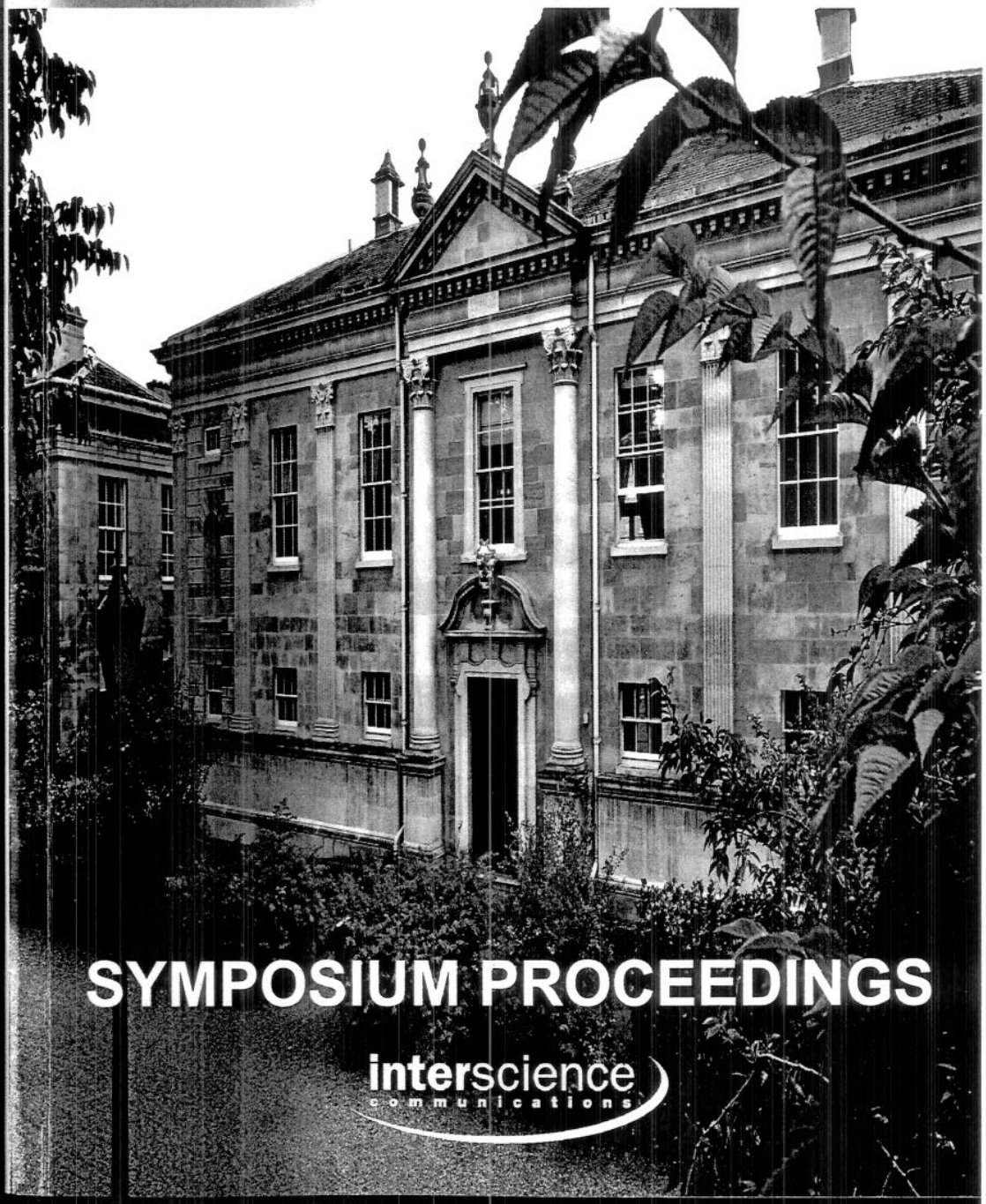
5th international Symposium

Human Behaviour in Fire 2012

Downing College, Cambridge, UK

19th - 21st September 2012



SYMPOSIUM PROCEEDINGS

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INTRODUCTION

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

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

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

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

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

Prof. T Jim Shields

Symposium Chair

INVESTIGATING THE IMPACT OF CULTURE ON EVACUATION BEHAVIOUR – A POLISH DATA-SET

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ABSTRACT

In this paper results from an unannounced evacuation trial conducted within a library in Warsaw Poland 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% of the measured value. In addition to presenting Response Phase data, a data-set suitable for the validation of evacuation models is also presented. This consists of both egress times and time dependent density measurements. buildingEXODUS predictions of the evacuation are compared with the validation data and shown to be in good agreement with the measured data.

INTRODUCTION

Project BeSeCu (Behaviour, Security and Culture)[1,2] 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 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. The experimental component of project BeSeCu addresses 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]. 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[3-7] (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[3]. In earlier papers the evacuation behaviour framework was presented along with a response time data-set derived from the first two evacuation experiments conducted in the Czech Republic[1] and Poland[2]. In this paper we present the evacuation data-set derived from the third evacuation trial conducted in Poland. This data-set also consists of an evacuation model validation data-set which includes egress times and transient crowd densities. Furthermore, the predictive response time model developed in[1] is applied to the Polish data-set to evaluate its robustness.

RESPONSE PHASE BEHAVIORAL FRAMEWORK

Within the proposed evacuation behaviour framework[3], 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[3] (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

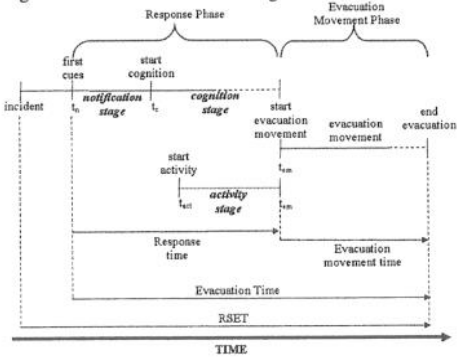
At the start of the Activity stage the occupant performs a series of Information and/or Action tasks[1,2,8] which were conceived during the Cognition stage (see figure 1). These are defined as follows:

- 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.

Evacuation behaviour was captured using 30 digital video cameras and a questionnaire administered to the evacuees post-evacuation. The questionnaire consisted of 29 questions and was translated into

Polish, the native language of the trial participants. The trial took place on the 26 May 2010 at the University of Warsaw library.

THE EVACUATION TRIAL

The building is a seven-storey structure used for library services, student computer labs, private study rooms, discussion rooms and open study space with a total floor space of almost 61,000 m^2. Students normally have access to three floors of the building. The structure has 9 stairs, 13 open spiral stairs, 19 lifts, 5 normal exits and 13 emergency exits not all of which are normally accessible by students. The building has 820 employees. The average monthly usage of the library building is approximately 94600. The maximum occupancy of the building is 2200. The building has fire drills every two years, the last one was in 2007 and staff receive annual training in procedures.

A population of 689 people occupied the building at the time of the trial as determined by an exit count. This was made of students, academic staff and administrative staff with ages ranging from 18 to 60 years, with 66% males and 34% females based on an exit survey completed by 134 (19%) of the participants. The alarm was a voice alarm which instructed occupants to evacuate immediately by their nearest exit. Building occupants evacuated on their own accord on hearing the alarm and the evacuation progressed without any staff intervention. Although emergency drills were previously performed in this building, the occupant population is transient and indicated (via the questionnaire) that they were largely unfamiliar with the evacuation procedures and alarm system in place. For instance, 94% of the population had never heard the alarm or taken part in a previous exercise while 71% of the population had received no formal training in evacuation procedures. Those that had taken part in a previous trial tended to be members of staff.

TRIAL RESULTS AND DISCUSSION

The presentation and discussion of the experimental results is in three parts, first the Response Phase data are presented, then the predictive response time model is investigated using the data from this experiment and finally the exit time and population density data is presented.

Analysis of Response Phase Data

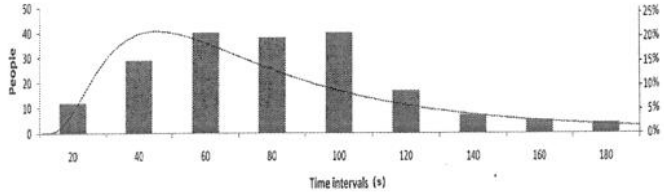
According to the video analysis, there were 710 people in the library, including library staff and students. Of the 710 people in the library, it was possible to determine response time and response behaviours for 192 students, 89 males and 103 females. These students were located as follows: 2 on the entrance stairs, 63 on Level 1 (ground floor), 124 on Level 2 and 3 on Level 3. The response time 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).

The response time distribution for the population is presented in figure 2. As can be seen the response time distribution approximately follows a log-normal profile, with 21% of the population responding within 40 s, 83% of the population responding within 100 s and 96% of the population responding within 150 s. The arithmetic average response time extracted from the 192 analysed people was 69.9 s, and ranged from 0.1 s to 178 s. The log-normal curve shown in figure 2 has a log mean of 4.06 and a log standard deviation of 0.77.

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. If we consider the duration of the Notification stage we note that 39% (74) of the population have completed the Notification stage and disengaged from their pre-notification activities within 5 s of the start of the notification cues while 71.9% (138) disengaged within 10 s. The longest Notification stage was 82.5

s, achieved by 0.5% (1) of the population while the average duration of the Notification stage is 8.3 s. We note from the questionnaire that 83% (105/126) noted that they heard the alarm at the start of the evacuation and 85% (91/107) reported that they understood what the alarm signified. The high recognition of the alarm may have resulted in the short average Notification time for the population.

Figure 2. Response time distribution for Polish library evacuation



The nature of the personal behaviours exhibited during the Activity stage can also be analysed in detail. A total of 1906 tasks were identified during the Response Phase for the entire building population, 1167 individual Action Tasks (AT) and 739 Information Tasks (IT). The average number of AT undertaken is 6.1 while the average number of IT is 3.8. On average a person undertakes more AT than IT and undertakes a total of 9.9 tasks prior to commencing the Evacuation Movement Phase. Furthermore, the distribution of the Action, Information and total number of tasks undertaken by the entire building population each follow an approximate log-normal distribution. The most common combination of tasks was 4 ATs and 2 ITs and this combination was completed by 12 people. The most common number of ATs was 4 performed by 25 people and the most common number of ITs was 2 performed by 34 people. The maximum number of tasks performed by a single person was 20 tasks (made up 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 10. In addition, the most common ITs, expressed as a percentage of the total number of ITs were; "Acquire information from the environment (looking, listening)" 76%, and "Engage in information exchange" 22%. The most common ATs, expressed as a percentage of the total number of ATs were "Collect Belongings" 48%, "Pick up bag" 23%, "Pickup, throw away rubbish, tidy area" 7% and "Work at computer" 5%.

The time to undertake each individual task can be determined from the video footage. In order to reduce the error associated with this measurement, it is based on the duration of 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 and which followed on immediately from the previous task. Using this approach the duration of 834 ATs and 149 ITs were measured. The average duration of a single AT was determined to be 6.4 s while the average duration of an IT was determined to be 6.1 s. Thus, on average, for this population ATs take approximately 5% longer than ITs. A similar analysis of Response Phase behaviours has already been undertaken for an evacuation of a library in the Czech Republic and Turkey. A further analysis is currently underway for one other library evacuation, one conducted in the UK. When this is completed all four data-sets will be compared in an attempt to identify potential similarities and differences which may be attributable to cultural differences in the populations.

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[1,2].

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

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:

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

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 then 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. 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:

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

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

NT = 8.3 sec, NAT = 6.1, NIT = 3.8, TNT = 9.9, ATT = 6.4 sec, ITT = 6.1 sec, FOL_{max} = NIT

Using the above values in equation 3 the average response time is RT = 67.8 s, whereas the measured average response time for the population was 69.9 s. 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%. 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 three different libraries in three different countries.

Data from one additional evacuation trial conducted in the UK is currently being analysed. Once this analysis is complete, the empirical response time model will be applied to this data-set and its level of agreement with the measured data will be established. If the empirical response time model can be demonstrated to be robust, its value goes beyond simply being a means of determining average response times for a population. Of more importance is the insight it provides into the behavioural factors driving the response time. Using this approach it will be 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 IT, or the number of ITs that are performed by a population.

Exit Time and Crowd Density Data

One of the aims of the BeSeCu project was to collect evacuation data that could be used as validation data-sets for evacuation models. In an earlier paper[2] a validation data-set based on the evacuation of the Turkish library was presented. Here we present exit time data, transient crowd density data and initial conditions for the Polish Evacuation Validation Data-set (PEVDS). In the Polish evacuation trial, insufficient data was collected during the trial to define a validation data set encompassing the evacuation of the entire library. This was due to the size of the Polish library, the number of exits and stairs in the library and the lack of sufficient video cameras to collect all the data required to define a suitable validation data set. However, sufficient data was collected of a small portion of the library evacuation to define a suitable validation data set. The region of interest defining the validation data set is the portion of the library just in front of the library main exit, between the base of the main entrance stairs and the main exit (see figure 3). The data that was collected defining the specification of the evacuation validation data set consists of the geometric specification of the physical region and the flow rate of people entering the region (see figure 4). This information specifies the initial and boundary conditions for the evacuation validation data-set. The outputs that the evacuation simulation software is intended to predict consist of the exit flow and the change in the population density just ahead of the exit. The buildingEXODUS[9] software is used to reproduce the PEVDS. This region of space was monitored by a video camera mounted high above the main exit. Using footage derived from this video camera it was possible to determine the rate at which people entered into the region, the rate at which people exited the region (and hence the building) and the transient variation of the crowd density of people within a portion of the region.

Figure 3. Physical extent of region defining Polish validation data set

(a) Physical extent of validation region

(b) View of validation region from video camera

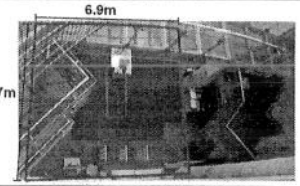
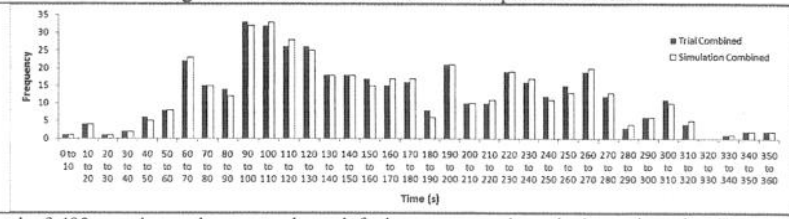


Figure 4. Measured and simulated occupant arrival rate



A total of 493 people are known to have left the geometry through the main exit. From a video camera aimed at the entry into the measurement region, the precise arrival time and arrival location of

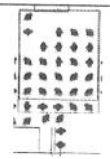
445 people are known. Of the remaining 48 people, 3 were already in the region at the start of the evacuation and 45 entered the region just out of camera view. The arrival time of these 45 people into the region is not known but is assumed to be during the peak period during the exit sequence. The arrival frequency of people into the region is shown in figure 4 along with the buildingEXODUS representation. The main exit consists of two door leafs, each of which was 0.8 m in width (see figure 3). Within buildingEXODUS a single node was used to represent the exit due to the channelling effect of the barriers just ahead of the exit – only a single file of people is likely to enter the barrier which is supported by the video evidence. To compensate for the smaller space allocated within the model, the flow rate for the exit was capped at a rate appropriate for a larger exit width, assuming the default HMSO unit flow rate (1.33 p/m/s). Using the default unit flow rate, a 0.5 m exit can expect to achieve a flow rate of 0.67 p/s while a 0.8 m exit could expect to achieve a flow rate of 1.1 p/s. Thus the 0.5 m exit was capped to a maximum of 1.1 p/s. This information provides initial conditions for the simulations.

The exit flow was measured using a video camera placed approximately 10 m above the exit. This video camera was also used to produce an approximate measure of the time varying density in a region just ahead of the exit. The density measurement box (see figure 5) used in the video analysis measures approximately 8.1 m^2 (2.9 m X 2.8 m). Due to the nodal structure within buildingEXODUS it is difficult to obtain an exact comparison with the dimensions and position of the experimental density measurement area. For this reason two different measurement areas were used in the model, one that has an area slightly smaller than the measured area and one that has an area slightly greater than the measured area. The first region, denoted by the inner box in figure 5b, has an area of 7.5 m^2 (3.0 m X 2.5 m) which is 7.4% less than the measured area and the outer box which has an area of 8.8 m^2 (3.5 m X 2.5 m) which is 8.6% larger than the measured area. Accurately measuring people in the target area is difficult given the angle of observation. To simplify the measurement process it was assumed that if anyone appeared to be less than 50% in the box they were considered to be out of the box, and if they appeared to be greater than 50% in the box, they were considered to be in the box. The measurements were undertaken by two people independently and if there was a disagreement in the measured values the differences were resolved.

Figure 5. Comparison of experimental and simulated crowd density calculation box

(a) Experimental crowd density box

(b) Model crowd density boxes

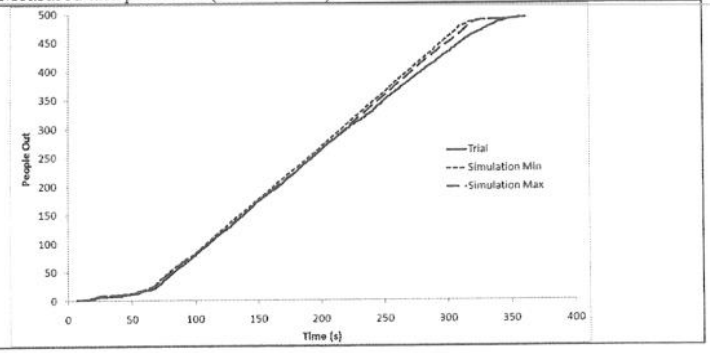


The buildingEXODUS was run a total of 10 times to produce the results presented here. Two key data sets are used in the validation analysis. The first is the exit curve for the main exit of the Polish library and the second is the transient density analysis. The exit curves are presented in figure 6 from which we note that the predicted evacuation is in excellent agreement with the actual evacuation for the first 50% of the evacuation as measured by the number of agents to exit the geometry.

For the last 50% of the evacuation, the predicted evacuation is faster than the actual evacuation. Towards the very end of the evacuation, the simulation exit flow decreases significantly and again closely matches the evacuation. At 300 s (midway in the second half of the evacuation) the measured number of people to exit the geometry was 431 while the predicted number varied from 446 to 456, an over-prediction of between 3.5% and 5.8%. Similarly, the measured time for 450 people to exit the geometry is 312 s while the minimum predicted time is 296 s, an under-estimation of between 5.1%. These differences are quite small and indicate that the prediction is in good agreement with the measured evacuation. The good level of agreement between model predictions and the measured

values may be expected due to the small and relatively simple nature of the geometry. However, the good agreement indicates that the software is capable of resolving the crowd dynamics associated with the congestion in the flow domain and the exiting behaviour.

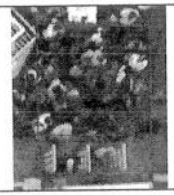
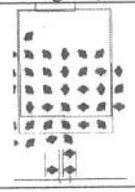
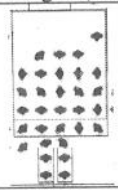
Figure 6. Measured and predicted (min and max) exit curves for the Polish validation case



A significantly more demanding prediction concerns the transient density in the exit region. This type of measurement is seldom made due to the difficult nature of the measurement and because in larger more complex situations, there are many other factors which may influence the density measurement at a particular location. This lack of control of the factors that may influence the density measurements makes it difficult to make a meaningful comparison with model predictions. However, in the case of the Polish library validation, by limiting the geometry to the main exit region and by specifying the arrival rate of people into the geometry a well controlled data set is produced.

The density predictions were found to be considerably more variable than the exit time predictions and so for comparison purposes the predictions from two different simulations (from the 10 that were run) are presented. As can be seen from comparing the measured with the predicted images in figure 7 the positioning of the people in the density box is similar, though not identical to the predicted positioning of the agents. Furthermore, the density predictions produced by simulation 1 can be considerably different from those produced by simulation 2.

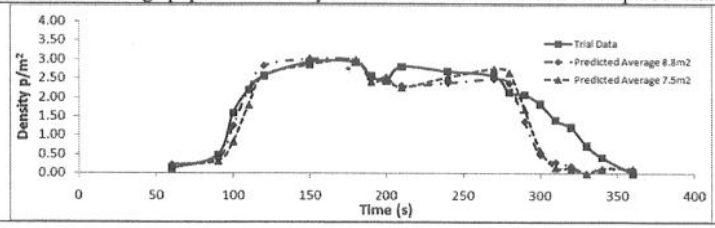
Figure 7. Measured and predicted crowd densities at 120 s

(a) Measured	(b) Simulation 1	(c) Simulation 2
21 people, 2.58 p/m^2	Area 1: 21 agents, 2.80 p/m^2 Area 2: 26 agents, 2.97 p/m^2	Area 1: 19 agents, 2.53 p/m^2 Area 2: 24 agents, 2.74 p/m^2
		

In total 10 simulations were run with each simulation producing two density measurements at each time step, for Area 1 and Area 2. It is noted that there is considerable variation between the predicted densities in both cases, with the larger area box showing the greater variation in predicted density. On the whole, the predictions follow the broad trends of the experimental data and the experimental results are on the whole bracketed between the predicted minimum and maximum values. The poorest parts of the predictions are towards the end of the evacuation where the model predictions fail to bracket the experimental data. Presented in figure 8 are the average density predictions for Area 1 and

Area 2. The predicted average density curves for both Area 1 and Area 2 are almost identical suggesting that the precise definition of the area is not critical. The predicted average density curves closely follow both the trends and density values measured in the experiment up until around 280 s. After this point, the predicted density, in all the simulations, drops away rapidly, while the measured density gradually decreases. This indicates that the predicted density diminishes much more rapidly than in the experiment, which also corresponds to the observed discrepancy in the exit graph. This suggests that after around 280 s the simulations are predicting a more rapid egress than was observed in the experiment, which is consistent with figure 6 i.e. that the model is predicting a more rapid egress.

Figure 8. Predicted average population density curves for Area 1 and Area 2 compared with trial data



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 Poland. 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 Polish evacuation produced a response time distribution which follows a log-normal curve as is commonly found in evacuation trials. The average response time extracted from the 192 analysed people was 69.9 s, and ranged from 0.1 s to 178 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 8.3 s, the average number of Action Tasks undertaken was 6.1, the average number of Information Tasks was 3.8, the average duration of an Action Task was 56.4 s, and the average duration of an Information task was 6.1 s. This basic information provides a means of characterising the Response Phase of the Polish library evacuation which goes far beyond simply measuring the response time. A similar analysis has already been undertaken for an evacuation in a library in the Czech Republic and Turkey. One further analysis is currently underway for a library evacuation conducted in the UK. 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 environment type, type of notification system and degree of training.

As part of this work an empirical response time model has been developed based on the analysis of Response Phase behaviours. This model was previously applied to the Czech Republic and Turkey

data-sets and found to produce an accurate prediction of the average response time for that evacuation. In the work presented in this paper, the same model (using the same constants) was applied to the Polish data-set and was also found to produce a prediction for the average response time within 3% of the measured value. 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 three different libraries in three different countries. The empirical response time model will also be applied to data derived from an additional evacuation trial conducted in the UK. If the empirical response time model can be demonstrated to be robust, its value goes beyond simply being a means of determining average response times for a population. Of more importance is the insight it provides into the behavioural factors driving the response time. Using this approach it should be 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 that are performed by a population.

Data from the evacuation trial was also collected to produce an evacuation model validation data-set. The Polish evacuation data provides a validation data set for evacuation models which includes transient density measurements along with the standard exit curve. While the geometry of the validation data set is small it uniquely provides a means of gauging the ability of evacuation simulation software to predict transient population density variations in the exit flow. As such, the data set is an important contribution to the development of evacuation models. The simulations of the Polish evacuation using the buildingEXODUS software demonstrate that this evacuation modelling tool is capable of reproducing the measured exiting times to within 5.8% and is capable of predicting the transient density variations to a good degree of accuracy. This indicates that the software is capable of resolving the crowd dynamics associated with congestion in the flow domain and the exiting behaviour.

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