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INVESTIGATING THE IMPACT OF CULTURE ON EVACUATION BEHAVIOUR

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

ABSTRACT

A framework to enable the systematic analysis of Response Phase behaviours is presented and applied to an unannounced evacuation trial in a university library in the Czech Republic. 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. The framework also provides a means of predicting average response times based on a number of empirical factors. This work forms the basis of a large study concerned with investigating the impact of culture on evacuation behaviour.

INTRODUCTION

The evacuation process can be considered to comprise two broad phases, here called the Response Phase and Evacuation Movement Phase[1]. 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[1-6]. 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. One exception is Ozkaya[7] who explored the impact of social and fire culture on the behaviour of children in fire situations in Turkey. Ozkaya argued that both social and fire culture will have a large impact in determining a child's response to fire and it was therefore inappropriate to assume that children in developing countries would necessarily behave the same way as children in developed countries. 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?

These questions are currently being pursued in an EU FP7 funded research project called BeSeCu (*Be*haviour, *Se*curity and *Cu*lture)[8]. The project's main aims are to examine 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 is being investigated through surveys of people who have had first-hand experience of real emergencies and through a series of unannounced evacuation trials. Survivors of natural disasters (e.g. floods, earthquakes) and more man-made incidents (e.g. fires in homes and public buildings, terrorist attacks such as the 7/7 London bombings) are being surveyed about their thoughts, feelings, and actions prior to, during, and after these emergencies. The surveys are being 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 is expected to generate 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 are also being collected and analysed. An initial study involving focus groups and interviews has already been completed. The data collected from this phase has been used to develop an in-depth questionnaire survey that is currently being administered to a larger number of individuals across countries.

Two questionnaires – one tailored for survivors and the other for fire-fighters – have been designed so that they tap into antecedents of behaviours (e.g. prior knowledge and experience of emergencies and evacuations), before focussing attention on a specific incident experienced. Questions to survivors explore such factors as what cues alerted them to the problem, their interpretation of those cues, what further information was sought, how quickly they were able to escape, and how they chose their exit route, overcoming any obstacles and challenges along the way. It is hoped that participants' answers will help identify the strengths and limitations of such things as fire alarms, emergency signage, and interactions with emergency responders. Moreover, these questions will explore scenarios where survivors were not specifically informed about the problem, or official aid in evacuating was not immediately available. That is, situations where survivors had to rely on their own senses (i.e. to notice changes in their environment such as smoke, structural damage, or sudden, unusual behaviour in others) and make dynamic decisions. Did they correctly interpret what was happening? Who did they first turn to for help and what was it that they actually wanted from them? Were their reactions automatic and instinctive or more conscious and rational? And what did they draw on to help guide them out? In addition, some factors are being studied across several different time points (e.g. emotions, threat assessments), and the questionnaire's focus envelops aspects often outside the remit of fire safety research; that is, what happens to survivors after they are out of the scene of immediate danger? What are their practical, psychological or medical needs and what help is actually made available to them? What are the longer-term consequences of having survived such an incident –

positive as well as negative? The first responder questionnaire should supplement the survivors' perspective, asking for observations of victim and bystander behaviour, and probing further issues surrounding communication - both verbal and non-verbal. Like the survivor questionnaire, it studies how people make decisions and considers the emotional and psychological aftermath of being involved in emergencies. Together, these questionnaires will provide insight into interactions between people, their environment and the threat posed to them, and whether such behaviours are universal or more culture/country-specific. Further details, including the questionnaire can be found on the project BeSeCu website[8].

The experimental component of project BeSeCu addresses issues associated with response times and the impact of culture. As part of project BeSeCu three unannounced library evacuations will be 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[1]. In this paper we describe this evacuation behaviour framework and present preliminary results from the first evacuation experiment conducted in the Czech Republic.

RESPONSE PHASE BEHAVIOURAL FRAMEWORK

In this framework[1] the evacuation process is considered to comprise 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. 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. This in turn can be used to explore issues such as the impact of culture on evacuation performance and may even allow us to develop procedures to tune Response Phase behaviours to optimise response times. Furthermore, 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 endpoints[1] (see figure 1).

Notification stage:

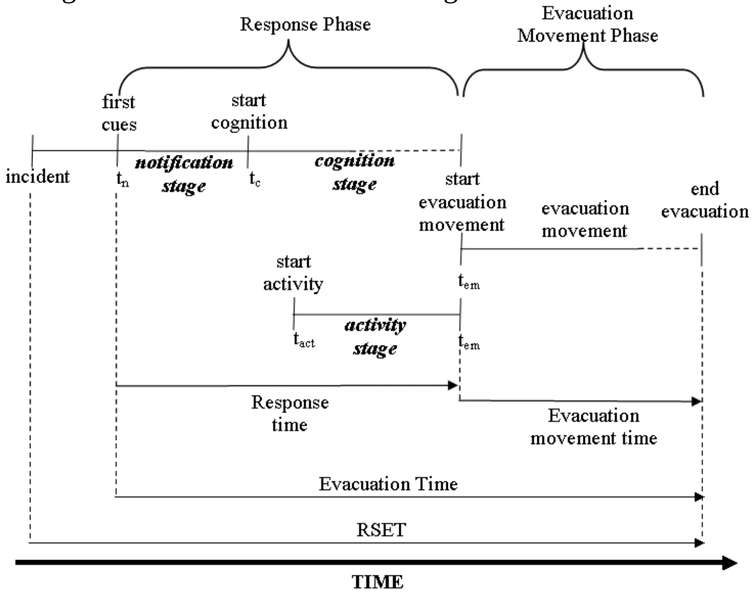
The first stage of the Response Phase is the Notification stage (see figure 1). In the Notification stage, notification cues such as an alarm conveys to the occupants that an unusual and potentially hazardous event has occurred, requiring the occupants to evacuate. The notification cues may be a traditional 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 recognised that the cues are relevant to their situation. For each exposed occupant, the end of 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 if they had re-engaged in their pre-notification activity, any additional cues, as signalling the need for immediate evacuation. As a result, the occupant immediately commences evacuation movement without undertaking any other activity. In this case 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.

Figure 1: Framework for describing evacuation behaviour



Activity stage:

At the start of the Activity stage the occupant performs a series of Information and/or Action tasks[9-11] 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.

As the Cognition stage may run in parallel to the Activity stage, 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.

VIDEO ANALYSIS:

Video footage collected from evacuation trials can be analysed to determine response times and Response Phase behaviours. This analysis is undertaken frame by frame using software tools such as Adobe Premiere. 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:

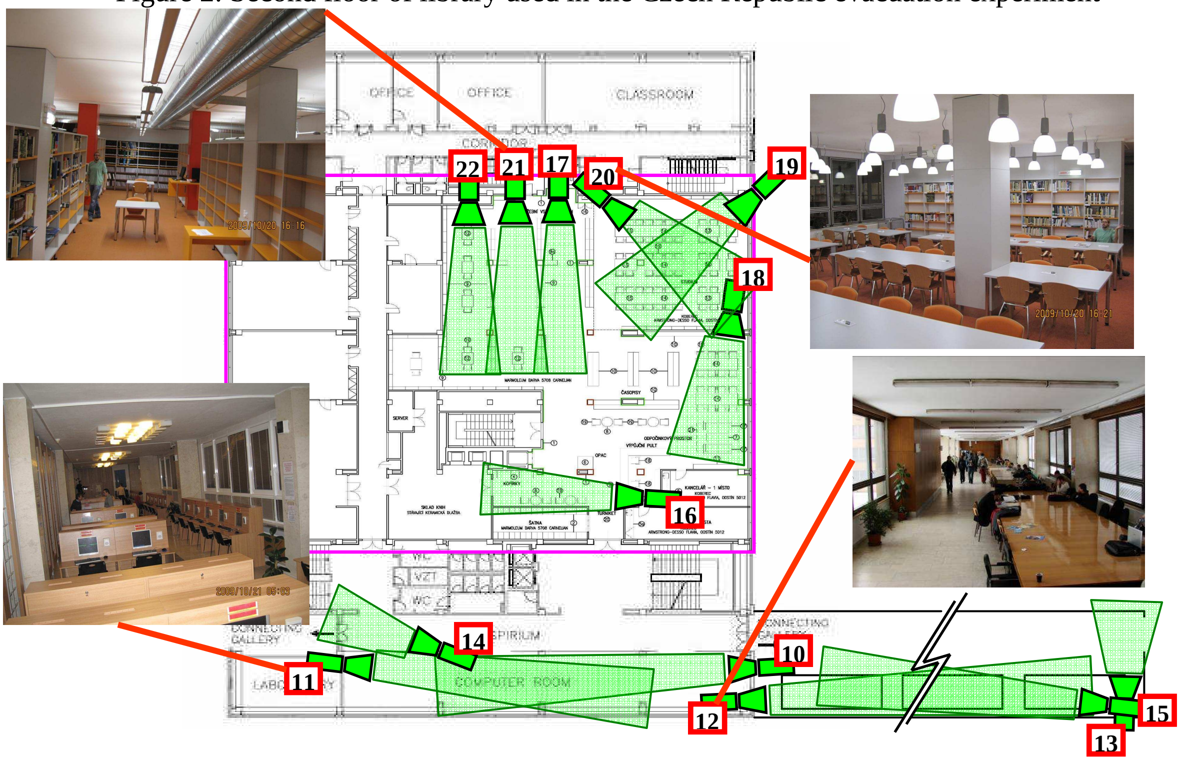
- The start of the Response Phase (i.e. the start of the Notification Stage) which is indicated by the first notification cues e.g. the sound of the alarm or staff intervention.
- The end/start of the Notification/Activity Stage where people begin to perform action and information tasks prior to starting 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.

Prior to commencing analysis of trial video footage, a set of definitions relating to the key Response Phase stages was developed. These clearly specify how to identify the start/end points of the Notification and Activity stages and identify a range of Action and Information tasks that may be undertaken during the Activity stage. The Action/Information tasks include 15 Action tasks (e.g., collect belongings, shut down computer, pickup bag, etc.) and 7 Information tasks (e.g., engage in information exchange, provide information/instructions to others, move to another location to acquire information, etc.). The analysis team were then trained in identifying and categorising the various Response Phase stages and Activity stage tasks. Finally, prior to commencing data extraction, the analysis team must successfully complete an inter-rater testing process to ensure that they can consistently identify the required data.

EQUIPMENT SET UP:

Evacuation behaviour was captured using 22 digital video cameras (see figure 2) and a questionnaire administered to the evacuees post evacuation. The questionnaire consisted of 29 questions and was translated into Czech, the native language of the trial participants. The video equipment was shipped to the location of the trial prior to the experiment in six cases weighing a total of 126 kg. The trial team consisted of a core of 5 people from FSEG and a support team of 11 people from a neighbouring institution to assist on the day of the trial. As the trial was unannounced, the equipment was set up in the library on the night before the trial after closing time and after the normal library staff had gone home. This was to ensure that the minimum number of people were alerted that something was being planned for the following day. The trial took place on the 21 October 2009 in the university library within the Czech Republic.

Figure 2: Second floor of library used in the Czech Republic evacuation experiment



THE EVACUATION TRIAL

The library has a floor area of some 15,000 m^2 and has 5 floors, although only 2 floors are used by students. The students have access to two stairs and three routes out of the library. The library building has mixed occupancy and accommodates staff offices, computer rooms, classrooms, study areas, reading rooms and auditoria. The library has 25 members of staff and an average monthly usage of 5000 visitors. The staff of the library receives procedural training every two years and fire drills are only run at the request of the local fire brigade. There had not been a fire drill in the library for several years. The alarm system within the library is zoned and consists of a combination of tones, recorded voice and live voice messages. The nature of the alarm message is to first inform the entire campus population that there is an incident on the campus, and then to inform the appropriate sub-population of the need to commence the evacuation process. The alarm actually consists of several messages, a translation of the messages that occurred on the day is as follows:

- **Alarm Sequence 1, t = 0 sec:** Alarm Tone, Alarm Tone – 54 sec duration.
- **Alarm Sequence 2, t = 54 sec:** Recorded Voice Message 1:
    - "Attention! Attention! I declare the emergency situation. Attention Attention, I declare the emergency situation. I am asking for all employees, students and everybody else to stay calm and wait for next informations. Prepare for evacuation. Attention, attention, prepare for evacuation and wait for next informations. Prepare for evacuation and wait for next informations" – 24 sec duration.
- Pause - 35 sec duration.
- **Alarm Sequence 3, t = 113 sec:** Live Voice Message 2:

    - "Library, Attention, the evacuation is only for the New library building.The other buildings are not endangered. For evacuation of the New library use the main entrance from library, on the second floor use the corridor to the Aula building and continue to Aula or continue to the building A – B. Do not use lifts and on the stairs people comming down floor above.have prioroty.Be careful about your personal safety and the new library building leave as fast as possible.
    - "Attention, all of these information is only for the new library building. I repeat, carry out all spaces of the new library building. For evacuation of the new library use the main entrance from library, on the second floor use the corridor to the Aula building or continue to the building B. Attention, the evacuation is only for the New library building.The other buildings are not endanger. I am asking for all students, employees and everybody else to stay calm and wait for next informations. I repeat, fire alarm is declared only for the New library building, other buildings are not endangered. Wait for the next informations. **–** 89 sec duration.
- Pause - 184 sec duration.
- **Alarm Sequence 4, t = 386 sec:** Live Voice Message 3:
    - Content not clear. – 80 sec duration.
- Entire alarm sequence is **466 sec (7 min 46 sec)** long.

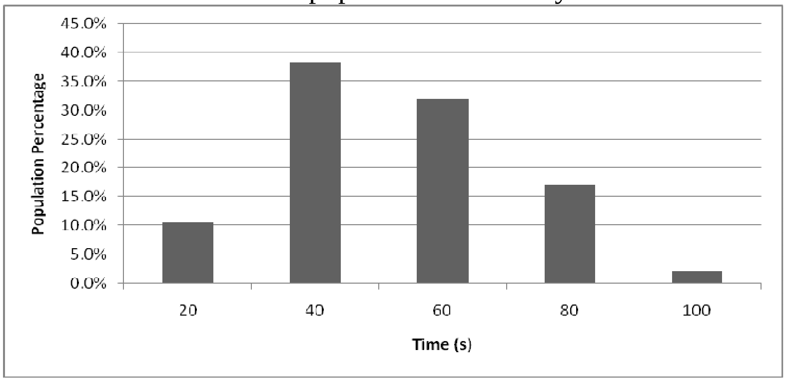
Unfortunately, on the day of the trial, a fault on the alarm system meant that the alarm system failed to operate throughout the library. The alarm could only be heard by the population in the large open study area (see area covered by cameras 12, 13 and 15 in Figure 2). For the remainder of the population in the library, the evacuation was initiated by staff intervention – where members of staff went around the library informing the population that they needed to evacuate the library immediately due to a suspect fire. From the questionnaires that were completed, at the time of the alarm, there were 68 students within the library, 54 within the main part of the library and 14 within the study area. According to the video analysis, there were 70 students within the library for which response time data could be determined, 47 within the main part of the library and 23 within the study area.

TRIAL RESULTS AND DISCUSSION

From the questionnaire, 78% (53) of the student population was male, 22% (15) were female and 93% (63) were in the age range 18-24; 6% (4) were in the age range 25-34 and 1% (1) was in the age range 35-44. Furthermore, 45% (30) were in the first year of study at the University; 12% (8) were in the second year; 18% (12) were in the third year; 25% (17) were in the fourth or more year of study at the University (note, one student did not specify their age). Given the failure of the alarm system, there were two student populations for which the response time was determined. Population 1 consisted of the students who did not hear the alarm but responded to staff intervention – a total of 47 people. For this population the response time was determined from the point of staff intervention (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). The response time distribution for Population 1 is presented in Figure 3. As can be seen from Figure 3, the response time distribution follows the typical log-normal profile, with over 48.9% of the population responding within 40 sec. The maximum response time for this population is in the range 80 to 100 sec (2.1% of the population).

The second group, Population 2, consisted of the population who reacted to the sound of the alarm – a total of 23 people. As there were four different alarm sequences at t = 0 sec; 54 sec; 113 sec and 386 sec; it is possible to determine four different sets of response times, based on each individual notification cue. If we take the response time as being determined from the start of the first notification cue, i.e. the start of the first alarm, we find that the response times are considerably longer than that for the population that responded to staff intervention. The shortest response time is 150 sec while the longest response time is less than 490 sec. The shortest response times for this population are longer than the longest response times for Population 1. Furthermore, we note that it is not until the third alarm sequence has sounded do people end their Response Phase and begin their Evacuation Movement Phase. Indeed, the first people to start their Evacuation Movement Phase do so 39 sec after the third alarm sequence has sounded.

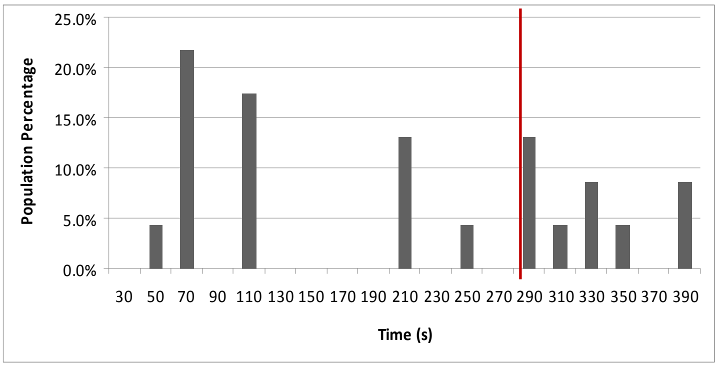
Figure 3: Response time distribution for population notified by staff intervention (Population 1)



This extended response time may be the result of the nature of the alarm messages. The second alarm sequence (first voice message) informs the population that there is no need to evacuate at this point in time. It simply informs the population to prepare to evacuate. It is only at the sounding of the third alarm sequence (second voice message) that the population is instructed to evacuate. It is also worth noting that 43% (29/68) of the student population that completed the questionnaire stated that they had received some form of fire safety training prior to the trial. However, only 2 (3%) of the respondents claimed that they had experienced an alarm previously in the building (a 1st year and a 4th year student); thus, almost 60% of the population did not know what to expect from the alarm system.

Presented in Figure 4 are the response times as measured from the third alarm sequence. It is a similar distribution to that which is determined from the sounding of the first alarm sequence, but shifted 120 sec to the left. Also shown in Figure 4 is an indication of when the fourth alarm sequence was sounded (vertical red line). As can be seen from Figure 4, the response time distribution has an approximate log-normal like profile. Even though the fourth alarm occurs some 273 sec after the start of the third alarm, 39% (9) of the population respond only after the fourth alarm. In comparison to the population responding to staff notification, 34.8% (8) of the population responding to the alarm respond within 100 sec of the third alarm sequence.

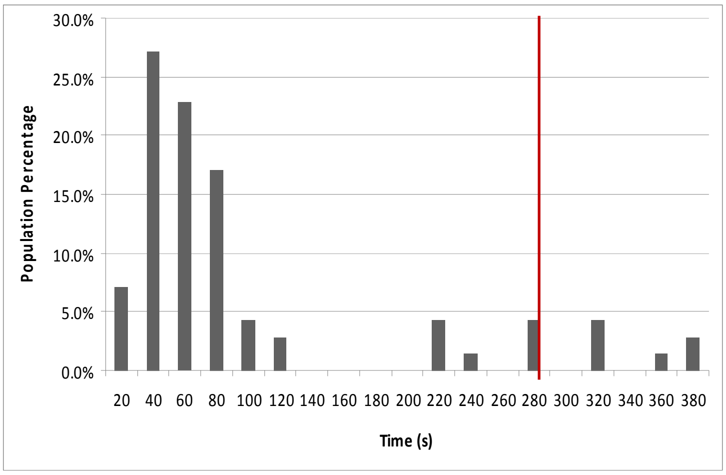
Figure 4: Response time distribution for population notified by alarm system measured from the third alarm sequence



The average response time for Population 1 is 43.3 sec while the average response time for Population 2 (measured from alarm 3) is 193.7 sec (measured from alarm 1, the average response time is 306.7 sec) and the average response time for the entire building population is 92.7 sec. Clearly the population responding to staff notification respond significantly faster (4.5 times faster) than the population responding to the alarm sequence only. Presented in Figure 5 is the response time distribution for the entire library. This comprises response times for Population 1, measured from the point of staff intervention and Population 2 measured from the sounding of the third alarm sequence. The long tail of this distribution is a result of the population responding to only the alarm sequence, with 100% (13/13) of the population with a response time greater than 120 sec being notified by the alarm sequence only while 84% (47/56) of the population responding in under 100 sec being notified by staff intervention only.

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 constitute stages as identified in Figure 1. If we consider the duration of the Notification stage for Population 1, we note that 63.8 % (30) of the population have completed the Notification stage and disengaged from their pre-notification activates within 5 sec of the start of the notification cues. The longest Notification stage for Population 1 was 45 sec, achieved by 8.5% (4) of the population while the average duration of the Notification stage for Population 1 is 7.2 sec. In contrast, the Notification stage for Population 2 was considerably longer. During alarm sequence 1 (0 – 54 sec), only 1 person disengaged from their pre-notification activities and this was after 14.2 sec, during alarm sequence 2 (54 - 113 sec) 10 persons disengaged after an average of 17.1 sec, during alarm sequence 3 (113 – 386 sec) 7 persons disengaged after an average of 224.1 sec and after alarm sequence 4 (386 – 466 sec) 2 persons disengaged after an average of 9.4 sec. Due to the complex nature of the alarm sequence it is difficult to determine a representative time to disengage from pre-notification activities for Population 2 however, the average duration of the Notification stage for Population 2 is 88.6 sec. Clearly, occupants exposed to just alarm notification cues take considerably longer to disengage from their pre-notification activities (12.3 times longer) than occupants exposed to staff intervention. The longer duration Notification stage for the population exposed to the alarm will tend to prolong the response time for these occupants compared to those exposed to staff intervention.

Figure 5: Response time for entire library population

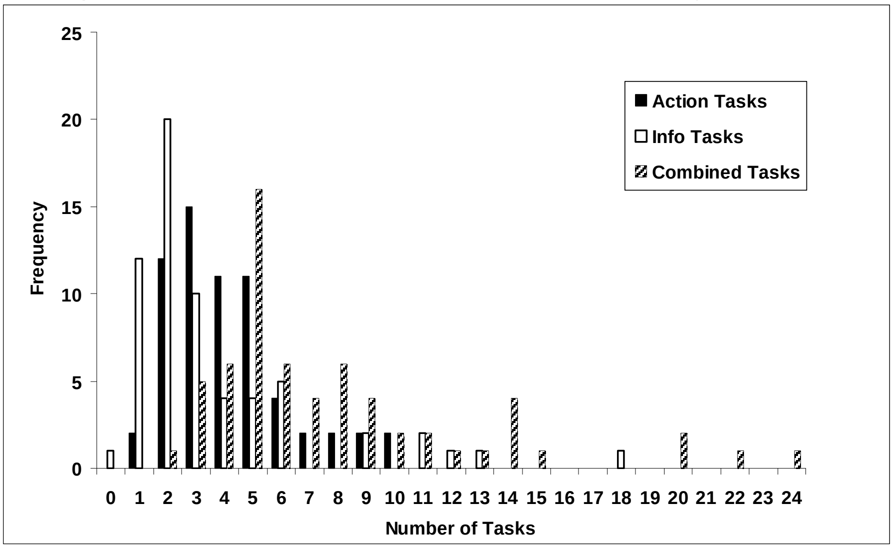


The nature of the personal behaviours exhibited during the Activity stage can also be analysed in detail. Presented in Figure 6 is a distribution of the Action, Information and total number of tasks undertaken by the entire building population during the Activity stage. As can be seen, the number of Action, Information and Total number of tasks each follow a log-normal distribution. A total of 268 individual Action tasks and 235 Information tasks were identified during the Response Phase for the entire building population. The average number of Action tasks undertaken is 4.3 while the average number of Information tasks is 3.7. On average a person undertakes more Action than Information tasks and undertakes a total of 8.0 tasks prior to commencing the Evacuation Movement Phase.

For Population 1 (staff intervention) we find that the average number of Action tasks is 3.6 while the average number of Information tasks is 2.0, producing an average of 5.6 tasks performed prior to commencing the Evacuation Movement Phase. Furthermore, the maximum number of tasks performed was 9 Action tasks, 6 Information tasks and the maximum total number of tasks was 14. The most common combination of tasks was 3 Action and 2 Information and this combination was completed by 10 people. The most common number of Action tasks was 3 performed by 13 people and the most common number of Information tasks was 2 performed by 17 people. In addition, the most common Information tasks, as a percentage of the total number of Information tasks were, "Acquire information from the environment (looking, listening)" 81% and "Engage in information exchange" 16.8%. The most common Action tasks, as a percentage of the total number of Action tasks were "Collect Belongings" 23% of the Action tasks; "Shut down computer" 17.4%; "Work at computer" 16.8% and "Collect clothing" 15.5%.

For Population 2 (alarm) we find that the average number of Action tasks is 5.7 while the average number of Information tasks is 7.4, producing an average of 13.1 tasks performed prior to commencing the Evacuation Movement Phase. Furthermore, the maximum number of tasks performed was 10 Action tasks, 18 Information tasks and the maximum total number of tasks was 24. The most common combination of tasks was 8 Action and 6 Information and this combination was completed by 2 people. The most common number of Action tasks was 4.5 performed by 4 people and the most common number of Information tasks was 4 performed by 3 people. In addition, the most common Information tasks were, "Acquire information from the environment (looking, listening)" 64% and "Engage in information exchange" 34%. The most common Action tasks were; "Pickup bag" 34%, "Collect Belongings" 24.5%; "Collect clothing" 11.3% and "Shut down computer" 10.4%.

Figure 6: Number of Tasks undertaken for entire library population



Once a person is notified by a member of staff, they undertake an average of 5.6 tasks prior to commencing their evacuation movement phase, compared to an average of 13.1 tasks for a person notified by the alarm system. Here we see that someone notified by the alarm undertakes more than twice as many tasks prior to starting to evacuate compared to someone who is notified by a member of staff. The greater number of tasks performed by the population exposed to the alarm will tend to prolong the response time for these occupants compared to those exposed to staff intervention. Furthermore, the maximum number of tasks undertaken by someone reacting to the alarm was 24 tasks while the maximum number of tasks for someone reacting to staff intervention is 14. Thus we note that not only will the average time for those reacting to the alarm be longer than the average time for those reacting to staff intervention, the maximum response times for those reacting to the alarm will be significantly longer than that for those reacting to staff intervention.

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If we further consider the type of tasks that are being undertaken, we again see a significant difference between the two populations. For those reacting to staff intervention, the average number of Action tasks is 3.6 while the average number of Information tasks is 2.0. For the group reacting to the alarm, the average number of Action tasks is 5.7 and the average number of Information tasks is 7.4. Thus, those reacting to the alarm undertake 3.7 times as many Information tasks and 1.6 times as many Action tasks as those reacting to staff intervention. Those reacting to staff intervention spend less time seeking confirmation or clarification information; i.e. undertake less Information tasks than those who have been notified by the alarm system. This is further supported by noting that significantly fewer Information Exchange tasks were performed by the population reacting to staff intervention compared with the population reacting to the alarm. In addition, those reacting to staff intervention also undertake less Action tasks (such as packing up belongings) than those reacting to the alarm system.

Finally, we note that those reacting to staff intervention undertake fewer Information tasks than Action tasks while those reacting to the alarm undertake more Information tasks than Action tasks. Furthermore, those responding to the alarm undertake proportionally more Information tasks (3.7x) than Action tasks (1.6x) compared to those reacting to staff intervention. The time to undertake each individual task can be determined from the video footage. However, it is difficult to reliably measure short duration activities when there is uncertainty in the start and end points of the activity. To increase the reliability of the measurement, the duration of only multiple tasks of the same type were measured. Thus, measurements were made for sequences of tasks in which at least two tasks of the same type were undertaken consecutively. Using this approach the duration for a total of 89 Action tasks and 114 Information tasks were measured. The average duration of a single Action task was determined to be 6.4 sec while the average duration of an Information task was determined to be 9.7 sec. Thus, on average, an Information task takes 1.5 times as long as an Action task. This is a significant result as it indicates that undertaking many Information tasks during the Response Phase can severely prolong the response time. The average duration of Action and Information tasks can be further broken down to compare the average time for the different populations. For Population 1, the average time for an Action task (based on 27 tasks) was 6.5 sec while the average time for an Information task was 6.7 sec (based on 8 tasks). This compares with 6.4 sec (based on 62 tasks) for an Action task and 9.9 sec (based on 106 tasks) for an Information task for Population 2. While the average duration of an Action task is virtually identical for both populations, there is a considerable difference in the average time to complete an Information task. For the population alerted by the alarm, not only is it necessary to perform more Information tasks, the duration of these tasks is also longer compared with the population alerted through staff intervention.

Using the above information it is possible to postulate an empirical predictive model for the average response time as shown in equation [1].

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

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

In this expression the first three terms on the right hand 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 Activity and Information tasks. The duration of the Notification stage, the number and type of tasks and the average duration of an Information and Action task are all dependent on the nature of the notification process, e.g. staff intervention and the type of environment e.g. library. It is possible that there is also a cultural component to each of these parameters.

The fourth term is a correction factor that takes into consideration that a proportion of Action tasks can be performed simultaneously with Information tasks thereby reducing the calculated response time.

The maximum number of overlapping tasks is dependent on the relative number of Action and Information tasks and is given by:

$$FOL_{max} = NIT \quad \text{if } NAT \geq NIT$$
$$FOL_{max} = NAT \text{ if } NAT < NIT \qquad [2]$$

In equation [1], the constant W is a measure of the likelihood of overlapping tasks occurring. It is difficult to estimate a value for this constant, but from observation of the video footage is estimated to be 25% (W = 0.25); i.e. 25% of the Action tasks overlap with Information tasks. The duration of overlap is dependent on the length of time of the Action task (ATT) and the degree of overlap (X%). For the current situation, video observation suggests that the most appropriate degree of overlap is 100% (X = 1.0); i.e. that the Action task totally overlaps the Information task.

The fifth term is another 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 then this, and the proportion of tasks that are followed by a cognition pause is represented by a constant Y. From analysis of the video footage, it is suggested that cognition pauses occur approximately 25% of the time (Y = 0.25). The duration of the cognition pause is difficult to estimate as it is variable and context specific. In most cases the cognition pause is a very brief period of time, while in some cases it can be relatively long. Here it is assumed to be a multiple Z of the average time for Action and Information tasks and we take an overall representative value of Z to be 20% (Z=0.2).

It should be noted that the constants W, X, Y and Z may be dependent on the nature of the notification process; e.g. staff intervention and the type of environment e.g. library. It is possible that there is also a cultural component to each of these constants. Using the assumed values for these constants, equation [1] simplifies to:

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

Using equation [3] it is possible to estimate the response time for the two populations. For Population 1 (staff intervention), we have the following average values for each parameter,

NT_S = 7.2 sec, NAT_S = 3.6, NIT_S = 2.0, ATT_S = 6.5 sec, ITT_S = 6.7 sec.

While for Population 2 (alarm intervention), we have the following average values for each parameter,

NT_A = 88.8 sec, NAT_A = 5.7, NIT_A = 7.4, ATT_A = 6.4 sec, ITT_A = 9.9 sec.

Using the above values in equation [3] we determine the average response times as follows;

RT_S = 42.6 sec and RT_A = 194.8 sec.

Using equation [3] the average response time for Population 1 is under-predicted by 1.6% while the average response time for Population 2 is over-predicted by 0.6%. The measured average response time for Population 2 was 4.5 times as large as the measured average response time for Population 1. Based on the predictive model, the average response time for Population 2 is also 4.6 times as large as that for Population 1.

As can be seen, this approach provides a good estimation of the response times for both populations. However, more important than this, it provides us with insight into the behavioural factors driving the response time. Thus it is possible to determine 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 Czech Republic. 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.

Analysis of the Czech evacuation data suggests that the average evacuation time for occupants notified by the alarm system is 4.5 times longer than the response time for occupants notified by staff intervention (193.7 sec compared to 43.3 sec). Analysis of the Response Phase behaviours using the framework revealed a number of significant differences between the two notification groups which explains the differences in the resultant response times for the two groups. Firstly, the population notified by the alarm take 12.3 times longer to disengage from their pre-notification activities than occupants exposed to staff intervention. The longer duration Notification stage for the population exposed to the alarm will tend to prolong the response time for these occupants compared to those exposed to staff intervention. Secondly, once disengaged from their pre-notification activities a person notified by the alarm system undertakes twice as many tasks on average as a person notified by staff intervention (13 tasks compared to 6.0 tasks). The greater number of tasks performed by the population exposed to the alarm will tend to prolong the response time for these occupants compared to those exposed to staff intervention.

Thirdly, those reacting to the alarm undertake 2.2 times as many Information tasks and 1.5 as many Action tasks as those reacting to staff intervention. On average an Information task takes 1.6 times as long as an Action task (10.0 sec compared to 6.4 sec). So the more Information tasks undertaken, the longer the overall response time. Furthermore, while the average duration of an Action task was identical for each population, the average duration of an Information task for the population exposed to the alarm is 1.5 times as long as that for the population exposed to staff intervention. Thus not only do the population reacting to the alarm undertake more Information tasks then the population reacting to staff intervention, the average duration of an Information task for the alarm population is 50% longer than for the population reacting to staff intervention. Thus notification of occupants by staff intervention reduces the need for occupants to perform so many time consuming Information tasks and furthermore reduces the average duration of an Information task, thereby reducing the overall response time for the occupants.

This work will be continued by applying the framework to an evacuation in a UK library and two other library evacuations within 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.

Finally, it is worth noting that the nature of the occupant training regime, the nature of the alarm testing regime (and indeed the failure of the alarm system) and the nature of the voice alarm messages are all examples of how local fire culture can impact overall evacuation performance.

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