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REAL TIME, REAL FIRE, REAL RESPONSE: AN ANALYSIS OF RESPONSE BEHAVIOUR IN HOUSING FOR VULNERABLE PEOPLE

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ABSTRACT

This paper analyses response behaviour during an evacuation caused by a fire that occurred late on a Friday night in a three storey building housing socially vulnerable people. One escape corridor became smoke logged. Twenty people were observed on CCTV during the evacuation with one person choosing to enter the smoke filled corridor to alert a friend. No-one was injured by the fire or during the evacuation. The paper considers response behaviour, travel speed and exit selection based on analysis of CCTV from inside the building. Behaviour exhibited by the residents was similar to that expected within a domestic dwelling rather than a hotel and average walk speeds were found to be larger than those normally used in engineering analysis.

INTRODUCTION

The fire at the Empire Theatre, Edinburgh, on 9 May 1911, is often cited as the origin of the convention that it should take 2½ minutes to evacuate a building. Contemporary newspapers also report some interesting human behaviour. Theatregoers originally thought that the fire was part of the act and delayed their evacuation then made a 'rush for the door' and '… while there was crushing and some danger of being trampled ….. the ample exits enabled the building to be emptied in about 3 minutes …'[1] It is well known that the manager, Mr C B Fountaine, ordered the band to play God Save the King as the audience of approximately 3000 people safely evacuated; it is not so well known that one of the musicians was killed. The safety curtain was lowered but 10 performers and staff, including the illusionist Sigmund Ignatius Neuburger (The Great Lafayette) were killed. Reports suggest some backstage exits had been locked and that Neuberger was killed as he re-entered the building to try to save his animals[1,2]. Since then there have been multiple fire incidents resulting in many casualties. Some of these such as the MGM Grand Hotel in 1980, World Trade Centre in 2001, and the Rhode Island Station Nightclub in 2003 have been studied in detail using interviews with survivors, deductive work and some film evidence[3-7]. However, the majority of quantitative information relating to human behaviour in fire is based on experimental evidence and observation of non-emergency behaviour[8,9]. Devon and Somerset Fire and Rescue Service (DSFRS) attended a fire, which started in a fluorescent light fitting, at Alexandra House, Exmouth, at 22:56 in November 2012. The building owners have provided CCTV covering approximately 68 minutes before the fire as well as the fire and evacuation itself. This video footage provides an opportunity to study and quantify response phase behaviour of vulnerable people subjected to a real fire incident and is the subject of this paper.

The evacuation process is considered to comprise of two broad phases the; Response Phase and Evacuation Movement Phase[8]. In this work we are primarily concerned with the Response Phase. The Response Phase can be categorised into three stages: Notification, Cognition and Activity; where the Cognition and Activity Stages run in parallel[8]. The Notification stage occurs when initial cues (such as alarms, the appearance of smoke or the behaviour of others) are conveyed to occupants, indicating an event that may require evacuation. This stage ends when occupants begin responding to the cues mentally and/or physically, thus entering the Cognition and Activity stages. During the

Cognition stage, occupants interpret the Notification cues and other sources of information and decide on activities. The Activity stage begins when occupants perform a series of tasks which were conceived during the Cognition stage, such as collecting their belongings (an Action Task) or communicating with others (Information Task). The end of the Activity stage denotes the end of the Response Phase and the beginning of the Evacuation Movement Phase. The response time (sometimes called pre-movement time) measures the duration of the Response Phase (start of the alarm to the end of the Activity Stage)[8]. Responses may be affected by a variety of factors such as culture, training, previous experience, familiarity with the building, interpersonal relationships and peer group behaviour.

BUILDING, OCCUPANCY AND INCIDENT

Alexandra House is a three storey building in Exmouth UK. Formerly a YWCA hostel it was converted into flats housing socially vulnerable adults. The building is L shaped, approximately 31 by 27 metres; the main stair and entrance/exit is in the middle of the building with alternative stairs and exits at each extremity (see Figure 1), with the top (second) floor being identical in layout to the first floor. In Figure 1, the second floor flat numbers are shown in parentheses. Most of the ground floor, apart from the reception area is not visible on the CCTV. The smoke logged corridor is shown in grey.

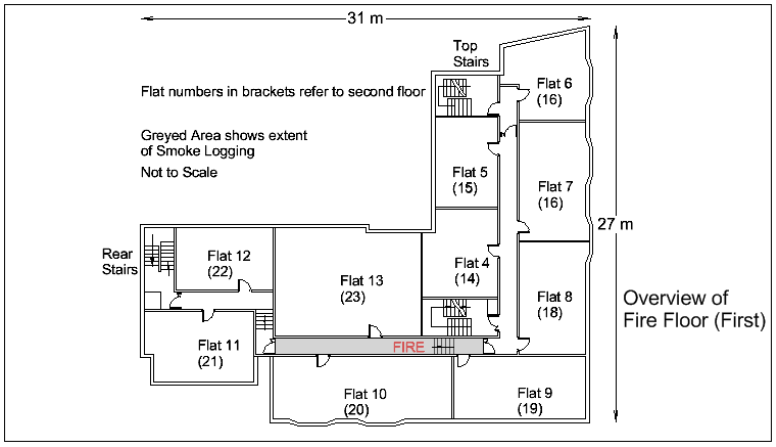

Figure 1: Simplified Building Layout Showing First Floor

Alexandra House provides supported accommodation for single people over the age of 18 with housing-related needs such as drug and alcohol misuse, mental health needs, domestic abuse, physical disability, and sensory impairment. Staff are on site six days a week offering group work, help with basic skills and organising social activities and outings. There are 23 furnished self-contained flats where residents can stay for up to 2 years. The house provides a safe environment within a stable community in which residents can learn how to maintain a tenancy in preparation for a move on to independent living. Tenants are unsupervised overnight and at weekends.

By the time this research was conducted all tenants present at the time of the fire had moved out of the building. At the time of the fire there are believed to have been at least 20 people in the building, 15 residents and five visitors, eight people on the second floor, 10 on the first floor and two on the ground floor. The actions and behaviours of 20 people were observed during the fire on the CCTV footage. eight other people were observed but they left the building before the fire broke out. Information about procedures and people was provided by members of staff. At the time of the fire only one person had been living there for less than six months. Tenants have the fire procedures explained and are given a tour of the escape routes before they move in. The house manual is issued to each tenant and contains a section on fire procedures. Compliance with fire procedures and taking part in fire drills is a condition of the tenancy agreement which they sign before moving in. Non-compliance, particularly failure to evacuate, is treated seriously and may result in a formal warning or even eviction. Fire drills are conducted every two to three months and sometimes include simulation

of an exit being unavailable. The building experiences a comparatively high number of small fires and false alarms. Prior to this incident in November there had been a small fire in a flat and a false alarm both during May so awareness of fire issues could have been heightened as the majority of tenants had previous experience of a fire in the building.

Each of the people are numbered as part of the analysis with a summary description of the persons vulnerabilities presented in

Person 26 (118s) is also located on the first floor. He exits and locks his room and moves towards the stairs after 63s. When he reaches the stairs he turns back and returns to his room, unlocks the door, enters, leaves, locks the door and starts his evacuation. Thus two of the lone people started their evacuation relatively quickly but returned to their room thereby delaying their response time. Thus all those alone responded in about 60s but two delayed their response by returning to their rooms.

It was not possible to observe the transition from Notification to Cognition and Start of Activity for most of the people as they were out of sight of the CCTV. Only four people did not undertake any Action or Information Tasks whilst being observed during the Response Phase. Three of these originated in the same room which they left between 33 and 36 s after AAT. The other person who commenced evacuation without their response time being observed left their room 39 s after AAT.

Table 5. It is worth noting that one of the residents had mobility difficulty due to spina bifida (16) and one person had a sight impairment (19). The five visitors were numbered 11, 17, 22, 23 and 24.

The first signs of fire are visible in the security video at 22:48:17 in the first floor corridor between flats 10 and 13 (see Figure 7a). A glow develops and smoke starts to fill the corridor. The nearest smoke detector is 7 m from the light fitting; the alarm activates 157 s after the first signs of fire. Visibility in the corridor is virtually nil within 7 min. DSFRS received a 999 call from a male caller via mobile phone at 22:49:06; this suggests that the clocks on the CCTV and fire service recording system are not synchronised. The caller stated that everyone had left the building. The fire started in the electronics of a recessed twin tube fluorescent light fitting that is approximately 1.2 m x 0.3 m. This type of fire is quite common and is usually confined to the electronics however, in this case, it spread to involve the opaque polystyrene diffuser. Approximately 50% of the diffuser was consumed. Burning droplets of polystyrene fell onto the carpet (see Figures 2 and 3).

Figure 2: Exemplar undamaged light fitting

Figure 3: Remains of light diffuser on carpet

METHODOLOGY

The CCTV was provided AJP file format and viewed using Backup CD Player[10]. The file contains images from 8 separate CCTV cameras; the locations of cameras used in the analysis are

summarised in table 1. Not all of the building and escape routes are covered by cameras. The cameras are motion activated and images are stamped with date and time.

Table 1 Position of CCTV Cameras

Camera	Target	Camera	Target
1	Main entrance	5	1st floor corridor (looking east)
2	Reception area	6	1st floor corridor (looking north)
3	Common Room	7	2nd floor corridor (looking east)
4	Rear car park (not used)	8	2nd floor corridor (looking north)

DSFRS had basic plans of the building but these were not drawn to scale. Nevertheless they formed a useful starting point for the preparation of CAD plans using TurboCAD[11]. The building was visited and key dimensions taken using a laser measuring device. The plans of the corridors, location of doors, staircases and areas visible on the CCTV cameras were then updated to an accuracy of approximately 1 cm; the remainder of the building is represented in outline detail only. A number of waypoints were created at the centre of each relevant doorway, at the foot of the main staircase and at the sofa in the living room. The distance between each waypoint along the centre line of the corridors was calculated using the measurement function of TurboCAD[11]; it was assumed that people leaving a room would reach the centre line of the corridor by the time they drew level with the door jamb. Travel distance on flights of stairs was calculated as the hypotenuse of a right angle triangle determined by multiplying the number of steps by the rise (height) and the going (length). Distance travelled by each person was calculated as the sum of the stages between the waypoints crossed for each person.

The images were analysed frame by frame and 28 people identified. Some people left the building before the fire. Data were gathered for these people to determine movement speeds in normal conditions. The time of events was entered into a Microsoft Excel spreadsheet and analysed. The time of each movement event was taken to be the time that person actually crossed the door threshold or other waypoint. Walking speed was calculated by dividing the distance by the time intervals between waypoints visible on a single camera. Speeds were not determined if: travel distances were less than 5.3m, doors were opened/closed, person was running or if there were several steps in the path. Each person was allocated a code by sequential number of appearance in the timeline, gender, group association, as well as floor and room of origin at the Alarm Activation Time (AAT). For example, Person 10, male, in group at AAT, second floor, room 20 is coded as, 10-m-Gr-2-20; while Person 18, female, alone at AAT, second floor room 19 is coded as, 18-f-S-2-19). The building has an automatic fire detection system. Some doors are held open by magnetic devices that release on the activation of the fire alarm. Simultaneous closing of doors was taken as the AAT. Individual behaviour was analysed using criteria determined in the BeSeCu[8] project, with key definitions presented in Table 2.

Table 2. Key Definitions Used in Behaviour Analysis[8]

Term	Definition	Term	Definition
Alarm Activation Time (AAT)	The time that the fire alarm sounded.	End Response Phase (ERP)	Time a person is seen to start purposeful movement towards the exit.
Start Cognition Stage (SCS)	Person responds to alarm by mentally or physically disengaging from previous task and recognising that something unusual may be occurring.	Exit	Time person crosses threshold of final exit
Start Activity Stage (SAS)	The activity stage starts when the occupant performs a series of information and/or action tasks which were conceived during the Cognition stage.	Action Task	Involves the occupant physically undertaking activity e.g. locking a door, putting on clothing, moving to another location

			for another action
Response time	Time from Alarm Activation to End Response Phase	Information Task	Seeking providing or exchanging information concerning the incident or course of action.
Notification Time	Time from Alarm Activation to Start of Activity	Activity Time	Time from Start of Activity to End Response

However, as CCTV is not available in the rooms of the occupants the analysis cannot cover all the activities that a person may undertake before starting their evacuation. Analysis is limited to the point when the occupants exit their room. As a result, the SAS was only recorded if a person was observed doing something other than heading straight for the exit. If no activity was observed the first sighting was considered to be ERP and an activity time of 0 seconds recorded. Persons 14 and 16 started in rooms over 7m from the first point of observation so were not included in calculations of SAS Stage. Two people exhibited atypical behaviour. The house policy is for tenants to evacuate immediately; however one tenant decided to investigate the alarm, confirming the fire and then performing a sweep of the building to ensure that everyone had left. In this case ERP was taken as the time when he had confirmed the presence of fire and started to move around the building informing others. A second person had commenced his own evacuation but decided to ensure that a friend, who may have been under the influence of alcohol or drugs, was able to evacuate by going to his flat via the fire affected corridor. In this case ERP was taken to be the time that he entered the corridor. Neither of these two people were observed leaving the building because their exit was not covered by a camera.

The number of people responding in 10 s 'bins' was determined for each phase and presented in bar graph format as a probability (i.e. number ÷ population) because different population sizes were observed during different phases of activity. A log-normal distribution curve was determined for each parameter using equation 1 and superimposed on each graph[8,12].

$$f(x) = \frac{1}{\sqrt{2\pi} \times x\,\sigma} \exp -\left(\frac{(\ln x - \mu^2)}{2 \times \sigma^2}\right) \quad [1]$$

Where: μ = Mean
σ = Standard deviation

The distance to alternative exits from their location at AAT and the difference between distance travelled and the shortest possible distance were calculated for each person.

There are several acknowledged limitations in this work. These include the following:

- As the sample of 20 people is comparatively small, population performance outliers can significantly skew distributions. As a result, it is difficult to draw firm conclusions and so the observed behaviours should be considered as exemplars of possible behaviour rather than definitive descriptions of typical behaviour.
- Only two people were in view of the cameras when the alarm activated; as a result the SAS is likely to be overestimated because there are no data relating to activities inside the flats.
- Escape routes were measured to an accuracy of less than 0.01 m for each section. These measurements have been transferred to a CAD plan and the route travelled estimated as the distance between waypoints along the centre line of the corridor. In reality people did not follow the route precisely however this method is believed to be a reasonable approximation.
- There is a greater margin of error in estimating the time each person passed a waypoint. This is due to a combination of the coarse frame rate (the cameras are motion activated and in some cases the time between frames exceeded 1 s) and that in some cases people are at a considerable distance from the camera. To minimise the error, only travel distances greater than 5.3m are considered however, these estimated speeds are still subject to error.

- CCTV cameras are positioned for general security rather than monitoring an evacuation; this means that some interesting events are obscured or completely out of view.

RESULTS AND DISCUSSION

It is noted that while the CCTV did not include sound it can be inferred that there is a growing amount of 'chatter' and awareness that there is a real fire in the building. Response times, behaviour and travel speed should be interpreted in this context. The evacuation population consisted of 11 males and 9 females ranging in age from 18 to the early 50s. A summary of the main results is presented in **Error! Reference source not found.**, which is sorted by response time. Ages have been grouped into late teens (18-20), and then by decades i.e. twenties, thirties etc.

Group Behaviour

In this type of accommodation, where there are a small number of single residents (no couples or families), who are in residence for extended periods of time and who share common challenges, it is likely that social groups will form. It is informative to explore the impact that such social bonds may have on the evacuation dynamics, in particular investigating if groups had a rapid or slow response to the alarm and if they evacuated as a group. If residents were in social groups at the time of the alarm, it may be expected that they will maintain their group structure and evacuate as a group.

In this particular case 65% (13/20) of the population were associated with five groups ranging in size from 2 to 4 at the time of the evacuation. These consisted of: 3 groups of 2, 1 group of 3 and 1 group of 4. Seven people were on their own at the time the alarm sounded: 4 females and 3 males (see

Table 3). Analysis of the video footage suggests that three of the five groups, g1, g2 and g4 did not evacuate as a group. One person in g1 (12) leaves the TV lounge to investigate the alarm, returns to the room, informs girlfriend (11) and leaves the room before 11 is ready. They eventually reunite just prior to exiting the building. One person in g2 (13) decided to check on a friend before commencing his evacuation and the other member of g2 (28) did not follow. A member of g4 (10) took on a staff role and went around the building alerting people, thus this persons response time is deemed to have ended when he started his investigation. Person 9 went to investigate the fire while person 27 stayed in the room for 118s, left the room, engaged in 84s of action/information tasks, walked to the stairs and then returned to her room, spent 28s in the room then left, generating a response time of 202s.

Table 3: Population Characteristics

Status at time of alarm	Male	Female	Group ID and person #	Group Nature	Response Time (s)	Evacuated as group?
Single	3	4	14,16,18,25,19, 15,26	-	-,-,30,39,43, 64,118	-
Group-Pair	1	1	g1 (11, 12)	11 female visitor, TV room, grd floor	112, 103	No
Group-Pair	1	1	g2 (13, 28)	28 mental health	106, 122	No
Group-Pair	2	0	g3 (17, 20)	17 visitor	42,43	Yes
Group-Three	1	2	g4 (9, 10, 27)	27 drug/alcohol	156,31,202	No
Group-Four	3	1	g5 (21, 22, 23, 24)	22,23,24 visitor	33,35,36,37	Yes

Only two groups maintained the group structure and evacuated as groups (g3 and g5). Both of these groups responded quite early, in less than 60s and both groups involved male visitors and hence people without additional social connectivity with the other residents in the building. One group involving a female visitor had a long response time and also did not evacuate as a group as a member of the group went to investigate the alarm. Each of the groups that did not evacuate as a group did so

because some or all of the group members decided to either investigate the incident or to warn others. This type of behaviour is similar to that observed in residential dwelling fires rather than hotel fires. The social bonds developed between residents of the facility and the feeling of 'home' associated with the property results in the residents undertaking investigation and alerting activities rather than simply evacuating on hearing the alarm as may be expected in a hotel.

Evacuation Time

The time required to evacuate 19 people is 3 min 50 s, measured from the sounding of the alarm. Evacuation times range from 49s to 230s with μ=99.1s; σ=48.4s. Presented in Figure 4 is the cumulative exit count, as a function of the time measured from the start of the alarm, for the 18 people observed leaving via the front door. 50% of the population completed their evacuation within 43s; 75% (14) in 1 min 52 s; 89% (16) in 2 min 2 s. The last two people to leave were considerably later: 2 min 36 s and 3 min 22 s. It is worth noting that four of the first six people to respond were in the same room. The tenant and three guests left the flat as a group between 33s and 37s after AAT.

Response Time and Response Phase Behaviour

The response time distribution for the entire population is presented in Figure 5 (Range 30s – 202s; n=18; μ=75.1s; σ=49.8s). As can be seen, the distribution is approximately log-normal in appearance. Presented in Figure 6 is the response time as a function of distance from the affected section of corridor. In this figure it is noted that all distances less than 20m are located on the fire floor. Distances depicted at 20m are all located on floors either above or below the fire floor. Two people, including person 13, were in a flat within the affected fire corridor and are recorded as zero distance. The distribution of response times presented in Figure 6 suggests that there is no relationship between proximity to the fire and response times. On the fire floor, people close to the fire can have long or short response times and people further from the fire can have short or long response times. Even people located on other floors can have long or short response times.

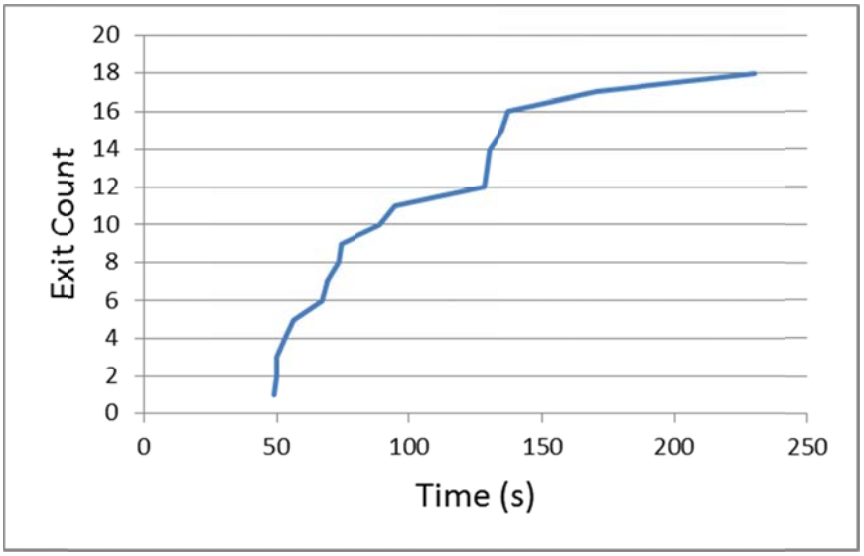

Figure 4 Cumulative Exit Count

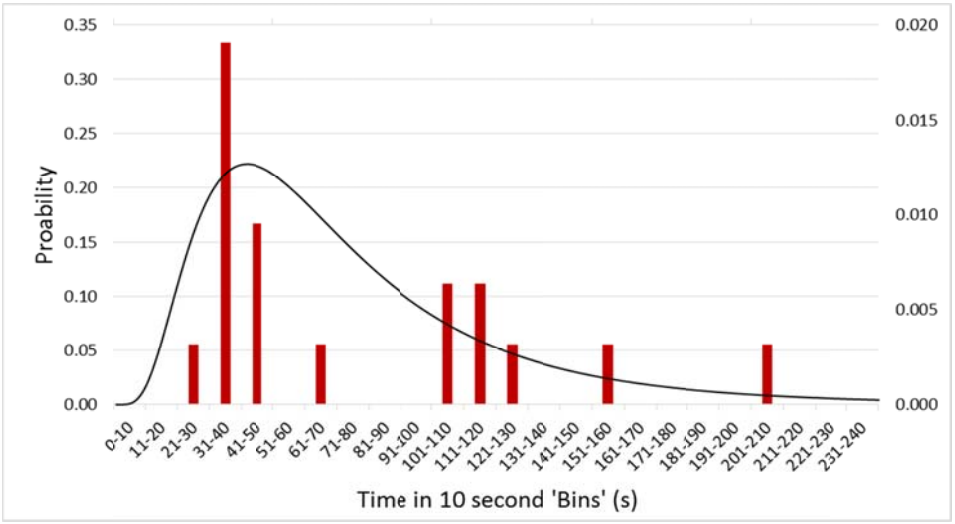

Figure 5. Response time (s)

Presented in Table 4 are the mean response times for people located on the fire floor compared to those who were elsewhere in the building. This suggests that average response time of people located on floors other than the fire floor was 40% larger than that for those on the fire floor. However, the average time for those on other floors was impacted by two significant outliers: the two last people to start their evacuation movement phase (9 and 27) who were located in the same flat on the second floor when the alarm sounded and who had response times of 156s (9) and 202s (27) respectively.

These two people were part of g4, the other member of g4 responded quite quickly (10, 31s) and assisted in alerting other people within the building. Person 9 initially left the room that g4 was located in after 40s (shortly after person 10). She moved to the door to the fire corridor and then returns to alert her friend (27) who is still in the g4 room. She then leaves the g4 room and again visits the door to the fire corridor and returns to the g4 room a second time before finally leaving with a response time of 156s. In total she undertakes 10 Information Tasks, providing information to three people. The other person in g4 (27) waited, left the room went to the stair, returned to the room and then finally left with a response time of 202s.

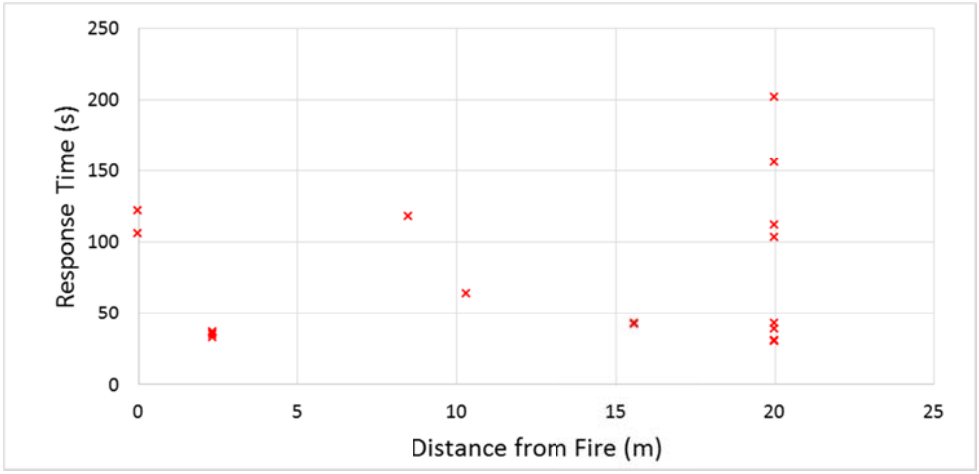

Figure 6. Response Time as a function of distance from the fire at AAT

Table 4. Response Time (s) by Location at AAT

	All	Fire Floor	Elsewhere in building
Mean	75	64	90
Min	30	33	30
Max	202	122	202

n	18	10	8

In total 10 people responded in less than 60s. Of these four were visitors (17, 22, 23, 24), three of which were members of g5 and one of which was a member of g2. Two others were residents and members of these two groups (21, 20). Another person (10) took on the role of a staff member and investigated the fire and alerted others. The remaining three people were alone at the time of the alarm (18, 19, 25). Of the seven people that are known to be alone at the time of the alarm, response times for two people (14 and 16) could not be determined. Of the remaining five people who are known to be alone at the time of the alarm, three people respond in less than 60s (18, 30s; 19, 43s; and 25, 39s). The remaining two took longer than 60s. Person 15 (64s) is located on the fire floor (first floor) in her room at the time of the alarm. She is seen to respond quite quickly and exits her room after 37s wearing night clothes. She gets as far as the stairs and returns to her flat, enters and comes out holding a pair of shoes and continues her evacuation. Her return to her flat to collect her shoes delayed her response.

Person 26 (118s) is also located on the first floor. He exits and locks his room and moves towards the stairs after 63s. When he reaches the stairs he turns back and returns to his room, unlocks the door, enters, leaves, locks the door and starts his evacuation. Thus two of the lone people started their evacuation relatively quickly but returned to their room thereby delaying their response time. Thus all those alone responded in about 60s but two delayed their response by returning to their rooms.

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Table 5: Summary of key results sorted by response time

Identifier	Age	Notification Time / s	Activity Time / s	Response Time / s	Distance From Fire / m	Flat speed / m/s (During Evacuation)	Flat speed / m/s (Normal conditions)	Stair speed / m/s (During Evacuation)	Background
18-f-S-2-19	40	26	4	30	26.23	1.3		1.1	MH (NW)
10-m-Gr-2-20	18	4	27	31	35.14	2.5 [g4]	1.2[g4]	1.7 [g4]	ADHD, CL
21-f-Gr-1-8	20	33	0	33	2.34	1.8 [g5]		1.2 [g5]	CL
22-m-Gr-1-8	V	35	0	35	2.34	1.4 [g5]		1.2 [g5]	Visitor
23-m-Gr-1-8	V	36	0	36	2.34	1.8 [g5]		1.2 [g5]	Visitor
24-m-Gr-1-8	V	37	0	37	2.34	1.8 [g5]		1.1 [g5]	Visitor
25-m-S-2-17	30	39	0	39	27.95	1.3		0.8	D/A HL
17-m-Gr-1-5	V	25	17	42	15.59	1.2 [g3]		1.1 [g3]	Visitor
19-f-S-2-18	20	32	11	43	22.92	1.8		0.8	LD, VI (NW)
20-m-Gr-1-5	19	32	11	43	15.59	1.2 [g3]		1.1 [g3]	CL
15-f-S-1-7	19	37	27	64	10.34	1.8	1.1	1.6	(NW)
12-m-Gr-g-CR	20	63	40	103	33.48	1.2 [g1]		N/O	
13-m-Gr-1-9	30	96	10	106	0	1.7 [smoke]	1.1	N/O [g2]	HL
11-f-Gr-g CR	V	92	20	112	33.48	1.6 [g1]		N/O	Visitor
26-m-S-1-4	20	63	55	118	8.46	1.2		1.4	HL
28-f-Gr-1-9	20	94	28	122	0	1.7 [g2]		1.2 [g2]	MH
9-f-Gr-2-20	20	40	116	156	35.14	2.3 [g4]	1.1[g4]	1.1 [g4]	

27-f-Gr-2-20	30	118	84	202	35.14	1.4 [g4]		1.2 [g4]	D/A, HL
14-f-S-g-2	50	N/O	N/O	N/O	23.86	--	0.4	N/O	MH, LD
16-m-S-2-22	19	N/O	N/O	N/O	40.76	1.2		0.8	Mob

Notes to table:

1) Not everyone was observed during normal conditions. The Superscript [g1-5] indicates when that person was in a group with one or more other people at the time the alarm sounded; the number indicates the group identification number (see table 3). The Superscript [smoke] indicates measured in smoke filled corridor

2) N/O = Not observed; D/A = Drugs and/or alcohol; MH = mental health issues; LD = Learning difficulties; HL = Homeless; ADHD = Attention Deficit Hyperactivity Disorder; CL = Care Leaver; Mob = Mobility difficulty; VI = Vision Impairment; G = Guest. (NW) = dressed in nightwear.

3) Ages are approximate: e.g. 18 = late teens (all tenants are over 18), 20 = twenties, 30 = thirties).

4) Persons 14 and 16 originated in rooms more than 7m from the point of first observation so activities could not be calculated accurately.

Excluding person 10 who took on the role of a member of staff, 13 people (72%) spent less than 30s engaged in activity tasks (see

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It was not possible to observe the transition from Notification to Cognition and Start of Activity for most of the people as they were out of sight of the CCTV. Only four people did not undertake any Action or Information Tasks whilst being observed during the Response Phase. Three of these originated in the same room which they left between 33 and 36 s after AAT. The other person who commenced evacuation without their response time being observed left their room 39 s after AAT.

Table 5) before starting positive movement to the exit. However, it is again emphasised that these people may have been engaged in activities out of CCTV view. Of these, four people took longer than 60s to respond (15, 64s; 13, 106s; 11, 112s and 28, 122s). These are; person 11, the visitor in the TV lounge who waited for her friend to return; person 28 a member of g2 who was left on her own, it is noted that this person had mental health issues; person 13 also a member of g2 who left the room to alert others and person 15 who was on her own and returned to her room to collect a pair of shoes. The four people (12%) who spent more than 40 s engaged in activity tasks (26, 9, 27, 12) returned to their room of origin at least once.

Of the 14 residents (excluding 10), four (9, 156s; 15, 64s; 26, 118s; 27, 202s) or 29% returned to their room prior to evacuating. Their response times varied from 64s to 202s. Furthermore, three residents (21%) prolonged their response by attempting to alert others (9, 156s; 12, 103s; 13, 106s) prior to evacuating. Their response times varied from 103s to 156s. Three residents attempt to investigate the fire (9, 10, 12). Thus six or 43% of the residents either, investigated the fire, returned to their room or attempted to warn others with one resident assuming the role of a member of staff. All those with a response time of less than 60s (excluding 10, but including the visitors, 18, 30s; 21, 33s; 22, 35s; 23, 36s; 24, 37s; 25, 39s; 17, 42s; 20, 43s; 19, 43s) did not attempt to warn others and did not return to their room. With the exception of 11 (112s) and 28 (122s), all those with a response time greater than 60s (12, 103s; 9, 156s; 27, 202s; 13, 106s; 15, 64s; 26, 118s) either returned to their room, attempted to warn others or investigated the fire. These activities clearly prolonged response times.

It is interesting to note that three women wearing nightclothes (15, 18, 19) were some of the earliest people to respond with notification times of 37s, 26s and 32s respectively. Two had short response

times (18, 30s and 19, 43s) but person 15 returned to her room to collect some shoes which extended her response time to 64s. It is assumed that as these people were wearing bedclothes they were either in bed or at least prepared to go to bed but this did not appear to delay their response significantly.

It is also worth discussing the activities of person 13 in some detail. Unfortunately, much of his interesting behaviour is out of view of the cameras. He is one of only two people who did not leave by the main entrance/exit. He is in his late 30s, was previously homeless and had no known alcohol, drug or other issues. He lived in flat 10 next door to his girlfriend in flat 9 (person 28). The doors to these flats are in the same corridor as the fire but at the time of the fire they were both in flat 9 which is at a lower level of the split level corridor; there are 6 steps and total rise of 1.14 m from this flat part of the corridor where the fire was. He is first seen 96s after the alarm sounds. He spends 7s in the corridor near the door to the main stairs where he spoke to 3 people before entering the main staircase. He then apparently changed his mind and re-entered the fire corridor after a short conversation with person 10 (the resident who took on the role of a staff member).

(a) Alarm activation time (Camera 5 floor 1)

(b) Male in smoke (Camera 5 floor 1)

Figure 7: Selected stills from CCTV Camera 5 showing fire corridor

Information provided by house staff suggests that he re-entered the corridor in order to ensure that his friend, who lived in flat 11 beyond the corridor, was aware of the fire. Person 13 thus makes a decision to enter a smoke filled corridor and passes through it travelling an estimated distance of 15.02 m. He can be seen with his hood up and hands covering his face 9s after entering the corridor in Figure 7b which shows conditions in the corridor at 22:50:52. His speed in the smoke-filled corridor is estimated to be 1.7 m/s. It is noted that this person's speed over flat terrain in a non-emergency setting was estimated at 1.1 m/s (see Table 5). Thus, rather than travelling slower in the smoke filled environment, this person is travelling 40% faster than their normal walk speed. It is presumed that he left the building via the rear staircase and exit so is not included in the calculations. He chose not to alert his friend by using the smoke free routes on the floor above or below.

Travel Speeds

A summary of average walk speeds during the evacuation is presented in **Error! Reference source not found.**. Person 10, who took on a staff role is excluded from the analysis. His average speed, including instances when he ran, was 2.5 m/s on the flat and 2.1 m/s downstairs and 3.2 m/s upstairs. Also excluded is person 13 who walked through the smoke filled corridor. The overall average walk speed on the flat was 1.5 m/s, with females outperforming males, both on the flat and on the stairs. Two people (9, 11) achieved walk speeds in excess of 2.0 m/s at any one time and both had response times in excess of 112s. All the average walk speeds, including the minimum average values are quite large. Even those with mobility and vision impairment (16 and 19) are larger than would normally be attributed to people with disabilities within engineering calculations. However, the limitations in measuring travel time must be recalled when reviewing these values.

Table 6: Average walk speed during evacuation (m/s)

	On Flat			Down Stairs		
	Min	**Max**	**Average**	**Min**	**Max**	**Average**

Females (7 on flat, 5 on stairs)	1.3	3.4	1.7	1.1	1.6	1.3
Males (8 on flat, 7 on stairs)	1.2	1.8	1.4	0.8	1.4	1.1
Person 16 (male, spina bifida)	1.2	1.2	1.2	0.8	0.8	0.8
Person 19 (female, vision impaired)	1.8	1.8	1.8	0.8	0.8	0.8

Exit Choice

Most of the people (18 out of 20) left the building by the main entrance/exit. The main exit was in fact the correct choice, i.e. the shortest and most direct route that avoided the hazard zone, for 10 of the occupants. However, for 10 people there was a shorter exit route available. For four of these people the difference was negligible, less than 3 m (approximately 2 s) longer. However for 6 people the additional distance travelled ranged between 5.4m and 20.9 m or 29-125%. The person who travelled the furthest extra distance had mobility difficulties due to spina bifida (16). The assembly point for the residents is at the front of the building. Although people may not have left by the nearest available exit, their route choice may have been a logical choice in that it was the shortest distance to the assembly point and they did not need to pass through the hazard zone. Thus, the residents may not have simply been using the main exit because it was their most familiar exit route. Thus the desire to minimise travel distance (hence time) to the final destination during an evacuation may be a point that should be recognised by fire engineers who design fire strategies, escape routes and training for building occupants.

CONCLUSION

The evacuation of a three storey building housing socially vulnerable people subjected to a real fire was studied using CCTV footage. The fire occurred late at night when some 15 residents and 5 visitors were present without the support of housing staff. While 65% of the population were associated with five social groups at the sounding of the alarm, only two of the groups actually evacuated as groups. The groups that evacuated as individuals did so because some or all of the group members decided to either investigate the incident, return to their rooms or to warn others. This type of behaviour is similar to that observed in residential dwelling fires rather than hotel fires. The groups that evacuated as groups involved visitors without the need to investigate or warn others. Overall, the response times ranged from 30s to 202s and were distributed in the typical log-normal manner. Those with a response time less than 60s did not attempt to warn others, investigate the fire or return to their rooms. Undertaking these activities – which 43% of the resident population attempted – prolonged response times. There appears to be no relationship between proximity to the fire and response time.

Average walk speeds on the flat for those without disabilities ranged from 1.2 m/s to 1.7 m/s with an overall average of 1.5 m/s, with females walking faster than males on average. Both stair and flat average walk speeds were greater than would normally be used in engineering calculations however; the limitations in measurement methodology must be taken into consideration. Ten people chose the ‘correct’ exit, i.e. the shortest and safest route, but 10 people chose the main exit which was actually further than they needed to travel. For three of these the difference was negligible but seven people travelled more than 29% further than they needed to. This should be seen in the context that the final destination was outside the main exit. The time required for 19 people to evacuate the building was 3 min 50 s.

Finally, design engineers may legitimately assume that the evacuation performance of residents in this type of facility is likely to be similar to that found in hotels, albeit with delayed response and reduced walking speeds. However, this analysis suggests that the response behaviour is similar to that found in domestic dwelling fire situations with walk speeds better than would normally be expected. When considering these types of facilities it is however essential to take into consideration the nature of the resident’s vulnerabilities and the level of fire safety training received as part of their residency.

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