Situation Awareness and Occupants’ Pre-Movement Times in Emergency Evacuations

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ABSTRACT

This paper outlines a study of human behaviour in fire examining the effect of situation awareness of building occupants on pre-movement times in an emergency fire evacuation. Situation awareness provides a framework to link various aspects of human behaviour, and a training programme was developed to bridge the gap between theoretical research findings and the practical workplace evacuation requirements. Key concepts of situation awareness required for an appropriate response to fire were identified for the foundation of the training programme developed and filmed as part of this research. An office facility participated in the study over a 15 month period. Two evacuation drills were conducted in two calendar years. The wardens and staff on two different levels of the facility were selected as the control and experimental groups in the second year. The wardens from the experimental group viewed the training programme before the yearly evacuation drill held the following day. Cameras recorded the time it took to enter the fire stairs and this time was used as an indicator of pre-movement time when all occupants cannot be directly observed. The anticipated finding of reduced pre-movement times in the experimental group did not occur. However, there was a slight difference between the mean pre-movement time of the wardens in both groups. A discussion on pre-movement time identified a limitation of the definition when applied to wardens and an extension of the accepted definition has been proposed.

BACKGROUND

The study of human behaviour in fire has attracted much interest over the last few decades. John L Bryan has been recognised as one of the pioneers in the field (Pauls, 1999) and his early work in 1980s was among the first to challenge the assumptions that people will panic in a fire and people will move directly to an exit (Bryan, 1983a, Bryan, 1983b). Instead, Bryan found that people will, in fact, demonstrate altruistic behaviours when caught in a fire and panic phenomenon is rare in fire emergencies. More importantly, he reported that there was a delay between the discovery of fire by occupants to their movement out of the building. These findings have been repeatedly confirmed by many other researchers (e.g., Sime, 1986, Blake et al., 2004, Proulx, 2008, Fahy et al., 2009b).

The issues surrounding the delayed movement of occupants have preoccupied many researchers ever since and the associated questions are still relevant today. What information do people need so they are able to make correct decisions to
evacuate quickly, if not immediately? What is the benefit of training and can it be quantified in relation to pre-movement times? The literature shows these two issues – training and the provision of timely and appropriate information – are unresolved (Pauls, 2012).

In recent times, the discussion on human behaviour in fire has been reframed in terms of ‘situation awareness’ (Pauls et al., 2009). Pauls (2012) believed that situation awareness by building occupants will have a direct impact on their decision making in an emergency. Poor situation awareness is likely to lead to incorrect and/or inadequate behavioural responses while good situation awareness is regarded as a critical factor in good decision making. This is an important development in the field and is used here to provide a framework linking the various aspects of human behaviour as an attempt is made to determine the impact of raised situation awareness.

The NIST investigation into the Station Nightclub fire (Grosshandler et al., 2005) and the World Trade Centre 9/11 tragedy (Averill et al., 2009) made recommendations about understanding human behaviour and measures to prepare for and to enhance an emergency evacuation. A survey of the International Symposia of Human Behaviour in Fire and other literature appears to indicate these areas of research have yet to be fully addressed. It is apparent that research is required into gaining further understanding of some practical aspects of raising situation awareness. In particular, the issue of training wardens/staff to respond immediately to any fire cues and take control of the evacuation is expected to produce a reduction in pre-movement time. Therefore, this study focussed on raising situation awareness of wardens through training and investigated the impact of this raised awareness on pre-movement times.

The major objective of this study is to determine if training can raise situation awareness by building occupants of fire emergencies in office working environments and effectively reduce pre-movement time in emergency evacuations. A video training programme was developed and evacuation drills were used to test the effect of the training. The hypothesis was “the appropriate training of fire wardens in an office can increase the situation awareness of occupants and lead to a reduction in all phases of pre-movement times”.

Another objective of the study was identify key attributes of situation awareness and then develop a framework of situation awareness relating to human behaviour in fire.

Previous research has demonstrated the importance of training and this study attempted to reinforce those findings with the training programme. Thus, a third objective of was to provide a link between theory and practice by the identification of the key elements of situation awareness and incorporating them into the training programme. The key attributes will provide a base upon which future research and training programmes and public education programmes can build.

The project was conducted over 15 months from September 2015 to December 2016. The video was delivered to the fire wardens of an office building. To test the effectiveness of the training program, two fire drills were conducted in the office building, one in November 2015 and the other in November 2016 after the fire wardens received the training. The fire drills were video recorded and were later
analysed to obtain the pre-movement time.

**TIMELINE ANALYSIS OF BUILDING OCCUPANT RESPONSE TO FIRE ALARMS**

A timeline analysis can be generated from the time a fire is initiated through the time it is detected to the time occupants have evacuated from the building to place of safety. This analysis is useful for assessing life safety of the occupants. This timeline analysis is used to quantify the required safe evacuation time (RSET) (ABCB, 2005).

There are several separate time periods in the quantification of RSET:
- Detection time: the time period from fire ignition to the time it is detected;
- Alarm time: the time period from the time the fire is detected to the time the alarm is raised. Both of these time periods can be achieved by automatic or manual means; and
- Evacuation time: the time period from which the alarm is raised to the time at which occupants have evacuated. Evacuation time consists of pre-movement time and movement time.

These time periods are shown graphically in Figure 1.

![Figure 1: Timeline and components of RSET](image)

**Pre-movement time**

This research focussed on one aspect of RSET, the pre-movement time. The British Standards Published Document, *PD 7974-6:2004* (BSI, 2004) defines pre-movement as the interval between the time at which a warning of fire is given and the time at which the first move is made towards an exit. This consists of the time required to recognise the emergency and then carry out a range of activities before travelling to exits.

PD 7974-6:2004 recognises two phases of pre-movement time: a recognition phase in which the first response occurs as the awareness of the fire cues are comprehended; and a response phase, in which activities are undertaken before evacuation movement commences. These are the components of pre-movement time deemed relevant to this study. The components of pre-movement time being examined in this research are highlighted by the red double arrow line in Figure 1.
Situation Awareness

Mica Endsley (1995) paved the way for an understanding of situation awareness (SA). Endsley found expert decision makers had an ability to classify a situation through a pattern matching process and developed a model of SA.

SA refers to the mental state of a person having understanding of what is happening in a current event. It involves three levels of complexity (Endsley, 1995):

- Level 1: perception of the situation;
- Level 2: comprehension of the situation; and
- Level 3: prediction of what will happen in this situation.

Endsley distinguished SA as a state of knowledge from the processes used to achieve that state. The processes were referred to as situation assessment or the process of achieving, acquiring or maintaining SA. She also described that SA didn’t refer to all knowledge, only that portion relevant to the particular dynamic environment. She described SA as a construct separate from decision making, performance and other constructs that might influence it (e.g., attention, working memory, workload and stress) (Endsley 1995).

In relation to human behaviour in fires, the preliminary discussion on SA occurred at the 4th International Symposium on Human Behaviour in Fire and attempted to provide an initial overview of its breadth (Pauls et al., 2009). Some of the pre-eminent human behaviour researchers presented during this overview, including Gwynne (Pauls et al., 2009), Kuligoswki (Pauls et al., 2009) and Meacham (Pauls et al., 2009). The constant themes of their presentations related to the provision of information to occupants, both before (through training and drills) and during the incident.

These themes assisted in the identification of the key attributes of SA. The identification of these attributes recognised that, if SA is to be improved, then the elements of a situation critical for SA must be specified and these elements might include processes as well as knowledge (Rousseau et al., 2004).

Key Attributes of Situation Awareness in Fire Emergencies

Key attributes of SA are the ones that enable him/her to perceive a situation, comprehend it, predict likely outcomes and determine an appropriate response based on these predictions. Key SA attributes form the foundation of the training programme and are categorised below.

Knowledge of building information (Level 1 SA)

Knowledge of the fire safety measures of a building/workplace was identified as one of the key SA attributes required to overcome delayed evacuation in which fire cues were perceived as ambiguous due to not correctly understanding or interpreting knowledge of the fire safety system within a building.
Knowledge of characteristics of fire and smoke (Level 1 SA)

Knowledge that is regarded as essential for good SA includes: fire growth; how smoke spreads; the danger of moving through smoke; and protective measures to prevent the spread of fire and smoke. It is expected this knowledge will enable a quick response in a fire situation instead of a delay as people try to gain understanding of what the presence of smoke might mean and what threat it might pose personally.

Knowledge to assist people to correctly respond to discovery of fire (Level 2 SA)

One of the recognised consequences of SA is that it is the actions of the individuals before the arrival of the emergency services that determine the chances of their survival. Incorrect actions may lead to increase in pre-movement time and even decrease in the available safe evacuation time (ASET).

One common acronym used to build knowledge of a correct response to fire is based on the acronym R A C E.

R – rescue/remove people from danger if safe.
A – raise the alarm (000 to the fire service) and alert others (in the building).
C – contain the fire and smoke by closing doors.
E – extinguish and/or evacuate

While some might see these actions as decisions arising from Level 2 SA, the researcher regards the basic response of R A C E as a response to the comprehension of the fire cues ie R A C E provides basic knowledge required to make sound decisions in a fire emergency.

Knowledge to assist wardens to respond immediately, take control and implement emergency procedures (Level 2 – Level 3 SA)

A critical feature of delayed response was a lack of defined leadership as the social process of seeking information to define the situation would often delay the response. Therefore, it is important for wardens to take control immediately after a fire is discovered or the alert tones sound. They need to be trained to do this as it cannot be learnt on the day of an emergency.

Taking control is also seen as basic knowledge for a warden once fire cues have been perceived and comprehended and an automatic response to the comprehension of those cues. In other words, if the alert tones are sounding or someone is yelling “fire”, a warden does not need to decide about whether he or she needs to take control.

Drills provide opportunity for the wardens to practise implementing the procedures as a team and reinforce the training. The anticipated result is internalised knowledge so the wardens’ level of SA is increased to enable them to function effectively and lead others in an emergency.
Knowledge to assist decision making in an emergency (Level 2 – Level 3 SA)

One of the aspects of human behaviour that caused delay was the uncertainty about the correct response. If no one has taken control, then those present need to comprehend the cues (Level 2 SA) and predict what will happen (Level 3 SA) so they can make a decision as to the correct response. The uncertainty about the correct response creates stress and causes further delay.

If the possible responses have been taught in advance and simplified to a few simplified options then the decision making process should be simplified and quickened.

Maintaining Situation Awareness in an emergency

The ability to maintain good SA in an emergency will be enhanced or hindered by the communication that occurs at all levels. The training programme discussed the importance of good communication. It also looked at occupant behaviours that wardens might be encounter and how the wardens’ SA can influence the response of others.

Communication within the warden team

This is a key component for maintaining SA in an emergency. It was identified from the problems encountered when communication between the warden team failed. Perhaps the most notable example of this was the evacuation that followed the WTC bombing in 1993 (Proulx and Fahy, 2003). A crucial aspect of a successful team response to an emergency is the communication between the team members as it is almost impossible for wardens to maintain an accurate SA of the emergency without good communication between them.

Communication between warden and other occupants

The information seeking process can be circumvented by the provision of accurate and timely information to the occupants during an emergency. This information will give them the situation awareness they need to willingly follow the lead of the wardens.

Wardens should know the type of information that needs to be conveyed to the occupants in an emergency and practice it in evacuation drills.

The social aspect of an emergency response

There are several social features that have commonly been seen in emergency evacuations. People will tend to think: there is nothing bad happening (normalcy bias); nothing bad will happen to them (optimism); not want to interrupt the normal routine (commitment); look to others to see their response and mimic it (social influence); and seek their friends (social affiliation). If the SA of the wardens is such that they understand the urgency of the situation, respond quickly, take control and implement their emergency procedures, then the occupants are likely to follow their lead.
**First attack firefighting (Level 2-3 SA)**

If a fire is discovered in its early stages, it might be able to be extinguished before it can grow. The action of extinguishing a fire can quickly bring a resolution to the incident and ensure the safety of everyone. However, any person considering such an action needs a level of knowledge to make a quick and accurate decision about their chances of being able to safely and effectively use a portable fire extinguisher or hose reel. The SA required for this decision can be imparted in training and reinforced by a practical session.

As discussed below, first attack firefighting was not addressed in the training programme.

**TRAINING PROGRAMME**

Thirty one key statements on SA were formulated based on the key attributes and were utilised as the basis of the training programme for wardens, which was filmed. It is recognised a complete training programme for wardens would encompass first attack firefighting. But first attack firefighting is a session in itself and outside the scope of this study.

The filmed session titled *Workplace Emergency Response* was divided into three parts and a worksheet was developed for all participants to complete in group activities at the end of each part. These activities involved discussion that aimed to assist the completion of tables in the worksheet – one table at the end of each part. The session covered the following topics:

**Part 1**
The first part of the programme introduced human response to fire and provided information to assist Level 1 SA through the information about building’s fire safety measures.

- Features of human behaviour in fire
- Fire safety measures in buildings

**Part 2**
The second part further developed Level 1 SA through the information about fire and smoke and then moved to Level 2 SA through the section about actions to take on fire discovery. This was based on the acronym R A C E as discussed above.

- Characteristics of fire and smoke
- Actions to take if you discover a fire

**Part 3**
Level 2 SA was extended and Level 3 SA was developed in part 3 of the programme. It also covered a crucial aspect of maintaining SA in an emergency, the communication between wardens and communication with the occupants.

- Taking control in an emergency
- Responses to a fire
- Communication in an emergency
  - communication between the warden team
  - communication with everyone else
The worksheet was seen as a means to bridge the gap of a generic pre-recorded training programme and specific details of the premises for which the participants are trained. The questions in the worksheet were developed as a means of promoting discussion among the participants/wardens and recording the specific details unable to be provided by the programme. An example of one of the tables is presented in Table 1.

Table 1: An example from the worksheet

<table>
<thead>
<tr>
<th>Questions</th>
<th>Answers</th>
</tr>
</thead>
<tbody>
<tr>
<td>How do we alert others around us in an emergency?</td>
<td></td>
</tr>
<tr>
<td>How do we alert the chief warden in an emergency?</td>
<td></td>
</tr>
<tr>
<td>Who is to make the 000 call in an emergency?</td>
<td></td>
</tr>
</tbody>
</table>

FIELD TRIAL

An office facility in Sydney, which was occupied by a sole organisation, was selected for a trial of the training program. The facility is a three-storey building. Most of the occupants were located on Levels 2 and 3, and Level 1 consisted of a carpark and a reception area.

The floor planes of both Levels 2 and 3 are very similar and the distances to the fire stairs from various positions on the floor were almost the same on both levels. See Figures 2 and 3.

Two drills were conducted over 14 months – one in 2015 and one in 2016. The wardens from one level were selected as the experimental group before the 2016 drill. They viewed the training programme and completed the worksheet during the group discussion at the end of each part. The wardens from the other level were the control group. They did not view the training programme.

First Evacuation Drill

The first drill was conducted in November, 2015. The footage of this drill was obtained from three cameras (outside one of the fire stairs at ground level and internally at the entrance to both fire stairs on level 3). The location of the internal cameras and their field of view is shown in Figure 2. The footage shows that 83 occupants exited from the south fire stairs on Level 1 and that 32 people entered the north fire stairs on one of the levels. Therefore, at least 115 occupants participated in the drill.
Selection and Training of Experimental Group

The training programme was shown to the experimental group the day before the second evacuation drill in November, 2016. The experimental group were the wardens from Level 3 of the building. Five of the six wardens from Level 3 and the chief warden attended and viewed the presentation.

The training session took one and a half hours to complete due to the enthusiastic discussion that ensued at the end of each part while the wardens were completing the worksheets. The researcher facilitated the discussions as the wardens completed the worksheet at the conclusion of each of the three parts of the training programme.

Perhaps the first point to be made relates to the previously identified limitation of a pre-recorded programme’s inability to address issues particular to a specific facility. These include the specific fire safety measures, wardens’ roles in an emergency evacuation, wardens’ communication with the chief warden and means of alerting others in an emergency. All of these were covered in detail during the ensuing
discussions. The participants demonstrated their enthusiasm towards the training programme which led to the identification of the issues important to the wardens.

There were other pertinent issues that were raised in the discussions. These included:

- how to respond if the alert tones sounded while a warden was on a different level;
- the use of the flip charts;
- the advantages of appointing back up wardens to take on the role in the absence of the appointed wardens;
- ensuring the chief warden’s phone number was in every warden’s mobile phone so they could contact and inform him at the start of the emergency;
- informing the rest of the staff of who are the wardens and; their roles are in an emergency evacuation; and
- the value of all staff members receiving a brief information session in order to raise their awareness of the dangers posed by fires.

A facilitator’s guide was developed as result of the discussion. This will enable any person who might be organising a training session to successfully facilitate the discussions and the completion of the worksheets at the end of each part.

All participating wardens provided very positive feedback on the programme through a survey. On a scale from 1-10, three wardens rated it 8 and three wardens rated it 9.

The following answers were recorded in response to the question about the main benefits of the training programme:

- “Discussion / promoting discussion / other wardens asking questions about roles” were the comments from three wardens;
- “Refresher” was mentioned by two wardens
- “Becoming fully aware of what is required to be prepared during fire evacuations” was written by the warden who was not able to answer question 8.
- In a similar vein, the warden who had not received previous training commented “Good overview of processes, understanding fire evacuation procedures” and another warden commented “To know what to do in a real emergency”
- “Raising greater awareness” was another comment, again reflecting the comment of the warden who was not able to answer question 8,

Another survey question asked the wardens to list the most important thing they learnt. The following answers were recorded:

- “Stay below smoke, flashover effect”
- “Cannot be sure how a fire grows quickly and not to trust that it'll be ok. If there’s fire evacuate.”
Second Evacuation Drill

There were not enough cameras to cover the entire workplace and view the responses of all occupants on the two levels. There were 3 cameras positioned in various locations on the level in which the control group operated, 4 cameras positioned in various locations on the level in which the experimental group operated and 2 external cameras at both fire stairs doors. The locations of the cameras and the area viewed by the cameras are shown in Figure 3 and Figure 4.

![Figure 3: 2016 Level 2 layout showing camera positions](image)
It can be seen that four of the cameras were positioned to observe the occupants as they entered the two fire stairs on each level. These cameras provided direct quantitative data on the time taken for people to enter the fire stairs which is regarded as a place of safety for the purpose of this research.

The other cameras were positioned in places overlooking significant numbers of staff on each level to provide further data on the responses of people once the tones started sounding. It is acknowledged that not all of the actions that contribute to pre-movement time could be observed by limited number of cameras. Notwithstanding, it is also acknowledged the time taken to enter the fire stairs is dependent on how quickly people commence to move. Hence, the times to enter the fire stairs in the two fire drills can be used to gauge pre-movement times and assess the effect of training.

Thirty two people from Level 2 and 56 staff from Level 3 participated in the drill. Of those participants there were 2 wardens on Level 2 (the control group) and 5 wardens on Level 3 (the experimental group).
DATA PROCESSING AND ANALYSIS

The footage from the evacuation drills in 2015 and 2016 were compared and also used to test the effectiveness of the training programme. The footage from the 2015 was obviously more limited than the footage from 2016 as the 2015 footage was only available from three cameras. While there are slight differences between the two years and some change of personnel, the influence of these changes on pre-movement time is considered negligible.

The results of the two fire drills were compared to identify the effect of the special programme for situation awareness training.

Definition of pre-movement time for wardens

Fire wardens have a definitive role to play in a fire emergency. Their time delay actions are different to ordinary occupants and in many cases, they may be the last persons to leave the building.

Once wardens start their roles, they have actually demonstrated a recognition and understanding of the event that is occurring and are taking positive steps to evacuate their area of responsibility. Their response as wardens facilitate the movement of the rest of the staff. Wardens have an appointed responsibility to delay their own movement towards an exit by undertaking actions which direct other occupants to move towards the exits. These actions delay their own movement but facilitate the movement of others. Another way of stating this is wardens’ extended pre-movement time results in reduced pre-movement times for the rest of the building occupants.

Therefore this research proposes an extension of the definition of pre-movement time to account for wardens. This definition of pre-movement time for wardens would state the pre-movement time as the interval starting at the time wardens become aware of the emergency to the time they begin to undertake their roles as wardens.

Like the pre-movement time for the general building occupants, there are two phases of pre-movement time for wardens. They are the recognition phase (the time taken to recognise the warning cues) and the response phase (the time taken from the first recognition to the cues to the first actions in their warden roles). It is their first actions as wardens that mark the end of the pre-movement time. It would be regarded that the response phase of wardens would be a negligible time period for those who were well trained and demonstrated an immediate response to the emergency.

In the research, the response that provided an indication the warden recognised the situation and was deviating from his or her normal work role was taken as the first action. Various responses were observed and accepted as first actions. For example, one warden was seen putting on his cap while sitting. This was regarded as his first action. Two wardens were observed standing at their desks and moving before putting on their caps. The standing and moving were regarded as their first actions.
Results

The results for the warden pre-movement times in 2015 and 2016 are summarised in Table 2 and Table 3. There was a slight difference in mean pre-movement times: 19 seconds for the level 2 wardens and 16 seconds for the level 3 wardens. The responses of the wardens on both levels are very quick and appears to indicate a high level of SA for wardens on both levels.

Table 2: Warden pre-movement time in the first fire drill (2015)

<table>
<thead>
<tr>
<th>Time (min:sec)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:41</td>
<td>Near south stairs</td>
</tr>
<tr>
<td>0:50</td>
<td>Near north stairs</td>
</tr>
<tr>
<td>0:45</td>
<td>Mean level 3 warden pre-movement time</td>
</tr>
</tbody>
</table>

Table 3: Warden pre-movement time in the second fire drill (2016)

<table>
<thead>
<tr>
<th>Time (min:sec)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:18</td>
<td>Near south stairs</td>
</tr>
<tr>
<td>0:20</td>
<td>Near north stairs</td>
</tr>
<tr>
<td>0:19</td>
<td>Mean level 2 warden pre-movement time</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Time (min:sec)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:11</td>
<td>South west area.</td>
</tr>
<tr>
<td>0:16</td>
<td>South west area.</td>
</tr>
<tr>
<td>0:07</td>
<td>North east area</td>
</tr>
<tr>
<td>0:16</td>
<td>North east area</td>
</tr>
<tr>
<td>0:29</td>
<td>Near north stairs</td>
</tr>
<tr>
<td>0:16</td>
<td>Mean level 3 warden pre-movement time</td>
</tr>
</tbody>
</table>

A comparison between the first and second drill results revealed a significant difference in the pre-movement time of one warden. The pre-movement time of the warden near the north stair on level 3 was significantly less in 2016. It would appear to indicate increased SA from 2015 to 2016 and the training programme might have been a significant factor in that increase.

The observed or deduced pre-movement times for staff in the 2016 drill are tabulated below in Table 4 and Table 5. The pre-movement time for staff at the fire stairs is a calculated time based on the time at which the first person was viewed entering the fire stairs. This person was assumed to have moved from the closest desk at a speed of 1.25 m/s (from Proulx 2008) which gives the most conservative result. The pre-movement time at the fire stairs was only calculated for the first person to enter the fire stairs.
The cameras that were not positioned at the fire stairs were able to observe all the staff in that particular area and the range of pre-movement times for those staff were recorded in the table. These people were obviously then recorded entering the fire stairs at a later point in the evacuation but their pre-movement time was directly observed by the camera and did not need to be calculated.

Table 4: Pre-movement times for staff on level 2 (2016)

<table>
<thead>
<tr>
<th>Camera Location</th>
<th>Pre-movement time calculated or observed</th>
<th>Pre-movement time (secs) (first person to reach fire stairs)</th>
<th>Pre-movement time (secs) (range of all people within the area)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location 1 - north stairs</td>
<td>Calculated</td>
<td>52</td>
<td></td>
</tr>
<tr>
<td>Location 2 - south stairs</td>
<td>Calculated</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Location 3 - south west office area</td>
<td>Observed</td>
<td></td>
<td>49 - 54</td>
</tr>
</tbody>
</table>

The tables above only record the first person to enter the fire stairs or the range or pre-movement time of all people in camera view for those cameras not positioned at the fire stairs.

The time taken for all of the occupants to enter the fire stairs on both levels was compared as an indicator of pre-movement time. The comparison was based on the premise that the time taken to reach the fire stairs is partially dependent on the pre-movement time (i.e., a long pre-movement time would result in a longer time to reach the fire stairs than a short pre-movement time). The similarities in the floor layout of both levels validates the comparison. The results are shown in Table 6 and Table 7.
### Table 6: Level 2 movement time to stairs (2016)

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>No of people</th>
<th>Percentage</th>
<th>Running percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:00 – 0:15</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0:16 – 0:30</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0:31 – 0:45</td>
<td>3</td>
<td>9.7</td>
<td>9.7</td>
</tr>
<tr>
<td>0:46 – 1:00</td>
<td>5</td>
<td>16.2</td>
<td>25.9</td>
</tr>
<tr>
<td>1:01 – 1:15</td>
<td>8</td>
<td>25.8</td>
<td>51.7</td>
</tr>
<tr>
<td>1:16 – 1:30</td>
<td>9</td>
<td>29</td>
<td>80.7</td>
</tr>
<tr>
<td>1:31 – 1:45</td>
<td>3</td>
<td>9.7</td>
<td>90.4</td>
</tr>
<tr>
<td>1:46 – 2:00</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2:01 – 2:15</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2:16 – 2:30</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2:31 – 2:45</td>
<td>2</td>
<td>6.4</td>
<td>96.8</td>
</tr>
<tr>
<td>2:46 – 3:00</td>
<td>1</td>
<td>3.2</td>
<td>100</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>31</strong></td>
<td><strong>100</strong></td>
<td></td>
</tr>
</tbody>
</table>

### Table 7: Level 3 movement time to stairs (2016)

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>No of people</th>
<th>Percentage</th>
<th>Running percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:00 – 0:15</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0:16 – 0:30</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0:31 – 0:45</td>
<td>2</td>
<td>3.6</td>
<td>3.6</td>
</tr>
<tr>
<td>0:46 – 1:00</td>
<td>8</td>
<td>14.2</td>
<td>17.8</td>
</tr>
<tr>
<td>1:01 – 1:15</td>
<td>13</td>
<td>23.2</td>
<td>41.0</td>
</tr>
<tr>
<td>1:16 – 1:30</td>
<td>14</td>
<td>25.0</td>
<td>66.0</td>
</tr>
<tr>
<td>1:31 – 1:45</td>
<td>12</td>
<td>21.4</td>
<td>87.4</td>
</tr>
<tr>
<td>1:46 – 2:00</td>
<td>1</td>
<td>1.8</td>
<td>89.2</td>
</tr>
<tr>
<td>2:01 – 2:15</td>
<td>1</td>
<td>1.8</td>
<td>91</td>
</tr>
<tr>
<td>2:16 – 2:30</td>
<td>0</td>
<td>0</td>
<td>91</td>
</tr>
<tr>
<td>2:31 – 2:45</td>
<td>3</td>
<td>5.4</td>
<td>96.4</td>
</tr>
<tr>
<td>2:46 – 3:00</td>
<td>2</td>
<td>3.6</td>
<td>100</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>56</strong></td>
<td><strong>100</strong></td>
<td></td>
</tr>
</tbody>
</table>

The results did not reveal any significant difference between the two levels in terms of pre-movement time. 50% of staff entered the fire stairs within 1 min 15 secs on level 2 and 1 min 30 secs on level 3. 80% of staff entered the fire stairs within 1 min 30 secs on level 2 and 1 min 45 secs on level 3. While the occupants on level 3 were essentially 15 seconds behind the occupants on level 2, there were less occupants.
on level 2. There were more wardens operating on level 3 evacuating the extra people which adds to the conclusion there was no real significant difference between the two levels in terms of pre-movement time.

It appeared the SA of the staff on both levels was very similar. The response to the tones and the direction to the wardens was very similar. Most people knew where they needed to go and the wardens were able to correctly inform those whose SA was deficient in some way.

Overall, a slight difference in pre-movement times was observed between the wardens on level 2 (control group) and level 3 (experimental group). While it supports the hypothesis, it is felt the response of both groups was excellent and therefore, it is difficult to emphatically state the hypothesis was proved by the testing of the control group against the experimental group.

As previously stated, a comparison between the 2015 and 2016 results revealed a significant difference in the pre-movement time of one warden which was regarded as supporting the hypothesis but not proving it. Without knowledge of the warden’s history in previous drills, the first slower pre-movement time might also have been an anomaly. Therefore, it remains an observation rather than a result that verifies the hypothesis.

The time taken for occupants to enter the fire stairs on Level 3 in 2015 are tabulated in Table 8.

*Table 8: Level 3 movement time to stairs (2015)*

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>No of people</th>
<th>Percentage</th>
<th>Running percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:00 – 0:15</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0:16 – 0:30</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0:31 – 0:45</td>
<td>6</td>
<td>10.3</td>
<td>10.3</td>
</tr>
<tr>
<td>0:46 – 1:00</td>
<td>9</td>
<td>15.5</td>
<td>25.8</td>
</tr>
<tr>
<td>1:01 – 1:15</td>
<td>7</td>
<td>12.1</td>
<td>37.9</td>
</tr>
<tr>
<td>1:16 – 1:30</td>
<td>13</td>
<td>22.4</td>
<td>60.3</td>
</tr>
<tr>
<td>1:31 – 1:45</td>
<td>11</td>
<td>19.0</td>
<td>79.3</td>
</tr>
<tr>
<td>1:46 – 2:00</td>
<td>6</td>
<td>10.3</td>
<td>89.6</td>
</tr>
<tr>
<td>2:01 – 2:15</td>
<td>4</td>
<td>7.0</td>
<td>96.6</td>
</tr>
<tr>
<td>2:16 – 2:30</td>
<td>0</td>
<td>0</td>
<td>96.6</td>
</tr>
<tr>
<td>2:31 – 2:45</td>
<td>1</td>
<td>1.7</td>
<td>98.3</td>
</tr>
<tr>
<td>2:46 – 3:00</td>
<td>0</td>
<td>0</td>
<td>98.3</td>
</tr>
<tr>
<td>3:01 – 3:15</td>
<td>0</td>
<td>0</td>
<td>98.3</td>
</tr>
<tr>
<td>3:16 – 3:30</td>
<td>1</td>
<td>1.7</td>
<td>100</td>
</tr>
</tbody>
</table>

*Total* | 58 | 100
At first glance, the results do not appear to reveal any significant difference between the two years in terms of pre-movement time. 50% of staff entered the fire stairs within 1 min 30 secs in 2015 and 2016. 80% of staff entered the fire stairs within 2 min in 2015 and 1 min 45 secs in 2016. 90% of staff entered the fire stairs within 2 min 15 secs in 2015 and 2016. However, there was an improvement in the evacuation commencing rate from 2015 to 2016 and this is discussed below.

The hypothesis was regarded as valid for a number of reasons. First, most of the wardens at the facility had received prior training and significant numbers of the staff had been present at previous drills. At least some of these received prior training and the facility had an induction process that provided some information about the emergency procedures and the location of the exits. This would indicate the level of SA among both wardens and staff had already been raised by previous experiences and was reflected in reduced pre-movement times.

In retrospect, it was thought the results might have been significantly different if the training programme had been presented at a facility where the wardens had not experienced prior training in workplace emergency response and/or previous drills had not been conducted.

The results might have also differed if one of the field trials had been a drill that simulated a fire on an actual floor. A scenario such as this would test the wardens’ response in a different way. The actual actions they would need to take to keep people safe and to move people away from the fire plus the possibility of an exit being blocked by the fire all pose complications that a standard drill scenario does not cover. A drill scenario like the one described above would be expected to provide significant insight into the levels of SA attained by wardens and staff.

Further verification of the excellent results can be gained by comparing these results with the values for pre-movement time detailed in Table C.1 of PD 7974-6: 2004. Utilising the modifying criteria from PD 7974-6: 2004, this author would categorise this facility in the following manner:

- Behavioural scenario A;
- Alarm level 1 system;
- Building level B2;
- Management level M1.

Table C.1 of PD 7974-6: 2004 prescribes a pre-movement time of 0.5 minute for the first percentile and an occupant distribution of 1 minute for the 99th percentile. The response of wardens and staff fit well within these times, particularly if the definition for warden pre-movement time is accepted by the reader. In fact, the results of this study are superior to the ascribed pre-movement times of PD 7974-6: 2004. The wardens had all responded to the tones in less than 0.5 minutes and more than 80% of the occupants had not only started moving within the next minute but had reached a place of safety in the fire stairs. The reduced pre-movement time of the staff is regarded as a direct result of the warden’s actions and adds weight to this researcher’s contention that warden pre-movement time should be defined separately to general pre-movement time.
EVACUATION COMMENCING RATE

In the work by Proulx et al. (1996), the result of pre-movement time study in office environments was presented as number distribution versus time. The summation of this parameter will give the total number of occupants who participated in the fire drill and evacuated from the building.

To give a rigorous interpretation of the result, the concept of evacuation commencing rate is introduced. The evacuation commencing rate, $E$, is defined as the number of people who start evacuation movement within a building per unit time. The number of people who have started evacuation movement from the building within a given time interval, $N(t_1,t_2)$, is simply the integration of the evacuation commencing rate over the time interval.

$$N(t_1, t_2) = \int_{t_1}^{t_2} E \, dt$$  \hspace{1cm} (1)

where the evacuation commencing rate has the unit of number per second or number per minute ($s^{-1}$ or $\text{min}^{-1}$). It can be a function of time, building occupancy class and occupant group. In fact, Proulx et al’s result can be interpreted as the evacuation commencing rate distribution over time for the particular office building in which the drill was conducted.

Without losing generality, the time at the start of pre-movement is set at zero. At any given time $t$, the number of occupants who have commenced evacuation in the building is expressed as

$$N(t) = \int_{0}^{t} E(t) \, dt$$  \hspace{1cm} (2)

Denote the total number of occupants inside a building by $N$. The parameter

$$F(t) = \frac{N(t)}{N}$$  \hspace{1cm} (3)

is the cumulative fraction of the building occupants who have commenced to evacuate the building at time $t$. Define parameter

$$f(t) = \frac{E(t)}{N}$$  \hspace{1cm} (4)

as the evacuation commencing fraction (or frequency) rate. From Eqs. (2), (3) and (4),

$$F(t) = \int_{0}^{t} f(t) \, dt$$  \hspace{1cm} (5)

Moreover, assuming that all occupants will eventually commit themselves to evacuating from the building given sufficiently long time, then

$$F(\infty) = \frac{N(\infty)}{N} = \int_{0}^{\infty} \frac{E(t)}{N} \, dt = 1$$  \hspace{1cm} (6)

To this end, the similarity of the introduced parameters to the probability description (Bean, 2001) is clear. Parameter $f(t)$ is equivalent to probability density distribution function for evacuation rate and $F(t)$ is the probability distribution for the evacuation
fraction.

By using fractional terms, general theoretical framework can be established and experimental results from different building premises can be compared.

In the current study, the occupants’ commencement time of evacuation movement was not measured. Instead, the arrival times to fire stairs by individuals were measured. This time can also be treated as a random variable. For the analysis of this arrival time, we define the arrival rate as the number of occupants arriving at fire stairs per unit time (1/s). All the foregoing discussions about the commencing rate are applicable to the arrival rate. For simplicity, the symbol $E$ can be used to denote arrival rate, and $f(t)$ and $F(t)$ are fractional occupant arrival rate and cumulative fraction of population arrival respectively.

The data presented in Table 7 and Table 8 was plotted in Figure 5 which shows the fractional occupant arrival rate and the calculated cumulative fraction of population arrival at fire stairs on Level 3 in the two fire drills. Figure 5(a) shows that the arrival rate at the fire stair in 2016 drill was higher than that in the 2015 drill for a significant duration of the evacuation drills. Therefore, the evacuation drill in 2016 was completed more quickly than the 2015 drill by about one half of a minute as shown in Figure 5(b). Note that there is a small peak at the end of the curves representing the fractional occupant arrival rate [Figure 5(a)]. This peak can be attributed to the last departure of fire wardens from the floor. It should also be noted that there was a slight difference in the number of initial occupants on Level 3 in the two drills. In 2015 this number was 58 and in 2016 it was 56.

![Figure 5: Plots of (a) fractional occupant arrival rate and (b) cumulative fraction of population arrival at fire stairs on Level 3 in the two fire drills](image)

Using the fractional occupant arrival rate and the cumulative fraction of population arrival at fire stairs, the evacuation performance of the occupants on different levels in the same fire drill can also be compared. Figure 6 presents the results for Level 2 and Level 3 occupants in the same drill in 2016. It can be discerned from this figure that although the occupants on Level 3 started to arrive at the fire stairs slightly later than the occupants on Level 2, the former maintained more or less the same fractional arrival rate or even slightly higher rate than the latter towards the end of the drill. As a consequence, the occupants on the two levels completed the
evacuation at about the same time.

![Figure 6: Plots of (a) fractional occupant arrival rate and (b) cumulative fraction of population arrival at fire stairs on Level 2 and Level 3 in the 2016 fire drill](image)

Proulx et al. (1996) compared the number distribution of pre-movement times observed from two office evacuation drills, one conducted in London and the other in Ottawa. Unfortunately, their results were not presented in terms of fractional evacuation commencing rate and, therefore, is reproduced here in Figure 7 for qualitative comparison.

![Figure 7: Number distribution of pre-movement times in offices (Proulx et al., 1996)](image)

From Figure 7 alone, one can only say that the total numbers of occupants in the two office buildings were different, but cannot say which evacuation is more efficient than the other. Although the evacuation commencing rate in the London office was lower than in the Ottawa, it was likely that the fire drill in the London office finished earlier...
than in the Ottawa office.

Comparing Figure 7 with Figure 6(a), the similarity between the London pre-movement time curve and the curve of fractional arrival time rate obtained in the current study is seen in the shape of the curves, particularly in the tail peak of the curves.

CONCLUSION

The training programme was received very positively by the wardens. While the results did not significantly differentiate the two groups in 2016, there was an improvement in the evacuation commencing fraction rate in 2016. Therefore, the training programme is believed to have had an impact in 2016 and led to a positive outcome. The programme also provides a basis for topics that this researcher regards as important to be covered in a thorough training programme on workplace emergency response.

The surprising finding was the need to extend the definition of pre-movement time for wardens. This is regarded as a more accurate definition as it takes into account the impact that wardens have on pre-movement time, a fact that has been noted on several occasions by previous researchers.

The hypothesis was supported by the study and provides a basis for further research particularly in facilities that have not received prior training or conducted previous drills. If research is undertaken to extend this study, it is recommended steps be taken to minimise uncertainty of wardens beyond the experimental group (ie ensure they do not have knowledge of the research that might impact their response in the field trial).
REFERENCES


