
18) Ble du hindret pga av kø? Hvis ja, hvor mange ganger?	
19) Hindret noen av det følgende deg i å nå samlingsstasjonen? Her kan du tegne flere sirkler	Kø/menneskemengde
	Forvirrende informasjon via høytaleranlegget
	Manglende informasjon
	Forvirrende informasjon
	Manglende skilting
	Forvirrende skilting
	For lite mannskap
	Dårlig kunnskap om skipets planløsning
	Skipets bevegelse
20) Omtrent hvor lang tid tok det før du nådde samlingsstasjonen?	0 - 2 min
	2 - 5 min
	5 - 10 min
	10 – 15 min
	Over 15 min
21) Synes du at øvelsen var stressende ?	1) Ikke i det hele tatt
	2) Veldig lite
	3) Litt
	4) Stressende
	5) Veldig stressende

13) Nachdem Sie den Alarm bemerkt hatten, haben / sind Sie	Direkt zum Sammelpunkt gegangen?
	Ihre Beschäftigung fortgesetzt?
	Auf Anweisungen gewartet?
	Diskutiert, was zu tun ist?
	Nach Ihrer Gruppe gesucht?
14) Falls Sie in einer Gruppe gereist sind, wie viele Gruppenmitglieder sind mit Ihnen zum Sammelpunkt gegangen?	
15) Hatten Sie Schwierigkeiten den Weg zum Sammelpunkt zu finden?	J N
16) Worauf haben Sie sich hauptsächlich während der Wegsuche zum Sammelpunkt verlassen?	Beschilderung
	Anderen Passagieren gefolgt
	Anweisungen der Besatzung
	Vorkenntnisse
17) Wie sehr hat Ihnen die Beschilderung geholfen, den Sammelpunkt zu finden?	1) Überhaupt nicht
	2) Sehr geringer Nutzen
	3) Ein wenig nützlich
	4) Nützlich
	5) Sehr nützlich
18) Waren Sie gezwungen aufgrund von Überfüllung anzuhalten? Wenn ja, wie oft?	
19) Hat einer der folgenden Punkte Ihr Vorankomm en zum Sammel-punkt behindert? Mehrere Antworten möglich	Überfüllung
	Irreführende Lautsprecherdurchsage
	Mangel an Anweisungen
	Verwirrende Anweisungen
	Unzureichende Beschilderung
	Verwirrende Beschilderung
	Zu wenig Besatzung
	Schlechte Kenntnisse des Schiffslayouts
	Schiffsbewegung
20) Wie lange haben Sie ungefähr gebraucht um den Sammelpunkt zu erreichen?	0 - 2 Min
	2 - 5 Min
	5 - 10 Min
	10 – 15 Min
	Mehr als 15 Min
21) Fanden Sie die Sammlungs-übung stressig?	1) Überhaupt nicht
	2) Sehr wenig stressig
	3) Ein wenig stressig
	4) Stressig
	5) Sehr stressig

13) After you were aware of the alarm, did you	Go directly to assembly area
	Continued activity
	Waited for instructions
	Discussed what to do
	Searched for your group
14) If you were travelling in a group, how many members of your group moved with you to the assembly area?	
15) Did you have any difficulty finding your way to the assembly area?	Y N
16) What did you rely on most in finding your way to the assembly area:	Signage
	Following Other passengers
	Crew's instructions
	Prior knowledge
17) How useful did you find the emergency signage in directing you to the assembly area?	1) Not at all
	2) Very Little use
	3) A little useful
	4) Useful
	5) Very useful
18) Were you forced to stop due to congestion, if so how many times?	
19) Did any of the following hinder your progress to the assembly area? You may circle more than one	Congestion
	Confusing PA information
	Lack of instructions
	Confusing instructions
	Lack of signage
	Confusing signage
	Insufficient crew
	Poor knowledge of ship layout
	Ship motion
20) Approximately, how long did it take you to reach the assembly area?	0 - 2 min
	2 - 5 min
	5 - 10 min
	10 – 15 min
	Over 15 min
21) Did you find the assembly exercise stressful?	1) Not at all
	2) Very Little stress
	3) A little stressful
	4) Stressful
	5) Very stressful

VENNLIGST RIV HER OG TA VARE PÅ NUMMERET FREM TIL LODDTREKNINGEN! BITTE ABREISSEN UND NUMMER FÜR VERLOSUNG AUFBEWAHREN! PLEASE TEAR OFF AND KEEP THIS NUMBER FOR THE PRIZE DRAW! Q0001

Figure B7 Questionnaire issued to passengers after the SS1 trials (page 2).

B3.0 Detailed Planning for Jewel of the Seas Trials

B3.1 Trial Team

The JoS team size was determined after careful consideration of the skill requirements identified above in Section 4.6, along with detailed discussions within the project team and with the vessel's Captain and officers.

To ensure the smooth running of the trial on JoS, it was determined that a team of 25 people was required. The research team was subdivided into smaller groups with clear, predefined roles required for the JoS (summarised in Table B2).

There were slight differences between the team make-up for SS1 and JoS trials. This included the removal of the "entry team", since it was not necessary to encourage passengers to wear the IR tag as they boarded the ship (instead, tags were delivered directly to the passengers' cabins). The JoS also used three teams not used on SS1 – technical team, collection team and tag team. These roles were developed in response to the expected additional complication of the trial due to the size of the vessel and number of passengers onboard. The tag team was responsible for bringing tags, leaflets and questionnaires on-board the ship. The tag team arrived at the Harwich International Port Terminal early on the departure day and delivered tags and questionnaires sealed in boxes to RCCL personnel on-shore. The tag team then boarded the vessel and assisted RCCL crew to ensure the tags and information leaflets were distributed to cabins throughout the ship. The tag team joined the assembly team during the trial. After the trial, the collection team and tag team were required to sweep the vessel for a significant period in order to ensure as many tags and questionnaires were returned as possible. In addition, for this trial, since the team was using the ship's own CCTV camera footage, two members of the setup team synchronised watches to each other and the CCTV system clock and recorded the precise time of the alarm. This time was also compared to the clock on the computer that was used to download the IR data after the trial. Thus, the setup team ensured an accurate and redundant synchronisation point for all data sources.

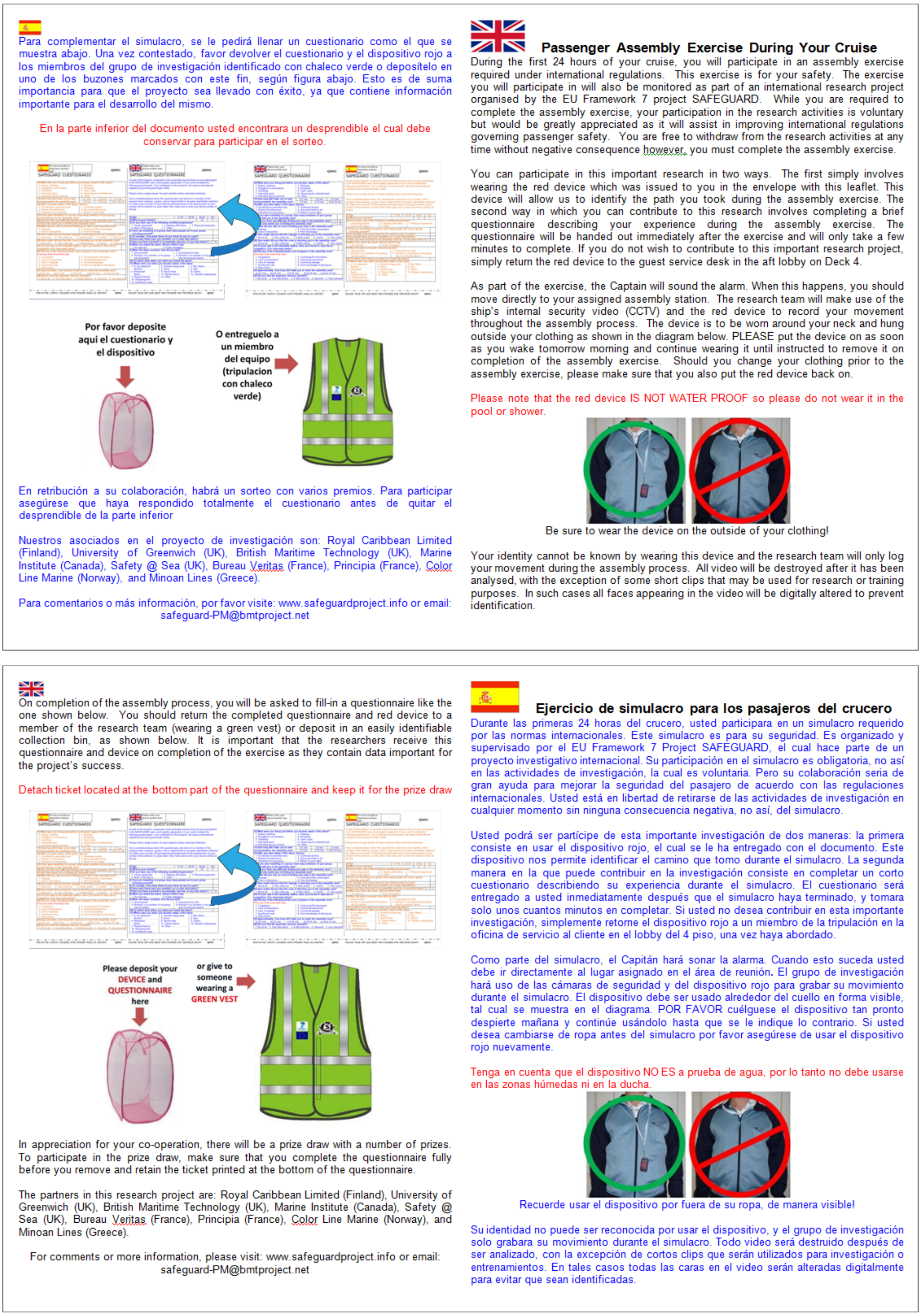
Table B2 Trials team sub-groups

Team #	Group	Number of People	Team Recycling
1	Technical team	5	
2	Setup team	5	Team 1
3	Controller + Ship liaison	2	
4	Assembly team	18	
5	Equipment collection team	5	Team 2
6	Data transfer team	5	Team 5
7	Collection team	4	Team 4
8	Tag team	4	Team 4

For this ship, the trial controller was invited to present to passengers in the main theatre after the trial and before the evening's entertainment began. Thus, it was necessary for the data transfer team to also collate some video footage and information about assembly times for each assembly station, along with some examples of passenger response time. Two members of the data transfer team copied IR tag data onto a computer and one data transfer team member worked with the ship's security officer to ensure all required video data from the ship's CCTV camera system was copied to the external hard drive.

B3.2 Information for Passengers

As outlined in Section 4.3 above and described for the SS1 trials, information was provided to the passengers on JoS in two main ways – information sheets (Figure B8) and through various announcements onboard the ship. Scripts were prepared with the detailed wording for these announcements and provided to RCCL personnel for approval in consultation and the Captain of the vessel. The Captain made five announcements at various stages in the voyage, which are outlined as scripts below. While the scripts for the JoS trial impart the same basic information about the research as was done on SS1, additional announcements were required on JoS because the trial happened on the day after departure and it was likely that many passengers would not remember to wear the IR tag. It is not expected that these slight differences have a significant impact on the passenger behaviour during the trial.



Para complementar el simulacro, se le pedirá llenar un cuestionario como el que se muestra abajo. Una vez contestado, favor devolver el cuestionario y el dispositivo rojo a los miembros del grupo de investigación identificado con chaleco verde o depositelo en uno de los buzones marcados con este fin, según figura abajo. Esto es de suma importancia para que el proyecto sea llevado con éxito, ya que contiene información importante para el desarrollo del mismo.

En la parte inferior del documento usted encontrara un desprendible el cual debe conservar para participar en el sorteo.

En retribución a su colaboración, habrá un sorteo con varios premios. Para participar asegúrese que haya respondido totalmente el cuestionario antes de quitar el desprendible de la parte inferior

Nuestros asociados en el proyecto de investigación son: Royal Caribbean Limited (Finland), University of Greenwich (UK), British Maritime Technology (UK), Marine Institute (Canada), Safety @ Sea (UK), Bureau Veritas (France), Principia (France), Color Line Marine (Norway), and Minoan Lines (Greece).

Para comentarios o más información, por favor visite: www.safeguardproject.info or email: safeguard-PM@bmtproject.net

Passenger Assembly Exercise During Your Cruise

During the first 24 hours of your cruise, you will participate in an assembly exercise required under international regulations. This exercise is for your safety. The exercise you will participate in will also be monitored as part of an international research project organised by the EU Framework 7 project SAFEGUARD. While you are required to complete the assembly exercise, your participation in the research activities is voluntary but would be greatly appreciated as it will assist in improving international regulations governing passenger safety. You are free to withdraw from the research activities at any time without negative consequence however, you must complete the assembly exercise.

You can participate in this important research in two ways. The first simply involves wearing the red device which was issued to you in the envelope with this leaflet. This device will allow us to identify the path you took during the assembly exercise. The second way in which you can contribute to this research involves completing a brief questionnaire describing your experience during the assembly exercise. The questionnaire will be handed out immediately after the exercise and will only take a few minutes to complete. If you do not wish to contribute to this important research project, simply return the red device to the guest service desk in the aft lobby on Deck 4.

As part of the exercise, the Captain will sound the alarm. When this happens, you should move directly to your assigned assembly station. The research team will make use of the ship's internal security video (CCTV) and the red device to record your movement throughout the assembly process. The device is to be worn around your neck and hung outside your clothing as shown in the diagram below. PLEASE put the device on as soon as you wake tomorrow morning and continue wearing it until instructed to remove it on completion of the assembly exercise. Should you change your clothing prior to the assembly exercise, please make sure that you also put the red device back on.

Please note that the red device IS NOT WATER PROOF so please do not wear it in the pool or shower.

Be sure to wear the device on the outside of your clothing!

Your identity cannot be known by wearing this device and the research team will only log your movement during the assembly process. All video will be destroyed after it has been analysed, with the exception of some short clips that may be used for research or training purposes. In such cases all faces appearing in the video will be digitally altered to prevent identification.

On completion of the assembly process, you will be asked to fill-in a questionnaire like the one shown below. You should return the completed questionnaire and red device to a member of the research team (wearing a green vest) or deposit in an easily identifiable collection bin, as shown below. It is important that the researchers receive this questionnaire and device on completion of the exercise as they contain data important for the project's success.

Detach ticket located at the bottom part of the questionnaire and keep it for the prize draw

In appreciation for your co-operation, there will be a prize draw with a number of prizes. To participate in the prize draw, make sure that you complete the questionnaire fully before you remove and retain the ticket printed at the bottom of the questionnaire.

The partners in this research project are: Royal Caribbean Limited (Finland), University of Greenwich (UK), British Maritime Technology (UK), Marine Institute (Canada), Safety @ Sea (UK), Bureau Veritas (France), Principia (France), Color Line Marine (Norway), and Minoan Lines (Greece).

For comments or more information, please visit: www.safeguardproject.info or email: safeguard-PM@bmtproject.net

Ejercicio de simulacro para los pasajeros del crucero

Durante las primeras 24 horas del crucero, usted participara en un simulacro requerido por las normas internacionales. Este simulacro es para su seguridad. Es organizado y supervisado por el EU Framework 7 Project SAFEGUARD, el cual hace parte de un proyecto investigativo internacional. Su participación en el simulacro es obligatoria, no así en las actividades de investigación, la cual es voluntaria. Pero su colaboración seria de gran ayuda para mejorar la seguridad del pasajero de acuerdo con las regulaciones internacionales. Usted está en libertad de retirarse de las actividades de investigación en cualquier momento sin ninguna consecuencia negativa, no así, del simulacro.

Usted podrá ser partícipe de esta importante investigación de dos maneras: la primera consiste en usar el dispositivo rojo, el cual se le ha entregado con el documento. Este dispositivo nos permite identificar el camino que tomo durante el simulacro. La segunda manera en la que puede contribuir en la investigación consiste en completar un corto cuestionario describiendo su experiencia durante el simulacro. El cuestionario será entregado a usted inmediatamente después que el simulacro haya terminado, y tomara solo unos cuantos minutos en completar. Si usted no desea contribuir en esta importante investigación, simplemente retorne el dispositivo rojo a un miembro de la tripulación en la oficina de servicio al cliente en el lobby del 4 piso, una vez haya abordado.

Como parte del simulacro, el Capitán hará sonar la alarma. Cuando esto suceda usted debe ir directamente al lugar asignado en el área de reunión. El grupo de investigación hará uso de las cámaras de seguridad y del dispositivo rojo para grabar su movimiento durante el simulacro. El dispositivo debe ser usado alrededor del cuello de manera visible, tal cual se muestra en el diagrama. POR FAVOR cuélguese el dispositivo tan pronto despierte mañana y continúe usándolo hasta que se le indique lo contrario. Si usted desea cambiarse de ropa antes del simulacro por favor asegúrese de usar el dispositivo rojo nuevamente.

Tenga en cuenta que el dispositivo NO ES a prueba de agua, por lo tanto no debe usarse en las zonas húmedas ni en la ducha.

Recuerde usar el dispositivo por fuera de su ropa, de manera visible!

Su identidad no puede ser reconocida por usar el dispositivo, y el grupo de investigación solo grabara su movimiento durante el simulacro. Todo video será destruido después de ser analizado, con la excepción de cortos clips que serán utilizados para investigación o entrenamientos. En tales casos todas las caras en el video serán alteradas digitalmente para evitar que sean identificadas.

Figure B8 Printed pamphlet, conveying trials information (in English and Spanish) to passengers onboard JoS, showing: English side 1 (top right) and English side 2 (bottom) left.

On recommendation of RCCL personnel, these scripts were translated into English and Spanish, as were the questionnaires and information sheets. The various scripts are shown below.

Captain Announcement #1 (made only once, shortly after setting sail):

"Ladies and Gentlemen, at some time during the next 24 hours, we will have an assembly exercise. This exercise is conducted every time the Jewel of the Sea begins a new cruise and is required by international regulations. On this occasion, you will also be participating in an international research project funded by the European Union. As part of this research project you are requested to wear a small red device that will be delivered to your stateroom this evening. Please ensure that you are wearing this device first thing tomorrow morning before you leave your stateroom.

The assembly exercise will start with the sounding of an alarm. When you hear the alarm, please proceed to your assigned assembly station and follow the instructions of the crew. Your decision to wear the small red device is completely voluntary but would be greatly appreciated, as it will help improve international regulations governing passenger safety on ships. If you do not wish to contribute to this important research, simply do not wear the small red device, but please do not discard the device, as it will be collected from you later.

At the end of the exercise, you will be given a questionnaire, which we would like you to complete and return along with the red device. Please remember to keep the prize ticket located at the bottom of your questionnaire, as a prize draw with 7 prizes will be held before we arrive in Copenhagen. As a mark of our appreciation for your participation in the research project, seven prize winners will be announced, thank-you."

Captain Announcement #2 (made once, reminding passengers to wear their IR tag):

"Ladies and Gentlemen, please remember we will be holding an assembly exercise at some point today. Please make sure that you are all now wearing the small red device that was delivered to your stateroom last night and please continue doing what you had planned to do at this time, thank-you."

Captain Announcement #3 (short announcement required by the Captain about the impending trial immediately before the sound of alarm):

"Ladies and Gentlemen, the assembly exercise will start immediately following this announcement. Please remember this is a drill, thank you."

Captain Announcement #4 (thanking passengers just after the exercise had finished):

"Ladies and Gentlemen, the assembly exercise is now completed. Thank you very much for your time and cooperation. We would ask that you now please hand-in your red device to the research staff wearing the green vests and take a few moments to complete the questionnaire being handed-out. Remember, when you return your questionnaire, remove and keep the prize ticket located at the bottom in order to be eligible for one of the seven prizes that will be awarded before we arrive in Copenhagen."

Captain Announcement #5 (announcing the winners of the prize draw):

"Ladies and Gentlemen, once again, thank-you for your participation in the assembly exercise today. You should be proud to know that by participating you will help improve passenger ship safety. You may be interested to know that the assembly time was [TIME] minutes, [well within the time required by international regulations].

We have held the prize draw and the following ticket holders should come to the Theatre on Deck 5 to collect their prizes: Ticket number [X1], Ticket number [X2], Ticket number [X3], Ticket number [X4], Ticket number [X5], Ticket number [X6] & Ticket number [X7]. Please remember to bring your ticket with you when you come to claim your prize.

Immediately following the presentation of prizes, we invite anyone interested to join us in the theatre for a short presentation about this morning's assembly exercise, which will be given by Professor Ed Galea from the University of Greenwich. Professor Galea will discuss the SAFEGUARD research project and show you some of the results from the exercise this morning.

If you have not already done so, please remember to return your small red device to the research staff wearing the green vests.

Thank-you and enjoy the rest of your voyage."

B3.3 Passenger Incentives

A total of seven prizes were given away during the raffle onboard JoS:

1. Upgrade to highest category cabin for the cruise (depending on availability after sailing)
2. Dinner for four with the ship's Captain and Hotel Director
3. Tour of the ship's bridge and engine room with the Captain and Chief Engineer for up to four people
4. Dinner for two in the onboard "Chops" restaurant
5. Dinner for two in the onboard "Portofino" restaurant
6. Late departure for up to four people upon return to Harwich
7. An iPod Shuffle

As with the SS1 trials, at the end of the JoS trial all completed questionnaires were taken by the project team to a meeting room on the vessel and placed in a bin. The project team members then randomly chose seven questionnaires as the raffle winners. The ticket numbers of the selected questionnaires were then delivered to the Captain so that he could announce the winners over the ship's public address system and thereafter distribute the prizes to the winning passengers at a suitable location onboard.

B3.4 Questionnaire

The questionnaire provided to passengers on JoS (Figure B9) was based on the SS1 questionnaire, with minor modifications to suit the needs of the ship type (cruise ship as opposed to a RO-PAX ferry). The questionnaire was printed in on both sides of a single A4 sheet with the bottom portion perforated to act as a raffle ticket. A total of 2,400 questionnaires were printed in English and Spanish.

Por favor escriba su dispositivo número aquí: | | **Q0001**

SAFEGUARD CUESTIONARIO

12) Antes de que sonara la alarma ¿que se encontraba usted haciendo?
1. Durmiendo
2. Comiendo / Tomando
3. Apostando
4. Conversando
5. Recreación pasiva individual
6. De compras
7. En actividades de integración
8. Deporte individual
9. Deporte en grupo
10. Otros...

13) ¿Cuánto tiempo le tomo para decidir ir al área de reunión?	0-1 min	1-2 min	2-3 min
	3-5 min	5-10 min	Más de 10 min

14) Al escuchar la alarma ¿que hizo? Indique y ordene las acciones realizadas, colocando un número dentro de los cuadros. (ej. 1-Primero, 2-segundo, etc.)
- Ir de inmediato al salón social ☐
- Esperar por mas instrucciones ☐
- Buscar su grupo ☐
- Seguir en su actividad ☐
- Pensar que hacer ☐
- Regresar a su camarote ☐
- Otros... ☐

15) ¿Si está viajando en grupo, cuantos de sus compañeros se dirigieron con usted al área de reunión?

16) ¿Se enfrento con alguna dificultad para encontrar el área de reunión? Si | No

17) ¿Le colaboró la tripulación a encontrar el área de reunión? Si | No

18) ¿Que le fue de mayor utilidad para encontrar el área de reunión?
1. Señalización
2. Instrucciones de la tripulación
3. Seguir a otros pasajeros
4. Conocimiento previo

19) ¿Que tan útil le fue la señalización para encontrar el área de reunión?
1. Nada 2. Muy poco 3. Un poco 4. Util 5. Muy útil

20) ¿Que tan útil fue la ayuda de la tripulación para encontrar el área de reunión?
1. Nada 2. Muy poco 3. Un poco 4. Útil 5. Muy útil

21) En su camino para el salón social, ¿fue usted obligado a parar por congestión? si así es, ¿cuántas veces?

22) ¿Fue alguno de los siguientes un impedimento para tener acceso al área de reunión?
(puede señalar más de una)
1. Congestión
2. Carencia de instrucciones
3. Instrucciones no claras
4. Ausencia de señalización
5. Señalización confusa
6. Anuncios no claros
7. Ausencia de tripulantes
8. Poco conocimiento de la distribución del barco
9. Movimiento del barco
10. Otro...

23) ¿Cuanto tardó aproximadamente en llegar al área de reunión?
a) 0-2 min b) 2-5 min c) 5-10 min d) 10-15 min e) Mas de 15 min

24) ¿Considera usted estresante el simulacro realizado?
1. No 2. Muy poco 3. Poco 4. Estresante 5. Muy estresante

POR FAVOR CORTE Y GUARDE ESTE NÚMERO PARA EL SORTEO! Q0001

Please write your device number here: | | **Q0001**

SAFEGUARD QUESTIONNAIRE

As part of the research component of the assembly exercise that you just participated in, the SAFEGUARD team would greatly appreciate if you could complete the following questionnaire. Your contribution to this research will improve international regulations governing passenger safety.

Please circle a single answer for each question unless instructed otherwise.

Once completed please return this questionnaire and the red device you were wearing to a member of the research team (wearing a green vest) or deposit both in an easily identifiable collection bin. Make sure you tear off and keep the perforated part of this questionnaire as your number will be entered in a prize draw! Also don't forget to write your red device number (found on the back of the device) in the box at the top of this document.

1) Age	11-19	20-39	40-64	65+
2) What is your Gender?		M		F

3) Do you have any of the following Impairments?
1. Visual impairment
2. Physical/mobility impairment
3. Hearing difficulties
4. Other...

4) If you are travelling in a group, how many people are in your group, including yourself?

5) On average, how many times do you travel by sea in a year?

6) How many times have you travelled on a cruise ship before?

7) Have you been involved in an assembly exercise on any ship before? Y | N

8) When you heard the alarm, did you think it was
1. An exercise 2. A real emergency 3. Other...

9) When the alarm sounded, how did you feel?
1. Unconcerned
2. Worried I or a member of my group may be injured
3. Concerned but safe
4. Worried I or a member of my group may be seriously injured

10) Which deck were you on when you heard the alarm?

11) Where were you when you became aware of the alarm?
1. In my stateroom Number.........................
2. Restaurant Name.........................
3. Theatre/Cinema
4. Shopping area
5. Conference area
6. Outside lounge area
7. Disco
8. Sports Area
9. Games Room
10. General seating area
11. Bar Name.........................
12. Spa
13. Casino
14. Other...

PLEASE TEAR OFF AND KEEP THIS NUMBER FOR THE PRIZE DRAW! Q0001

Please write your device number here: | | **Q0001**

SAFEGUARD QUESTIONNAIRE

12) What were you doing just before you became aware of the alarm?
1. Sleeping
2. Eating / drinking
3. Gambling
4. Engaged in conversation
5. Individual passive activity
6. Shopping
7. Observing live entertainment
8. Individual sport
9. Team sport
10. Other ....

13) How long did it take you to start moving towards the assembly area?	0-1 min	1-2 min	2-3 min
	3-5 min	5-10 min	Over 10 min

14) What did you do after you became aware of the alarm? Indicate all that apply and also indicate the order you performed these actions by placing appropriate numbers in the boxes (i.e. 1-first, 2-second , 3-third etc)
- Go directly to assembly area ☐
- Wait for further instructions ☐
- Search for your group ☐
- Continue activity ☐
- Discuss what to do ☐
- Return to your stateroom ☐
- Other .... ☐

15) If you were travelling in a group, how many members of your group moved with you to the assembly area?

16) Did you have any difficulty finding your way to the assembly area? Y | N

17) Did crew assist you in finding the assembly area? Y | N

18) What did you rely on most in finding your way to the assembly area?
1. Signage
2. Crew instructions
3. Following other passengers
4. Prior knowledge

19) How useful did you find the signage in directing you to the assembly area?
1. Not at all 2. Very Little use 3. A little useful 4. Useful 5. Very useful

20) How useful did you find the crew in directing you to the assembly area?
1. Not at all 2. Very Little use 3. A little useful 4. Useful 5. Very useful

21) On your way to the assembly station, were you forced to stop due to congestion, if so how many times?

22) Did any of the following hinder your progress to the assembly area?
(You may circle more than one)
1. Congestion
2. Lack of instructions
3. Confusing instructions
4. Lack of signage
5. Confusing signage
6. Confusing announcements
7. Insufficient crew
8. Poor knowledge of ship layout
9. Ship motion
10. Other ....

23) Approximately, how long did it take you to reach the assembly area?
a) 0-2 min b) 2-5 min c) 5-10 min d) 10-15 min e) Over 15 min

24) Did you find the assembly exercise stressful?
1. Not at all 2. Very little stress 3. A little stressful 4. Stressful 5. Very stressful

PLEASE TEAR OFF AND KEEP THIS NUMBER FOR THE PRIZE DRAW! Q0001

Por favor escriba su dispositivo número aquí: | | **Q0001**

SAFEGUARD CUESTIONARIO

Como parte complementaria del simulacro en el que acaba de participar, el grupo SAFEGUARD le agradecería su colaboración con el siguiente cuestionario. Su contribución ayudará a mejorar las regulaciones internacionales para la seguridad del pasajero.

Por favor marque una sola respuesta en cada pregunta, al menos que se le indique lo contrario.

Una vez contestado el cuestionario favor devolverlo con el dispositivo a un miembro del grupo de investigación, identificados con chaleco verde, o depositelo en uno de los buzones marcados para este fin. Asegúrese de cortar y guardar el desprendible, para que con ese número participe en el ¡sorteo que se realizará! No olvide escribir el número de su dispositivo en la parte superior del cuestionario.

1) Edad	11-19	20-39	40-64	65+
2) Genero			M	F

3) ¿Tiene alguno de los siguientes impedimentos?
1. Visual
2. Físico/movilidad
3. Auditivos
4. Otro...

4) Si está viajando en grupo, ¿con cuantas personas, incluyéndose?

5) ¿Cuantos viajes marítimos realiza por año?

6) ¿Cuántas veces ha realizado viajes en crucero?

7) ¿Ha participado de simulacros en otros barcos? Si | No

8) Al escuchar usted la alarma, pensó:
1. Es un simulacro 2. Una emergencia 3. Otro...

9) ¿Que sintió cuando la alarma sonó?
1. Despreocupación
2. Preocupado que alguien de mi grupo o yo saliera herido
3. Seguro pero preocupado
4. Preocupado que alguien de mi grupo o yo saliera seriamente herido

10) ¿En qué nivel estaba usted cuando oyó la alarma?

11) ¿Donde estaba usted cuando se percató de la alarma?
1. En el camarote Numero.........................
2. Restaurante Nombre.........................
3. Teatro/cine
4. Zona de compras
5. Salón de conferencias
6. Area publica exterior
7. Discoteca
8. Area deportiva
9. Zona de juegos
10. Zonas de descanso
11. Bar Nombre.........................
12. Spa
13. Casino
14. Otro...

POR FAVOR CORTE Y GUARDE ESTE NÚMERO PARA EL SORTEO! Q0001

Figure B9 Questionnaire issued to passengers after the assembly trial on JoS (top: page 1; bottom: page 2).

B4.0 Detailed Planning for Olympia Palace Trials

B4.1 Trial Team

To ensure the smooth running of the trials it was determined that a team of 22 people would be required for trials on Olympia Palace. Most of the people selected had prior experience in assisting during large-scale egress trials. For the purposes of the trials, the research team was subdivided into smaller groups with clear, predefined roles for the different tasks during the trials. In most cases and to keep the size of the team to a minimum, the team members of one group were "recycled" by becoming part of a different team with different roles once their duties in a particular team had been completed. The division of the research team into sub-groups is summarised in Table B3. Detailed descriptions of these different subgroups and their roles are provided in Section 4.6.

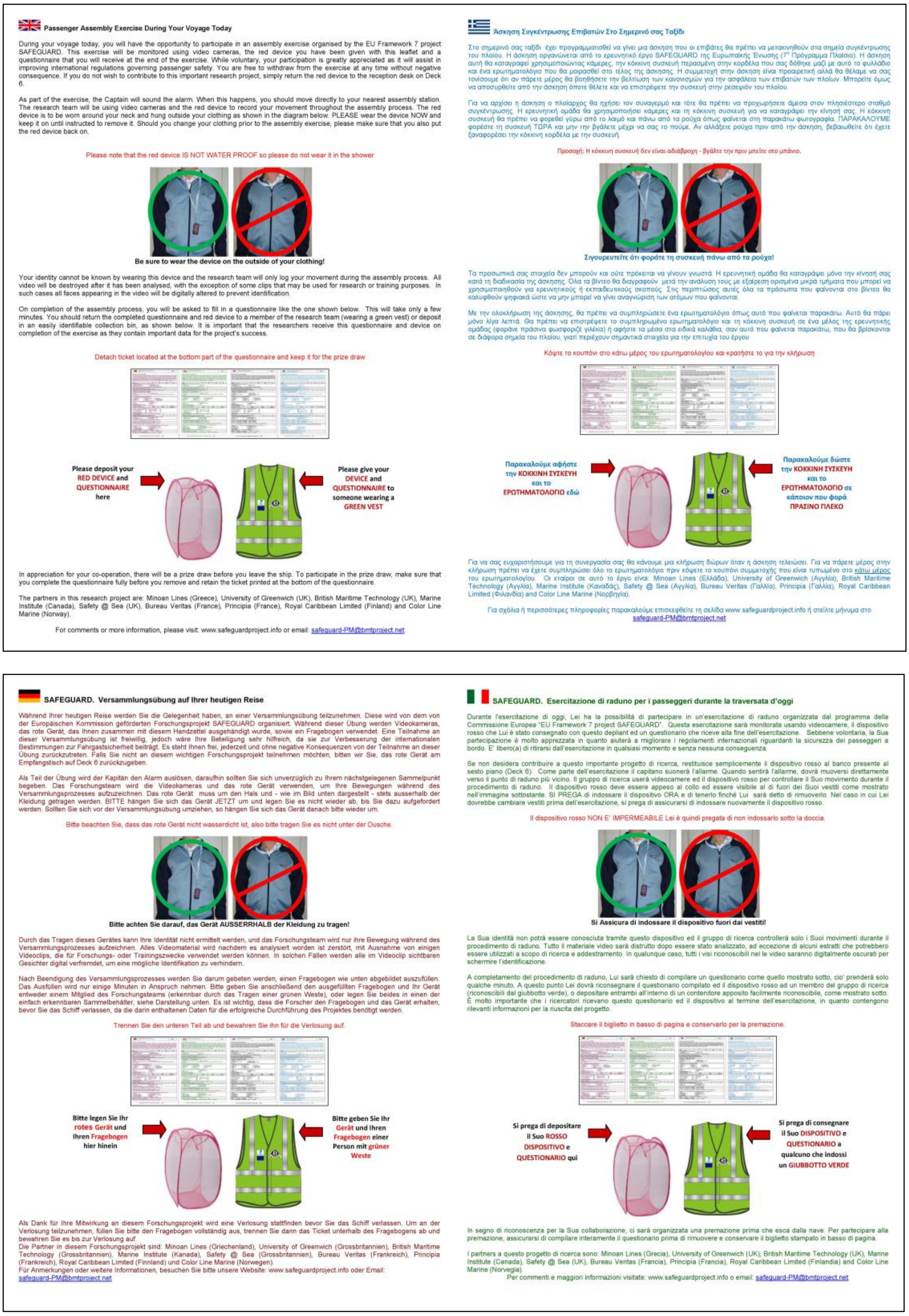
Table B3 Trials team sub-groups for trials on the Olympia Palace.

Team #	Group	Number of People	Team Recycling
1	Technical team	5	
2	Setup team	5	Team 1
3	Controller + Ship liaison	2	
4	Entry team	9	
5	Assembly team	16	Team 4 + 7 others
6	Equipment collection team	5	Team 2
7	Data transfer team	5	Team 2

B4.2 Information for Passengers

As in the previous trials, information was provided to passengers in a leaflet (Figure B10), printed in Greek and English, verbally by members of the entry team at boarding time, as well as through announcements over the ship's public address system. The information leaflet was based on the designs used during the previous trials, with modifications to reflect the trial time range.

Several announcements were made to passengers to explain what was expected of them and what they should do. Based on the previous trials, detailed wording was prepared for these announcements, which was then approved by Minoan Lines personnel. The announcements were made by the Captain and were provided in the Greek and English languages.



Passenger Assembly Exercise During Your Voyage Today

During your voyage today, you will have the opportunity to participate in an assembly exercise organised by the EU Framework 7 project SAFEGUARD. This exercise will be monitored using video cameras, the red device you have been given with this leaflet and a questionnaire that you will receive at the end of the exercise. While voluntary, your participation is greatly appreciated as it will assist in improving international regulations governing passenger safety. You are free to withdraw from the exercise at any time without negative consequence. If you do not wish to contribute to this important research project, simply return the red device to the reception desk on Deck 6.

As part of the exercise, the Captain will sound the alarm. When this happens, you should move directly to your nearest assembly station. The research team will be using video cameras and the red device to record your movement throughout the assembly process. The red device is to be worn around your neck and hung outside your clothing as shown in the diagram below. PLEASE wear the device NOW and keep it on until instructed to remove it. Should you change your clothing prior to the assembly exercise, please make sure that you also put the red device back on.

Please note that the red device IS NOT WATER PROOF so please do not wear it in the shower

Be sure to wear the device on the outside of your clothing!

Your identity cannot be known by wearing this device and the research team will only log your movement during the assembly process. All video will be destroyed after it has been analysed, with the exception of some clips that may be used for research or training purposes. In such cases all faces appearing in the video will be digitally altered to prevent identification.

On completion of the assembly process, you will be asked to fill in a questionnaire like the one shown below. This will take only a few minutes. You should return the completed questionnaire and red device to a member of the research team (wearing a green vest) or deposit in an easily identifiable collection bin, as shown below. It is important that the researchers receive this questionnaire and device on completion of the exercise as they contain important data for the project's success.

Detach ticket located at the bottom part of the questionnaire and keep it for the prize draw

In appreciation for your co-operation, there will be a prize draw before you leave the ship. To participate in the prize draw, make sure that you complete the questionnaire fully before you remove and retain the ticket printed at the bottom of the questionnaire.

The partners in this research project are: Minoan Lines (Greece), University of Greenwich (UK), British Maritime Technology (UK), Marine Institute (Canada), Safety @ Sea (UK), Bureau Veritas (France), Principia (France), Royal Caribbean Limited (Finland) and Color Line Marine (Norway).

For comments or more information, please visit: www.safeguardproject.info or email: safeguard-PM@bmtproject.net

Limited (Φιλανδία) and Color Line Marine (Νορβηγία).

Για σχόλια ή περισσότερες πληροφορίες παρακαλούμε επισκεφθείτε τη σελίδα www.safeguardproject.info ή στείλτε μήνυμα στο safeguard-PM@bmtproject.net

SAFEGUARD. Versammlungsübung auf Ihrer heutigen Reise

Während Ihrer heutigen Reise werden Sie die Gelegenheit haben, an einer Versammlungsübung teilzunehmen. Diese wird von dem von der Europäischen Kommission geförderten Forschungsprojekt SAFEGUARD organisiert. Während dieser Übung werden Videokameras, das rote Gerät, das Ihnen zusammen mit diesem Handzettel ausgehändigt wurde, sowie ein Fragebogen verwendet. Eine Teilnahme an dieser Versammlungsübung ist freiwillig, jedoch wäre Ihre Beteiligung sehr hilfreich, da sie zur Verbesserung der internationalen Bestimmungen zur Fahrgastsicherheit beiträgt. Es steht Ihnen frei, jederzeit und ohne negative Konsequenzen von der Teilnahme an dieser Übung zurückzutreten. Falls Sie nicht an diesem wichtigen Forschungsprojekt teilnehmen möchten, bitten wir Sie, das rote Gerät am Empfangstisch auf Deck 6 zurückzugeben.

Als Teil der Übung wird der Kapitän den Alarm auslösen, daraufhin sollten Sie sich unverzüglich zu Ihrem nächstgelegenen Sammelpunkt begeben. Das Forschungsteam wird die Videokameras und das rote Gerät verwenden, um Ihre Bewegungen während des Versammlungsprozesses aufzuzeichnen. Das rote Gerät muss um den Hals und - wie im Bild unten dargestellt - stets ausserhalb der Kleidung getragen werden. BITTE hängen Sie sich das Gerät JETZT um und legen Sie es nicht wieder ab, bis Sie dazu aufgefordert werden. Sollten Sie sich vor der Versammlungsübung umziehen, so hängen Sie sich das Gerät danach bitte wieder um.

Bitte beachten Sie, dass das rote Gerät nicht wasserdicht ist, also bitte tragen Sie es nicht unter der Dusche.

Bitte achten Sie darauf, das Gerät AUSSERRHALB der Kleidung zu tragen!

Durch das Tragen dieses Gerätes kann Ihre Identität nicht ermittelt werden, und das Forschungsteam wird nur Ihre Bewegung während des Versammlungsprozesses aufzeichnen. Alles Videomaterial wird nachdem es analysiert worden ist zerstört, mit Ausnahme von einigen Videoclips, die für Forschungs- oder Trainingszwecke verwendet werden können. In solchen Fällen werden alle im Videoclip sichtbaren Gesichter digital verfremdet, um eine mögliche Identifikation zu verhindern.

Nach Beendigung des Versammlungsprozesses werden Sie darum gebeten werden, einen Fragebogen wie unten abgebildet auszufüllen. Das Ausfüllen wird nur einige Minuten in Anspruch nehmen. Bitte geben Sie anschließend den ausgefüllten Fragebogen und Ihr Gerät entweder einem Mitglied des Forschungsteams (erkennbar durch das Tragen einer grünen Weste), oder legen Sie beides in einen der einfach erkennbaren Sammelbehälter, siehe Darstellung unten. Es ist wichtig, dass die Forscher den Fragebogen und das Gerät erhalten, bevor Sie das Schiff verlassen, da die darin enthaltenen Daten für die erfolgreiche Durchführung des Projektes benötigt werden.

Trennen Sie den unteren Teil ab und bewahren Sie ihn für die Verlosung auf.

Als Dank für Ihre Mitwirkung an diesem Forschungsprojekt wird eine Verlosung stattfinden bevor Sie das Schiff verlassen. Um an der Verlosung teilzunehmen, füllen Sie bitte den Fragebogen vollständig aus, trennen Sie dann das Ticket unterhalb des Fragebogens ab und bewahren Sie es bis zur Verlosung auf.
Die Partner in diesem Forschungsprojekt sind: Minoan Lines (Griechenland), University of Greenwich (Grossbritannien), British Maritime Technology (Grossbritannien), Marine Institute (Kanada), Safety @ Sea (Grossbritannien), Bureau Veritas (Frankreich), Principia (Frankreich), Royal Caribbean Limited (Finnland) und Color Line Marine (Norwegen).
Für Anmerkungen oder weitere Informationen, besuchen Sie bitte unsere Website: www.safeguardproject.info oder Email: safeguard-PM@bmtproject.net

SAFEGUARD. Esercitazione di raduno per i passeggeri durante la traversata d'oggi

Durante l'esercitazione di oggi, Lei ha la possibilità di partecipare in un'esercitazione di raduno organizzata dal programma della Commissione Europea "EU Framework 7 project SAFEGUARD". Questa esercitazione sarà monitorata usando videocamere, il dispositivo rosso che Lui è stato consegnato con questo depliant ed un questionario che riceve alla fine dell'esercitazione. Sebbene volontaria, la Sua partecipazione è molto apprezzata in quanto aiuterà a migliorare i regolamenti internazionali riguardanti la sicurezza dei passeggeri a bordo. E' libero(a) di ritirarsi dall'esercitazione in qualsiasi momento e senza nessuna conseguenza.

Se non desidera contribuire a questo importante progetto di ricerca, restituisce semplicemente il dispositivo rosso al banco presente al sesto piano (Deck 6). Come parte dell'esercitazione il capitano suonerà l'allarme. Quando sentirà l'allarme, dovrà muoversi direttamente verso il punto di raduno più vicino. Il gruppo di ricerca userà videocamere ed il dispositivo rosso per controllare il Suo movimento durante il procedimento di raduno. Il dispositivo rosso deve essere appeso al collo ed essere visibile al di fuori dei Suoi vestiti come mostrato nell'immagine sottostante. SI PREGA di indossare il dispositivo ORA e di tenerlo finché Lui sarà detto di rimuoverlo. Nel caso in cui Lei dovrebbe cambiare vestiti prima dell'esercitazione, si prega di assicurarsi di indossare nuovamente il dispositivo rosso.

Il dispositivo rosso NON E' IMPERMEABILE Lei è quindi pregata di non indossarlo sotto la doccia.

Si Assicura di indossare il dispositivo fuori dai vestiti!

La Sua identità non potrà essere conosciuta tramite questo dispositivo ed il gruppo di ricerca controllerà solo i Suoi movimenti durante il procedimento di raduno. Tutto il materiale video sarà distrutto dopo essere stato analizzato, ad eccezione di alcuni estratti che potrebbero essere utilizzati a scopo di ricerca e addestramento. In qualunque caso, tutti i visi riconoscibili nel le video saranno digitalmente oscurati per schermire l'identificazione.

A completamento del procedimento di raduno, Lui sarà chiesto di compilare un questionario come quello mostrato sotto, cio' prenderà solo qualche minuto. A questo punto Lei dovrà riconsegnare il questionario compilato ed il dispositivo rosso ad un membro del gruppo di ricerca (riconoscibili dal giubbotto verde), o depositare entrambi all'interno di un contenitore apposito facilmente riconoscibile, come mostrato sotto. È molto importante che i ricercatori ricevano questo questionario ed il dispositivo al termine dell'esercitazione, in quanto contengono rilevanti informazioni per la riuscita del progetto.

Staccare il biglietto in basso di pagina e conservarlo per la premazione.

In segno di riconoscenza per la Sua collaborazione, ci sarà organizzata una premazione prima che esca dalla nave. Per partecipare alla premazione, assicurarsi di compilare interamente il questionario prima di rimuovere e conservare il biglietto stampato in basso di pagina.

I partners a questo progetto di ricerca sono: Minoan Lines (Grecia), University of Greenwich (UK), British Maritime Technology (UK), Marine Institute (Canada), Safety @ Sea (UK), Bureau Veritas (Francia), Principia (Francia), Royal Caribbean Limited (Finlandia) and Color Line Marine (Norvegia).
Per commenti e maggiori informazioni visitate: www.safeguardproject.info o email: safeguard-PM@bmtproject.net

Figure B10 Information leaflet for OP trials.

Minoan personnel indicated that crew could also relay information provided in the scripts in Italian and German if deemed necessary. The scripts used are provided below.

Captain Announcement #1 (read once, just after leaving port):

"Ladies and Gentlemen, as explained in the information sheet you were given during embarkation, at some time during this voyage we will be holding an assembly exercise. As part of this exercise it is essential that you all wear the small red device given to you during embarkation. So, I ask you to please make sure that you are all wearing this device now.

The assembly exercise will start with the sounding of an alarm. When you hear the alarm please proceed to your nearest assembly station. Your participation in the exercise is voluntary but would be greatly appreciated as it will help improve international regulations governing passenger safety on ships. If you do not wish to participate in the exercise, please do not discard the red device but return it to reception.

At the end of the exercise, you will be given a questionnaire which we would like you to complete and return along with the red device. Please remember to keep the prize ticket located at the end of your questionnaire as a prize draw will be held before we arrive in Kerkira. As a mark of our appreciation for your participation, three prize winners will be announced.

Please now make sure that you are all wearing the small device and continue doing what you normally had planned to do at this time. Thank-you"

Captain Announcement #2 (brief announcement 20 minutes before the alarm):

"Ladies and Gentlemen, please remember that we will be holding an assembly exercise at some point today and you should now be wearing your red device. Thank-you"

Captain Announcement #3 (thanking passengers just after the exercise had finished):

"Ladies and Gentlemen, the assembly exercise is now completed. Thank you very much for your time and cooperation. We would ask that you now please hand-in your

red device to the research staff wearing the green vests and take a few moments to complete the questionnaire being handed-out. Remember, when you return your questionnaire, remove and keep the prize ticket located at the end of the questionnaire in order to be eligible for one of the three prizes that will be announced before we arrive at Kerkira."

Captain Announcement #4 (announcing the winners of the prize draw):

"Ladies and Gentlemen, once again, thank-you for your participation in today's assembly exercise. You should be proud to know that by participating you will help improve passenger ship safety. You may be interested to know that the assembly time was [X] minutes, well within the time required by international regulations.

We have held the prize draw and the following ticket holders should come to [LOCATION] to collect their prizes: Ticket number [X] has won the first prize of [ITEM 1], Ticket number [Y] has won the second prize of [ITEM 2], and Ticket number [Z] has won the third prize of [ITEM 3]. Please remember to bring your ticket with you when you come to claim your prize. If you have not already done so, please remember to return you red devices to the research staff wearing the green vests.

Thank you and enjoy the rest of your voyage."

Entry Team Script (used as passengers boarded the ship):

"Please note that on your voyage today, we will be holding an assembly exercise. As part of the exercise we are providing you with a small device that we would like everyone over the age of 11 to wear around their neck. Once the exercise is over you will be asked to return this device. Also, here is an information leaflet about the exercise, which you should read through. Please wear the device now and keep it on until after the trial. It is worn like this. For all of those who participate in the trial there will be a draw for three prizes for three lucky participants!"

B4.3 Passenger Incentives

A total of three prizes were given away during the raffle onboard Olympia Palace:

- Voucher for free ticket with shared cabin on the route Patras to Venice
- Voucher for free meal en route from Venice to Patras
- An iPod MP3 player

At the end of the trials, all completed questionnaires were taken to the project workroom and placed in a container. The project team then randomly chose three questionnaires as the raffle winners. The ticket numbers were then delivered to the Captain to announce the winners over the ship's public address system and thereafter distribute the prizes to the winning passengers at a suitable location onboard.

B4.4 Questionnaires

The questionnaire provided to passengers on Olympia Palace (Figure B11) was based on the SS1 and JoS questionnaires, with minor modifications to suit the needs of the ship. The questionnaire was printed on both sides of a single A4 sheet with the bottom portion perforated to act as a raffle ticket. Questionnaires were printed in four languages – Greek, German, Italian and English, based on information provided by Minoan Lines about typical passenger demographics for this route. A total of 800 questionnaires were printed for trials on OP – 400 for each.

Please write your device number here: Q0001

SAFEGUARD QUESTIONNAIRE

As part of the research component of the assembly exercise that you just participated in, the SAFEGUARD team would greatly appreciate if you could complete the following questionnaire. Your contribution to this research will improve international regulations governing passenger safety. **Please circle a single answer for each question unless instructed otherwise.** Once completed please return this questionnaire and the red device you were wearing to a member of the research team (wearing a green vest) or deposit both in an easily identifiable collection bin. Make sure you tear off and keep the perforated part of this questionnaire as your number will be entered in a prize draw! **Also don't forget to write your red device number (found on the back of the device) in the box at the top of this document.**

1) Age 11-19 | 20-39 | 40-64 | 65+
2) What is your Gender? M | F
3) Do you have any of the following Impairments?
1. Visual impairment 2. Physical/mobility impairment 3. Hearing difficulties 4. Other.......
4) If you are travelling in a group, how many people are in your group, including yourself?
5) On average, how many times do you travel by sea in a year?
6) How many times have you travelled on a high speed ferry before?
7) Have you been involved in an assembly exercise on any ship before? Y | N
8) When you heard the alarm, did you think it was
1. An exercise 2. A real emergency 3. Other.......
9) When the alarm sounded, how did you feel?
1. Unconcerned 2. Worried I or a member of my group may be injured 3. Concerned but safe 4. Worried I or a member of my group may be seriously injured
10) Which deck were you on when you heard the alarm?
11) Where were you when you became aware of the alarm?
1. In cabin number....... 2. Air seats 3. Shopping area 4. Casino 5. Aft lounge 6. Central snack bar 7. Restaurant 8. Self service cafeteria 9. Outside deck 6 10. Top deck disco/cafe 11. Swimming pool area 12. Other.......
12) What were you doing just before you became aware of the alarm?
1. Sleeping 2. Eating / drinking 3. Gambling / playing electronic games 4. Engaged in conversation 5. Individual passive activity 6. Shopping 7. Other ....
13) How long did it take you to start moving towards the assembly area? 0-1 min | 1-2 min | 2-3 min | 3-5 min | 5-10 min | Over 10 min
14) What did you do after you became aware of the alarm? Indicate all that apply and also indicate the order you performed these actions by placing appropriate numbers in the boxes (i.e. 1-first, 2-second , 3-third etc)
- Go directly to assembly area ☐ - Continue activity ☐ - Other .... ☐
- Wait for further instructions ☐ - Discuss what to do ☐
- Search for your group ☐ - Return to cabin ☐

15) If you were travelling in a group, how many members of your group moved with you to the assembly area?
16) Did you have any difficulty finding your way to the assembly area? Y | N
17) Did crew assist you in finding the assembly area? Y | N
18) What did you rely on most in finding your way to the assembly area?
1. Signage 2. Crew instructions 3. Following other passengers 4. Prior knowledge
19) How useful did you find the signage in directing you to the assembly area?
1. Not at all 2. Very Little use 3. A little useful 4. Useful 5. Very useful
20) How useful did you find the crew in directing you to the assembly area?
1. Not at all 2. Very Little use 3. A little useful 4. Useful 5. Very useful
21) On your way to the assembly station, were you forced to stop due to congestion, if so how many times?
22) Did any of the following hinder your progress to the assembly area? (You may circle more than one)
1. Congestion 2. Lack of instructions 3. Confusing instructions 4. Lack of signage 5. Confusing signage 6. Confusing announcements 7. Insufficient crew 8. Poor knowledge of ship layout 9. Ship motion 10. Other.......
23) Approximately, how long did it take you to reach the assembly area?
a) 0-2 min b) 2-5 min c) 5-10 min d) 10-15 min e) Over 15 min
24) Did you find the assembly exercise stressful?
1. Not at all 2. Very little stress 3. A little stressful 4. Stressful 5. Very stressful

PLEASE TEAR OFF AND KEEP THIS NUMBER FOR THE PRIZE DRAW! Q0001

Παρακαλούμε γράψτε τον αριθμό από το πίσω μέρος συσκευής εδώ: Q0001

ΕΡΩΤΗΜΑΤΟΛΟΓΙΟ SAFEGUARD

Παρακαλούμε συμπληρώνατε το παρακάτω ερωτηματολόγιο. Η συνεισφορά σας σε αυτή την έρευνα θα βελτιώσει διεθνείς κανονισμούς που διέπουν την ασφάλεια των επιβατών στα πλοία. **Παρακαλούμε για κάθε ερώτηση βάλτε κύκλο σε μία μόνο επιλογή εκτός και αν υποδεικνύεται κάτι διαφορετικό.** Επιστρέψτε το συμπληρωμένο ερωτηματολόγιο και την κόκκινη συσκευή στην ερευνητική ομάδα (φοράνε πράσινα φωσφοριζέ γιλέκα) ή αφήστε τα μέσα στα ειδικά καλάθια που θα βρείτε σε διάφορα σημεία του πλοίου. Πρώτα όμως κόψτε και κρατήστε το κάτω μέρος γιατί περιέχει τον αριθμό συμμετοχής σας στην κλήρωση. **Επιπλέον σημειώστε τον αριθμό της κόκκινης συσκευής σας που θα τον βρείτε στο πίσω μέρος της στο άδειο κουτάκι στο πάνω μέρος του ερωτηματολογίου.**

1) Ηλικία 11-19 | 20-39 | 40-64 | 65+
2) Φύλο Α | Γ
3) Έχετε κάποια από τα παρακάτω προβλήματα ;
1. Πρόβλημα όρασης 2. Δυσκολία κίνησης 3. Δυσκολία ακοής 4. Άλλο.......
4) Αν ταξιδεύετε με άλλους πόσα άτομα είναι στο γκρουπ σας μαζί με εσάς;
5) Κατά μέσο όρο πόσες φορές ταξιδεύετε με πλοίο το χρόνο;
6) Πόσες φορές έχετε ταξιδέψει με ταχύπλοα φέριμποτ συνολικά στο παρελθόν;
7) Έχετε πάρει μέρος σε άλλη άσκηση συγκέντρωσης ποτέ; ΝΑΙ | ΟΧΙ
8) Όταν ακούσατε τον συναγερμό, νομίσατε ότι είναι
1. Άσκηση 2. Πραγματική έκτακτη ανάγκη 3. Άλλο.......
9) Πώς νοιώσατε όταν ακούστηκε ο συναγερμός;
1. Αδιάφορα 2. Ανησύχησα πως εγώ ή μέλος του γκρουπ μου μπορεί να τραυματιστεί 3. Ανήσυχα αλλά ασφαλής 4. Ανησύχησα πως εγώ ή μέλος του γκρουπ μου μπορεί να τραυματιστεί σοβαρά
10) Σε ποιο κατάστρωμα βρισκόσασταν όταν ακούσατε τον συναγερμό;
11) Πού ήσασταν όταν συνειδητοποιήσατε ότι χτυπούσε ο συναγερμός;
1. Καμπίνα, νούμερο .... 2. Αεροπορικές θέσεις 3. Περιοχή μαγαζιών 4. Καζίνο 5. Σαλόνι στη πρύμνη 6. Κεντρικό σνακ μπαρ 7. Εστιατόριο 8. Καφετέρια σελφ σέρβις 9. Έξω στο κατάστρωμα 6 10. Ντίσκο/καφέ πάνω κατάστρωμα 11. Περιοχή πισίνας 12. Άλλο.......
12) Τι κάνατε αμέσως πριν συνειδητοποιήσετε ότι χτυπούσε ο συναγερμός;
1. Κοιμόμουν 2. Έτρωγα / Έπινα 3. Έπαιζα τυχερά/ηλεκτρονικά παιχνίδια 4. Συζητούσα 5. Άλλη ατομική δραστηριότητα 6. Ψώνιζα 7. Άλλο ....
13) Πόση ώρα σας πήρε για να αρχίσετε να κατευθύνεστε προς το σημείο συγκέντρωσης; 0-1 λεπτό | 1-2 λεπτά | 2-3 λεπτά | 3-5 λεπτά | 5-10 λεπτά | Πάνω από 10 λεπτά
14) Τι κάνατε αφού συνειδητοποιήσατε ότι χτυπάει ο συναγερμός; Σημειώστε όλες τις ενέργειές σας και την σειρά που τις κάνατε βάζοντας το ανάλογο νούμερο στα πλαίσια (δηλ. 1-πρώτη, 2-δεύτερη, 3-τρίτη πράξη)
- Πήγα κατευθείαν στο σημείο συγκέντρωσης ☐ - Συνέχισα ότι έκανα πριν ☐ - Άλλο .... ☐
- Περίμενα περεταίρω οδηγίες ☐ - Συζήτησα τι να κάνω ☐
- Αναζήτησα το γκρουπ μου ☐ - Επέστρεψα στη καμπίνα ☐

15) Αν ταξιδεύετε με γκρουπ πόσα μέλη του γκρουπ προχώρησαν μαζί με εσάς προς το σημείο συγκέντρωσης;
16) Αντιμετωπίσατε κάποια δυσκολία για να βρείτε τη διαδρομή προς το σημείο συγκέντρωσης; ΝΑΙ | ΟΧΙ
17) Σας βοήθησε το πλήρωμα ώστε να βρείτε το σημείο συγκέντρωσης ΝΑΙ | ΟΧΙ
18) Σε τι βασιστήκατε πιο πολύ για να βρείτε τη διαδρομή προς το σημείο συγκέντρωσης;
1. Ειδικά σήματα 2. Οδηγίες πληρώματος 3. Ακολούθησα άλλους επιβάτες 4. Προηγούμενη εμπειρία
19) Πόσο χρήσιμα βρήκατε τα ειδικά σήματα για να φθάσετε στο σημείο συγκέντρωσης;
1. Καθόλου 2. Πολύ λίγο 3. Λίγο χρήσιμα 4. Χρήσιμα 5. Πολύ χρήσιμα
20) Πόσο χρήσιμες βρήκατε τις οδηγίες του πληρώματος για να φθάσετε στο σημείο συγκέντρωσης;
1. Καθόλου 2. Πολύ λίγο 3. Λίγο χρήσιμες 4. Χρήσιμες 5. Πολύ χρήσιμες
21) Στην διαδρομή προς το σημείο συγκέντρωσης σταματήσατε καθόλου λόγω συνωστισμού και αν ναι πόσες φορές;
22) Σας δυσκόλεψε κάτι από τα παρακάτω όσο κατευθυνόσασταν προς το σημείο συγκέντρωσης; (μπορείτε να βάλετε σε κύκλο περισσότερες από μια επιλογές)
1. Συνωστισμός 2. Έλλειψη οδηγιών 3. Ακατανόητες οδηγίες 4. Έλλειψη σήμανσης 5. Ακατανόητη σήμανση 6. Ακατανόητες ανακοινώσεις 7. Ανεπαρκές πλήρωμα 8. Ελλιπής γνώση του πλοίου 9. Η κίνηση του πλοίου 10. Άλλο ....
23) Περίπου πόσο χρόνο σας πήρε για να φθάσετε στο σημείο συγκέντρωσης;
α) 0-2 λεπτά β) 2-5 λεπτά γ) 5-10 λεπτά δ) 10-15 λεπτά ε) πάνω από 15 λεπτά
24) Νοιώσατε άγχος κατά την διάρκεια της άσκησης;
1. Καθόλου 2. Πολύ λίγο 3. Λίγο 4. Αρκετό άγχος 5. Πολύ άγχος

ΠΑΡΑΚΑΛΟΥΜΕ ΚΟΨΤΕ ΚΑΙ ΚΡΑΤΗΣΤΕ ΑΥΤΟΝ ΤΟΝ ΑΡΙΘΜΟ ΓΙΑ ΤΗΝ ΚΛΗΡΩΣΗ! Q0001

Bitte tragen Sie Ihre Gerätenummer hier ein: Q0001

SAFEGUARD FRAGEBOGEN

Als Teil der Rettungsübung, an der Sie gerade teilgenommen haben, bitten wir Sie, den folgenden Fragebogen auszufüllen. Das SAFEGUARD Team ist Ihnen für Ihre Mitwirkung sehr dankbar – Ihr Beitrag zu unserer Forschung wird helfen, die internationalen Bestimmungen zu verbessern und die Sicherheit für Passagiere zu erhöhen. **Wenn nicht anders angegeben, kreisen Sie bitte eine Antwort pro Frage an.** Wenn Sie fertig sind, geben Sie bitte den Fragebogen und das rote Gerät, das Sie während der Übung getragen haben, an ein Mitglied des Forschungsteams (in den grünen Westen) zurück oder legen Sie beides in eine der leicht erkennbaren Sammelboxen. Bitte achten Sie darauf, den perforierten Teil des Fragebogens abzutrennen und aufzubewahren, damit Sie an unserem Gewinnspiel teilnehmen können! **Des weiteren möchten wir Sie bitten, die Nummer Ihres roten Gerätes (auf der Rückseite des Gehäuses) in das Kästchen oben auf dem Fragebogen zu schreiben.**

1) Alter 11-19 | 20-39 | 40-64 | 65+
2) Ihr Geschlecht? M | W
3) Leiden Sie unter irgendwelchen der folgenden Beeinträchtigungen?
1. Eingeschränktes Sehvermögen 2. Eingeschränkte Mobilität 3. Eingeschränktes Hörvermögen 4. Sonstige Beeinträchtigung.......
4) Falls Sie in einer Gruppe reisen, wieviele Personen gehören zu Ihrer Gruppe (inkl. Ihnen)?
5) Wie oft reisen Sie im Durchschnitt pro Jahr auf See?
6) Wie oft sind Sie bisher mit einer Hochgeschwindigkeitsfähre gereist?
7) Haben Sie vorher schon einmal an einer Versammlungsübung auf einem Schiff teilgenommen? J | N
8) Als Sie den Alarm gehört haben, dachten Sie es war
1. Eine Übung 2. Ein wirklicher Notfall 3. Sonstiges.......
9) Wie haben Sie sich gefühlt als Sie den Alarm hörten?
1. Unbesorgt 2. Besorgt, dass ich oder ein Mitglied meiner Gruppe verletzt werden könnte 3. Etwas besorgt, aber sicher 4. Besorgt, dass ich oder ein Mitglied meiner Gruppe ernsthaft verletzt werden könnte
10) Auf welchem Deck waren Sie, als Sie den Alarm hörten?
11) Wo waren Sie als Sie den Alarm realisiert haben?
1. In Kabine Nummer..... 2. Flugzeugsitze 3. Einkaufspassage 4. Casino 5. Hinterer Aufenthaltsraum 6. Zentrale snack bar 7. Restaurant 8. Selbstbedienungs Cafeteria 9. Freiluft Deck 6 10. Oberdeck Disko/Cafe 11. Schwimmbad Bereich 12. Sonstiger Bereich
12) Womit waren Sie beschäftigt, bevor Sie den Alarm bemerkten?
1. Schlafen 2. Essen/Trinken 3. Glücksspiel/ Elektronische Unterhaltung 4. Unterhaltung mit anderen 5. Einzelbeschäftigung 6. Einkaufen 7. Sonstiges.......
13) Wie lange hat es gedauert, bis Sie zum Sammelpunkt aufgebrochen sind? 0-1 Min | 1-2 Min | 2-3 Min | 3-5 Min | 5-10 Min | Mehr als 10 Min
14) Nachdem Sie den Alarm bemerkt hatten, haben / sind Sie: (wenn mehrere Punkte auf Sie zutreffen, schreiben Sie bitte Zahlen in die Kästchen, um die Reihenfolge anzugeben) (z.B. 1-erstes, 2-zweites , 3-drittes usw.)
- Direkt zum Sammelpunkt gegangen? ☐ - Ihre Beschäftigung fortgesetzt? ☐ - Sonstiges....... ☐
- Auf Anweisungen gewartet? ☐ - Diskutiert, was zu tun ist? ☐
- Nach Ihrer Gruppe gesucht? ☐ - Zur Kabine zurückgegangen? ☐

15) Falls Sie in einer Gruppe gereist sind, wie viele Gruppenmitglieder sind mit Ihnen zum Sammelpunkt gegangen?
16) Hatten Sie Schwierigkeiten, den Weg zum Sammelpunkt zu finden? J | N
17) Hat Ihnen die Besatzung geholfen, den Sammelpunkt zu finden? J | N
18) Worauf haben Sie sich hauptsächlich während der Wegsuche zum Sammelpunkt verlassen?
1. Beschilderung 2. Anweisungen der Besatzung 3. Anderen Passagieren gefolgt 4. Vorkenntnisse
19) Wie sehr hat Ihnen die Beschilderung geholfen, den Sammelpunkt zu finden?
1. Überhaupt nicht 2. Sehr geringer Nutzen 3. Ein wenig nützlich 4. Nützlich 5. Sehr nützlich
20) Wie hilfreich war die Besatzung bei der Suche nach dem Sammelpunkt?
1. Überhaupt nicht hilfreich 2. Wenig hilfreich 3. Etwas hilfreich 4. Hilfreich 5. Sehr hilfreich
21) Waren Sie gezwungen, aufgrund von Überfüllung anzuhalten? Wenn ja, wie oft?
22) Hat einer der folgenden Punkte Ihr Vorankommen zum Sammelpunkt behindert? (Mehrere Antworten möglich)
1. Überfüllung 2. Mangel an Anweisungen 3. Anweisungen verwirrend 4. Unzureichende Beschilderung 5. Verwirrende Beschilderung 6. Irreführende Lautsprecherdurchsage 7. Zu wenig Besatzung 8. Schlechte Kenntnisse des Schiffslayouts 9. Schiffsbewegung 10. Sonstiges.......
23) Wie lange haben Sie ungefähr gebraucht, um den Sammelpunkt zu erreichen?
a) 0-2 Min b) 2-5 Min c) 5-10 Min d) 10-15 Min e) Mehr als 15 Min
24) Fanden Sie die Sammlungsübung belastend?
1. Überhaupt nicht 2. Sehr wenig belastend 3. Etwas belastend 4. Belastend 5. Sehr belastend

BITTE ABREISSEN UND FÜR DIE VERLOSUNG AUFBEWAHREN! Q0001

Scrivere il numero del dispositivo qui: Q0001

QUESTIONARIO SAFEGUARD

In quanto elemento di ricerca parte dell'esercitazione alla quale avete appena partecipato, il team "SAFEGUARD" vi sarebbe grato se poteste compilare il seguente questionario. Il vostro contributo a questa indagine potrà migliorare le norme internazionali riguardanti la sicurezza dei passeggeri a bordo. **Si prega di cerchiare una sola ed unica risposta per ogni domanda a meno che specificato diversamente.** Una volta compilato, restituite il questionario ed il dispositivo rosso indossato finora, ad un membro del gruppo di ricerca (riconoscibili dal giubbotto verde) o depositate entrambi all'interno di un contenitore apposito facilmente riconoscibile. Fate attenzione a staccare e conservare la parte perforata del questionario, alla quale parteciperà ad un'estrazione a premi! **Non dimenticatevi inoltre, di scrivere il numero del vostro dispositivo rosso (visibile sul retro del dispositivo) nel riquadro presente in cima a questa pagina.**

1) Età 11-19 | 20-39 | 40-64 | 65+
2) Sesso M | F
3) Sei affetto da alcuno di questi impedimenti fisici?
1. Problemi di vista 2. Problemi di movimento 3. Problemi d'udito 4. Altro.......
4) Se viaggi in gruppo, quante persone ci sono nel gruppo incluso tu?
5) In media, quanto volte viaggi in mare in un anno?
6) Quante volte hai viaggiato in un traghetto ad alta velocità prima d'ora?
7) Hai mai fatto parte di un'esercitazione di gruppo in una nave prima d'ora? Sì | No
8) Quando hai sentito l'allarme, cosa hai pensato fosse?
1. Un'esercitazione 2. Una vera emergenza 3. Altro.......
9) Come ti sei sentito quando ha suonato l'allarme?
1. Indifferente 2. Preoccupato che io od un membro del mio gruppo potessimo ferirci 3. Preoccupato ma tranquillo 4. Preoccupato che io od un membro del mio gruppo potessimo ferirci seriamente
10) Su quale piano eri quando hai sentito l'allarme?
11) Dove ti trovavi quando ti sei reso conto dell'allarme?
1. Nella cabina numero 2. Sedili all'aperto 3. Shopping area 4. Casino 5. Sala (lounge) di poppa 6. Snack bar centrale 7. Ristorante 8. Caffetteria self-service 9. All'esterno del sesto piano 10. Ultimo piano disco/cafè 11. Area piscina 12. Altro.......
12) Che cosa stavi facendo appena prima di renderti conto dell'allarme?
1. Dormivo 2. Mangiavo / Bevevo 3. Giocavo d'azzardo / giochi elettronici 4. Ero nel mezzo di una conversazione 5. Attività passiva individuale 6. Acquisti 7. Altro.
13) Quanto tempo hai impiegato per iniziare ad andare verso la il punto d'incontro? 0-1 min | 1-2 min | 2-3 min | 3-5 min | 5-10 min | più di 10 min
14) Che cosa hai fatto dopo che ti sei accorto dell'allarme? Indicate tutte quelle pertinenti, indicando l'ordine nel quale avete svolto le seguenti azioni (es. 1-prima, 2-seconda, 3-terza ecc)
- Sono andato direttamente al punto d'incontro ☐ - Ho continuato la mia attività ☐ - Altro....... ☐
- Ho aspettato per ulteriori istruzioni ☐ - Ho discusso il da farsi ☐
- Ho cercato il gruppo ☐ - Sono ritornato alla cabina ☐

15) Se stavi viaggiando in gruppo, quanti membri del tuo gruppo si sono mobilitati con te verso il punto d'incontro?
16) Hai avuto difficoltà a trovare il percorso verso il punto d'incontro? Sì | No
17) Sei stato assistito dall'equipaggio nel trovare il punto d'incontro? Sì | No
18) A cosa ti sei affidato maggiormente per trovare il percorso verso il punto d'incontro??
1. Segnaletica 2. Istruzioni dell'equipaggio 3. Seguire altri passeggeri 4. Conoscenze precedenti
19) Quanto ti è stata utile la segnaletica nel dirigerti verso il punto d'incontro?
1. Per niente utile 2. Scarsamente utile 3. Leggermente utile 4. Useful 5. Very useful
20) Quanto ti è stato utile l'equipaggio nell'dirigerti verso il punto d'incontro?
1. Per niente utile 2. Scarsamente utile 3. Leggermente utile 4. Useful 5. Very useful
21) Durante il tuo percorso verso il punto d'incontro sei stato costretto a fermarti a causa d'ingorghi, se sì quante volte?
22) Hai trovato alcuno dei seguenti ostacoli nel raggiungere il punto d'incontro? (puoi cerchiarne più di uno)
1. Ingorgo 2. Mancanza d'istruzioni 3. Istruzioni poco chiare 4. Mancanza di segnaletica 5. Segnaletica poco chiara 6. Annunci poco chiari 7. Insufficienza d'equipaggio 8. Scarsa conoscenza della struttura della nave 9. Movimento della nave 10. Altro.......
23) All'incirca, quanto hai impiegato per raggiungere il punto d'incontro?
a) 0-2 min b) 2-5 min c) 5-10 min d) 10-15 min e) più di 15 min
24) Ti è sembrata stressante l'esercitazione?
1. Per niente stressante 2. Scarsamente stressante 3. Leggermente stressante 4. Stressante 5. Molto stressante

STACCARE E CONSERVARE QUESTO NUMERO PER L'ESTRAZIONE A PREMI Q0001

Figure B11 Questionnaire issued to passengers after the trials on Olympia Palace.