WILL CURRENT EMERGENCY EVACUATION SYSTEMS BE ACCESSIBLE, SAFE AND USABLE IN 2030?

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ABSTRACT

By 2030 30% of workers in high rise offices will be unable to evacuate by stairs due to the increasing incidence of obesity, functional ability and the ageing of the workforce. Australian Studies from 1980 confirm that 18% of office workers are unable to evacuate buildings of more than 19 storeys using the stairs. The impact of this non stair user is reflected in the World Trade Centre Incidents. The macroscopic evacuation model is challenged by the group dynamics. A longitudinal study plan to test these issues is discussed. The framework of an integrated risk based evacuation ability model that will provide for the testing of an integrated solution utilising elevators is presented. Issues on elevator capacity are also presented. Factors requiring additional research are noted throughout the paper. It is concluded that a safe and inclusive evacuation strategy geared to the height of the building should be provided.

KEYWORDS: elevator, evacuation, inclusive design, risk, stairs.

INTRODUCTION

In the evacuation of World Trade Centre, Tower 1, the average surviving occupant spent 48 seconds per floor descending the stairwell (0.2m/sec) (NIST, 2005). This slow descent speed was not just due to density but also due to the presence of those with mobility impairments who required assistance. A group of people all travel down stairs at the speed of the slowest mover (Fahy and Proulx, 2001), This can occur with a family group, or any group (MacLennan et al, 2007; Fahy and Proulx 2001). Trial evacuations of high rise buildings have shown that it is not always the crowded stairs where slow descent speeds are encountered (Proulx et al, 2006). The traditional design approach is macroscopic and relies on density homogeneous (groups). This approach assumes merging at each floor so that the density increases and the descent speed slows (Nelson and Mowrer, 2006). There is other evidence to the contrary where groups are formed, and one group defers to the other, causing one group to wait (MacLennan et al, 2007; Proulx et al, 1996 and 2006). Other stair users may be slow movers due to age, obesity and other impairments not covered by the traditional definition of “disabled persons”. Obese persons with a Body Mass index (BMI) > 35 will occupy more space on the stairs (MacLennan et al, 2007) and travel at a slower speed (Proulx et al, 2006; Moody, 2000). Society is rapidly ageing, and obesity is at critical levels in the UK and USA (Center on an Aging Society, 2003). According to the World Health Organisation Data Base over 30% of the UK and US populations are at risk just due to ageing and obesity. This is significant in that the risk of injury due to the means of evacuation may be equivalent to that of lift failure due to fire. 3000 persons were able to evacuate Tower 2 of the World Trade Center in 16 minutes (NIST, 2005). There is a strong argument for an integrated evacuation solution utilising stairs and lifts (Groner and Levin, 1992). An inclusive approach is required so that office workers can have access to a ‘toolkit” in order to determine whether or not they can cope with stairs in the building in question, and that this toolkit is based on a predictive model developed and tested in the field. The development of this inclusive design evacuation toolkit is in progress and a framework is presented in this paper.

IS DENSITY THE ISSUE?

The Concept of the "Plug"

The use of density models in the analysis of the evacuations of office buildings promote the merging of occupants at each floor. The macroscopic approach where stair users merge and the density increases thereby slowing the rate of descent (Fruin, 1985; Nelson and Mowrer, 2006) has been challenged by research (NIST, 2005; MacLennan et al, 2007; Proulx, 2006). where merging behaviour is replaced by deferment, group dynamics, and the functional ability which are all microscopic issues These behaviours require more investigation in the field. In fact the impact of group dynamics in terms of entry behaviour, or group dynamics combined with functional ability limitations, are supported by new microscopic evacuation models (Castle, 2007) and the results of field observations (MacLennan et al, 2007; Proulx et al, 1996 and 2006; Fahy and Proulx, 2001). Table 1 provides some examples.

There is also the spatial impact due to obesity and an increased body ellipse of $0.44m^2$ derived by MacLennan et al (2007) from CT scan data (Geraghty and Boone, 2003) and arm anthropometric data (Ostchega et al, 2006). The slow moving group, group entry sequence and the obstruction created by the obese person creates a 'plug' in the evacuation stream which naturally increases the density of the following group (Fahy and Proulx, 2001) and slows the descent speed. The descent speed here is critical and can be directly related or derived from the physical characteristics of the stair user (Fahy and Proulx, 2001).

Evacuation Height and Limitations in Descent Ability

Many of the stair users in the evacuation of the WTC Towers reported that they were totally unprepared for the physical challenge of the evacuation with many of them having to rest during descent (NIST, 2005). This brings into question the total distance that the stair users would be able to travel before needing to rest. A pedestrian study in Leeds showed that a significant percentage of the sample comprising older and mobility impaired pedestrians were not able to travel further than 135m without a rest (Leake et al, 1992). Translating this into a stair descent equivalent (Fujiyama, 2005) would impose a 15 storey limit on stair users with identical characteristics. An Australian study carried out in the 1980's which has now been incorporated into the writer's research plan (MacLennan et al, 2007) in the form of a longitudinal study showed that 10% of the sample spread across eight high rise office buildings would not be able to evacuate more than 19 storeys.

Further Work Required

Further trial evacuations are proposed to complete this longitudinal study, from this data a multiple regression based model can be developed, based on functional ability and other physical characteristics to predict stair evacuation capability and limitations. This would provide the basis for the inclusive design evacuation toolkit, providing the office worker and facility manager with the necessary support for the use of elevators for evacuation, using a microscopic approach.

Table 1. Speed and Density Comparisons

Study	Stairwell	Density p/m^2	Observed Mean Speed m/sec	Calculated Speed (s=1.08-0.29d) m/sec (Proulx et al. 2006)
Proulx et al 2006	E	1.6	0.40 (min 0.17); substantial delay due to obese persons and person using a cane with two assisting.	0.62
MacLennan et al, 2007	Manchester Piccadilly Station	2.2	0.32 (family group of grandparents and two children with bags holding up general flow)	0.44
NIST, 2005	Not noted	3.1 (calculated from flow)	0.2 (large number of mobility impaired stair users removed from stairs to allow increase in flow rate and people tiring or resting)	0.25

OCCUPANT CHARACTERIZATION – FUNCTIONAL ABILITY AND DESCENT CAPABILITY

A snapshot of the UK population profile shows up those sections of the population whose functional ability will vary their circulation ability:

- Ageing and associated health disorders where approximately 10% of the population are over 65 years and that this will grow to 11.5% in 2025.(US Census Bureau, 2007)
- 19.7% of the population are disabled people, of these 15.77% have impairments that would affect their functional ability to circulate.(DRC,2007)
- Approximately 29% of the population has a BMI > 30 and 5% > 40. (The Information Centre, 2006)

The above represents an overall population profile where 1 in every 5 persons could be at risk so that these need to be analyzed in more detail to assist with building occupant characterization (Boyce, 1999). The framework is shown in Table 2 (LTNZ 2004). This process of characterisation is in line with international guidelines (ABCB, 2005) and can also be coupled with stair environment and building characterisation. The stair environment is critical as current research still confirms the contribution of stair geometry, slippery surfaces and other factors to accidents (Scott, 2005). Table 2 provides the characterisation format together with examples of occupant characteristics. When this is viewed with a profile of the UK population it demonstrates that 1 in every 5 persons has some kind of characteristic that will impact on stair descent performance then stair capability should be viewed as an integral component of evacuation design and research. The references are also provided in Table 2.

Following on the work of Boyce et al (1999) on characterisation which highlighted information about a significant section of the population Fahy and Proulx (2001) proposed the basis of a data base format that could be used to formulate a critical stair descent rate. An evacuation simulation could be carried out using one of the accepted microscopic evacuation software packages (Castle, 2007) with different input evacuation scenarios. These scenarios could also be inclusively developed via a representative focus group. An example of the data base format is provided in Table 3. Table 3 also provides a cross section of the type of data that is available[1]. There is no doubt that these data have been gathered for over 20 years, but data relating to obesity[3], age related disorders[2] and other impairments[2] especially relating to endurance (Leake et al, 1991) (MacLennan et al, 2007) require further research. This research forms part of the model outlined in Figure 1.

Table 2. Characterization Framework (LTNZ, 2004) (Boyce et al, 1999)

Characteristic or Behaviour	**Resulting in**	**Impacting Upon**	**Reference**
All age groups – Group Dynamics when a group of friends form prior to stair descent	Talking between themselves and become distracted and linked with their associate	Move as a group occupying the same space, reducing descent speed and replacing merging behaviour at each floor with deference.	Finnis and Walton, 2007; MacLennan et al, 2007;(Via questionnaire – part of longitudinal study)
Obese – BMI> 30 and waist to hip ratio > 0.9	Greater amount of space occupied and lack of endurance/ stability due to associated conditions such as fatigue, breathlessness, cardiac problems; Body ellipse of 0.44m^2	Reduces descent speed and in stairs less than 1100mm between handrails creates blockage as well as total height that can be evacuated.	Lahli-Koski, 2001; Messler, 2007; Geraghty and Boone, 2003; MacLennan et al, 2007; Proulx et al, 2006; Center on an Aging Society, 2003
BMI > 30 where this has been prevalent for adult life – manifesting in age group 50+.	Possible knee osteoarthritis, type 2 diabetes, foot problems, hip disorders, dementia, poor balance etc.	Reduced endurance and descent speed because of perception of falling, pain in knees/hips/feet.	Moody, 2000
Impaired Vision, Mobility Impaired measured by increased ADL's.	Require assistance in using the stairs	Reduced stair descent speed, holding up other evacuees. Also reduces total height that can be evacuated.	NIST, 2005; Proulx et al, 2006; Fahy and Proulx, 2001; Leake et al, 1991; (interpolated from walking distance)
Older People 65+ - many conditions exacerbated through obesity.	Balance, reduced strength, and endurance and other lower limb muscular skeletal disorders.	Reduced stair descent speed and vastly reduced dynamic stability.	Hamel et al, 2004; Messler, 2007; Center on an Aging Society, 2003

The research proposed will provide real world cross cultural data and comparisons from trial evacuations of high rise buildings between 15-30 storeys. The real world data will be further supported by selected controlled trials where more detailed measurements are required e.g. gait cycle and dynamic stability performance and begin to fill in the gaps as well as providing the basis of the proposed predictive model.

Table 3. Possible Data Base Framework (Fahy and Proulx, 2001)

Occupant Characteristics	Min	1st Quartile	3rd Quartile	Max	Mean
All impairments[1]	0.10	0.42	0.7	1.83	0.60
Mobility impairment[1]	0.10	0.42	0.7	1.22	0.58
No aid[1]	0.28	0.45	0.94	1.22	0.68
Crutches[1]	0.42	-	-	0.53	0.47
Cane[1]	0.18	0.35	0.7	1.04	0.51
Walking Frame[1]	0.10	-	-	0.52	0.36
Assisted mobility impairment[1]	0.42; 0.2 WTC	0.52	0.86	1.05	0.69
Vision impairment[2]	0.25	-	-	-	-
Older people[2]	0.35	-	-	0.94	0.62
BMI > 30 and Waist to Hip ratio >0.9[3]	Instances of stair descent speeds as low as 0.2m/sec – references are varied – lower muscular skeletal problems that cause pain will have an increased affect e.g. knee osteoarthritis and feet problems – see Table 2.				

[1 – 3]See text in the paragraph immediately preceding Table 3.

THE RISK ASSESSMENT MODEL FRAMEWORK

Much of the performance based evacuation design at present relies on an adaptation of the Density Model (Fruin, 1985). The research that underpinned this Model was carried out in the late 1960's. There is concern amongst the life safety professionals about the accuracy of the data being used in macroscopic evacuation models (Castle, 2007) especially in terms of the rapid increase in ageing, obesity and the significant numbers of people who were limited by their impairments to evacuate buildings via stairs (Groner and Levin, 1992). The microscopic approach to evacuation research reveals areas where there is a paucity of data. Further tests are therefore required in these areas and the results analysed and presented in the form of a predictive model to demonstrate which means of evacuation would most suitable for each building occupant (stairs or elevators) . This approach is supported by the findings of the World Trade Centre Incident Study (NIST, 2005) and other high rise evacuation research (Groner and in, 1992). A proposed framework for the model is shown in Figure 1.

The data gathered from the testing activities (numbered 2-4) will comprise field measurements and observations as well as estimates from expert and user opinion. The output from the predictive model in activity 5 needs to be integrated with the estimates from activity 4.The most appropriate simulation tool for the testing of these outputs is a risk based simulation tool such as Risk AMP ® (Structured Data, 2007). This research is still in the early stages of development and will involve close liaison with risk data model developers. The ultimate aim of the model shown in Figure 1 is therefore to:

- Gather the missing stair descent data and associated user characteristics / functional abilities from a series of 6 international trial evacuations (NZ, Australia, Dubai, Hong Kong, UK and USA.
- Further corroborate the real world results via controlled stair descent tests.
- Analyze the data and develop a predictive model that will test the hypothesis especially in terms of occupant endurance (safe evacuation height in terms of ability)
- Test the predictive model via expert and user derived scenarios and estimates (e.g. minimum, most likely and maximum evacuation times where possible) using an appropriate simulation tool such as RiskAMP® (Structured Data, 2007).

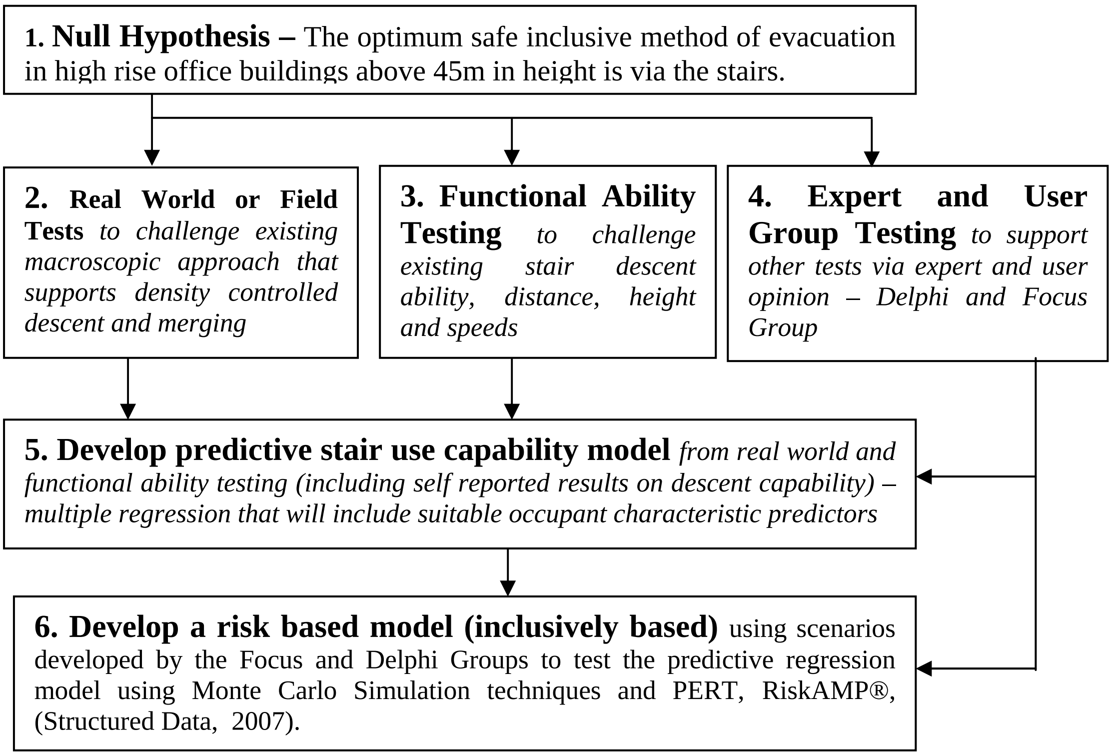

Figure 1. Risk Evaluation Model / Process

The model will be developed concurrently with gathering and analysis of data collected in each of the trial evacuations to be carried out in 2008, and presented in a series of journal papers. The Delphi and Focus Groups will be assembled at the same time.

THE NEED FOR AN INCLUSIVE INTEGRATED SOLUTION

Lessons Learned

Approximately 3000 building occupants were able to evacuate Tower 2 of the World Trade Centre during the 16 minutes prior to aircraft impact (NIST, 2005), which corresponds to a flow rate of 183.5 persons/minute, an extremely efficient outcome. Guidelines are already available for the use of elevators for emergency evacuations (Klemencic et al, 2004) that involve the use of staging areas. Such an approach may not be inclusive and has been challenged (Groner and Levin, 1992). The World Trade Centre Incident of September 11, 2001 shows the way forward as there is a need to develop a solution for the entire population.

Elevator Passenger Capacity Issues

This paper does not address the design of the system components as these are highlighted in guidelines prepared for use in evacuation (Klemencic et al, 2004). There are issues of concern regarding elevator capacities and passenger loadings arising from this paper in terms of the characteristics of those occupants who would be at risk using the stairs.

Table 4. Revised Passenger Elevator Service Capacities

Normal Capacity (Kg.)	Normal Passenger Capacity	Emergency Evacuation Passenger Capacity
1600	23* (17)	10+
1800	27* (19)	11+

*+ Based on a mass of 115Kg (Geraghty and Boone, 2003) and a standing body ellipse of 0.44m² (MacLennan, 2007) * This number is based on a mean individual passenger mass of 68 Kg whilst the figure in parentheses represents an accepted standing body ellipse currently used in pedestrian system design (Rouphail et al, 1998).*

THE INTEGRATED EVACUATION PLAN PROCESS AS INPUT FOR RISK ASSESSMENT

It is envisaged that a comprehensive systems approach that links the lift system design and traffic analysis with a inclusively based user derived evacuation and access plan (US Army Corps of Engineers, 1998) (MacLennan et al, 2007) (Groner and Levin 1992) would be used to derive the evacuation scenarios required for the proposed Monte Carlo Simulation (RiskAMP, 2006). The Focus/ Delphi Groups will formulate the scenario inputs following standard performance based design protocols set down in international fire and emergency engineering guidelines (ABCB, 2005).

CONCLUSION

Comments by NIST (2005) in the Life Safety section of their report on the WTC Evacuation (NIST, 2005) that a number of persons had to be removed from the stairs as they were slowing up the evacuation, that elevators in Tower 2 were able to quickly evacuate a significant number of people and that these arguments had been presented since 1992 (Groner and Levin. 1992) demonstrate the need for the proposed predictive stair user capability model as presented in Figure 1

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