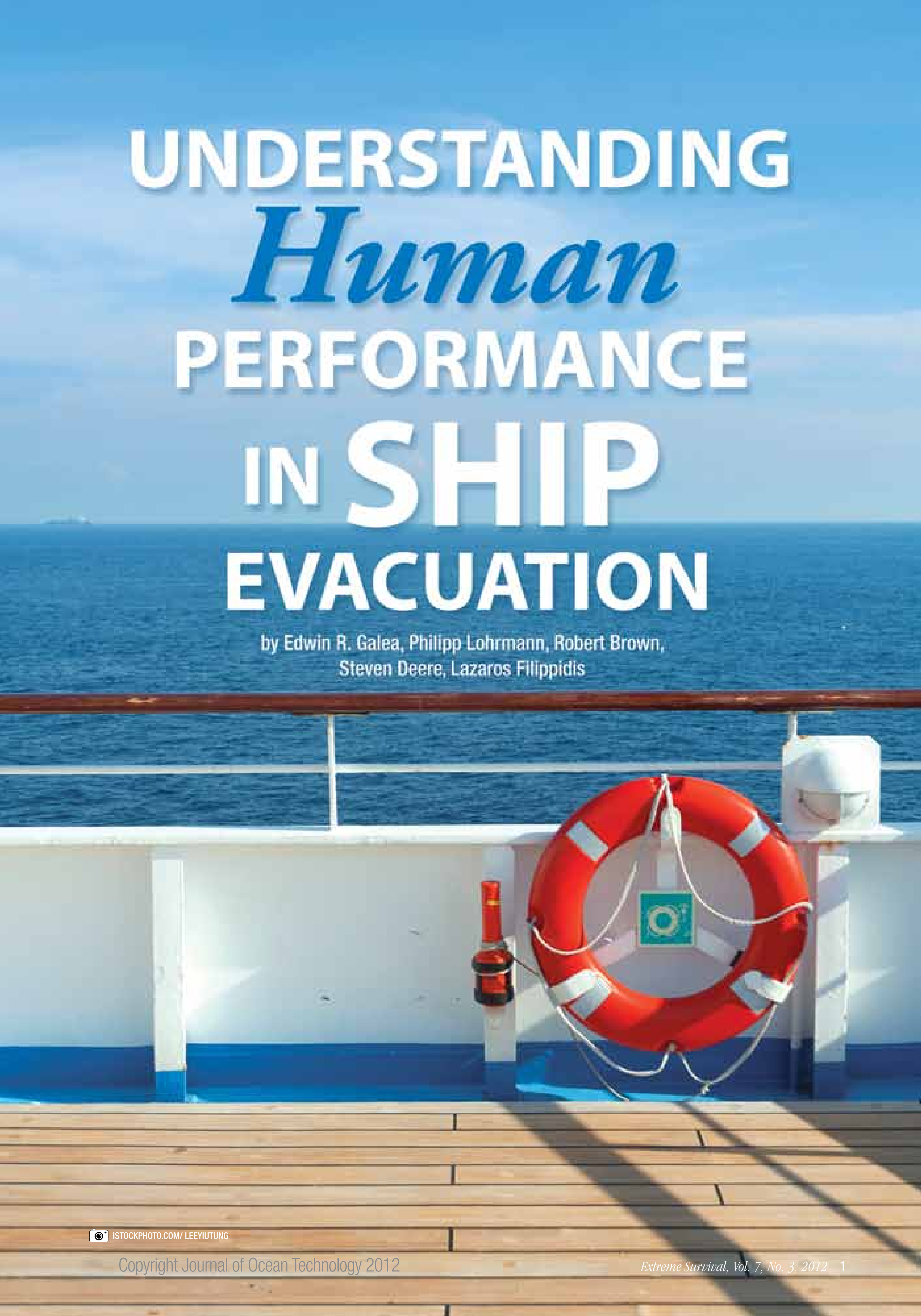
UNDERSTANDING *Human* PERFORMANCE IN SHIP EVACUATION

by Edwin R. Galea, Philipp Lohrmann, Robert Brown, Steven Deere, Lazaros Filippidis



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In order to develop realistic and robust maritime evacuation procedures, it is vital to understand how passengers behave in emergency situations. An essential component of this understanding is the collection and characterization of human performance data. However, little data relating to passenger response time or full-scale validation data in maritime environments exists. Although the International Maritime Organization's (IMO) evacuation protocol Maritime Safety Committee (MSC) *Circ. 1033 and its successor, MSC Circ. 1238, are of great use, it is known in the industry that the existing data is not representative of passenger ships in general.*

The SAFEGUARD project addresses the IMO Fire Protection Sub Committee's requirement to collect full-scale data for calibration and validation of ship-based evacuation models, as well as proposing and investigating additional benchmark scenarios to be used in certification analysis. Funded through the European Commission's 7th Framework Programme, the Newfoundland and Labrador Research and Development Corporation and Transport Canada (Marine Safety), SAFEGUARD has brought together leading industry experts and the project findings will play an integral role in framing the next iteration of international guidelines for ship evacuation analysis.

This essay describes the methodology undertaken within the full-scale assembly trials that were carried out – one of which included the largest ever real-life assembly trial on a passenger ship. The main findings are presented and highlight what this will mean for the future of ship evacuation.

The first recognized document to specify protocols for the use of ship evacuation models in order to analyze and certify passenger ship design was IMO MSC Circ. 1033 (2002). However, further research indicated that IMO MSC Circ. 1033 was unrepresentative of actual passenger response time and was liable to produce incorrect or misleading conclusions surrounding the suitability of ship design for evacuation. As part of the European Union FP5 Competitive and Sustainable Growth Programme, a project called FIRE-EXIT (led by BMT and featuring the SAFEGUARD partners University of Greenwich and the Offshore Safety and Survival Centre (OSSC)) collected passenger response time data for a passenger ship at sea during 2003 and 2004. This data was then accepted by the IMO and used in the formulation of IMO MSC Circ. 1238, the modified protocols for passenger ship evacuation analysis and certification. However, only a small amount of response time data was produced by FIRE-EXIT and it related to only one type of ship. The data collected was therefore not considered representative of passenger ships as a whole. Furthermore, no assembly time data was gathered – a crucial component of validation data.

Following this project, SAFEGUARD was proposed in order to meet a further requirement by the IMO Fire Protection Committee to measure passenger behaviour during planned assembly trials at sea. SAFEGUARD proposed to perform trials on three different types of vessels – a ferry with cabins (night passengers), a ferry without cabins (day passengers) and a cruise ship. As well as collecting response times, i.e., the amount of time it takes passengers to begin moving once the alarm has been sounded, SAFEGUARD recognized the importance of collecting assembly time data sets for use as validation data. The latter refers to the length of time it takes for a passenger to reach the designated assembly area.

The first vessel on which full-scale trials were conducted was a large Roll-on-Roll-off-Passenger-Ship/Ferry (RO-PAX) ferry called *SuperSpeed 1* (SS1), operated by Color Line, which can accommodate approximately 2,000 passengers and crew, as well as over 700 vehicles. The route taken by the vessel during the data collection trials was from Kristiansand in Norway to Hirtshals in Denmark – a trip which takes approximately three hours and 15 minutes. The ship configuration is a mixture of public passenger spaces spread over three decks including business and traveller class seating areas, large retail and restaurant/catering areas, indoor and outdoor seating areas and general circulation spaces.

To analyze a passenger's response time, a number of cameras were installed on board the ships (between 30 and 106, depending on the ship). It is important to note that once an audible alarm is sounded, each passenger's reaction will vary. The behaviour during the early stage of an evacuation can have a major impact on how the evacuation progresses; therefore, it is vital that this stage is properly understood and quantified.

Operated by Royal Caribbean Cruise Lines International, the *Jewel of the Seas* (JoS), which has a capacity of 2,500 passengers and 842 crew members, was the second vessel to be used in these real-life trials. The ship contains a variety of spaces spread over 12 passenger decks and features all of the amenities you would expect from a cruise ship of this size such as restaurant and bar areas, theatre, gym and casino, etc. The route taken by the vessel during the data collection trial was from Harwich, United Kingdom, to St. Petersburg in Russia, via Copenhagen, Denmark, a total voyage of nearly seven days. The trial was conducted on the leg of the voyage to Copenhagen. This particular trial is certainly noteworthy as it is the largest real-life monitored assembly trial ever conducted on a passenger ship while at sea.

The final vessel used was the *Olympia Palace*, an overnight ferry operated by Minoan Lines which has a maximum passenger capacity of 2,182 and can carry approximately 600 cars. This vessel performs a round trip from Patras to Venice, stopping at Corfu and Igoumenitsa on the way. One leg of the journey takes about 30 hours in total. The vessel layout is similar to SS1 with the addition of passenger cabins.

A great deal of planning was required to ensure successful data acquisition, as well as to ensure the safety of passengers and that the trials were as realistic as possible. Part of this process included receiving approval from the Research Ethics Board at the University of Greenwich before proceeding to testing. While passengers on each ship were given prior notice of the trials before boarding, they were unaware as to when exactly the alarm would happen on the journey. In order to gather the necessary data, three different data collection approaches were adopted by the SAFEGUARD team. The first was to provide the passengers with a written questionnaire after the trial had taken place. This would help to collect their own thoughts on certain aspects of the evacuation including how long they felt it took to get to the assembly point.

Secondly, to be able to analyze a passenger's response time, a number of cameras were installed on board the ships (between 30 and 106, depending on the ship). It is important to note that once an audible alarm is sounded, each passenger's reaction will vary – some may start moving towards the assembly point straight away, while others may be asleep in their cabins and respond more slowly. This behaviour during the early stage of an evacuation can have a major impact on how the evacuation progresses; therefore, it is vital that this stage is properly understood and quantified.

In order to acquire a robust set of validation data for assembly times, SAFEGUARD introduced a third approach developed by the University of Greenwich and OSSC. This methodology utilized infrared tags which were worn around the neck by each of the passengers. Up to 70 infrared (IR) beacons were positioned throughout the ships, each generating a uniquely identifiable IR light field. When a passenger passed a beacon, his/her tag would detect the unique beacon ID and record its number and the time. This meant that the passengers' start and end locations and associated times at each were recorded. Using this information, it was possible to accurately identify the exact length of time it took for passengers to reach the assembly points. This infrared based tracking system was particularly effective as it was able to accurately record the arrival time of large numbers of individuals as they entered the assembly stations. Furthermore, this system was considered more versatile than other automatic tracking systems such as radio-frequency identification (RFID) because it required no external power supplies or cables; therefore, transportation and set up was simple.

Five full-scale trials (two on SS1, two on *Olympia Palace* and one on the JoS) were performed with more than 4,300 passengers assembled. Over 100 Gigabytes of video data,

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as well as over 3,000 questionnaires, were collected and evaluated by the SAFEGUARD consortium. Response times were collected from video for all five trials and provide a robust set of response time data. The IR system was found to be very effective; however, due to a dysfunctional beacon in one of the SS1 trials, the collection of assembly time data was not possible in this particular trial. Furthermore, in each of the two trials for the *Olympia Palace*, more than 50% of the passengers were already inside the assembly stations and less than half the passengers on board participated in the trials, which meant that the resulting assembly time data sets were not suitable for use as validation data. Despite these challenges, SAFEGUARD has been able to produce two robust validation data sets – one from the second trial on the SS1 and the other from the JoS.

So what did the trials actually reveal? A comprehensive data analysis performed by the University of Greenwich and OSSC produced the following results. In total, response times from over 2,200 people were collected making it the largest response time data set ever collected on land or sea. In order to collect the response time for a passenger, one must observe the passenger's behaviour following the alarm and record the time that has elapsed to the point when the passenger is deemed to have started purposeful movement to the assembly station. The team spent many months analyzing video to collect these times and the resulting dataset provided a Response Time Distribution (RTD) for each of the trials conducted.

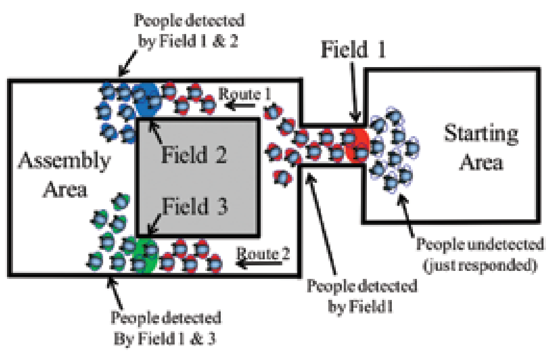
Interestingly, the RTD for each of the trials that took place on the SS1 are very similar, despite the fact that each of the trials was carried out with different people. This would suggest that if the trial were to be repeated again within the same environment with a different group of similar people, we would expect to generate the same RTD – certainly a powerful result. As there were no significant differences between the two RTDs for the SS1, the results from both days can be combined to form a single data set that is representative of RO-PAX ferries without cabins.

When considering the results of the assembly trial that took place during breakfast on the JoS, it is important to note that a number of passengers were still located in their cabins when the alarm sounded. The passenger response times collected were therefore divided into two main groups – passengers who were in their cabins and those who were in public areas. Comparing the RTDs for each of these groups shows that the results were quite different, which would suggest that different RTDs should be used to represent passengers in cabins and those in public spaces on cruise ships. It was clear that passengers in cabins take considerably longer to respond than those who are in public areas – they may have been asleep, for example.

As the JoS is a different class of vessel to the SS1 (RO-PAX without cabins), it was vital to determine if there were any similarities in the resulting RTDs for public spaces on each vessel. The data showed that the distributions are statistically different – another significant outcome – further showing that an RTD generated for one class of vessel cannot necessarily be applied to another type of ship. Furthermore, the data revealed that passengers in public spaces on a cruise ship take considerably longer to respond to the alarm than passengers in public spaces on a RO-PAX vessel.

The implication of this finding is that the current RTD used in IMO MSC Circ. 1238, which is derived from the assembly trials on a RO-PAX vessel from the earlier FIRE-EXIT project, is not appropriate for all ship classes and different RTDs should be used for cruise and RO-PAX vessels. It is further noted that all the trials took place at approximately the same time of day – therefore this is not considered to be a contributory factor in the differences observed.

In addition to determining response time distributions, SAFEGUARD will also enhance



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the existing benchmark scenarios for evacuation analysis by introducing new scenarios that include the effects of heel and trim angles, as well as fire on board a ship. Both of these aspects can have significant consequences on the evacuation process. In particular, any heel of the vessel can reduce the walking speed of the passengers and crew and thus delay the assembly process. Fire, on the other hand, can block off important escape routes and assembly stations and the presence of smoke, heat and toxic gases can also result in a reduction of walking speeds. In spite of their importance, both of these scenarios are currently missing from the international regulations. The development of these new scenarios is based on an in-depth analysis of previous maritime accidents (as performed by Bureau Veritas) and on extensive software simulations, undertaken by Safety at Sea, Principia and the University of Greenwich.

In summary, the SAFEGUARD project will provide three main results to the maritime community:

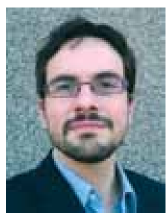
1. A robust set of response time distributions based on real-life passenger trials for more realistic evacuation simulations.

2. Two validation data sets for the calibration and testing of evacuation simulation software.

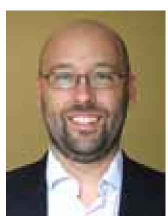
3. Enhanced benchmark scenarios, taking into account the effects of heel, trim and fire.

These results will be presented at a one day seminar to be held at the Royal Institution of Naval Architects (RINA) in London on November 30, 2012. The SAFEGUARD team in association with RINA will also shortly be presenting the main results to the IMO in the form of three information papers.

Professor Edwin R. Galea is the founding director of the Fire Safety Engineering Group (FSEG) of the University of Greenwich in London where he has worked in the area of Computational Fire Engineering research since 1986. FSEG are developers of the EXODUS suite of evacuation software and the SMARTFIRE fire simulation software. Professor Galea's personal research interests include human behaviour in emergency evacuation situations, pedestrian dynamics, evacuation and pedestrian dynamics simulation, fire dynamics and CFD fire simulation. Professor Galea is the author of over 200 academic and professional publications and serves on a number of standards committees concerned with fire and evacuation for organizations such as IMO, ISO, BSI and the SFPE Task Group on Human Behaviour in Fire. He also sits on several UK government committees concerned with civil defence. He has served on several major inquiries and legal cases as an expert in fire and evacuation including the Paddington Rail Crash, the Swiss Air MD11 crash, and the Admiral Duncan Pub bombing and assisted the IMO in framing MSC Circ.1033 and 1238. Professor Galea is the technical lead to the EU FP7 project SAFEGUARD and is involved in the EU FP7 project FIREPROOF which is concerned with fires on passenger ships.



Dr. Philipp Lohrmann holds a PhD in Mathematics from King's College London. Since joining BMT in 2010, he has been working on several FP7 projects concerning ship safety, including FLOODSTAND and FIREPROOF. He has been project manager of SAFEGUARD since 2011.



Robert Brown is a professional engineer with 15 years experience in the planning, conduct and dissemination of applied research. For the last nine years, Mr. Brown has led research at the Offshore Safety and Survival Centre (OSSC) of the Marine Institute, examining aspects of evacuation, survival and rescue at sea. He holds a master of engineering from Memorial University (ship manoeuvrability in sea ice) and is currently completing a doctor of philosophy from the University of Greenwich with a focus on human performance during the mustering process on large-scale passenger ships. Mr. Brown is a member of the Society of Naval Architects and Marine Engineers as well as a fellow of the Royal Institute of Naval Architects. He was a guest editor for *The Journal of Ocean Technology's* safety at sea issue in 2010.

Steven Deere is a Research Fellow in the Fire Safety Engineering Group at the University of Greenwich. Dr. Deere's undergraduate degree was in computer science and his PhD focused on improving the efficiency of naval vessels in both emergency and non-emergency scenarios in terms of human factors performance. His PhD work was used to update the international regulations governing the evacuation analysis of vessels.

Lazaros Filippidis has been a member of the Fire Safety Engineering Group of the University of Greenwich since 1996. He is involved in the research and development of the EXODUS evacuation models. He has worked on numerous large scale projects including the EU funded Framework 5 projects FIRE-EXIT and VELA, Framework 6 projects AVATARS and NACRE, and the Framework 7 project BESECU and SAFEGUARD. His work on these projects includes the design and implementation of very large full-scale evacuation experiments for data collection, model development and validation protocols for aircraft, buildings and ships. Mr. Filippidis' key research interests include adaptive behaviour of people to stimuli such as instruction from others, signage, reaction to fire, etc. He has a main role in the annual Principles and Practice of Evacuation Modelling short course that attracts an international audience of professionals working in the fire safety field. His teaching role also includes the preparation and delivery of short courses in other countries and institutions. The courses cover all aspects of fire safety engineering and human behaviour in emergency and circulation situations.