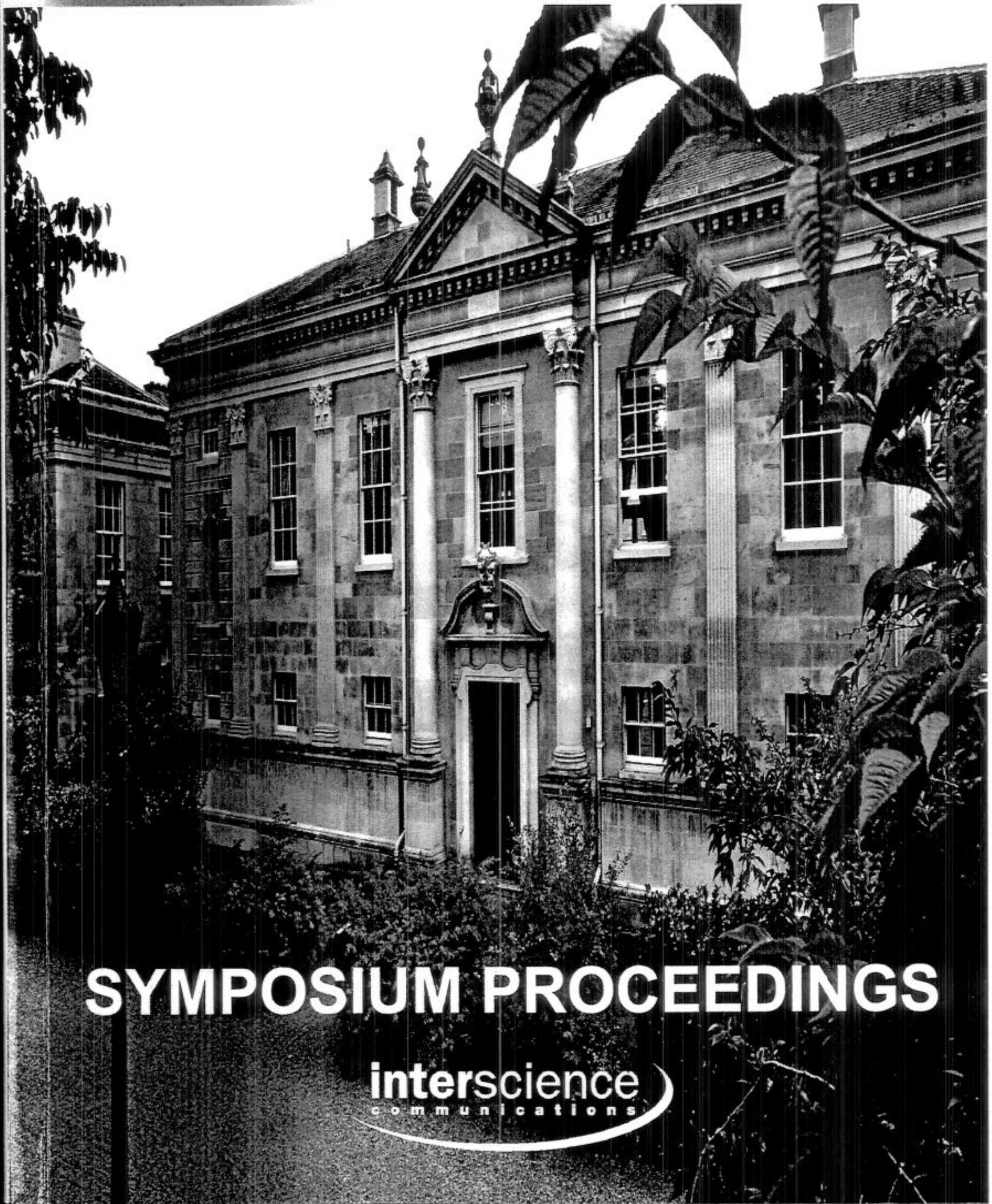
5th international Symposium

Human Behaviour in Fire 2012

Downing College, Cambridge, UK **19th - 21st September 2012**



SYMPOSIUM PROCEEDINGS

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ORGANISING COMMITTEE

INTRODUCTION

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

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

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

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

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

Prof. T Jim Shields

Symposium Chair

AN ANALYSIS OF THE PERFORMACE OF TRAINED STAFF USING MOVEMENT ASSIST DEVICES TO EVACUATE THE NON-AMBULANT

Aoife Hunt, Edwin R. Galea and Peter J. Lawrence
Fire Safety Engineering Group
University of Greenwich

ABSTRACT

This paper describes a series of trials undertaken to quantify the performance of trained hospital staff in evacuating a test subject through 11 floors of Ghent University Hospital using four commonly used movement assistance devices: stretcher, carry-chair, evacuation chair and rescue sheet. In total 32 trials were conducted, using both male and female assist teams. Presented in the paper are performance results, including: device preparation time, horizontal speeds, vertical speeds, and overtaking potential in stairwells. These data, alongside those established in questionnaire data from the experiment participants, form the basis of the device performance evaluation presented in this paper. A comparative methodology is derived to assess the efficiency of the devices. This methodology enabled performance differences to be established, according to the devices employed and the staff involved.

INTRODUCTION

Evacuating People with Reduced Mobility (PRM) is a challenging task, especially in buildings with many people that require assistance to evacuate. Care homes and hospitals are likely to have a large proportion of such non-ambulant people, and also have the second highest number of building fires per annum in the UK [1]. The evacuation process in a healthcare environment is complex, due to the (potentially small) number of staff on duty to assist in the evacuation (e.g. during night shifts), the need to have multiple staff assisting single patients, the fatigue experienced by staff making repeated trips and the possible blocking of stairs by the teams assisting patients leading to delayed evacuation of others. While some of the evacuation process is likely to be undertaken by emergency services, the 2006 UK Regulatory Reform (Fire Safety) Order emphasises that in establishments such as health care facilities, it is the management's 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 [2]. This places an additional emphasis on the in-house emergency procedures.

A number of commercially available devices can be used to assist in evacuating PRM, however there is little consistent data quantifying the performance of these devices. This paper describes a series of trials undertaken to quantify the performance of trained hospital staff in evacuating non-ambulant patients through 11 floors of Ghent University Hospital using four commonly used movement devices (stretcher, carry chair, evacuation chair and rescue sheet) [3]. This paper presents the process, results and comparative analyses of these 32 trials, in which male and female teams evacuated the PRM.

Detailed video analysis was undertaken to document the process of each trial. The resulting data, as presented in this paper, includes:

- Preparation Time - the time required for manual handling teams to secure a PRM from a wheelchair into each device.
- Horizontal Speeds – how quickly each device travelled along a hospital corridor with hard vinyl flooring and for opening various types of doors while operating the device.

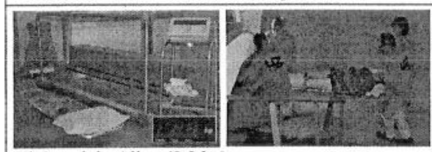
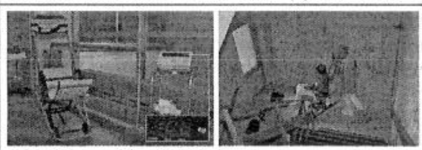
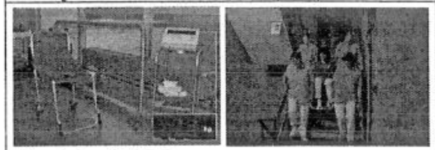
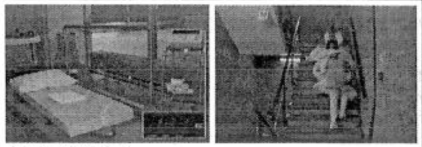
- Vertical Speeds – how quickly each device descended the hospital emergency stairwell, including speed per floor and an analysis of rest breaks that the operating teams took while traversing the stairs.
- Overtaking Potential – the ease at which other building occupants can evacuate alongside each device, including the space taken up on while turning on landing, the number of lanes occupied by the device on stairs and the overtaking experience of participants (derived from questionnaire data.)

These data, alongside those established in questionnaire data from the experiment participants, form the basis of the device performance evaluation presented in this paper.

EXPERIMENT METHODOLOGY

This section describes the series of trials conducted in the University of Ghent Hospital in 2008 [3], to quantify the performance of trained hospital staff in evacuating non-ambulant patients. Four commonly used movement devices were tested: stretcher, carry chair, evacuation chair, and rescue sheet. Trained hospital staff from the manual handling team of the University of Ghent Hospital served as device operators during the trials. These staff are expert in the manual handling of patients and in the use of each of the devices. Thus the data derived from these trials are intended to quantify the performance capabilities of the devices in expert hands, and therefore provide an indication of the best performance that can be expected using each of the devices. The staff were allocated to four handling teams: two teams consisted of four male handlers and two teams of four female handlers. Additionally, one male and one female staff member were assigned the role of the PRM. The simulated PRM was instructed to remain inactive during the trial process in order to replicate mobility impairment. In order to ensure that both PRMs weighed the same, the lighter PRM wore weights to match the other's 70 kilogram weight. Table 1 compares the various attributes of each movement device model used for the trials: its weight, material, and dimensions.

Table 1. The attributes of each movement device.

Stretcher *"Ferno Stretcher Scoop Model 65"*	**Evacuation Chair** *"Evac+Chair (R) 300H AMB"*
	
Lightweight Alloy (8.9 kg) Length/Width: 120cm/43cm	Aluminium tubing (10.6kg) Height/Width/Depth: 138 cm/52cm/77cm
Carry Chair *"Ferno model 42 (4204)"*	**Rescue Sheet** *"GSI Rescue 108088"*
	
Aluminium (7.3 kg) Height/Width/Depth: 95cm/48cm/61cm	Fabric (13.1 kg) Length/Width: 200cm/75cm

Procedure

A total of 32 trials were conducted over two days, with handling teams taking rest breaks between trials. The four teams of operators (Male 1, Male 2, Female 1, and Female 2) followed a predetermined procedure for each device. Prior to each trial, the required members of the handling team were situated behind a starting-line in a corridor on the 11th floor of Ghent University Hospital. At the start of the trial, the handling team retrieved the device equipment from a set area and entered

the preparation room to collect the PRM. The experimental procedure consisted of the following phases:

- ***Preparation Phase:*** The handling team transferred the PRM from a wheelchair to the movement device. Once secured into the device, the team moved the PRM out of the preparation room into the corridor.
- ***Corridor Phase:*** The PRM was moved through 60 metres of corridor with areas that required travel in a straight line, as well as areas in which the devices had to navigate a turn. There were four sets of doors on this path, all of which were closed prior to the commencement of each trial.
- ***Stairwell Phase:*** The PRM was moved down 11 floors via the stairs. The emergency stairwell had a dog-leg configuration; therefore, for every floor, the handling team negotiated a main landing, a flight of 12 risers, a middle landing, and another flight of 12 risers.

A second set of trials were conducted, again using each team and each device but in addition, a group of 24 volunteers were injected into the emergency stairwell. The handling team began on the 11th floor, while the group of volunteers (all young, fit and agile people) queued on the 6th floor. Once the device team reached the 5th floor, the group of 24 enter the stairs and begin their journey down to the ground. The procedure for the group trials was complete once the PRM, the handling team and every member of the group had all crossed a finish-line.

Data Collection

The progress of each trial was captured using several techniques to ensure comprehensive recording of the experiment. 13 video cameras were mounted within the emergency stairwell; one camera placed in the same position on each floor, one on the ground floor and an additional camera on the landing between floor 4 and floor 3. A member of the video team also operated a roaming camera during each trial, closely following the handling team, and recording every phase of the experiment. This filming was conducted at an appropriate distance and from behind the handling team, so as not to interfere with the progress of the trial. A control room was established within the building premises with live feeds from each camera to ensure that the experiment was being adequately recorded and, importantly, to monitor the safety of the participants during each trial. Also, a team of assistants were positioned on every floor of the emergency stairwell to document key times using stopwatches. Additionally, questionnaires were completed immediately after every trial in order to document the experiences of every trial participant. Different survey questions were posed to the handling team members, the 24 volunteers introduced into the stairwell and the PRM themselves. For each of these roles subjective views of device performance were assessed, particularly concerning:

- The perceived level of safety of the PRM and the handling team;
- The ease in which the device could be prepared and operated;
- The physical demands experienced by the handling teams during the trials;
- Personal estimates by the handling teams of how much further each handler could sustain the required physical effort.

VIDEO ANALYSIS

Collectively, 14 cameras provided over 1.5 terabytes of video footage of the two day trial. The video was captured at 25 frames per second; therefore analysis could be conducted to a relatively high degree of accuracy. Collating this footage in Adobe Premiere Pro C3, the air horn prompt at the beginning of each trial was used to synchronise footage from the various sources and precise markers were placed on the video timeline, indicating the time at which events occurred. Careful definition, assumption and interpretation were required during the analysis process.

Active Team Members

When tracking the devices' progress during the trials, it was necessary to differentiate between the phases in which members of the Handling Team were actively employed in the transportation of the PRM and the phases in which they were inactive (i.e. simply moving alongside the device without contributing to its progress). For example, when transporting the carry chair horizontally, only one member of the handling team was active; but when transporting it vertically, all of the members of the handling team were active. The Active Device Team (ADT) was considered to be the collection of the PRM in the device and the active members of the Handling Team (i.e. those physically touching the device). This definition ensured that each device could be tracked as one travelling unit, inclusive of the people actively transporting it at any given time. Additionally, varying roles of the active team members during each experiment phase were noted as part of the video analysis. As detailed in Table 2, three levels were established to describe the influence of each role at each phase: "Essential", "Major support" and "Minor support".

Table 2. Identification of handling team roles, per experiment phase.

	Preparation Phase	Corridor Phase	Stairwell Phase
Essential Role: *Members who were physically required to carry out experiment phase.*	Lifting and preparation of PRM.	Physically transporting PRM through corridor.	Physically transporting PRM down stairs.
Major Support Role: *Members who contributed major actions that significantly contributed to the teams' efficiency.*	Preparing the device only.	Unlocking and opening doors in advance of device.	Supporting device movement and occasionally swapping into essential role.
Minor Support Role: *Members who contributed minor actions but not significantly contributed to the teams' efficiency.*	Placing straps and pillows.	Walking alongside device.	Providing safety support ahead of device.

The footage showed that, for every device and gender, there were a constant number of team members in each role; these results are outlined in table 3. These data are necessary for subsequent comparative analyses, as they enable the assessment of device performance based on the person power required per task.

Table 3. The number of operators and their roles for each device

Experiment Phase		Stretcher	Evac Chair	Carry Chair M	Carry Chair F	Rescue Sheet
Preparation	Essential	2	2	2	2	2
	Major	1	0	1	1	0
	Minor	1	0	0	1	0
Corridor	Essential	4	1	1	1	2
	Major	0	1	1	1	0
	Minor	0	0	1	2	0
Stairwell	Essential	4	1	2	4	2
	Major	0	0	1	0	0
	Minor	0	1	0	0	0
Total number of operators		4	2	3	4	2

Observation Criteria

In determining the phase-by-phase progress of the device teams, their entire journey was divided into sections, each bound by lines as depicted in Figure 1. The corridor portion was divided into seven sections: the preparation room and six corridor sections; these portions were bounded by the door thresholds. The start of the corner was identified by a line (see D in Figure 1) which was used to determine the start of the turning manoeuvre. The times at which the devices reached and crossed all of these lines were recorded.

When tracking the teams through these observation points, the interrogation of the video footage was subject to interpretation and so it was essential to outline criteria to classify events consistently for each trial video. Typically, the required observations pertained to the crossing of the threshold of a door or the edge of a stair riser. In these cases, the first and last parts of the active team members were the focus of analysis. For example, in determining the point at which the entire team had exited the preparation room, the last foot of the last team member was observed. The definition at this event was: "the point at which the hind part of the last active team member's foot had fully crossed the line of interest".

Figure 1: Video observation points

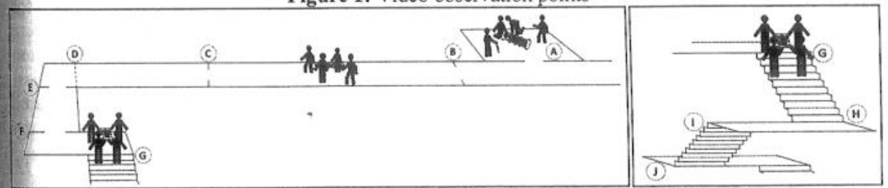


Fig Ref	Video Observation Point	Fig Ref	Video Observation Point
A	Preparation Room/Door 1	F	Door 5
B	Door 2	G	Floor - Stair threshold
C	Door 3	H	Stair - Landing threshold
D	Assumed corner divide	I	Landing - Stair threshold
E	Door 4	J	Stair - Floor threshold

Aside from the calculation of speeds for the devices, additional qualitative observations were also made in the video analysis. Observations were made to find the times at which the operators lifted the PRM in preparation, the transition through doorways, the level of overtaking in the group trials, and the times at which the teams had stopped to rest in the stairwell. These observation points had their own assumptions and specific criteria, and are therefore described alongside the respective results in the next section. A full matrix was developed with the possible observation definitions, and a set of codes devised to efficiently label the markers placed in the video footage. A program designed by the analysis team then extracted the times of every marker, alongside the code that was assigned, allowing the complete data set from each trial to be collated and examined in a spreadsheet.

Path Measurements

To enable the numerical analysis of this extracted video data, it was also necessary to make assumptions regarding the distance travelled by the teams. The shape of presumed travel paths can significantly influence any subsequent speed calculations; therefore it is important that the paths reflect the route taken. During the trials, teams typically travelled along the central path of the corridor. In the same way the devices were descended through the staircases centrally, with the most common deviation being a slight inclination toward the inner hand rail for support. Here, therefore, it is assumed that the teams traversed the central line path through the corridors, stairs and landings, and that the distance traversed in stair descent is calculated as the Pythagorean diagonal. 10 floors of the emergency staircase had identical dimensions, with the central path per floor measured as 14.7m. The measured corridor distances totalled 60m and the entire stairwell portion, including landings, totalled 158m. Therefore, for each trial operators travelled 218m to evacuate the PRM.

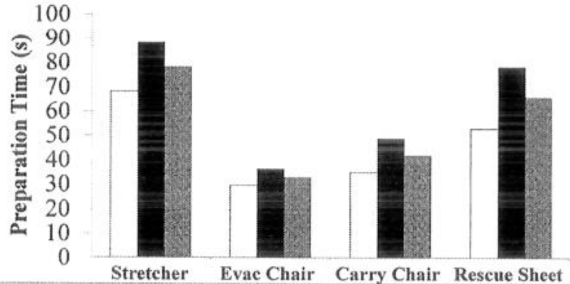
RESULTS

The analysis of the video footage from the trials resulted in a collection of times that documented the evacuation progress of each team. These times, as outlined in the previous section, were used alongside the central path measurements to determine the speeds of each handling team. The resulting data, as presented in this section, include preparation time, horizontal speeds, vertical speeds and overtaking potential.

Preparation Time

Two key times were observed from the video footage of the manual handling teams moving the PRM from the wheelchair to the device: the time at which a member of the handling team first makes physical contact with the PRM and the time at which the preparation is complete, as determined by the first forward evacuation movement by the team. The average preparation times, as presented in Figure 2, indicate that the evacuation chair is the quickest device to prepare. The stretcher is the slowest, taking more than twice as long as the evacuation chair. Male teams are faster than female teams when preparing the PRM, but it is notable that for both genders the preparation times for devices where the patient was secured in a sitting position (the evacuation chair and carry chair) were significantly faster than the time taken with devices where the patient was secured in a laying position (the stretcher and the rescue sheet). The difference between male and female performance is smallest for the evacuation chair (24%) and greatest for the rescue sheet (47%). Each handling team repeated the preparation process for each device and the respective results show that, on average, teams are 3.5% faster to complete the patient preparation process the second time.

Figure 2: Average times taken to prepare the PRM with each device



	Stretcher	Evac Chair	Carry Chair	Rescue Sheet
Male Average (s)	68	29	35	53
Female Average (s)	88	36	49	78
Overall Average (s)	78	33	42	65

It is noted that the preparation times for the rescue sheet may not be representative of the times required to prepare a patient in hospital or a care facility. This is because, for moving patients with this particular device, it is likely that the patient would already be in bed. Therefore a transfer from wheelchair to rescue sheet is unlikely. However, there would still be a preparation time as the PRM would need to be secured to the device and the device lowered to the floor. In addition, there are other rescue sheet type devices on the market such as the Albacmat Rescue Mat and the Evacupod which would require the transfer of a PRM from a wheelchair to a device.

Horizontal Speed

Horizontal traversal times were determined for: straight-line sections of corridors, for travelling around corners, and for opening various types of doors while operating the device. Where appropriate, these times were converted to horizontal travel speeds. In addition, the average horizontal speed from exiting the preparation room to entering the stair is determined. Presented in Table 4 are the average horizontal travel speeds for both male and female handling teams and the overall cross gender average speeds.

Table 4. Average Horizontal Transportation Speeds

	Stretcher	Evacuation Chair	Carry Chair	Rescue Sheet
Male Average	1.09 m/s	1.55 m/s	1.54 m/s	1.16 m/s
Female Average	0.99 m/s	1.39 m/s	1.46 m/s	0.72 m/s
Overall Average	1.04 m/s	1.46 m/s	1.50 m/s	0.89 m/s

These results indicate that in horizontal transportation the devices with wheels (i.e. the evacuation chair and carry chair) are the fastest, with average speeds of 1.5 m/s, slightly better than the average free walking speed quoted by Fruin [4] of 1.4 m/s. The rescue sheet is the slowest with an average speed of 0.9 m/s. For each device, male teams are faster than female teams when travelling along the corridor, with the carry chair having the smallest difference between male and female performance (5.1%) and the rescue sheet having the greatest difference (38%).

Door Transition Times

The four corridor doors were closed prior to the commencement of each experiment, therefore the teams had to open and traverse them while manoeuvring the device. Two times were observed from the video footage: the time at which the first member of the handling team touched the door (normally, the handle) and the time at which the last part of the last handling team member's foot crossed the doorway. This indicated the time taken to transition each door (see table 5).

As detailed in the previous section, not all handling team members were required to push the evacuation chair and carry chair horizontally, therefore team members not involved in moving the PRM were available to open doors in advance of the device. Therefore it was not possible to determine a time for the handlers to negotiate the closed door for these devices. However, additional trials were conducted at the University of Greenwich, where three males and three females repeatedly moved the Evac+Chair device through a door with the same attributes as door 2 of the Ghent trials. These trials were recorded by video and analysed in accordance with the methodology outlined in this paper. Thus in Table 5 the door transition times derived from the Ghent trials and the transition times derived from the University of Greenwich trials for the evacuation chair are presented. The opening direction indicates the movement of the door leaf as it is approached by the handling team; whether it opens towards the operators, or away from them.

Table 5. Average door transition times (seconds)

Door	No. of Leaves	Opening Direction	Door bolt	Leaf Opening Order	Stretcher		Rescue Sheet		Evac Chair	
					M	F	M	F	M	F
2	2	Toward	N	Left, right	7	7	8	12	5	6
3	2	Away	N	Right, left	5	4	6	7	-	-
4	2	Away	Y	Right, left	12	16	11	20	-	-
5	1	Away	N	Right leaf	6	7	6	11	-	-

The results indicate that female teams take longer than male teams to manoeuvre closed doors while using movement devices. A cross comparison across three devices is only possible for door 2. Here we find that the evacuation chair is the fastest with an average traversal time of 5.5 s while the rescue sheet is the slowest with an average traversal time of 10 s. We also note that it is easier for the handlers to negotiate doors which open away from the handlers. When doors are bolted shut, the male teams take on average twice as long to negotiate the door while the female teams take on average 3.5 times as long.

Vertical (Stair) Speeds

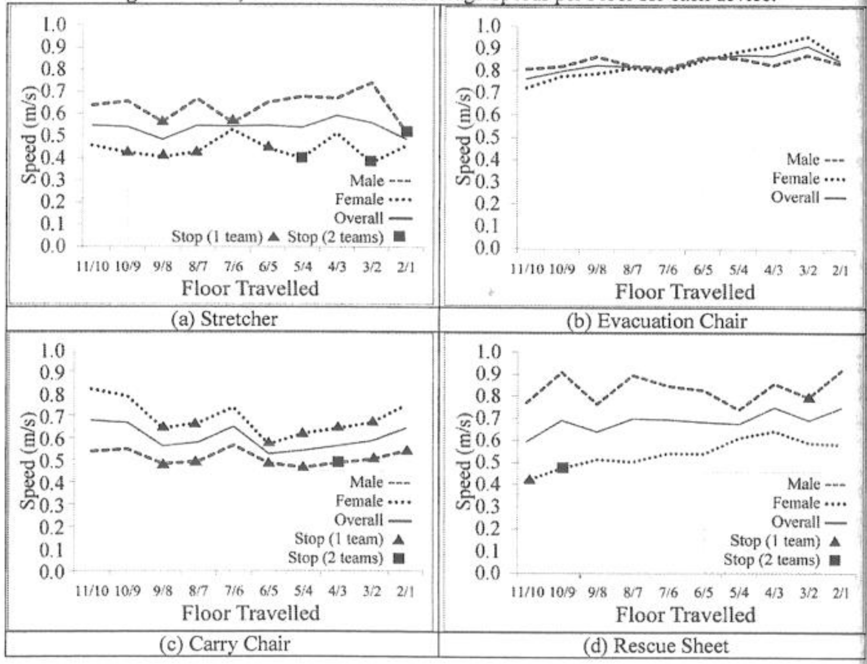
Travel speeds on stairs were determined as an average from top to bottom (see Table 6) and also on a floor by floor basis (see Figure 3). The average travel speed was determined from the time the trailing leg of the last person in the handling team crossed the threshold between landing and stair at the top floor and the time for the trailing leg of the last person in the handling team to cross the threshold between stair and landing on the ground floor.

The average stair speeds indicate that the evacuation chair is the fastest device with an overall average descent speed of 0.83 m/s, being 57% faster than the slowest device, the stretcher at 0.53 m/s. However, gender had a strong influence on the average speed, with the female speeds being generally considerably slower than the male speeds for most devices, with the exception of the evacuation chair and the carry chair. The evacuation chair is the only device for which male and female speeds are alike (1.2% difference). The results for the carry chair suggest that the female descent speed is greater than the male descent speed. However, it is noted that this was achieved with a four person handling team for the females and a two person handling team for the males. It is noted that the male team had three members, but only two actually carried the chair at any one time. When one of the male operators needed a rest, the third person would take their place. The female stretcher team was 30% slower than the male team and the female rescue sheet team was 37% slower than the male team. These results suggest that the evacuation chair was the least physically demanding as it produced the greatest average speed and there was no gender difference in performance. Furthermore, the female descent speed using the evacuation chair is greater than the average stair descent speed for 30 year females according to Fruin data [4] (0.755 m/s) while all other devices were considerably slower.

Table 6. Average speeds over the whole stairwell portion

	Stretcher	Evacuation Chair	Carry Chair	Rescue Sheet
Male Average	0.63 m/s	0.83 m/s	0.50 m/s	0.82 m/s
Female Average	0.44 m/s	0.82 m/s	0.66 m/s	0.52 m/s
Overall Average	0.53 m/s	0.83 m/s	0.58 m/s	0.67 m/s

Figure 3. Male, female and overall Average Speeds per Floor for each device.



(a) Stretcher

(b) Evacuation Chair

(c) Carry Chair

(d) Rescue Sheet

In addition to the overall stair descent speed, the average descent speed per floor was determined as shown in Figure 3. Also shown on this curve is the number of stops required by the male and female teams (see next section). While the curves indicate a number of stops were necessary, in particular for the stretcher and the carry chair, there is no indication of handler fatigue. Had handler fatigue been an issue, the curves would have had an overall negative gradient, with the travel speed reducing as the number of floors travelled increased. The most uniform and consistent performance was achieved by the evacuation chair. Furthermore, the gender independence of the evacuation chair performance is again noted in Figure 3.

Device Stoppages on Stairs

Stoppages were defined in the video analysis as a time where the device was stationary (for more than 2 s) in order for the team to; adjust the device, or change handling positions, or change handlers or rest. The footage showed that devices tended to pause at the top step of every flight of stairs, to change handling technique (e.g. in the case of the stretcher) or to tilt the device (in the case of the evacuation chair) but these pauses were not recorded as part of the stopping analysis as they were generally shorter than 2 s, occurred at every floor and were already accounted for in the floor speed of the device. Table 7 shows the number of stops recorded during the teams' stairwell descent and the total stoppage time.

Table 7. Number of Stops Recorded and Total Stoppage Duration per Trial.

	Stretcher		Evacuation Chair		Carry Chair		Rescue Sheet	
Teams	# stops	Duration (seconds)	# stops	Duration (seconds)	# stops	Duration (seconds)	# stops	Duration (seconds)
Male 1	2	19	0	0	7	59	1	8
Male 2	2	22	0	0	2	13	0	0
Female 1	4	45	0	0	3	22	2	7
Female 2	5	82	0	0	3	42	1	3
Average stopping duration	**M:** 10 s **F:** 14 s		**M:** 0 s **F:** 0 s		**M:** 8 s **F:** 11 s		**M:** 8 s **F:** 3 s	

All stops occurred when the handling teams were partly on a flight of stairs and partly on a landing. When carrying the carry chair and the stretcher, teams primarily stopped to swap position (thereby resting an arm that was carrying the weight) and to wipe their hands or the handles of the device. The rescue sheet operators stopped to readjust the strapping of the device (and once because they had accidentally dropped the device and PRM). The female handling teams did generally stop more than the male teams, possibly indicating higher levels of muscular fatigue. It is noted that the rescue sheet did not stop for very long in any trial however, and the evacuation chair was the only device that did not stop at any time during the descent.

Overtaking Potential

The ability for other evacuees to use the stair when the PRM is being assisted down the stairs is an important consideration. The stairs in the building were quite wide, being 1.4m from handrail to handrail and is therefore sufficiently wide to allow two people to comfortably descend side by side. Thus, when the device only occupies one stair lane, other stair users could evacuate alongside the device and overtake the handling team. When two lanes were occupied by the device and handlers, no one else could overtake the device on the stairs as the stairs were completely blocked. In some cases, the device and handlers occupied more than a lane but less than two lanes. In this case, some of the other evacuees could pass the device and handlers, but not all. In the post-trial questionnaire participants were asked; "How easy was it to overtake the Handling Team with the PRM?" and responded with a rating from 1 to 5, where 1 was "very difficult" and 5 was "very easy". The average responses from 353 questionnaires are presented as the overtaking rating in table 8. However, there are several difficulties with the responses. First is the translation into Flemish. The literal translation may not have conveyed the correct meaning. Furthermore, the participants may have misunderstood the meaning of the question. For example in the case of the evacuation chair, the device was moving very fast and from the video footage it is clear that many of the participants had difficulty in catching the chair. The relatively low ranking of the evacuation chair could indicate that they *did not* overtake instead of the *difficulty* experienced in overtaking. In addition, when the handlers of the stretcher stopped on the landing/stair interface, occupants were able to pass the stationary device, hence the high score for the device. Thus, in addition to the questionnaire results, the number of stair lanes the device/handlers occupied is noted in table 8 as this provides an indication of overtaking potential.

The video footage clearly demonstrated that people would overtake when there was a physical opportunity to do so. As the evacuation chair and the carry chair (male handlers) only occupied one lane, the other evacuees could easily overtake these devices. The rescue sheet occupied more than one lane, and group members took the opportunity to overtake in the instances when there was sufficient space. For the stretcher and the carry chair with female handling team, it was impossible to overtake while concurrently descending the stairs; the group waited for the device to stop before passing.

Table 8. Overtaking potential, per device.

	Stretcher		Evac Chair		Carry Chair		Rescue Sheet	
	Male	Female	Male	Female	Male	Female	Male	Female
No. Stair lanes occupied	2	2	1	1	1	2	1.5	1.5
Overtaking rating	3.4	2.7	3.5	3.2	3.9	1.9	3.6	2.9

DEVICE PERFORMANCE METRIC

The performance factors presented in this paper are some of the factors that may be considered when selecting the most appropriate device to use in a particular application. However, it is difficult to determine which device may be best to use based on the individual factors taken in isolation. The overall performance of a device will be a function of some or all of these factors and some factors may be of greater significance to potential users or in particular applications than other factors. For example, a situation involving one PRM located on the upper floor of a building with lots of potential device handlers will have different requirements to a situation involving lots of PRM located on the upper floor of a building with few device handlers available. In an attempt to provide a way of combining the factors in a transparent, flexible and meaningful manner a simple metric is devised based on the weighted sum of each factor (see equation 1). The factor weights (W_f) can be selected based on the requirements of the user and the demands of the intended application. For each factor (f), the devices are allocated a normalised performance rating (NPR_f), which is the performance rating derived from the Ghent experiments normalised by the poorest performance score for that factor. So the poorest performing device will have an NPR_f of 1.0 while the other devices will have an NPR_f greater than 1.0. The overall performance score (OPS) for the device is then given by the sum of each normalised performance rating multiplied by the user-defined factor weighting as shown in equation 1. The device with the best combination of performance factors for the identified application will have the largest OPS.

$$OPS = \sum_{f_1}^{f_n} NPR_f . W_f \qquad [1]$$

The performance rating for each factor can be based on the male performance, the female performance or the average performance. For the analysis presented here the average performance is used. As the average performance is used, a set of additional factors is introduced which measures the difference in gender performance. Ideally, the device performance should be gender-independent. Thus the gender factor measures the degree to which the device is gender-independent. The device which is the most gender-independent as measured by a particular factor will have the highest normalised gender factor. For example, for the preparation time factor, the device with the largest relative difference in preparation time is the rescue sheet with a 47% relative difference between male and female performance. In contrast, the evacuation chair, with a relative difference of 24% in male/female preparation time has the smallest relative difference. Thus the normalised gender factor for preparation time for the rescue sheet is 1.0 while for the evacuation chair it is 2.0. As the normalised gender factors can be quite large, in one case as large as 37, in order not to swamp the other factors, normalised gender performance differences greater than or equal to 2.0 will be assigned the value of 1.0 and all values less than 2.0 will be assigned the value of 0.0. Presented in Table 9 are the various factors for each device and the sum of the normalised performance factors assuming all factors are equally weighted to 1.0.

Assuming all the performance factors carry equal weight, the evacuation chair comes out a clear winner, scoring 139% better than the stretcher, 100% better than the rescue sheet and 42% better than the carry chair. However, performance assessment criteria depend significantly on the environment in which the use of devices is being considered. For example, in a situation where vertical performance, horizontal performance and preparation time are considered to be of paramount importance e.g. the PRM is located on the upper floor of a high rise building which has long corridors that need to be traversed, but staffing is not an issue, then the weights for all the other NPR can be ignored (W_f = 0.0), the weight for the vertical performance (NPR_7) can by increased from its default value (1.0) to 2.0 and the weights for the preparation time and horizontal performance kept at their default values (1.0). In this case, the OPS for the stretcher, evacuation chair, carry chair and rescue sheet become: 4.2, 7.2, 5.8, and 4.8 respectively. In this case the evacuation chair scores 71% better than the stretcher, 50% better than the rescue sheet and 24% better than the carry chair. Therefore while the evacuation chair still offers the best performance, the advantage over the other devices is diminished.

Table 9. Rated factors in device performance

		Stretcher	Evac Chair	Carry Chair	Rescue Sheet
	Prep Time (s)	78	33	42	65
NPR_1	**Norm Prep Time**	**1**	**2.4**	**1.9**	**1.2**
	Gender performance diff (%)	30	24	40	47
NPR_2	**Norm GPD**	**0.0 (1.6)**	**1.0 (2.0)**	**0.0 (1.2)**	**0.0 (1.0)**
	No. Prep Operators	2	2	2	2
NPR_3	**Norm Prep Operators**	**1.0**	**1.0**	**1.0**	**1.0**
	H. Speed (m/s)	1.04	1.46	1.50	0.89
NPR_4	**Norm H. Speed**	**1.2**	**1.6**	**1.7**	**1.0**
	Gender performance diff (%)	9	10	5	38
NPR_5	**Norm GPD**	**1.0 (4.2)**	**1.0 (3.8)**	**1.0 (7.6)**	**0.0 (1.0)**
	No. H. Operators	4	1	1	2
NPR_6	**Norm H Operators**	**1**	**4**	**4**	**2**
	V. Speed (m/s)	0.53	0.83	0.58	0.67
NPR_7	**Norm V. Speed**	**1.0**	**1.6**	**1.1**	**1.3**
	Gender performance diff (%)	30	1	32	37
NPR_8	**Norm GPD**	**0.0 (1.2)**	**1.0 (37)**	**0.0 (1.2)**	**0.0 (1.0)**
	No. V. Operators*	4	1	3.5	2
NPR_9	**Norm V. Operators**	**1.0**	**4.0**	**1.1**	**2.0**
	No. lanes occupied	2	1	1	1.5
NPR_{10}	**Norm lanes**	**1.0**	**2.0**	**2.0**	**1.3**
	Sum Norm Rating	**8.2**	**19.6**	**13.8**	**9.8**

* **Number of operators based on the Essential and Major roles.**

In another example, staffing may be the predominant issue, for example a situation when there are a number of PRM and only a small number of staff prepared to be handlers. In this case, the weight for the staffing performance factors, NPR_3, NPR_6 and NPR_9 may be increased from their default value (1.0) to 2.0 while all other parameters are kept at their default values. In this case the OPS for the stretcher, evacuation chair, carry chair and rescue sheet become: 11.2, 28.6, 19.9, and 14.8 respectively. In this case the evacuation chair is 155% better than the stretcher, 93% better than the rescue sheet and 44% better than the carry chair. Thus the evacuation chair still offers the best performance and returns a similar advantage over the carry chair and rescue sheet but a considerable improvement in performance over the stretcher compared to the case where all the factors are of equal weight.

This metric offers a simple approach to gauge the overall performance advantage of one device over another, allowing user-based priorities and user specific performance factors not already included to be incorporated in the assessment. Logistical considerations can be included, such as: the cost of the devices, their storage and maintenance requirements, and associated training requirements. In this analysis it is assumed that the medical requirements of the PRM have already been used to filter out inappropriate devices. For example, if the PRM cannot be physically moved from a wheelchair to the assist device then none of the above devices would be considered appropriate, regardless of the score. Furthermore, if the PRM has a condition which means that they cannot lie down this would rule out the stretcher and the rescue sheet, or if they could not sit up, this would rule out the evacuation chair and the carry chair.

CONCLUSIONS

This paper has described a series of trials undertaken to quantify the performance of trained hospital staff in evacuating non-ambulant patients from a multi-story building. The results presented indicate that in horizontal transportation the devices with wheels, i.e. the evacuation chair and carry chair, are the fastest, with average speeds of 1.5 m/s, comparable to the average free walking speed quoted by Fruin of 1.4 m/s. The rescue sheet is the slowest device with an average speed of 0.9 m/s. In vertical movement, the results indicate that the evacuation chair is the fastest device, averaging 0.83 m/s while the stretcher is the slowest device, averaging 0.53 m/s. Fatigue does not appear to be an issue in the vertical descent speed of any of the devices however; the devices stopped frequently during the stair descent, with only the evacuation chair not stopping once during this phase. The devices with the best overtaking potential for other stair users was the evacuation chair as it only blocked one lane on the stair; the stretcher was the worst as it blocked the entire stair. The carry chair was similar to the stretcher when operated by female handlers and similar to the evacuation chair when operated by male handlers. The number of operators required to utilise the device is also of great importance, especially in situations where there may be many PRM or in situations where there are few trained device handlers. The evacuation chair was the best device in this respect, only requiring a single handler for both horizontal and vertical movement, while the other devices required two or four handlers. Ideally, the device performance should be gender independent, with the same performance being achieved by male and female handlers. In horizontal movement, the carry chair had the smallest difference in gender performance (5.1%) while the rescue sheet had the greatest difference (38%). In vertical movement, the evacuation chair had the smallest difference (1.2%) while the rescue sheet had the greatest (37%); however, the carry chair utilised an additional female handler.

In an attempt to provide a way of combining the performance factors in a transparent, flexible and meaningful manner a simple metric was devised based on the weighted sum of each performance factor. The metric offers a simple approach to gauge the overall performance advantage of one device over another, allowing user-based priorities and user-specific performance factors to be considered. The metric can be expanded by taking into consideration other factors such as: logistical factors i.e. operator training and device cost; additional performance factors i.e. cornering ability; or user factors such as handler/PRM perceived safety. The collected data is also being used in the buildingEXODUS software for simulations of evacuation simulations of PRM from multi-story buildings.

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