Proceedings of the 13th International Fire Science & Engineering Conference, Interflam 2013 24-26th June 2013, Royal Holloway College, London, UK, **Volume 2, pp. 893-906. ISBN 978 0 9556548-9-3, 2013.**

INVESTIGATING THE IMPACT OF CULTURE ON EVACAUTION BEHAVIOUR – A UK DATA-SET

Edwin Richard Galea, Gary Sharp, Lazaros Filippidis, Steven Deere, Markus Sauter
Fire Safety Engineering Group, University of Greenwich, 30 Park Row, Greenwich
London SE10 9LS UK

ABSTRACT

In this paper results from an unannounced evacuation trial conducted within a library in London, UK are presented and discussed. This experimental evacuation is part of a large international study investigating the impact of culture on evacuation behaviour. In addition, a framework to enable the systematic analysis of Response Phase behaviours is presented and applied to the trial data. The framework not only provides a consistent method for describing Response Phase behaviour, but also provides a framework for classifying and quantifying the Response Phase other than simply using the overall response time. An empirical response time model, based on data generated using the framework is also presented and applied to the evacuation trial data. The empirical response time model produces a prediction for the average response time for the trial population which is within 3.9% of the measured value. Taken across all four evacuation trials, undertaken in four different buildings in four different countries, the empirical response time model is able to predict the average response time to within 5.0%.

INTRODUCTION

Project BeSeCu (Behaviour, Security and Culture)[1-4] is an EU FP7 funded research project with the aim of studying how people react in an emergency, and to determine whether there are any cultural factors – both social culture and fire safety culture – which impact emergency behaviour. By social culture we mean a society's shared system of values, beliefs and attitudes that influences that society's perception of the world and its behavioural response to both every day encounters and unusual incidents. When discussing social cultures it must be emphasised that we are not talking about individuals but of large populations and so are attempting to compare one normal distribution of behavioural response for one population with that of another. Aspects of social culture which may differ from one society to another include degree of physical contact, nature and extent of eye contact, degree of physical social separation, sense of community, feelings of fatalism, levels of machismo, risk perception, response to authority, acceptable levels of public and private signs of emotion, etc. By fire safety culture we mean the regulatory fire safety framework, supported by legislation, prescriptive guidance, education efforts, performance guides and most important enforcement that exists within a society. This top-down safety culture (where safety levels are imposed) is, to some degree, supported by a bottom-up expectation of the public regarding safety levels in general. This extends far beyond fire safety with the public having high expectations regarding the functionality and safety levels reached in all aspects of life.

It is often suggested that differences in culture may influence the response of the public to emergency procedures. Specifically, it is hypothesised that the differences in both the social and fire cultures may result in differences in response behaviours and response times. As part of project BeSeCu, evacuation behaviour was investigated through surveys of people who have had first-hand experience of real emergencies and through a series of unannounced evacuation trials. The surveys were conducted in several countries – namely, the Czech Republic, Germany, Italy, Poland, Spain, Sweden, Turkey, and the UK. With samples including adults of different ages, gender, socio-economic status, and ethnic groups, this part of the project generated an evidence base of inter-individual differences that may be used to enhance communications and procedures in emergency interventions. In order to have a more rounded perspective of communications and procedures, the vast professional experiences of first responders from different regions and ranks were also collected and analysed[4]. The experimental component of project BeSeCu addressed issues associated with Response Phase behaviours and the impact of culture. The evacuation process can be considered to comprise two broad phases, called the Response Phase and Evacuation Movement Phase[1-3,5]. It is now widely accepted that a key factor which can determine the success of an evacuation is the speed with which occupants respond to the call to evacuate and begin purposeful movement to a place of safety, commonly referred to as the response time[5-9] (also called pre-movement time). In practical fire engineering applications it is common practice to assume that evacuation related data can be reliably applied more widely than the context from which the data was collected. In particular, this type of data is often applied to situations within cultural environments – both social and fire – different to that from which the data was collected. The majority of readily available published evacuation data (both response time and total evacuation time) that is used in fire engineering applications throughout the world originates from a small number of countries with broadly similar cultural backgrounds; i.e., UK, USA, Canada, Australia and New Zealand. There has been very little effort in exploring the impact of culture on fire evacuation behaviour, especially outside of the small number of countries mentioned. Here we take culture to mean both the social culture and the fire safety culture of the society that the occupants belong to. This begs the question, can response time data collected from predominately Western European/North American type social cultures (UK, Australia, Canada, USA, New Zealand) be applied in significantly different social cultures such as in Japan, China, Korea, Turkey, Czech Republic, Brazil, etc? Is there a cultural component to the time required to complete the Response Phase? Furthermore, can response time data derived from countries with a well developed fire culture and legislative framework e.g., UK, Australia, Canada, USA, New Zealand, Japan be applied in countries with a less well developed fire culture and legislative framework e.g. Turkey, Brazil, Korea, Czech Republic, etc? Does a well-developed fire culture influence the time required to complete the Response Phase and commence the Evacuation Movement Phase?

The experimental component of project BeSeCu involved three unannounced library evacuations run in the Czech Republic, Turkey and Poland. Response Phase behaviours derived from these trials will be compared with data generated from a similar evacuation conducted in the UK. These comparative studies are based not simply on response times but on a framework, developed as part of project BeSeCu, to describe Response Phase behaviours[5]. In earlier papers the evacuation behaviour framework was presented along with a response time data-set derived from the first three evacuation experiments conducted in the Czech Republic[1], Turkey[2] and Poland[3]. In this paper we present the evacuation data-set derived from the fourth and final evacuation trial conducted in the UK.

RESPONSE PHASE BEHAVIOURAL FRAMEWORK

Within the proposed evacuation behaviour framework[5], the evacuation process is considered to comprise of two broad phases the; Response Phase and Evacuation Movement Phase (see figure 1). The framework attempts to convey the nature of the human factors processes that characterise Response Phase behaviours. This description not only provides a consistent method for describing Response Phase behaviour, but also provides a useful framework for classifying and quantifying the Response Phase other than simply using the overall response time. Using this framework we may eventually be able to develop predictive models to estimate response times. A key part of the Response Phase analysis is the determination of the Notification, Cognition and Activity stage start and end points[5] (see figure 1).

Notification Stage

The first stage of the Response Phase is the Notification stage (see figure 1). In the Notification stage, notification cues such as an alarm conveys to the occupants that an unusual and potentially hazardous event has occurred, requiring the occupants to evacuate. The notification cues may be a traditional alarm such as a siren or an alarm bell, a voice alarm, intervention by staff or environment cues such as the smell of smoke etc. The start of the Notification stage is marked by the occupants being exposed to the first cues. During the Notification stage the occupant may (knowingly or unknowingly) ignore the cues and continue with their normal activities as they have not accepted or recognized that the cues are relevant to their situation. For each exposed occupant, the end of the Notification stage is marked by the occupants responding to the notification cues by mentally and/or physical disengaging from the tasks they were previously involved in and the recognition that the cue(s) they have been subjected to indicate that something unusual may be occurring in their environment. At the end of the Notification stage, while the occupants are alerted that something unusual is occurring in their environment, they have not started to physically react to the situation. The end of the Notification stage marks the beginning of the Cognition stage.

Cognition Stage

During the Cognition stage the alerted occupants interpret the information provided by the initial notification cues, and potentially other sources of information (e.g. further incident related cues, staff intervention, etc), and decide how they should respond (see figure 1). There are essentially three broad types of response the occupant may decide to undertake:

- In the first type of response, the initial notification cues have been insufficient to convey to the occupant the immediate need for evacuation and so the occupant re-engages in their previous activity until further cues or information is received. In this case, the Cognition stage continues until one of the other two possible responses occur.
- In the second type of response, the occupant has recognised the initial notification cues and as a result, immediately commences evacuation movement without undertaking any other activity. Alternatively, the occupant may have ignored the initial notification cues and re-engaged in their pre-notification activity but then acknowledges additional cues and as a result immediately commences evacuation movement without undertaking any other activity. In these cases the end of the Cognition stage also marks the end of the Response Phase and the beginning of the Evacuation Movement Phase.
- In the third type of response, the occupant acknowledges that the notification cues indicate that something potentially hazardous is occurring in their environment and as a result undertakes a series of Action and/or Information tasks, marking the start of the Activity stage. In this case, cognitions may be occurring at the same time as activities, activities could be sparking new cognitions and cognitions could initiate one or more new activities. As a result, the Activity stage can run in parallel to the Cognition stage. However, the physical duration of the Cognition stage is less well defined as it may have several possible end points and so is taken to run to the end of the Activity stage.

Activity Stage

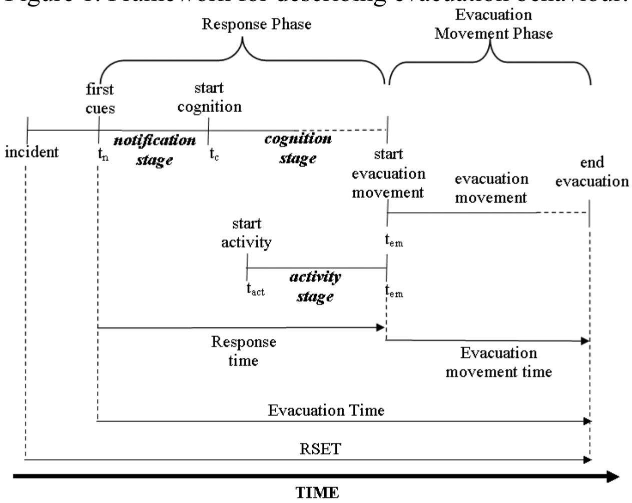
At the start of the Activity stage the occupant performs a series of Information and/or Action tasks[1-3,10] which were conceived during the Cognition stage (see figure 1). These are defined as follows:

- An Action task involves the occupant physically undertaking an activity such as: shutting down a work station; packing work items; packing/collecting personal belongings in the immediate vicinity; physically moving to another location to perform an action (e.g. fight fire, collect an item).
- An Information task involves the occupant seeking, providing or exchanging information concerning the incident or required course of action and may include; calling someone on the phone to seek / provide information; seeking / providing information in person; engaging with

electronic media (e.g. television, radio, text services, etc); investigating the incident. Information tasks may thus involve the physical movement of the occupant; however, what distinguishes this activity from an Action task is the end purpose of the movement i.e. to obtain information or to undertake a physical task.

It is hypothesised that the Cognition stage may run in parallel to the Activity stage, and so the occupant may return to the Cognition stage to interpret new information gained, assess their current situation and contemplate their next course of action, which may in turn require further Action/Information tasks to be executed. Thus, during the Activity stage, there may be brief periods where the occupant appears to be undertaking no specific task. The start of the Activity stage is marked by the commencement of the planned tasks while the end of the Activity stage is marked by the completion of all tasks conceived during the Cognition stage. The end of the Activity stage usually denotes the end of the Response Phase and the beginning of the Evacuation Movement Phase. It is only at the start of the Evacuation Movement Phase that the occupant begins their purposeful movement to an exit or stair or place of safety.

Figure 1. Framework for describing evacuation behaviour.



VIDEO ANALYSIS AND EQUIPMENT SET UP

Video footage collected from the evacuation trials is analysed frame by frame to determine response times and Response Phase behaviours. In this type of analysis, for the most part, it is not possible to determine the end of the Notification and start of the Cognition stages. This is because from the video footage alone it is difficult to determine when incident related cognitions occur. However, using the video footage it is possible to determine when someone’s behaviour changes from that which they were involved in prior to the Notification stage to those behaviours defined in the Activity stage such as seeking information, packing away belongings and shutting down equipment, etc. Thus, in the video analysis, the Cognition and Activity stages are combined and referred to simply as the Activity stage. As a result the video analysis provides the following information:

- The start of the Response Phase (i.e. the start of the Notification stage) which is indicated by the first notification cues e.g. the sound of the alarm or staff intervention.
- The end/start of the Notification/Activity stage where people begin to perform action and information tasks prior to starting the Evacuation Movement Phase.
- The number, type and duration of Action and Information tasks performed.
- The end point of the Activity stage and the commencement of the Evacuation Movement Phase.
- Response Time.

Proceedings of the 13th International Fire Science & Engineering Conference, Interflam 2013 24-26th June 2013, Royal Holloway College, London, UK, **Volume 2, pp. 893-906. ISBN 978 0 9556548-9-3, 2013.**

Unlike the other three evacuation trials, in-house CCTV cameras were used to collect the required data. A total of 22 rooms in the library were under surveillance through CCTV cameras, of which a total of 15 proved useful for analysis. Thus, data from 15 internal CCTV cameras (see figure 2) were used in this analysis. The evacuation trial took place on the 22 January 2007 in the University of Greenwich Dreadnought Library.

Figure 2. Views from 6 of the 15 CCTV cameras used in the Response Phase analysis

Camera 150

Camera 189

Camera 374

Camera 360b

THE EVACUATION TRIAL

The building has three floors each with a usable area of 3000 m^2 with dimensions of each floor approximately 50m x 60m. The structure has six staircases and eight exits, of which only one is in normal use, the other seven being emergency exits. The library building has mixed occupancy and accommodates staff offices, computer rooms, study areas, reading rooms, discussion rooms etc. The library has 27 members of staff and an average monthly usage of 5200 visitors. The library has three unannounced evacuation drills per year in which the entire library is evacuated. Staff are trained to ensure that their section of the library is cleared prior to evacuating. Academic staff with classes in the library are also trained to ensure that their class evacuated prior to leaving the building. The alarm system consists of a simple alarm bell. In this evacuation the following procedure was employed: the alarm sounded; a large number of staff performed a sweep encouraging the population to evacuate; evacuees then moved to a designated assembly point.

It is noted that this evacuation trial was not undertaken as part of project BeSeCu but was undertaken by FSEG in 2007. The collected CCTV data was reanalysed using the BeSeCu protocols. At the time of the alarm there were 453 people in the library based on an exit count. From the video analysis, the response phase behaviour of 104 students could be analysed, of which 53 were males and 51 were females. From the results of the exit questionnaire, 55% of the population had never heard the alarm in the building or evacuated from the building prior to this evacuation trial.

TRIAL RESULTS AND DISCUSSION

Based on the video analysis at the time of the alarm, 53% of the entire population were working at a computer, 36% were engaged in other work related activities and 9% were involved in social engagement. The remainder of the population were engaged in a variety of activities such as sitting, walking, sleeping, etc. Thus 89% of the population was engaged in a work related activity at the time of the alarm with 53% engaged in computer activities.

Analysis of Response Phase Data

The response time for each person is determined from the start of the alarm (first cue and start of the Notification Stage), to the point where the person began purposive movement towards an exit (end of Activity Stage and start of Evacuation Movement Phase). Video analysis suggests that there were two distinct populations in the library:

- Pop1: those who responded just to the sound of the alarm, which consisted of 63 people, and
- Pop2: those that responded to both the alarm and staff intervention, which consisted of 41 people.

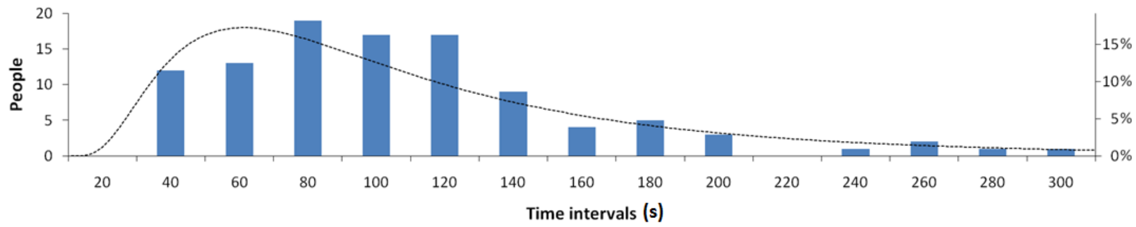
Pop2 can be further subdivided into two sub-populations:

- Pop2a: those that started their Activity stage AFTER staff intervention (13 or 32%), and
- Pop2b: those that started the Activity stage PRIOR to staff intervention (28 or 68%).

The response time distribution for the population is presented in figure 3, while the response time distribution for Pop1 and Pop2 are presented in figures 4 and 5 respectively. As can be seen from figures 3-5, each response time distribution approximately follows a broadly log-normal profile. The log-normal curves shown in figures 3, 4 and 5 have log means of 4.40, 4.32 and 4.60 respectively and log standard deviations of 0.57, 0.64 and 0.39 respectively. The average response times for the various populations and sub-populations are as follows:

- Total - 98 sec; Pop1 – 92 sec; Pop2 – 108 sec; Pop2a – 133 sec; Pop2b – 97 sec.
- Total: 12% respond in 40 sec; 59% respond in 100 sec; 84% respond in 150 sec.
- Pop1: 19% respond in 40 sec; 63% respond in 100 sec; 87% respond in 150 sec.
- Pop2: 0% respond in 40 sec; 51% respond in 100 sec; 80% respond in 150 sec.

Figure 3. Response time distribution for entire student population (UK)



Proceedings of the 13th International Fire Science & Engineering Conference, Interflam 2013 24-26th June 2013, Royal Holloway College, London, UK, **Volume 2, pp. 893-906. ISBN 978 0 9556548-9-3, 2013.**

Figure 4. Response time distribution for population reacting only to alarm, Pop1

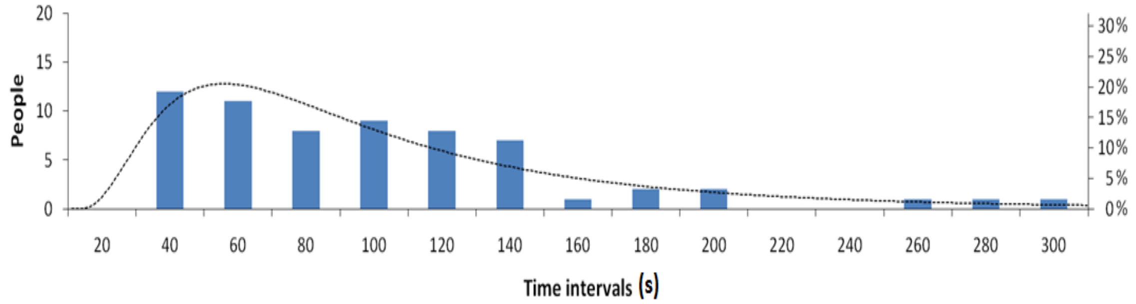
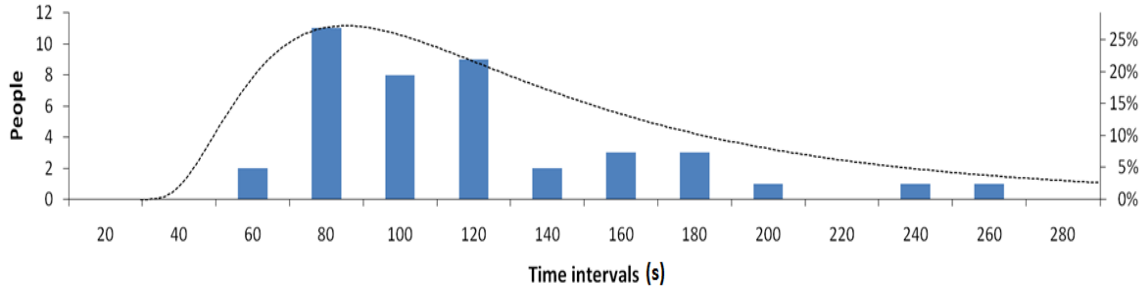


Figure 5. Response time distribution for population reacting to alarm and staff intervention, Pop2



The average response time for the entire population is quite long. This may be a result of the use of a tone alarm or that 45% of the population had experienced an alarm previously in the library. Furthermore, a significant proportion of the population was engaged in a work related activity (89%) prior to the alarm, with 55% engaged in computer based work. This may also explain why the population had a relatively long response time. While the average response time for Pop1, the population that did not involve a staff intervention, was similar to that of Pop2, the population with staff intervention, Pop1 had a higher proportion of rapid responders.

Simply considering the overall response time does not provide insight into the nature of the Response Phase behaviours. To gain a better understanding of the factors contributing to the observed response time distributions it is necessary to decompose the Response Phase into the constituent stages as identified in figure 1. This is achieved through detailed analysis of the video footage.

A total of 957 tasks were identified during the Response Phase for the entire building population, 515 individual Action Tasks (AT) and 442 Information Tasks (IT). The most common combination of tasks was 5 ATs and 2 ITs and this combination was completed by 7 people. The most common number of ATs was 5 performed by 19 people and the most common number of ITs was 2 performed by 21 people. The maximum number of tasks performed by a single person was 22 tasks (made from a combination of ATs and ITs), while the maximum number of ATs performed by a single person was 13 and the maximum number of ITs performed by a single person was 13. In addition, the most common ITs, expressed as a percentage of the total number of ITs were; "Acquire information from the environment (looking, listening)" 71%, and "Engage in information exchange" 24%. The most common ATs, expressed as a percentage of the total number of ATs were "Collect Belongings" 36%, "Pick up bag" 23%, "Collect clothing" 16% and "Secure computer" 6%.

The key findings of the functional analysis can be summarised as follows:

- **Average Notification Time:**

  - Total – 20.9 sec; Pop1 – 17.8 sec; Pop2 – 25.6 sec; Pop2a – 69.8 sec; Pop2b – 5.1 sec
  - Total: 65% in 5.0 sec; 70% in 10 sec.
  - Pop1: 73% in 5.0 sec; 78% in 10 sec.
  - Pop2: 54% in 5.0 sec; 59% in 10 sec.
  - Pop2a: 0% in 5.0 sec; 0% in 10 sec.
  - Pop2b: 79% in 5.0 sec; 86% in 10 sec.
  - While the average Notification time for Pop1 is quite long, a significant proportion of the population (78%) have notification times of less than 10 sec. Two members of Pop1 have extremely long notification times (193 sec and 231 sec). These two were involved in computer work prior to the alarm. If these two times are excluded, the average Notification time for Pop1 drops to 11.5 sec.
  - Pop2 has a very long average Notification time, and a significant proportion of Pop2 (41%) have Notification times longer than 10 sec. Pop2 is made up of two sub-populations with long Notification times (Pop2a) and short Notification times (Pop2b).
  - Pop2a – comprising 32% of Pop2 - started their Activity stage only after staff intervention. The average notification time for this sub-population was 69.8 sec with an average staff intervention time of 45.3 sec. For this sub-population, staff intervention was required to encourage the participants to disengage from their pre-alarm activities – 100% of which was work related. On average, Pop2a disengaged from their pre-alarm activities 24.5 sec after the staff intervention. It is noted that this time is longer than the Notification time for Pop1 (17.8 sec). This produces an average response time measured from (the first) staff intervention of 87 sec. It is possible that without staff intervention, Pop2a would have incurred even longer Notification times. The average response time for Pop2a measured from the first staff intervention is comparable to the average response time for Pop1, but is some 45% longer than Pop1 if measured from the alarm.
  - Pop2b – comprising 68% of Pop2 - started their Activity stage prior to staff intervention which occurred on average at 50.5 sec after the alarm. The average Notification time for this sub-population was 5.1 sec, so for this sub-population staff intervention was not required to disengage from their pre-alarm activities. The average response time for this sub-population was 97 sec or 46 sec measured from the staff intervention. The average response time for Pop2b measured from the alarm is comparable to that of Pop1, thus with the staff intervention, Pop2b achieved an average response time only marginally longer than the average response time for Pop1.
  - Thus for Pop2b, staff intervention had no impact on Notification time while for Pop2a it may have prevented the population from incurring even longer Notification times.

- **Average Total Number of Tasks:**
  - Total – 9.2; Pop1 – 8.8; Pop2 – 9.8; Pop2a – 7.7; Pop2b – 10.7
  - On average the population reacting only to the alarm (Pop1) undertook fewer tasks than the population subjected to the alarm and staff intervention (Pop2). This supports the observation that Pop1 had a shorter average response time. However, the two alarm and intervention sub-populations behaved significantly differently to each other.
  - For sub-population Pop2a, staff intervention did slightly reduce the number of tasks undertaken compared to the alarm only group (Pop1). While Pop2a undertook the least number of tasks, they still completed a significant number of tasks on average, suggesting that the Activity stage was not significantly reduced to compensate for the extremely long Notification stage. The fewer number of tasks completed in the Activity stage would suggest that the Activity stage for Pop2a was shorter than that for Pop1.
  - Sub-population Pop2b undertook significantly more tasks than Pop2a and more tasks than Pop1. Thus rather than undertaking fewer tasks during the Activity stage as maybe expected through staff intervention, this sub-population has undertaken more

tasks compared to the alarm only group (Pop1). The large number of tasks undertaken by Pop2b contributed to the long response time. However, it is possible that the staff intervention may have prevented this sub-population from undertaking even more tasks which would have led to an even longer response time.

  - Thus for Pop2a, staff intervention may have slightly reduced the number of tasks undertaken during the Activity stage and shortened the duration of the Activity stage. For Pop2b, staff intervention appears to have had no impact on the number of tasks undertaken during the Activity stage, but may have prevented even more tasks from being undertaken.

- **Average Number of Action and Info Tasks:**
  - Total: 5.0 and 4.3; Pop1: 4.9 and 3.9; Pop2: 5.0 and 4.8**;**
  - Pop2a: 4.7 and 3.0; Pop2b: 5.1 and 5.6
  - For the total population, Pop1 and Pop2, more Action Tasks than Information Tasks were undertaken. Overall, the total population undertakes 16% more Action than Information Tasks. The population exposed to just the alarm (Pop1) undertake 26% more Action than Information Tasks while the population exposed to the alarm and staff intervention (Pop2) undertake only 4% more Action than Information tasks. However, the two alarm and intervention sub-populations behaved significantly differently to each other.
  - Sub-population Pop2a undertakes 57% more Action than Information Tasks. Pop2a undertakes significantly less Information Tasks than Pop1. The fewer Information tasks undertaken by this sub-population may be the result of not needing to receive confirmation or transfer information following the staff intervention – which for this group was repeated up to three times. However, the number of Action Tasks undertaken is similar to that of Pop1, suggesting that a minimum number of Action tasks are required to be completed prior to commencing the movement phase.
  - Sub-population Pop2b undertakes 10% more Information than Action Tasks. This is a complete reversal of the trends for the other population groups. While the number of Action Tasks is similar to the other population groups, the number of Information tasks is 44% greater than that of Pop1. This is the result of four individuals, who were engaged in social engagement activities prior to the alarm, each undertaking more than 10 Information Tasks. If these four are excluded from the analysis, the number of tasks undertaken by Pop2b become 4.5 and 3.9, which follows the trends of more Action than Information tasks.
  - Overall the population undertakes more 16% Action than Information Tasks. For Pop2a, staff intervention has not reduced the number of Action Tasks but has reduced the number of Information Tasks. The (repeated) presence of the staff member reducing the need for information exchanges between the sub-population. For Pop2b, staff intervention has not reduced the number of Action Tasks however, the number of Information Tasks has increased. This is the result of four members of the population engaging in social exchanges prior to the alarm and during the alarm.

- **Average Duration of Action and Info Tasks:**
  - Total: 8.3 and 10.3 sec; Pop1: 7.6 and 11.2 sec; Pop2: 9.2 and 9.4 sec
  - Information Tasks take longer than Action Tasks for all populations.
  - Overall, the population takes 24% longer to undertake an Information Task than an Action Task.
  - For Pop1 (the population exposed just to the alarm) Information Tasks take 47% longer than Action Tasks.
  - For Pop2 (the population exposed to alarm and staff intervention), Information Tasks take only 2% longer than Action Tasks.

- An Information Task is 19% longer for Pop1 (alarm only) compared to Pop2 (alarm and intervention). This is thought to be due to occupants exposed to a staff intervention being provided with additional information not available to those exposed to the simple tone.

Staff intervention is intended to shorten the response phase of individuals, in particular those individuals that may take excessive time responding. The staff intervention process achieves this by reducing the targeted occupants Notification stage or Activity stage or both stages of the Response Phase.

In the UK evacuation trial the staff intervention population consisted of two distinct groups. The first group (Pop2a) had exceptionally long Notification times. For this group the average Notification time (69.8 sec) exceeded the average notification time for the alarm only population (17.8 sec) and the average staff intervention time (45.3 sec). On average this population disengaged from their pre-alarm activities 24.5 sec after the staff intervention – a longer notification time than that for the alarm only population. Clearly, this sub-population was intent on completing their pre-alarm activities. However, without staff intervention, these individuals may have incurred even longer Notification times. So staff intervention may have resulted in these individuals completing the Notification stage sooner than would otherwise have occurred. Furthermore, these individuals undertook fewer tasks in total (7.7) during the Activity stage than the alarm only group (8.8). This resulted in a shorter Activity stage compared to the alarm only group. The response time for this group (133 sec) was significantly longer than that for the alarm only group (92 sec), but may have been even longer without the staff intervention. For this group, staff intervention potentially reduced what are exceptionally long Notification times from being even longer and reduced the duration of the Activity stage.

The second group (Pop2b) had completed the Notification stage (5.2 sec) and commenced the Activity stage well before any staff members appeared (50.8 sec). For this group the Notification time was extremely short and was not influenced by the staff intervention. However, this group undertook more tasks during the Activity stage (10.7) than the alarm only group (8.8) (Pop1). It is possible that the staff intervention prevented even more tasks from being undertaken during the Activity Stage, preventing the Activity stage from taking even longer. The response time for this group (97 sec) was marginally longer than that for the alarm only group (92 sec). For this group, staff intervention potentially reduced the duration of the Activity stage.

Predictive Response Time Model

An empirical model was developed to predict the average response time for a population based on the Response Phase parameters defined using the framework, as shown in equation 1[1-3].

$$RT = [NT + (NAT \times ATT) + (NIT \times ITT)] - [W \times X \times FOL_{max} \times ATT] + [Y \times Z \times TNT \times (ATT + ITT)/2] \quad (1)$$

Where: RT = Response Time (s); NT = Notification Time (s); NAT = Number of Action Tasks; NIT = Number of Information Tasks; TNT = Total number of tasks; ITT = Information Task time (s); ATT = Action Task time (s); FOL_{max} = Max number of overlapping tasks; W, X, Y and Z are constants.

In this expression the first three terms on the right side measure the sequential nature of the Notification and Activity stages. The bulk of the time in the Activity stage is simply made up of the time required to perform a number of ATs and ITs. The duration of the Notification stage, the number and type of tasks and the average duration of an AT and IT are all dependent on the nature of the notification process, e.g. staff intervention and the type of environment e.g. library. It is also possible that there is a cultural component to each of these parameters. The fourth term is a correction factor that takes into consideration that a proportion of ATs can be performed simultaneously with ITs thereby reducing the calculated response time. The maximum number of overlapping tasks is dependent on the relative number of ATs and ITs and is given by:

$$FOL_{max} = NIT \text{ if } NAT \geq NIT \qquad (2)$$
$$FOL_{max} = NAT \text{ if } NAT < NIT$$

In equation 1, W is a measure of the likelihood that tasks overlap and *X* is a measure of the degree of task overlap. The last term in equation 1 is a correction factor that takes into account brief periods during the Activity stage where no task is undertaken. This is assumed to be when the occupant is considering their next course of action and so represents a brief Cognitive stage or cognition pause. In this case the Cognitive stage does not occur in parallel to the Activity stage but in sequence to it. To compensate for this a small portion of time, representing the cognition pause, is added to the total response time. Cognition pauses can occur following each of the *TNT* tasks. However, they are observed to occur significantly less frequently than this, and the proportion of tasks that are followed by a cognition pause is represented by a constant *Y*. In most cases the cognition pause is a very brief period of time, while in some cases it can be relatively long. It is assumed to be a multiple *Z* of the average time for ATs and ITs. The constants *W*, *X*, *Y* and *Z* in equation 1 were determined from analysis of the video footage derived from the Czech Republic evacuation trial[1]. From that analysis, the constants *W*, *X*, *Y* and *Z* were estimated to be 0.25, 1.0, 0.25, 0.2[1]. The same values for the constants will be used in this analysis. It should be noted that the constants *W*, *X*, *Y* and *Z* may be dependent on the nature of the notification process; e.g. voice alarm and the type of environment e.g. library. It is also noted that it may be possible that there is a cultural component to each of these constants. In this assessment, we will investigate if the constant values derived from one library evacuation can be applied to an evacuation in a different library. Using the assumed values for these constants, equation 1 simplifies to:

$$RT = [NT + (NAT \times ATT) + (NIT \times ITT)] - [0.25 \times FOL_{max} \times ATT] + [0.05 \times TNT \times (ATT + ITT)/2] \qquad (3)$$

Using equation 3, it is possible to estimate the response time for the population. Based on the data derived from the UK evacuation trial, we have the following average values for each parameter:

- For the overall population, we have the following average values for each parameter;

NT = 20.9 sec, NAT = 5.0, NIT = 4.3, TNT = 9.2, ATT = 8.3 sec, ITT = 10.3 sec, FOL_{max} = NIT
Using equation 3 and the above values for the various parameters, the average response time for the overall population is RT = 102.0 sec. The measured average response time for the entire population was 98.3 sec. Thus in this case using the empirical response time model, the average response time is over-predicted by 3.8%.

- For Pop1 (alarm intervention), we have the following average values for each parameter;

NT = 17.8 sec, NAT = 4.9, NIT = 3.9, TNT = 8.8, ATT = 7.6 sec, ITT = 11.2 sec, FOL_{max} = NIT
Using equation 3 and the above values for the various parameters, the average response time for the overall population is RT = 95.4 sec. The measured average response time for Pop1 was 91.8 sec. Thus in this case using the empirical response time model, the average response time is over-predicted by 3.9%.

- For Pop2 (alarm and staff intervention), we have the following average values for each parameter;

NT = 25.6 sec, NAT = 5.0, NIT = 4.8, TNT = 9.8, ATT = 9.2 sec, ITT = 9.4 sec, FOL_{max} = NIT
Using equation 3 and the above values for the various parameters, the average response time for the overall population is RT = 110.2 sec. The measured average response time for Pop1 was 108.1 sec.

Thus in this case using the empirical response time model, the average response time is over-predicted by 1.9%.

Using equation 3 the average response time for the UK library population is over-predicted by between 1.9% and 3.9%.

As can be seen, the empirical response time model provides a good estimation of the average response time for the population. Thus using the empirical response time model, the average response time is under-predicted by 3.0%. As can be seen the empirical response time model provides a good estimation of the average response time for the population. From the earlier analysis of the evacuation trial in the Czech Republic[1], the empirical response time model produced average response times which were within 1.6% of the measured average response time for that population while Turkey[2] was within 11.3% and for the Poland[3] population it was within 3.0%. The average error across all four trials is 5.0%.

Thus the constants used in the empirical response time model appear to be reasonably robust, providing a good level of agreement for three evacuation trials conducted in four different libraries in four different countries using four different alarm types i.e. voice alarm only, tone only, staff intervention only and tone and staff intervention.

As can be seen, this approach provides a good estimation of average response times. However, more important than this, it provides us with insight into the behavioural factors driving the response time. Thus it is possible to estimate the impact of introducing technical or procedural measures to address various behavioural determinants of response time such as the duration of the average information task, or the number of information tasks.

CONCLUSIONS

A framework to enable the systematic analysis of Response Phase behaviours has been developed and applied to an unannounced evacuation trial in a University library in the UK. The framework not only provides a consistent method for describing Response Phase behaviour, but also provides a framework for classifying and quantifying the Response Phase other than simply using the overall response time. By understanding and quantifying the factors which influence and ultimately determine the Response Phase we are better able to compare and contrast different evacuation situations. In addition, the framework provides an empirical means of predicting population average response times based on average number of Information/Action tasks, average task duration and average notification time.

The UK evacuation produced response time distributions which follow a log-normal curve as is commonly found in evacuation trials. The average response time for the overall population (extracted from the 104 analysed people) was 98 s, with 84% if the population responding in 150 s. Using the framework the Response Phase behaviours were analysed and decomposed into their constituent components. The results of this analysis suggests the following; the average duration of the Notification stage was 20.9 s, the average number of Action Tasks undertaken was 5.0, the average number of Information Tasks was 4.3, the average duration of an Action Task was 8.3 s, and the average duration of an Information task was 10.3 s. This basic information provides a means of characterizing the Response Phase of the UK library evacuation which goes far beyond simply measuring the response time. It was also noted that these parameters varied between the sub-populations that responded only to the sound of the alarm and those that responded to a combination of the sound of the alarm and staff intervention. Staff intervention is intended to shorten the response phase of those individuals that may take excessive time responding. The analysis of the data derived from this trial demonstrates that the staff intervention process achieves this by reducing the targeted occupants Notification stage or Activity stage or both.

A similar analysis has already been undertaken for an evacuation in a library in the Czech Republic, Turkey and Poland. A key aim of this work is to investigate whether culture plays a significant role in evacuation behaviour. Using the framework, it is planned to explore whether social culture will impact behavioural determinates such as number, type and average duration of tasks performed in the Activity stage and the duration of the Notification stage. It should be noted that even if these factors are not dependent on social culture, they are expected to be dependent on the nature of the environment e.g. library, shopping complex, high-rise building, the nature of the notification system e.g. staff intervention, alarm, voice alarm, and the level of training of the occupants. Thus, it will be important to determine the dependence of the identified behavioural determinates on type of environment, type of notification system and degree of training.

ACKNOWLEDGEMENT

Project BeSeCu (contract 218324) is funded under the European Union Framework 7 Security initiative. The authors acknowledge the co-operation of their project partners: Ernst-Moritz-Arndt-Universität Greifswald, Dept Health & Protection, Germany (project co-ordinator); University of Greenwich, FSEG, UK; Institute of Public Security of Catalunya, Spain; Hamburg Fire and Emergency Service Academy, Germany; Man-Technology-Organisation, Sweden; Prague Psychiatric Centre, Czech Republic and Association of Emergency Ambulance Physicians, Turkey; in undertaking this work and in allowing the project findings to be published.

REFERENCES

[1] Galea, E.R., Deere, S., Sharp, G., Filippidis L., and Hulse, L., "Investigating the impact of culture on evacuation behaviour," Proceedings of the 12th International Conference, Interflam 2010, Intersciences, 2010, pp. 879-892.

[2] Galea, E.R., Sauter, M., Deere, S.J., Filippidis, L., Investigating the Impact of Culture on Evacuation Behaviour – A Turkish Data-Set". Proceedings of the Tenth International Symposium on Fire Safety Science, University of Maryland, 19-24 June 2011, pp. 709-722. ISSN 1817-4299. DOI: 10.3801/IAFFS.FSS.10-709

[3] Galea, E.R., Sharp, G., Sauter, M., Deere, S.J., Filippidis, L., "Investigating the impact of culture on evacuation behaviour – A Polish Data-Set", Proceedings of the 5th International Symposium, Human Behaviour in Fire, Cambridge UK, 2012, Interscience Communications Ltd, ISBN 978-0-9556548-8-6, pp 62-73, 2012.

[4] Hulse, L.M. and Galea, E.R., "The UK BeSeCu Fire Fighter Study: A Study of UK Fire Fighters' Emotional, Cognitive and Behavioural Reactions to Emergencies", Proceedings of the 5th International Symposium, Human Behaviour in Fire, Cambridge UK, 2012, Interscience Communications Ltd, ISBN 978-0-9556548-8-6, pp 860-97, 2012.

[5] Galea, E.R., "Evacuation Response Phase Behaviour," CMS Press 09/IM/147, London, 2009, pp1- 30.

[6] Sime, J., "Human Behaviour In Fires Summary Report," CFBAC Rept No.450, Ports, 1992, pp. 1-20.

[7] Sime, J., "Escape Behaviour In Fires And Evacuations," Fires And Human Behaviour, Fulton, London, 1990, pp. 56-87.

[8] Proulx, G., "Time Delay To Start Evacuating Upon Hearing The Fire Alarm," Human Factors And Ergonomics Society 38th Annual Meeting, Ergonomics Society, 1994, pp. 811-815.

[9] Proulx, G. and Sime, J., (1991) To Prevent 'Panic' In An Underground Emergency: Why Not Tell People The Truth?, Fire Safety Science 3: 843-852, http://dx.doi.org/10.3801/IAFSS.FSS.3-843.

[10] Galea, E.R., Hulse, L., Day, R., Siddiqui, and A., and Sharp, G. , "The UK WTC9/11 Evacuation Study: An Overview of the Methodologies Employed and some analysis relating to fatigue, stair travel speeds and occupant response times," Human Behaviour in Fire, 4th Int. Symp, Intersciences, 2009, pp. 27-40.

Proceedings of the 13th International Fire Science & Engineering Conference, Interflam 2013 24-26th June 2013, Royal Holloway College, London, UK, **Volume 2, pp. 893-906. ISBN 978 0 9556548-9-3, 2013.**