Paper presented at PED 2010, NIST, Maryland USA, March 8-10 2010

An Experimental Evaluation of Movement Devices used to assist People with Reduced Mobility in High-Rise Building Evacuations

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Abstract Evacuating People with Reduced Mobility (PRM) from multi-storey buildings can be a difficult task. A number of commercially available devices can be used to assist in moving the PRM to the ground however, there is little consistent data quantifying the relative performance of these devices. In this paper four commonly used assist devices, the Evac+Chair, Carry-Chair, Stretcher and Drag Mattress are used in a series of 32 evacuation trials designed to assess their performance. The trials involve moving a PRM from a wheelchair to the device, moving the PRM along a long corridor to a stair and then down 11 floors to the ground. The performance of the devices is then assessed in terms of travel speed on the flat and stairs, number of handlers required to operate and ease of overtaking by other stair users.

Introduction

Evacuating People with Reduced Mobility (PRM) from multi-storey buildings can be a difficult task. In the UK, some high-rise buildings are equipped with fire fighter lifts which are designed to be operated in fire conditions and can be used to evacuate PRM. However, in most cases PRM are expected to remain within the building in a refuge or place of safety or can be assisted out of the building by fellow occupants. In some countries there is the expectation that the fire brigade will be able to rescue PRM located in refuges or places of safety. While the fire brigade (department) may be able to rescue PRM taking refuge in places of safety, there are several examples where this has tragically not been the case, for example the WTC [1], where many PRM left in places of safety were not able to be rescued. The recent Lakanal House fire [2] in the UK which claimed the lives of six residents who were trapped by smoke in their 14 storey apartment building also serves to demonstrate that the fire brigade may not always be able to rescue people seeking refuge in perceived places of safety. Indeed, in the UK, the Regulatory Reform (Fire Safety) Order 2006, which relates to places of employment, assembly, health care facilities, educational establishments, etc emphasises that it is a

managements responsibility to ensure that everyone can evacuate a building safely and that it is not acceptable to simply rely on the Fire and Rescue Services intervention to enable the safe evacuation of occupants [3].

(a) Female handling team with Carry-Chair and female PRM

(b) Female handling team with Evac+Chair and male PRM

Fig. 1. Carry-Chair (a) and Evac+Chair (b) assist devices.

While evacuating PRM from high-rise buildings may be a difficult task, an even more daunting situation involves the evacuation of hospitals and care facilities. The recent Royal Marsden Hospital fire in the UK [4] demonstrates that it may be necessary not simply to undertake a progressive horizontal evacuation of patients to places of relative safety, but to fully evacuate an entire hospital. The added complexity in hospital evacuations is due to a number of reasons including; the large number of occupants (patients) requiring assistance to evacuate, the (potentially) relatively small number of staff present to assist in the evacuation of patients (e.g. during night shifts), the need to have multiple staff to assist in the evacuation of single patients, the impact of fatigue resulting from the need for staff to make repeat trips, the time required to prepare patients for assisted evacuation and the potential blocking of stairs due to the assist teams carrying PRM delaying the evacuation of able body occupants.

In both high-rise buildings and hospitals, PRM may be evacuated using a number of different assist devices. Devices commonly used to assist in the evacuation of PRM include; Carry-Chair and Evac+Chair, see Figure 1. In addition to these two devices, in hospitals the drag mattress (with slide sheet) and the stretcher are also used, see Figure 2. While these assist devices are commonly used in both high-rise buildings and hospitals, there is little consistent data quantifying their relative performance or identifying the level of training required to safely and efficiently operate the devices. This includes issues such as, the relative ease (including number of required operators) in transporting the PRM to the assist device, the movement speed of the assist device on the flat and on stairs, the number of peo-

ple required to operate the assist device, the impact that the device may have on the evacuation of others and the training required by device operators. It is thus difficult for safety managers to assess the relative merits of each device and more importantly, realistically plan how the device should be deployed in their buildings. A key recommendation from the recent Homeland Security Standards Panel of ANSI was that additional work is required specify standards for assist devices and their usage [5]. Furthermore, if these devices are to be represented within computer based evacuation models, it is essential that their performance is quantified.

(a) Female handling team with Drag Mattress (with slide sheet)

(b) Female handling team with Stretcher

Fig. 2. Drag Mattress (a) and Stretcher (b) assist devices

This paper addresses these issues by presenting preliminary results from a series of experiments conducted by the Fire Safety Engineering Group (FSEG) of the University of Greenwich in collaboration with the Universitair Ziekenhuis (UZ) Gent (University Hospital of Gent) in Belgium measuring the performance of four commonly used assist devices (see Figures 1 and 2). The trials were designed by FSEG and conducted on the premises of UZ using UZ staff.

Trial Plan, Building Layout and Data Collection Methodology

In total a series of 32 trials were undertaken over a two day period from 17 to18 September 2008. The trials were conducted in a 14 floor building of the University Hospital of Gent (see Figure 3) using trained staff from the UZ hospital. Four handling teams, two male and two female, used each of the four devices shown in Figures 1 and 2. Two volunteers from the UZ acted as the PRM. All 18 staff (16 in the handling teams and 2 PRM) were highly trained in the use of the devices and in handling patients and were members of the UZ Manutentie Team. Using highly trained handlers removes the issue of training from the device performance

analysis. While the two PRMs had different body weights, for consistency the weight of the two was made identical (i.e. 75 kg) through inserting lead weights into the pockets of the lighter PRM. Half the trials consisted of individual device trials while the other half consisted of trials in which a group of 24 people (students from UZ) were injected onto the stair from the 6th floor to investigate the ease with which other evacuees could pass the assist team with the PRM down the stairs.

Fig. 3. Building in which evacuation trials undertaken.

For each trial the PRM was located in a room on the 11th floor of the building and was positioned in a wheelchair. At the sounding of the 'go' signal, the assist team would enter the room, move the PRM to the device, move the PRM out of the room into the corridor, travel 63.0 m along the corridor, pass through three sets of doors along the corridor, negotiate a left 90 degree turn into another corridor, move past the lifts (elevators), enter the stair case (see Fig. 4.) and descend 11 floors to the ground level, exit the stairwell, travel 5.0 m along the ground floor, exit the building and travel a further 32.1 m to an end point outside the building. The stairs were dog-legged, with a single flight down to half landing followed by another flight down to the next floor. The stairs were inclined at an angle of 34^0, were 1.4 m wide (handrail to handrail) and each flight had a drop of 2.1 m from floor to half landing and from half landing to the next floor, with the exception of the last flight which has a slightly shorter drop. The main landing on each floor measured 3.3 m x 2.1 m while the half landing measured 3.3 m x 1.4 m. The total travel distance down the stairs (as measured from the stair entry point on the 11th floor to the stair exit point on the ground floor taking a central path) was 169 m.

The progress of the handling teams was recorded using fixed and roaming video cameras and fixed observers with stop watches on each floor. The fixed video cameras were positioned on each floor and recorded the movement of the handling team down the stair and on the landings. The roaming video camera followed the handling team from the point that they first touched the PRM, transferred him/her

to the assist device, moved them down the corridor onto and down the stair in each trial. In addition, at the end of each trial, the assist teams and the PRM completed a questionnaire. Separate questionnaires were administered to the handling team, the PRM and the group of people attempting to overtake the PRM.

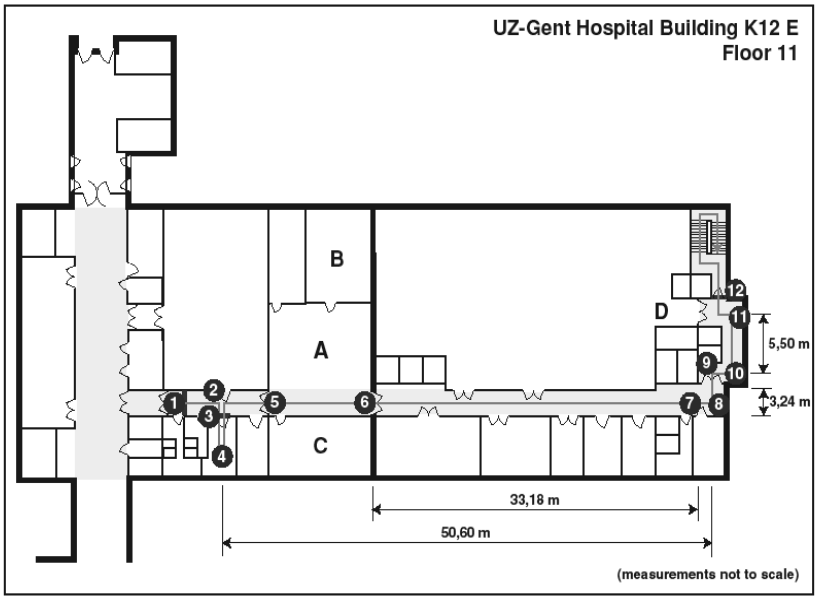

Fig. 4. Floor plan of starting floor (floor 11).

Results and Discussion

Here we present preliminary results based on timings derived from the stopwatch data, some observations from video footage and some analysis of the assist team questionnaire data. Presented in Table 1 is a summary of the movement results for the corridor. This involves moving the PRM from their starting location to the stair entry point a total distance of 63.0 m. Along this route the PRM must pass through three sets of doors which were all originally closed. The results presented in Table 1 represent an average of eight trials per device and represent trials with both male and female assist teams and for the group and individual trials. Clearly, the nature of the group trials did not have an effect on the corridor performance and so these performance results have been included in these averages.

As seen in Table 1, the Evac+Chair and the Carry-Chair are the fastest device, achieving an average speed of 1.5 m/s. The drag mattress is the slowest device achieving 0.9 m/s. The Evac+Chair and Carry-Chair are some 50% faster than the

other two devices. However, all four devices produce reasonable speeds, with the Evac+Chair and the Carry-Chair producing speeds comparable to unobstructed fast walking speeds. It should be noted that in all these trials, the corridors where unobstructed by other evacuating individuals.

Table 1. Average horizontal performance for 8 trials for each device.

Device	Average Travel Time (sec)	Number of Handlers in Emergency	Average Speed (m/s)
Evac+Chair	41	1 (+1 for doors)	1.5
Carry-Chair	41	1 (+1 for doors)	1.5
Stretcher	58	4	1.1
Drag Mattress	69	2	0.9

The number of handlers required to operate the device is another important operating parameter. Clearly the fewer handlers required to operate the device, the more efficient the process as this places a lower operating burden on the facility, is more likely to be successful as reliance is placed on fewer individuals and frees staff to assist other PRM. For the Evac+Chair and the Carry-Chair only a single handler is required to move the device along the corridor. However, when closed doors are encountered, a second handler can be used to open the doors. This is the method used in the trials. Alternatively, the handler pushing the device would need to stop, turn the device around and while holding the door open, pull the device through, then turn the device around and continue. While this is possible, it would clearly have a negative impact the horizontal travel speed performance. The Stretcher is not only one of the slowest of the devices, but as it requires four handlers, requires the most number of handlers to operate. It should be noted that the Drag Mattress was pulled by both operators along the corridor. As both the Stretcher and the Drag Mattress had operators in the front of the device, this proved relatively easy to negotiate closed doors however; the device did have to stop as the door was opened. In addition, both these devices occupy a large footprint when moving along the corridor. Compared to the other devices, which have a considerably smaller footprint, this may prove a disadvantage in crowded situations.

Presented in Table 2 is a summary of the movement results down the stairs. This involves moving the PRM from entry point of the stairs on the 11th floor down 21 flights of stairs to the exit point of the stairs on the ground floor, a total distance of 169.0 m. The results presented in Table 2 represent an average of four trials per device and represent trials with both male and female assist teams. Unlike the horizontal results presented in Table 1, the stair results are only for the individual trials. As seen in Table 2, the Evac+Chair is clearly the fastest device, achieving an average speed of 0.81 m/s. This is some 30% faster than the next fastest de-

vice, the Drag Mattress. However, all three other devices produce comparable speeds of approximately 0.58 m/s. The speed of the Evac+Chair on the stair is approximately half that of the same device on the flat. A significant difference between the performance of the devices on the flat and down the stairs is that when going down the stairs a number of stops were required. This was for a number of reasons including, resting the handlers, rotating the handlers or improving the handlers grip on the device. The number of stops for each device varied considerably as did the duration of the stop and contributed to the difference in performance. However, the Evac+Chair did not stop a single time during the descent.

Table 2. Average vertical performance for 4 trials for each device.

Device	Average Travel Time (sec)	Number of Handlers in Emergency	Average Speed (m/s)
Evac+Chair	209	1	0.81
Carry-Chair	297	3 male or 4 female	0.57
Stretcher	305	4	0.55
Drag Mattress	272	2	0.62

As with device performance on the flat, the number of handlers required to operate each device on the stairs varied between devices. Only the Evac+Chair required a single handler. It should be noted that while only a single handler is required, it is considered good practice to have a second handler in front of the device to reassure the PRM during the descent. During these trials the Evac+Chair was used in this way however, the second handler played no role in the stair descent. It is suggested in an actual emergency evacuation situation it would be possible to operate the device with only a single handler. The Drag Mattress required two handlers, one at the front and one in the rear. The handler at the rear assisted the descent in a number of ways such as, supporting the end of the mattress thereby reducing the jolting to the head of PRM during the descent, acting as a break so that the descent was controlled and assisting to turn the mattress on the landings (see Figure 2a). The Stretcher required the largest number of handlers, requiring four as on the flat.

The Carry-Chair proved to be the only device that was sensitive to the gender of the handlers. Using an all female handling team, the Carry-Chair required four operators, as shown in Figure 1a, while using an all male handling team the Carry-Chair required three handlers. When using three handlers, the Carry-Chair would only be carried by two handlers, one at the front and one at the rear. When the carry team needed a rest, the third handler would relieve one of the carry team. In the four person female team, when the handlers needed a rest, they would rotate their location around the chair.

In an attempt to gauge the impact of the devices on other people simultaneously using the stairs a series of 16 group trials were also conducted. These involved a group of 24 people who enter the stairs on the 6th floor just after the device has passed their location and who attempt to overtake the device. From observing video footage of these trials it is clear that the Evac+Chair creates the least obstruction to other stair users. Other stair users are easily able to overtake the device on the stairs (see Figure 1b) as the device and its handler occupies a single lane on the 1.4 m wide stair. Other users can also get around the device on the landings. The Drag Mattress is the next best in offering least resistance to other stair users. The Drag Mattress can also be overtaken on the stairs (see Figure 2a) but does occupy more of the width of the stair than the Evac+Chair. However, the Drag Mattress is more difficult to overtake on the landings, requiring a greater turning circle than the Evac+Chair. This is particularly noticeable on the half landing which is not as deep as the main landing.

The Carry-Chair when operated by all female handlers does not provide an opportunity for overtaking on the stairs (see Figure 1a). Other stair users can only overtake when the handlers stop on the landing and allow other users to pass. When operated by all male handlers, the Carry-Chair can be overtaken on stairs. In this configuration, the Carry-Chair can also be overtaken on the landing if the handlers stop and let the other users by. The Stretcher cannot be overtaken on the stairs (see Figure 2b) and can only be overtaken if the handlers stop on the landing and let the other users by. It should be noted that these observations are specific to the stair configuration found in these trials. The stairs are particularly wide at 1.4 m and the landings are also quite wide. Stairs found in a typical office building can be somewhat narrower, for example, two of the stairs in the WTC (Stair A and C) were 1.1 m wide while the third stair (Stair B) was 1.4 m wide [1]. In addition, training of the handlers is also an important aspect to consider when assessing the obstruction caused by the devices. Handlers of devices such as the Evac+Chair and the Drag Mattress should be trained not to block the stairs handlers of all devices should be trained to allow others to pass on landings where possible.

The questionnaires provided an opportunity for the participants to express their opinion on a range of issues associated with the devices. The questions were in Flemish and generally used a five point Likert Scale. The questionnaire for the handlers consisted of 15 questions, some with multiple parts and a section at the end for comments. Question 2c asked the handling team to “Please rate this device on the physical effort to transport the PRM down the stairs (how demanding)”. Respondents could select from 1 (Very Difficult), 2 (Difficult), 3 (Neither Difficult nor Easy), 4 (Easy) and 5 (Very Easy). Each person in the handling teams were requested to complete the questionnaires for each of trials. As the size of the handling teams differed, the number of response also differed. For example, a Stretcher handling team consisted of four people and they undertake eight different trials and so there would be 32 replies to Question 2c for the Stretcher, whereas for the Drag Mattress, the handling team only consisted of two people

and hence there would only be 16 replies to Question 2c. The responses for each device in each category was thus normalised by dividing by the total number of responses for that device. In response to Question 2c, 81.3% of the handlers responses classed the Evac+Chair in the Easy/Very Easy categories while none of the responses for the Evac+Chair were in the Hard/Very Hard category. In contrast, 88.6% (67.9% and 53.2%) of the responses classed the Drag Mattress (Carry-Chair and Stretcher respectively) in the Hard/Very Hard category. Clearly, the experienced handlers find that the Evac+Chair required the least effort of all the devices while the Drag Mattress required the greatest effort in descending 11 floors. Question 11 asked the handlers to, "Please rate this device on your level of discomfort from muscle soreness in the arms". Respondents could select from 1 (Very Much), 2 (Much), 3 (Neither Much nor Little), 4 (Little) and 5 (Very Little). In response to Question 11, 93.8% of the handlers responses classed the Evac+Chair in the Little/Very Little categories while 32.2% (32.2% and 21.4%) of the responses classed the Stretcher (Carry-Chair and Drag Mattress respectively) in the Little/Very Little categories. For the Evac+Chair, 0% of the respondents classed the Evac+Chair in the Much/Very Much categories. In contrast, 71.5% (48.4% and 39.3%) of the responses classed the Drag Mattress (Stretcher and Carry-Chair respectively) in the Much/Very Much categories. Clearly, all the experienced handlers found little muscle strain while using the Evac+Chair while the greatest muscle strain was experienced when using the Drag Mattress.

Conclusions

A series of 32 evacuation trials assessing the movement capabilities of four different assist devices; Evac+Chair, Carry-Chair, Stretcher and Drag Mattress, have been successfully completed. The trials evaluated a number of performance criteria including; travel speed along a corridor and on stairs, number of handlers required, ease of overtaking by other stair users and subjective to questionnaires by handlers, PRMs and other stair users. Preliminary analysis presented in this paper is based on stopwatch timings, observations of video footage and questionnaire responses. These results allow different aspects of device performance to be assessed, providing building operators and safety managers a quantified basis upon which to make implementation decisions.

The results clearly show that in the hands of experienced handlers, the devices have significantly different performance capabilities. When travelling over 63 m of corridor, the Evac+Chair and the Carry-Chair are equal fastest (1.5 m/s), being some 50% faster than the other devices and requiring the least number of handlers. While descending 11 floors using the stairs, the Evac+Chair is the fastest device (0.81 m/s) being some 30% faster than the other devices and requiring the least number of handlers. The Evac+Chair also offered the least degree of obstruction to other stair users, enabling them to overtake both on landings and on the stairs.

It should be noted that these observations are specific to the stair configuration found in these trials. Furthermore, it again must be emphasised that the handlers used in these trials were professional staff of UZ, trained in the correct use of each devices. All the devices require that handlers are professionally trained in their use if they are to be used correctly and efficiently and in a manner that minimises the threat of injury to the handlers, the PRM and other stair users.

Acknowledgements

The authors are indebted to a number of people who enabled this project to happen and who assisted in carrying out the work, in particular, Prof N Fraeyman of UZ who permitted the work to be undertaken at UZ, utilising both UZ buildings and staff, Mr Filip Buckens the coordinator of the UZ Manutentie Team and his 18 staff who donated their time to the project and did all the heavy lifting (and sitting), the 24 UZ student volunteers who ran up and down the stairs, the team of UZ administrative staff who contributed to the logistics of the operation, the 11 friends of Mr Adams who volunteered to assist with the stopwatch observations, the video camera team and finally, Ms Aoife Hunt, a PhD student from FSEG who assisted with the trials and who is currently undertaking a detailed analysis of the video footage as part of her PhD studies.

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