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Accessible Emergency Egress – Literature Review and Scoping Study

AP Robbins and NR Buckett

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Preface

This is the first of a series of reports prepared during research into accessible emergency egress. This is a summary of the preliminary research intended to be used to scope industry workshops planned for a subsequent stage of this research.

Acknowledgments

This work was funded by BRANZ from the Building Research Levy.

Note

This report is intended for regulatory authorities, fire researchers, scientists, engineers and architects.

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Units

Standard International (SI) units are used throughout.

Accessible Emergency Egress – Literature Review and Scoping Study

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Reference

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Abstract

There is little quality data available surrounding the emergency building egress characteristics of the New Zealand population. What is available is not well defined, in terms of holistic metrics of the performance of the occupancy group, for use in performance-based design and assessment. Furthermore, actual emergency data is not as readily available as other data sources while less directly-related data sets (e.g. from drills or controlled laboratory experiments etc.) are already utilised.

Metric values that are currently available in the literature related to emergency egress are sourced from controlled experiments with or without elements of a fire, announced evacuation drills and fire incident case studies. Actual emergency data is most desirable and might provide the most realistic predictor of behaviour, however it is not as readily available as evacuation drill data or controlled experiments. Influences that may bias the data sets must be taken into consideration when using the values in a modelling context and the subsequent analysis of the results.

Variations in data sets have been found in studies using comparable occupant descriptions in comparable settings. Therefore the source of the data sets and the influence of the potential variability of the data sets must be taken into account for each intended application.

There is the potential to utilise a wider range of characteristic metric data sets that are already collected for our communities for a diverse range of reasons other than emergency egress. Collation of this diverse data on the characteristics of our population and its subsets into metrics may provide a clearer description of the distribution of capabilities in order to inform emergency building egress. One way to do this is to take a snapshot of related characteristics from a collage of metrics collected by others to describe the characteristics of their respective interest groups.

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Abbreviations

ABCB	Australian Building Codes Board
ACC	Applied Concepts Corporation
ADA	Americans with Disabilities Act
ANSI	American National Standards Institute
ASET	Available Safe Evacuation Time
BSI	British Standards Institute
C/AS	C/AS1 to C/AS7 Acceptable Solutions for New Zealand Building Code Clauses C1-C6 Protection from Fire (MBIE, 2013a)
C/VM2	C/VM2 Verification Method Framework for Fire Safety Design for New Zealand Building Code Clauses C1-C6 Protection from Fire (MIBE, 2013b)
CDC	(US) Centers for Disease Control and Prevention
CPA	Canadian Paraplegic Association
CPSC	(US) Consumer Product Safety Commission
DEWO	Department of the Environment and the Welsh Office
FEB	Fire Engineering Brief
FIFARS	(US) Federal Interagency Forum on Aging-Related Statistics
ICC	International Code Council
IFEG	International Fire Engineering Guidelines (Edition 2005)
ISO	International Standards Organisation
NBC	National Building Code (of Canada)
NBS	(formerly, US) National Bureau of Standards (currently NIST)
NFPA	(US) National Fire Protection Association
NIST	(US) National Institute of Standards and Technology
NSISS	(US) National Injury Surveillance System
NZBC	New Zealand Building Code
RSET	Required Safe Evacuation Time
SCIC	Spinal Cord Injury Canada (formally Canadian Paraplegic Association)
SFPE	(US) Society of Fire Protection Engineers
SIPP	(US) Survey of Income and Program Participation
SNZ	Statistics New Zealand
USCB	United States Census Bureau

1. INTRODUCTION

The focus of the research summarised here is investigating accessibility of emergency egress in the context of New Zealand buildings. This report is a summary of the results of the literature and data set review of the first stage of the overall project.

In the New Zealand Building Code Clause D1.1.c objective, accessibility of the entry to and activities within buildings is explicitly stated. However, by omission, accessibility of buildings for people with disabilities is not explicitly extended to include movement out of buildings, such as the case for emergency egress. However, an holistic interpretation of “people” in relation to movement into, within and out of a building (Objective D.1.1.a), would include all of the intended occupants for a building and therefore include the diverse range of individuals that would make up the intended building occupants.

Sectors such as our aging population and people with disabilities living in the community are expected to increase in size and higher density living is expected to increase in areas such as Auckland. This will strongly influence not only the occupancy characteristics of residential buildings but also surrounding community buildings. However, buildings intentionally targeting these sectors of the New Zealand population (e.g. residential targeting retirees, halfway/rehabilitation houses, etc.) that are not appropriately described by the characteristics of the “general cross-section of the population” or “average of the population”, are being designed for life safety based on the building occupancy being assumed to be represented by the “general population”. There is currently an insufficient description of the characteristic capabilities of the general population, let alone any particular subset of it.

In the 2006 Disability Survey (SNZ, 2007), approximately 660,000 people identified having a disability. This represents approximately 17% of the New Zealand population. These figures do not capture estimates of the numbers of people who do not identify themselves with the term “disabled”. For example, where individuals expect themselves to experience a reduction in capabilities over time, they adapt their daily routines for this. People with temporary reductions in capabilities due to injury, symptoms of illness, medication or pregnancy may not identify themselves as “disabled”. In addition, those caring for individuals with limited capability or disability, such as parents with prams or elder carers, would not define themselves as disabled despite being restricted in what they can do at times through virtue of their caregiving role and responsibilities (Baggio, 1999). Perhaps there are “two types of people: those with disabilities and those that haven’t found theirs yet” (Downey, 2013). Therefore, the portion of the New Zealand population with temporary or longer term reductions in mobility and sensory capabilities can be reasonably expected to exceed the 2006 survey estimates.

Considering the concept that “disability is an equal opportunity provider; everybody is welcome” (Downey, 2013), whereby ranges of capabilities exist in all cross-sections of our population, in combination with the above statistics, a significant proportion of the community may not precisely fit an “average” value.

Events, such as the 2001 World Trade Center attacks and subsequent collapse (Averill et al, 2005; Shields et al, 2009; Kuligowski et al, 2012), have prompted the reconsideration of evacuation strategies and engineering calculations (e.g. the Required Safe Evacuation Time [RSET]) for people with mobility impairments (NFPA, 2008a; Kuligowski et al, 2012). Data sets describing human performance are complicated to collect and difficult to interpret (Gwynne, 2010). Internationally, researchers are collecting data sets related to samples of people with various impairments that may influence emergency egress (e.g. Fruin, 1987; Boyce et al, 1999; Fujiyama and Tyler, 2004; Kuligowski et al, 2012). There is a need to collate available data and consider the applicability to the New Zealand context, and to identify where data sets are lacking or need improved description and robustness.

From a general perspective, when modelling emergency egress, a deterministic or probabilistic approach can be used.

Deterministic approaches use single values for model parameters describing the intended building occupants. For example, thresholds for tenability (NZBC Clause C4.3) or travel speeds (e.g. based on occupant density correlations, Paragraph 3.2.4, C/VM2, 2013; and Nelson and Mowrer, 2002). Model parameter values are typically chosen to represent an "average" individual of the intended building occupancy based on available data sets typically from experimental observations of young adult volunteers in various situations (e.g. Jin, 1978; Jin and Yamada, 1985).

Probabilistic approaches can incorporate model parameters with distributed values (e.g. Vistnes et al, 2005; Thomas, 2003; Fraser-Mitchell, 1998; Raboud et al, 2002), whereby for example individuals walk at various speeds on the same type of surface. However, data for communities and building occupancies is limited. The assembly of such distributions results in an inevitable collection, as a result of drawing from investigations of small samples of various targeted sectors of the international community. The metric values being collected may vary with individuals, type of group (e.g. societal and cultural influences) as well as specific building features (e.g. NFPA, 2008a; Hunt et al, 2013; Sorensen and Dederichs, 2013).

This report into the first stage of the Accessible Emergency Egress research project, summarises two aspects which start to address this problem within the New Zealand context:

- Firstly, collating available international egress data sets and considering the applicability of incorporating them to represent the range of capabilities of the New Zealand population.
- Secondly, gathering data sets from potential sources outside of emergency egress without subjecting individuals to simulated fire conditions, from such perspectives as health groups, disability groups, aging groups, universal design experts and health and disability professionals, that may be utilised to provide a snapshot of the New Zealand population that relates to corollaries or fundamental capabilities that influence an individual's ability to self-rescue in an emergency.

It is intended that the information collected from these two types of sources will be analysed and the mapping of potential fire safety solutions to the New Zealand emergency egress context will be performed to provide recommendations for optimum potential solutions and identify current voids, where more information or alternative solutions are needed.

This report is a summary of the results of the first stage of the project, collating available international building egress data sets in consideration of the New Zealand context.

1.1 Objectives

The objective of the overall research project is to:

- Provide recommendations for optimum potential solutions for emergency egress in the New Zealand context and identify current voids in data sets or understanding, where more information or alternative solutions are needed.

The objectives of this report are to:

- Provide a snapshot of the current state of New Zealand and international building egress data sets that could be used to describe the characteristics of the New Zealand population and subsets of the population, as appropriate for various intended building occupancies.
- Provide recommendations for the next stage of the research project.

1.1.1 Scope

The scope of the work is to establish a description of an intended building occupant in relation to designing and assessing a building design for emergency egress. That is not to focus entirely on one type of capability, but to form a basis for estimating the distribution of characteristics for various types of the New Zealand population – in other words, finding a better description of an "average" occupant.

In addition, emergency egress from buildings may be required for a variety of events such as fire, bomb threat, post-earthquake, etc. The details associated with each of the type of events that may require emergency egress of building occupants may vary. The primary focus of this literature review is on fire safety, as related to New Zealand regulations, since this is the dominant influence for building emergency egress design.

2. BACKGROUND

For the discussion here, the three general concepts for fire safety of occupants are:

1. For the movement of occupants to a place of safety (that may be internal or external and would be defined as during the preparation of the Fire Engineering Brief [FEB]).
2. For the movement of occupants to a fire safe refuge, where occupants then wait for rescue.
3. To encourage occupants to remain where they are, referred to as “protect in place”.

The evacuation plan (as defined in the FEB) for a building defines which of these concepts is to be used along with the parameters to describe the occupants (FEB “design occupant groups”) to be used in design and analysis.

2.1 Design occupant groups in building design and assessment

The FEB design occupant groups (ABCB, 2005) description includes the dominant occupant characteristics and parameters. A building may have more than one type of occupant group, each containing a wide range of individuals. The recommendation suggested in the *International Fire Engineering Guidelines* is to “identify the most common and influential of vulnerable occupant groups and base the analysis on these groups” (ABCB, 2005). These design occupant groups may dominate different aspects of an evacuation. The group(s) to use (or include in considerations) at different aspects of an evacuation analysis is to be identified as part of the FEB preparation.

A list of suggested dominant characters for consideration in describing a design occupant group (ABCB, 2005) in terms of both intended and foreseeable future occupancies of a building, is presented in Table 1.

Table 1 A list of suggested "design occupant group" dominant characteristics for consideration. Extracted from ABCB (2005).

Category	Parameter Description
Distribution	Number
	Gender
	Age
	Location
State	Awake or asleep
	Intoxicated or sober
	Unconscious or fully conscious
Physical attributes	Mobility
	Speed of travel
	Hearing ability
	Visual ability
Mental attributes	Level of understanding
	Potential emergency behaviour
	Ability to interpret cues
	Ability to take and implement decisions independently
Level of assistance required	Requires full assistance, requires some assistance or does not require assistance
Level of assistance available	Shift schedules
	Staff numbers and type
Emergency training	Trained or untrained
Occupant roles	Parent or child Teacher or student Nurse or patient Staff or customer
Activity at the outbreak of fire	Asleep or awake, working in a noisy environment, watching a performance
Familiarity with the building	Unfamiliar, relatively familiar or familiar

2.2 Designing and assessing evacuation

When considering estimating the movement of occupants to a place of safety, the estimate of time to evacuate the building is called the Required Safe Evacuation Time (RSET). A general overview of RSET involves the following components (ABCB, 2005):

- Cue period – the time between the start of a fire event and initiation of cues to alert the occupants.
- Response period – the time between occurrence of fire cues and the comprehension of occupants of the need for action.
- Delay period – the time between the alerting of occupants and the initiation of movement of the occupants.
- Movement period – the time between the initiation of the movement and the completion of movement to a place of safety.

The estimate of time taken for the occupancy to reach a place of safety may be based on engineering variables such as:

- Pre-evacuation delay.
- Building geometry.
- Movement speeds.
- Local population density.

These variables are then utilised in engineering models for building evacuation (Gwynne et al, 2012; Ronchi et al, 2013) to estimate the performance of egress systems, emergency planning or even reconstruction of a past event.

For assessment of a building design, the RSET is compared to the time available until the building conditions are untenable for the occupants, referred to as the Available Safe Evacuation Time (ASET). The tenability limits for occupants are set as part of the acceptance criteria for the analysis, during the preparation of the FEB.

An example of the tenability limits for occupants that might be set at the preparation stage of the FEB is:

> "*ASET* is defined as the time between ignition of the *design fire* and the time when the first tenability criterion is exceeded in a specified room within the *building*. The tenability parameters measured at a height of 2.0 m above floor level, as specified in NZBC C4.3, are:
>
> a) Visibility.
> b) $FED_{(thermal)}$.
> c) $FED_{(CO)}$.
>
> Exceptions can be applied, as outlined in NZBC C4.4 (a *building* with an automatic sprinkler system and more than 1000 people cannot be exposed to conditions exceeding the *visibility* limits or $FED_{thermal}$ limits)." C/VM2 Paragraph 3.5 (MBIE, 2013b).

2.3 Current state of egress models

A diverse range of egress models in various stages of development and validation are available, each with various advantages and disadvantages, and developed for different intended applications, etc. Kuligowski et al's (2010) review of available egress models is thorough. Of particular relevance to the focus of this report is the general types of model calculation approach that may be used in an analysis, that being deterministic versus probabilistic.

A deterministic modelling approach uses single-point values, assumed for each model parameter used in the calculation. That is, each model parameter is not expected to realistically represent the value of the range of capabilities of the intended building occupancy. Instead the value may be chosen to represent the "average" occupant. For a distribution to be considered, the value must be manually changed by the user and then the model run multiple times with varied input values.

A probabilistic approach involves the assumption of the type of model input parameter and distributions of values for each. With limited directly relevant data available, the user may have difficulty in choosing appropriate evidenced input values, in addition to the challenge of testing the validity of the model and input values for an applicable situation compared to their design building.

2.4 Current state of metrics

Data has been collected on movement speeds since at least the beginning of the 20th Century (NBS, 1935). There are wide variations in the methods of collection and the situations from which they are collected. Few data sets are directly applicable to an emergency building egress scenario and less consider limitations of capabilities.

In combination with the metrics selected, the details of the model are also a consideration. When selecting a model for use, it is important to demonstrate that the assumptions inherent in the model and the input values are, in combination, valid for the intended application. This includes understanding which data sets were used in the model development and ensuring that the identical data sets are not used in the validation of the model for the intended use. Reuse of the same data set would only verify whether the initial model assumptions had been coded accurately and for which the model would had been tailored, providing no further validation than would be documented in the specific technical guide.

Data sets have been reported for various building geometries and observations made of people in isolation or within a diverse group (e.g. Fruin, 1978; Fujiyama and Tyler, 2004; Proulx et al, 1995; Kuligowski et al, 2012) and in experimental controlled environments or during an announced evacuation drill. Actual emergency data is the most desirable and might provide the most realistic predictor of behaviour (Kuligowski et al, 2012), however it is not as readily available as evacuation drill data or laboratory results due to the infrequency and nature of such events. Such influences on the data sets must be taken into consideration when using the values in a modelling context and in subsequent analysis of the results.

Data sets for studies using similar types of occupant descriptions (e.g. using a cane, elderly with no assistance, using a stair descent device) in various situations (e.g. an announced evacuation drill or in a controlled laboratory environment) were compared. (Kuligowski et al, 2012). A graph of the different values for different groups of participant and other values published in literature for similar groups was presented. An extract of this comparison is shown in Figure 1 (Kuligowski et al, 2012). Differences between the detailed results from an evacuation drill and literature are particularly obvious for values associated with elderly participants. Therefore, the source of the data sets and the influence of the potential variability of the data sets must be taken into account for each intended application.

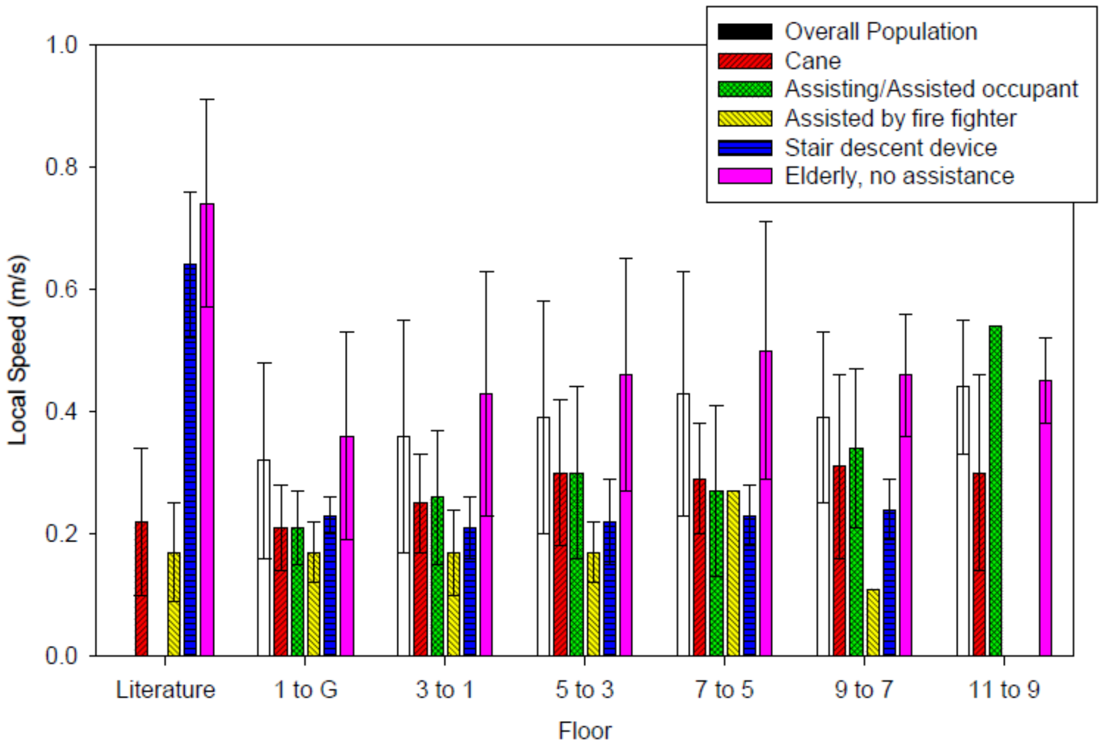

Figure 1 Comparison of results from unannounced local occupant stair descent speeds for various types of occupant descriptions to values reported in a selection of published literature. Extracted from Kuligowski et al (2012).

The following is a summary of the available literature associated with emergency egress metrics typically utilised in fire safety analyses where diverse occupant capabilities are included or considered.

2.4.1 Alerting effectiveness of alarm and notification systems

Research has indicated that alarms bells alone are generally less efficient than voice notification systems and visual display alarms (Canter et al, 1988; Technicia, 1990; Gwynne, 2007; Kuligowski and Omori, 2014).

One British and three US studies were conducted, focusing on identifying the initial means of awareness of individuals to an actual fire incident in residential occupancies (NFPA, 2008a; NFPA, 2008b). The participants of the studies were of a range of ages and abilities, and therefore provide a general indication of the methods by which individuals become initially aware of a fire event without a distribution of occupant characteristics. A summary of the results is presented in Table 2.

Table 2 Examples of initial means of awareness of a fire incident in a residential occupancy from studies conducted in Britain and the US (NFPA, 2008a; NFPA, 2008b).

Initial Means of Awareness of a Fire Incident	Percentage of Participants from Each Study			
	British Study[a]	United States of America		
		Study A[b]	Study B[c] Occupant in Fire Room	Study B[c] Occupant Not in Fire Room
Saw flame	15	7	23	6
Smelled smoke	34	35	12	9
Heard noises	9	11	15	12
Heard shouts or was told	33	35	12	35
Heard alarm	7	7	8	8
Other	2	3	31	30

Table Notes:

[a] From a study reported in Wood (1972). Total of 2193 participants.

[b] From a study reported in Bryan (1977). Total of 569 participants.

[c] From a study reported in Purser and Kuipers (2004). Total of 26 participant of occupants in the fire room. Total of 93 participant of occupants not in the fire room.

Two major influences are to be taken into account when considering these data sets. Firstly, the study participants are only those who have survived a fire incident and, secondly, the fire safety features of the building in which they were located during the incident would be a dominant influence on the results (e.g. if the evacuation plan relied on personal notification of the occupants by other occupants or the type of alarm system that was present and its effectiveness for the specific situation). Therefore, the results of these studies are only included as a general indication of the types of cues reported by individuals and may be more useful as an indication of what cues individuals either accepted or used as notification of the emergency.

“Hearing an alarm” consistently featured a low percentage of reports as being the initial means of awareness of a fire incident, whereas “being told or hearing shouts” consistently featured highly. Smelling, seeing or hearing other noises associated with a fire incident relies on the perception and recognition of the individual of possibly ambiguous cues. Therefore, the intelligent use of a human voice alarm might be designed as a combination of these two means of alerting, informing and directing the occupants of a building (SFPE, 2008). The message would need to be tailored to the intended occupants and the specific building.

For an alarm to be as effective as possible, it was suggested that the sound intensity at the pillow should have the highest chance of arousing the most at risk of fire deaths, which include the young and the elderly. 90 dBA was suggested for smoke alarms installed in bedrooms (CPSC, 2004). The signal level, of which the amplitude is only one measure, and the type of sound or signal have been reported to affect the probability of awakening a sleeping subject (Bruck and Thomas, 2009; Thomas and Bruck, 2010) or detection by individuals who were hard-of-hearing (Bruck and Thomas, 2007) or alcohol-impaired (Bruck et al, 2007). Awakening is discussed in more detail in the following section.

If individual assessment of residences are performed, an additional consideration is whether or not individuals are wearing hearing aids at the time of the assessment. Furthermore, whether there is a difference in response to the alarm when the individual is wearing or not wearing (e.g. turned off or taken out) the aid. Therefore multiple signal types might be useful to notify the resident without being debilitating or ignorable.

Considering emergency voice notification systems, Gwynne (2007) listed the aging population as being vulnerable for having difficulties perceiving, paying attention to and/or comprehending a fire notification warning. Other functional conditions that may also make an intended occupancy vulnerable included (Gwynne, 2007):

- Sensory disability of individuals (such as hearing impairments or loss and vision impairments or loss).
- Cognitive disabilities of individuals (including thinking and learning disabilities).
- Children.
- Large groups.
- Isolated people.
- Sleeping people.
- Intoxicated, medicated or sleep-deprived people.
- Non-native speakers.
- Untrained or unprimed people.
- People who are committed to an activity before the warning begins.

This list may additionally apply to the aging people group, further complicating the functionality of individuals. Therefore care must be paid to the content, style and frequency of the message (Mileti and Sorensen, 1990) intended to inform the building occupants of the situation and provide instructions. In addition, other evacuation systems and procedures should also account for such functional limitations of the intended building occupants.

Furthermore, stress and anxiety experienced as a reaction to an emergency situation has been shown to reduce an individual's capacity to pay attention and process information (Kesselman et al, 2005; Chandler, 2010). On the other hand, individuals in a familiar environment may overlook new information and messages, responding to the situation based on previously learned habits and conditioning (Chandler, 2010). There have also been accounts of elderly people responding to an alarm sounding with panicked dispersion and having to be located individually (Fahy et al, 2009). Therefore a diverse range of behaviour may be expected in response to an alarm.

Studies of the ability to hear smoke detector noise levels (Berry, 1978; NFPA, 2008a) indicate that a level exceeding 100 dB may be required when individuals have hearing impairments or are affected by sleeping pills or other medication.

Another consideration is that an alarm may be attenuated by the surroundings. A reduction of up to 40 dB can be expected when sound passes through a ceiling or wall and a reduction of up to 15 dB can be expected when sound passes through a door. An alarm may also be masked by other noises, such as an air conditioning unit, which is typically of the order of 55 dB (Nober et al, 1982; NFPA, 2008a). If such considerations were to be taken into account in excess of the minimum suggestion of 100 dB for hearing-impaired or medicated individuals, then it would be worth considering what the threshold is whereby the noise level becomes debilitating or counterproductive for escape of the individual, as this would not be the beneficial.

It has been suggested that effective fire signals in occupancies with hearing-impaired persons include flashing or activated lights (Cohen, 1982; NFPA, 2008a). Bruck and Thomas (2007) investigated the awakening effectiveness of visual signals on hard-of-hearing participants and performed a similar study (Bruck et al, 2007) investigating alcohol-impaired participants.

The effectiveness of visual alarm systems have also been investigated. DeVoss (1991) reported on a series of experiments to identify minimum effective intensities for reliable (> 90%) detection by awake and sleeping individuals, including hearing-impaired. A minimum effective intensity of 15 cd (Candela) was associated with reliable detection of awake individuals and 100 cd seemed to provide reliable waking of sleeping individuals. These findings were similar for direct viewing of the system by awake individuals (Schifiliti, 2006). However, approximately only one-third of participants detected the signal when viewed indirectly.

Research performed for the US Architectural and Transportation Barriers Compliance Board (Applied Concepts Corporation, 1988) recommended a minimum of 75 cd in units of light energy.

The 1994 edition of the Americans with Disabilities Act (ADA, 1994) Standards for Accessible Design, requires a minimum intensity of 75 cd as measured on the axis of direct line of sight.

2.4.1.1 Awakening

Sleeping has a strong influence on the likelihood of the occurrence of fire casualties and fatalities (Hasofer and Thomas, 2006), therefore the methods for awakening and alerting occupants is of high concern in design, particularly of sleeping spaces (such as residential or accommodation buildings).

Studies investigating the auditory arousal thresholds of sleeping individuals (Ball and Bruck, 2004; NFPA, 2008a; Bruck, 2001) reported more frequent awakenings in response to lower stimulus intensity as age of the individual increased. It was also reported that individual differences accounted for more variability of the recorded thresholds than sleep stage or age. Therefore, although age of the intended occupants may be a consideration, other attributes of the individuals may be more important in determining the most effective alarm for awakening intended occupants.

For older adults without hearing impairments, it was reported by Bruck and Thomas (2008) that the most effective signal for waking sleeping experiment participants was a mixed frequency T-3 signal (500 to 2500 Hz). Furthermore, the median auditory arousal threshold for the mixed frequency signal was 20 dB lower than the mean required when the high pitched T-3 signal was used.

A study by Bruck and Thomas (2007) involving hearing-impaired (but not deaf) individuals, reported that visual signals exceeding NFPA 72 (2010) were found to awaken just over a quarter of the study participants. It was stated that although these results indicated that visual signalling may be of little value for hard-of-hearing occupants, this may not be the case for totally-deaf individuals. A review of literature on visual function of deaf individuals by Bavelier et al (2006) summarised that generally, there was little difference between the response of deaf and visual-functioning individuals, except for peripheral visual measures, including stimulus onset and motion processing.

Similarly a study on alcohol-impaired individuals by Bruck et al (2007) also indicated that visual signals exceeding NFPA 72 (2010) were found to awaken just over a quarter of the study participants.

2.4.1.2 Ambiguous incident cues

Ambiguous cues to alert an individual of a fire incident, such as mixed or partial messages or a history of false alarms, will extend the time until the occupant recognises the situation due to either sensory or comprehension limitations. This leads to a delayed evacuation. Lessening the time available for escape may increase stress on the individual, leading to non-adaptive flight behaviours and inhibition of assistance behaviour (NFPA, 2008a).

2.4.2 Pre-movement delay

The pre-movement delay, or pre-evacuation, time is the time between the alarm being raised (by an automatic building system or manual notification by another building occupant) to the initiation of escape behaviour by the occupant. The methods of communicating the need for evacuation behaviour has been shown to be influential on the pre-movement time (Canter et al, 1988; Technicia, 1990; Proulx et al, 1994; Gwynne, 2007; NFPA, 2008a; NFPA, 2008b).

Pre-movement data sets are scarce (Fahy and Proulx, 2001; Gwynne, 2007). Investigations including mixed-ability occupants is rarer (Proulx et al, 1994; Gwynne et al, 2003).

In general, distributions of pre-movement time have been estimated as uni-modal and positively-skewed. Therefore a normal, log-normal or Weibull distribution may be more appropriate (Gwynne et al, 2001).

PD 7975-6 (BSI, 2004) provides guidance on ranges of pre-movement times. However, the document notes that the suggested values (of Table C.1 of PD 7975-6) are based on limited available data and recommends improvement of the database. It is also noted that the suggested distribution values (from the 1st to the 99th percentile of a log-normal distribution) "depend upon the presence of sufficient staff to assist evacuation of handicapped occupants". The dependence or influence on the value is not quantified.

Some investigations have included occupants with mixed abilities. For example, Proulx et al (1994) reported results from evacuation drills at an apartment complex. Another example was reported by Gwynne et al (2003) for pre-evacuation times for an unannounced evacuation drill of an outpatient facility (comprising of mostly fully-ambulant patients and staff) for a pathology and physiotherapy department. The small number of evacuees (14 staff and 19 patients) provided statistically insignificant results, however the data is available for general comparison with other data sets. Mean and standard deviations (for assumed normal distributions) were reported for the different areas and different types of occupant (i.e. patient versus staff). There was insufficient data to test the assumption of normality of the distribution (e.g. using a Kruskal-Wallis test or testing for skewness). In this particular case, patient movement was observed only after prompting by staff for each of the areas included in the drill. This highlights the importance of staff training and their influence on patient behaviour. For these particular cases, a minor statistically-insignificant increase in pre-movement time of approximately 4% was reported for the outpatient facility mean pre-movement delay time compared to another study performed by Gwynne et al (2003) in a student-populated library.

2.4.3 Wayfinding

Wayfinding is the process used by an occupant in decision making for direction of movement (Weisman, 1981), in this context it is during emergency egress. Wayfinding for occupants in an unfamiliar situation relies on environmental cues to decide which direction to move toward (Nilsson et al, 2008; Fridolf et al, 2014). Components of the cues used by an occupant for wayfinding during emergency egress may include layout of the building, signage, etc.

2.4.3.1 Signage

Visibility of signage is one contributing element to wayfinding during emergency egress. Collins et al (1990, 1992) reported participant-documented levels of visibility of various types of signage in clear and smoky conditions. Boyce et al (1999c) reported the distance at which a sign (either non-illuminated, illuminated or LED) could be read by people with and without a sight disability.

Another consideration during wayfinding is the identification of the directions or comprehension of the signage (Ronchi et al, 2012) or other directional egress cues identified by individuals (Nilsson et al, 2008; Fridolf et al, 2014), for example flashing lights over one exit (Nilsson, 2009), etc.

2.4.4 Movement through a building

Movement of occupants through a building is generally in horizontal (e.g. across a floor) or vertical (e.g. up or down stairs) directions. The following is a summary of selected metrics where potentially useful data has been collected in the context of building access and possible emergency building evacuation for occupants with a range of capabilities and limitations.

2.4.4.1 Horizontal movement

Movement of disabled male and female volunteers through a corridor with a 90° bend was reported by Boyce et al (1999d), as summarised in Table 3. The participants ranged between the ages of 20 and 85, and the tests were conducted in normal/non-evacuation conditions (Boyce et al, 1999a).

Table 3 Summary of speed on a horizontal surface for different types of mobility capabilities (Boyce et al, 1999a).

Group Description (No. Participants)	Mean Speed (m/s)	Range (m/s)	Inter-Quartile Range (m/s)
All disabled (107)	1.00	0.10-1.77	0.71-1.28
All with mobility disability (101)	0.80	0.10-1.68	0.57-1.02
Unaided (52)	0.95	0.24-1.68	0.70-1.02
Crutches (6)	0.94	0.63-1.35	0.67-1.24
Walking stick (33)	0.81	0.26-1.60	0.49-1.08
Walking frame or rollator (10)	0.57	0.10-1.02	0.34-0.83
Without mobility disability (6)	1.25	0.82-1.77	1.05-1.34

Another investigation reported the walking speeds of various types of building users at shopping centres in non-emergency/non-evacuation conditions (Hokugo et al, 2001). A summary of the collated results is included in Table 4.

Table 4 Summary of average walking speeds of users at two shopping centres (Hokugo et al, 2001).

Group Description (No. Participants)	Mean Speed (Standard Deviation, m/s)
Adult with difficulty walking	
Older adult walking very slowly (21)	0.83 (0.20)
Adult with walking disability (8)	0.78 (0.19)
Pregnant woman (4)	0.79 (0.12)
Older adult (155)	0.93 (0.41)
Older adult walking with another person (49)	0.88 (0.23)
Older adult walking alone (103)	0.96 (0.22)
Able-bodied adult	
Walking with another person (314)	0.93 (0.25)
Walking alone (446)	1.14 (0.27)

Similarly, ranges of walking speeds for different types of disabilities are summarised in Table 4.2.3 of the Fire Protection Handbook (NFPA, 2008a). However, the values for these metrics are not as simple as means with ranges or sample standard deviations, as these vary with the individual as well as specific building features and local conditions, e.g. Figures 4.2.6 and 4.2.7 of NFPA (2008a). Therefore care must be used when applying the values to the metrics for a specific application.

Another consideration is that some egress models include different parameter values for different segments of the population. For example, Simulex (Thompson and Marchant, 1995; Thompson et al, 2003) and MASSEgress (Pan Z et al, 2006) have population types to represent an adult male, adult female, child and elderly person. The estimated parameter values are based on other-than-building evacuation sources, such as controlled experiments in laboratory conditions and normal (non-emergency) conditions in mass transit stations, etc.

For example, unimpeded travel speeds based on subway station egress results (Ando et al, 1988; Kady, Gwynne and Davis, 2009) used within Simulex were estimated for:

- A generic person to be 0.8 to 1.7 m/s.
- An adult male to be 1.35 ± 0.2 m/s.
- An adult female to be 1.15 ± 0.2 m/s.
- A child to be 0.8 ± 0.3 m/s.
- An older person to be 0.9 ± 0.3 m/s.

Similarly, based on pedestrian results (Eubanks and Hill, 1998), the average travel speeds used within MASSEgress were estimated for:

- A generic person to be 1.30 m/s, with a maximum when running on the flat in the open of 4.10 m/s.
- An adult male to be 1.35 m/s, with a maximum of 4.10 m/s for running on the flat in the open.
- An adult female to be 1.15 m/s, with a maximum of 4.10 m/s for running on the flat in the open.
- A child to be 0.90 m/s, with a maximum of 3.40 m/s for running on the flat in the open.
- An older person to be 0.80 m/s, with a maximum of 2.75 m/s for running on the flat in the open.

2.4.5 Movement through doorways, dexterity and strength

Evacuation movement data, such as speeds and flows through doors, have been collected during various studies focused on able-bodied occupants (Predtechenskii and Milinskii, 1978; Pauls, 1995; Lord et al, 2005; Gwynne and Rosenbaum, 2008).

Boyce et al (1999b) reported participants' ability and time taken to negotiate a door (single leaf with 750 mm clear width), by either pushing or pulling the door open. A range of closing forces for the combinations of disability and aid combinations were also included in the investigation.

Table 5 Percentages of the total mobile adult population of Northern Ireland who have degrees of difficulty with a range of activities (Boyce et al, 1999d).

Action	Degree of Difficulty			Total Percentage of Mobile Adult Population
	Some	Great	Impossible	
Cross door saddles	0.3	0.1	0.04	0.5
Go through doors	0.2	0.03	0.02	0.3
Turn door knobs	0.4	0.1	0.1	0.6

2.4.5.1 Movement on stairs

Movement of people on stairs has been studied for able-bodied participants and a select range of types of disabilities and range of capabilities, for a small number of volunteers.

Boyce et al (1999d) reported percentages for a range of potential emergency egress-related activities such as movement up and down stairs, as summarised in Table 6. However, these values do not include the wider range of the population who experience temporary or long-term limitations that are not typically classified as disabilities.

Table 6 Percentages of the total mobile adult population of Northern Ireland who have degrees of difficulty with a range of activities (Boyce et al, 1999d).

Action	Degree of Difficulty			Total Percentage of Mobile Adult Population
	Some	Great	Impossible	
Go up and down stairs	2.6	1.7	0.4	4.7
Climb outside steps	1.8	1.1	0.4	3.3

Results for walking down a stairway, as reported by Boyce et al (1999a), are summarised in Table 7. The results are included here for consideration of the ranges of average speed for each type of disability and aid combination and type of test.

Table 7 Summary of speed downwards on stairs for different types of mobility capabilities (Boyce et al, 1999a).

Group Description (No. Participants)	Mean Speed (m/s)	Range (m/s)	Inter-Quartile Range (m/s)
All with mobility disability (30)	0.33	0.11-0.70	0.22-0.45
Unaided (19)	0.36	0.13-0.70	0.20-0.47
Crutches (1)	0.22	-	-
Walking stick (9)	0.32	0.11-0.49	0.24-0.46
Rollator (1)	0.16	-	-
Without mobility disability (8)	0.70	0.45-1.10	0.53-0.90

Kuligowski et al (2012) presented movement speed data sets based on observations made during an announced evacuation drill conducted in 2009 at an assisted living facility for elderly and disabled residents. The building had 13 storeys and was located on the East Coast of the US. Overall (the average during egress) and local (between each camera location during egress) values for travel speed were reported. Evacuees were described in the collection of the data, so analysis results could be reported for groups with similar disability types. The data set was made publicly available at http://www.nist.gov/el/fire_research/egress.cfm (NIST, 2013).

The assisted-living facility occupancy was observed to evacuate using a range of methods including (Kuligowski et al, 2012):

- Self-evacuation without assistance.
- Self-evacuation using a cane as a mobility aid.
- Assistance from another occupant or a fire fighter.
- Assistance using an evacuation chair.

A summary of the reported movement speeds on stairs for this range of studies is presented in Table 8.

Table 8 Summary of reported movement speeds (along the pitch of the stair) on stairs from selected literature.

Reported Movement Speed on Stairsℓ (m/s)	Building Geometry Description	Occupant Description	Observation Conditions	Ref.
0.67†	0.18 x 0.29 m stair₮	Male, ≥ 50 years	Normal/non-evacuation, isolated individuals, number of stairs and flights not reported	Ref.1
0.56†		Female, ≥ 50 years		
0.67†	0.15 x 0.30 m stair₮	Male, ≥ 50 years		
0.63†		Female, ≥ 50 years		
0.88†	Building A, 14-storey, during warm weather	3 mobility-impaired evacuees	Residential evacuation drills, Canada	Ref.2
0.61†	Building B, 14-storey, during warm weather (DEOW 1992)	8 mobility-impaired evacuees		
0.57†		3 evacuees ≥ 65 years		
0.57†	Building C, 12-storey, during cold weather	21 mobility-impaired evacuees		
0.58†		18 evacuees ≥ 65 years		
Could not use the stairs	Number and geometry of stairs not reported, stairs compliant with Document M (DEOW 1992)	Of 103 volunteers, only 34 could use the stairs	Disabled volunteers, normal/non-evacuation experiment conditions, UK	Ref.3
0.36 ± 0.14* 0.13 to 0.70§		Disability, no movement aid		
0.22 ± 0.12* 0.11 to 0.49§		Disability, with use of a cane		
0.13† 0.11 to 0.23§		4 participants ≥ 70 years, with assistance		
0.60 ± 0.12*	1 flight, 0.19 x 0.23 m stair₮	12 females, 6 males, 60 to 81 years	Normal/ non-evacuation experiment conditions	Ref.4
0.70 ± 0.12*	1 flight, 0.18 x 0.25 m stair₮			
0.74 ± 0.13*	1 flight, 0.16 x 0.27 m stair₮			
0.88 ± 0.17*	1 flight, 0.15 x 0.33 m stair₮			
0.80 ± 0.17*	1 flight, 0.19 x 0.23 m stair₮	12 females, 6 males, 60 to 81 years	Subjects were requested to travel faster by observers, normal/non-evacuation experiment conditions, Japan	
0.85 ± 0.18*	1 flight, 0.18 x 0.25 m stair₮			
0.97 ± 0.18*	1 flight, 0.16 x 0.27 m stair₮			
1.11 ± 0.26*	1 flight, 0.15 x 0.33 m stair₮			
0.81†	11-storey hospital	Evacuee plus chair‡ only 1 handler required to operate, with a second in front of the evacuee	32 evacuation trials, 4 trained staff (2 male and 2 female) available, 1 disabled person normal/non-evacuation experiment conditions, UK	Ref.5
0.57†		Carry chair‡		
0.55†		Stretcher‡		
0.62†		Drag mattress‡		

Table 8 (continued) Summary of reported movement speeds (along the pitch of the stair) on stairs from selected literature.

Reported Movement Speed on Stairs[ℓ] (m/s)	Building Geometry Description	Occupant Description	Observation Conditions	Ref.
0.35 ± 0.17* 0.11 to 0.91§	0.15 x 0.32 m stair[Ŧ], stair width (including handrails) 1.37 m, exit width 0.90 m, 9-step flights and 3 flights per storey, 13-storey residential-assisted living facility	119 occupants	Residential-assisted living facility, announced evacuation drill, US (East Coast)	Ref.6
0.23 ± 0.08* 0.11 to 0.33§		14 occupants using a cane		
0.25 ± 0.13* 0.13 to 0.21§		4 occupants assisted by another evacuee		
0.25 ± 0.13* 0.13 to 0.21§		3 occupants assisted by a fire fighter		
0.25 ± 0.13* 0.13 to 0.21§		83 elderly occupants		

Table 8 Notes:

ℓ Movement speed on stair is the speed along the pitch of the stair and was converted where needed from reported values to be consistent.
Ŧ Stair geometry is reported as rise x tread depth.
† Mean value, assuming a normal distribution.
* Standard deviation, assuming a normal distribution.
§ Minimum to maximum value.
‡ Commercially-available evacuation devices.
Ref.1 Fruin (1978), Kuligowski et al (2012).
Ref.2 Proulx et al (1995).
Ref.3 Boyce et al (1999).
Ref.4 Fujiyama and Tyler (2004).
Ref.5 Adams and Galea (2011).
Ref.6 Kuligowski et al (2012).

2.4.5.1.1 Upward movement on stairs

Results for walking up a stairway, as reported by Boyce et al (1999a), are summarised in Table 9. The results are included here for consideration of the ranges of average speed for each type of disability, aid combination and type of test.

Table 9 Summary of speed upwards on stairs for different types of mobility capabilities (Boyce et al, 1999a).

Group Description (No. Participants)	Mean Speed (m/s)	Range (m/s)	Inter-Quartile Range (m/s)
All with mobility disability (30)	0.38	0.13-0.62	0.26-0.52
Unaided (19)	0.43	0.14-0.62	0.35-0.55
Crutches (1)	0.22	-	-
Walking stick (9)	0.35	0.18-0.49	0.26-0.45
Rollator (1)	0.14	-	-
Without mobility disability (8)	0.70	0.55-0.82	0.55-0.78

Instead of involving elderly people in stressful situations of evacuations or drills, one example of a method for estimating the response of elderly occupants in emergency evacuation simulations is the use of “temporary elderly” evacuees (Furukawa et al, 2007; Okada et al, 2009; Okada et al, 2012).

These temporary elderly were created using equipment to be worn by younger people to simulate elderly people by reducing their sight (using goggles), hearing (using earplugs), touch (using a glove) and mobility (using joint restricting bands, wrist and ankle weights and a walking stick). The reproducibility of the equipment to be used to simulate the evacuation capability of elderly people (with an intended simulation target of people approximately 75 to 80 years old) has been verified (Furukawa et al, 2007), but the fatigue of the equipment wearer compared to an actual elderly evacuee was not expected to be representative as it had not been compared at the time of the analysis (Furukawa et al, 2007; Okada et al, 2009).

Average upward walking velocities for a group of university students (with average age of 21 years), where 12 wore the equipment for the temporary elderly and 38 did not, were reported for scenarios including (Furukawa et al, 2007; Okada et al, 2009):

- A flight of stairs
    - With a rise of 0.15 m, tread of 0.3 m, width of steps 2.5 m, width between handrails 2.538 m, horizontal length of steps 14.5 m with a 1.8 m landing midway, vertical height of 5.7 m.
- A short escalator
    - With a rise of 0.2 m, tread of 0.4 m, width of steps 0.99 m, width between handrails 1.19 m, horizontal length of 12.276 m, vertical height of 5.7 m.
- A long escalator
    - With a rise of 0.2 m, tread of 0.4 m, width of steps 1.015 m, width between handrails of 1.2 m, horizontal length of 49.5 m, vertical height of 22.0 m.

The escalators were considered both running (at 0.5 m/s) and still. The simulated evacuees were considered in four configurations: walking solo, a square configuration of seven parallel lines with the temporary elderly arranged randomly, a pair of two parallel lines with the temporary elderly arranged randomly (as shown in Figure 2) and a pair of two parallel lines with the temporary elderly only located in the right-hand line (as shown in Figure 3), (Okada et al, 2009).

A summary of average measurements from the range of experiments is included in Table 10. Distributions of the average upward walking speeds of each of the participants of the still stair escalator with two parallel lines of randomly-located, unimpeded students and temporary elderly are shown in Figure 2. Distributions for the unimpeded students and the temporary elderly for the configuration with all of the temporary elderly located in the right-hand side of the two parallel lines of test evacuees are shown in Figure 3 (Okada et al, 2009).

This set of simulated evacuation results using temporary elderly to estimate the impact of limited sensory and mobility function on individuals showed both a lower average walking speed and a narrower range of the observed distributions of average walking speed for the individuals within the group. Although this sample is a small size and the impact of endurance/fatigue was not incorporated in the simulated temporary elderly approach described here, there is still a marked difference between the unimpeded students and those with the simulated limits in aspects of functionality during the evacuation tests.

Distributions were also published for the still short escalator as approached by a group of participants. The entrance to the escalator was approached in the square formation shown in the top-right of Figure 4. The location of the test participants wearing the temporary elderly equipment in the group was chosen without a conscious pattern (Okada et al, 2009).

Table 10 Summary of simulated evacuation experiment results including “temporary elderly” (Okada et al, 2009).

		Simulated Evacuee Configuration							
		Solo		Square Configuration		2 Parallel Lines with Random “Temporary Elderly”[a]		2 Parallel Lines with “Temporary Elderly” on the Right[b]	
Type of Evacuee		Student	“Temp. Elderly”	Student	“Temp. Elderly”	Student	“Temp. Elderly”	Student	“Temp. Elderly”
Simulated Escape Route Description	Stairs	0.75	0.51	0.68	0.54	-	-	-	-
	Short Escalator Running	1.21	0.93	0.95	0.90	-	-	-	-
	Short Escalator Still	0.78	0.53	0.54	0.48	0.55	0.51	0.68	0.50
	Long Escalator Running	1.26	0.93	1.01	0.93	-	-	-	-
	Long Escalator Still	0.79	0.50	0.54	0.47	-	-	-	-

Table 10 Notes:
[a] The evacuee configuration is as shown in the schematic included in Figure 2.
[b] The evacuee configuration is as shown in the schematic included in Figure 3.

The distribution of the average walking speed of the 12 temporary elderly participants ranged from 0.38 to 0.60 m/s. The average walking speed for the 38 students without additional equipment ranged from 0.41 to 0.79 m/s. These ranges of average walking speed include people who were restricted because they did not overtake slower moving people, who were walking abreast (Okada et al, 2009).

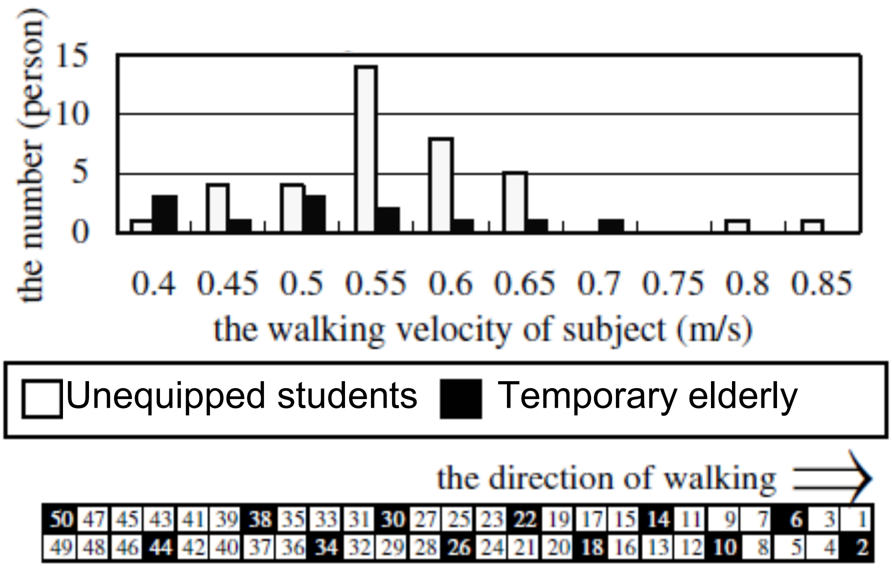

Figure 2 Distribution of average upward walking speeds of the unequipped students and “temporary elderly” for third configuration of people. Extracted from Okada et al (2009).

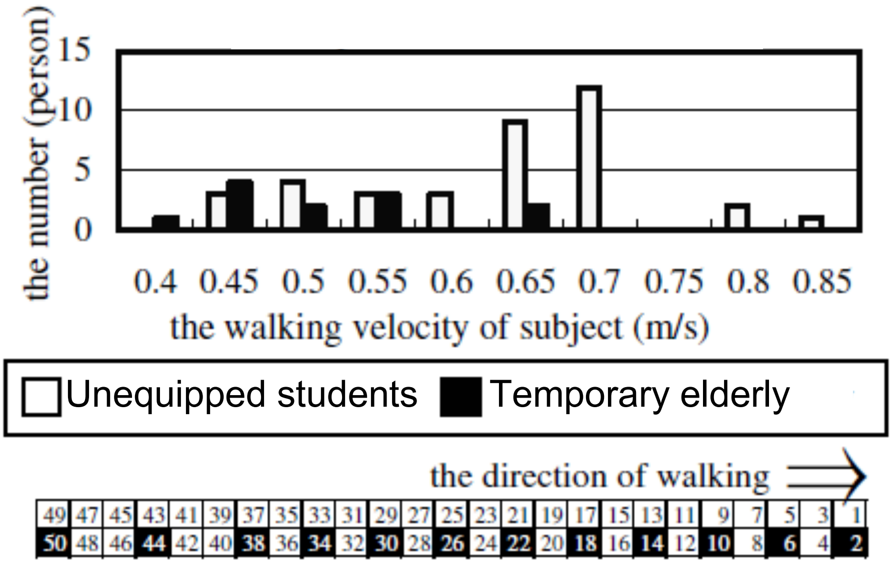

Figure 3 Distribution of average upward walking speeds of the unequipped students and "temporary elderly" for fourth configuration of people. Extracted from Okada et al (2009).

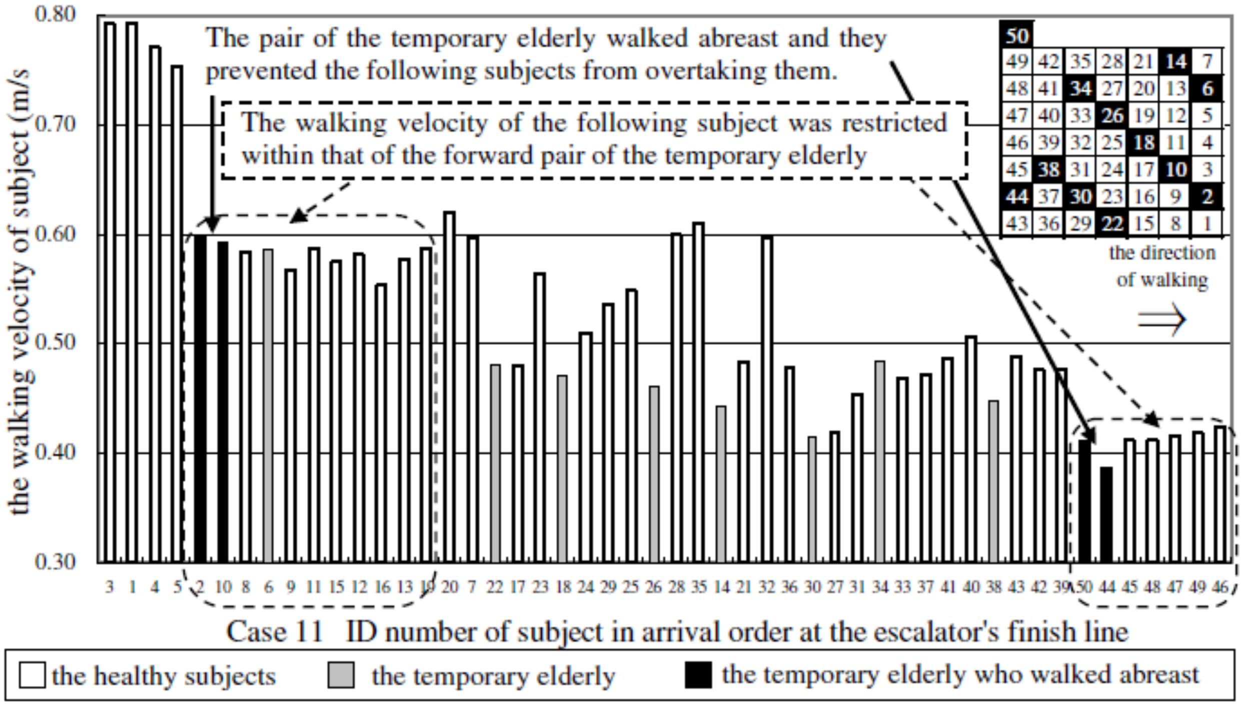

Figure 4 The walking velocity of 50 individual test participants in the order of those who reached the top of the static short stair escalator first. Extracted from Okada et al (2009).

2.4.6 Effect of fire conditions on movement

Visibility and walking speeds may be affected by the presence of smoke in various concentrations and species (whether irritant or asphyxiant). Experiments have utilised able-bodied volunteers in controlled smoke conditions with self-assessment (Jin, 1997; Bryan, 2002; Fridolf et al, 2013). Data sets are scarce.

2.4.7 Maximum flow rates and flow capacities

The maximum flow rates and flow capacities of exitways are affected by the types of occupants in terms of movement speeds as well as how much space an individual may need, e.g. depending on walking aids, etc.

2.4.7.1 Boundary layer widths

When travelling an individual may keep a certain distance between themselves and various building features. This personal distance is termed a boundary layer and it effectively reduces the functional width of a corridor, doorway or stair (BSI, 2004).

General building accessibility guidance provides minimum total clear widths for access (e.g. for wheelchair access of spaces), but not in terms of boundary layers for occupant flow calculations within a building as it is utilised in emergency egress analysis.

2.4.8 Assistance behaviour

Assistance behaviour is the altruistic response of able-bodied occupants to help facilitate the escape of other occupants that are not as able-bodied (Proulx and Pineau, 1996).

Assistance behaviour has been reported in post-emergency case studies (NFPA, 2008b), where disabled occupants have successfully escaped with the assistance of other occupants that they may or may not have been acquainted.

It has been questioned as to how to appropriately handle modelling of emergency egress with altruistic assistance behaviour (Pan et al, 2006).

There is insufficient data available to assess the reliability of assistance behaviour in the successful escape of individuals with ranges of capabilities. In order to assess the extent of assistance behaviour during an emergency evacuation and whether persons with disabilities have escaped predominantly because of altruistic actions of others, it would be useful to compare data sets for:

- Successful escape of occupants with disabilities with assistance of other occupants.
- Successful escape of occupants with disabilities without assistance of other occupants.
- Occupants with disabilities who did not successfully escape, although they did have other occupant(s) assisting them.
- Occupants with disabilities who did not successfully escape and did not have assistance of other occupants (e.g. Thomas et al, 2009).

It would also be useful, in terms of improving design for evacuation, to compile the reasons or situations where occupants with disabilities could not self-rescue.

In addition, as it has been previously suggested, shortening of available time for escape may lead to non-adaptive flight behaviours and inhibition of assistance behaviour (NFPA, 2008b).

Therefore it is unreasonable to rely on the ideal, altruistic assistance behaviour of an occupancy as part of an evacuation scheme or plan. Where the intended occupancy of a building includes a range of capabilities of individuals, then it is necessary to design for the self-evacuation of the full range of the intended occupancy.

2.4.9 Occupant tenability criteria

The calculated accumulated fractional effective doses (whether for accumulative thermal or asphyxiant gas exposure) are compared to predetermined total fractional effective dose criteria, representative of an “acceptable” level of incapacitation.

A radiant heat flux threshold, resulting in severe pain to unprotected skin, of 2.5 kW/m² (based on work by Purser, 2002) for 30 seconds is suggested in PD7975-6 (BSI, 2004). It is estimated that exposure to 2.5 kW/m² of radiative heat flux can be tolerated for several minutes (BSI, 2004).

Convective heat flux thresholds are related to the air temperatures in combination with a relative humidity for a duration considered to cause pain and burns (Purser, 2002), such as 100°C at < 10% volume H_2O per total volume for eight minutes (BSI, 2004).

For the average of the populations considered for various thermal exposures, it has been noted that exposure of 30% of the skin surface to a thermal dose of 2000 $(kW/m^2)^{4/3}s$ would be sufficient to have resulted in fatalities of approximately 50% and approximately 420 to 960 $(kW/m^2)^{4/3}s$ would be sufficient to have resulted in fatalities of approximately 1% (Purser, 2002; Hockey and Rew, 1996). Whereas, thermal doses of 420 to 500 $(kW/m^2)^{1.33}s$ would be sufficient to have resulted in fatalities of approximately 1% of vulnerable populations, where the vulnerable population was considered to be those 65 years and older (Hockey and Rew, 1996).

It is noted in PD7975-6 (BSI, 2004) that for low FED values, that may mean individuals would experience a reduction in exercise capability. For “occupants with heart conditions, there could be a serious problem, such as angina pain at low levels of activity”. It is expected that a population will have a range of sensitivities to asphyxiants. Based on the work by Purser (2002), a suggested estimate of 90% of the population would experience minimal reduction in exercise capability up to 0.3 FED, with a reduction to an estimate of 0.1 FED for vulnerable sub-populations – e.g. health care or residential care facilities (BSI, 2004).

3. STANDARDS, REGULATIONS AND GUIDELINES

This section focuses on New Zealand regulations and potential international sources that may assist in the New Zealand context.

3.1 New Zealand building regulations

Requirements relating to the capabilities of building occupants in the New Zealand Building Code (Tizard, 1992), Protection from Fire Clauses, are in Clause C4 Movement to a Place of Safety, with a functional requirement of:

> **"C4.2** *Buildings* must be provided with means of escape to ensure that there is a low probability of occupants of those buildings being unreasonably delayed or impeded from moving to a *place of safety* and that those occupants will not suffer injury or illness as a result." (Tizard, 1992)

And associated performance requirements of:

> "**C4.3** The *evacuation time* must allow occupants of a building to move to a *place of safety* in the event of a fire so that occupants are not exposed to any of the following:
> (a) A *fractional effective dose* of carbon monoxide greater than 0.3.
> (b) A *fractional effective dose* of thermal effects greater than 0.3.
> (c) Conditions where, due to smoke obscuration, visibility is less than 10 m except in rooms of less than 100 m² where visibility may fall to 5 m.
> **C4.4** Clause C4.3(b) and (c) do not apply where it is not possible to expose more than 1,000 occupants in a *firecell* protected with an automatic *fire* sprinkler system.
> **C4.5** Means of escape to a *place of safety* in *buildings* must be designed and constructed with regard to the likelihood and consequence of failure of any *fire safety systems.*" (Tizard, 1992)

Considering requirement for accessibility of buildings in accordance with the New Zealand Building Code (Tizard, 1992), Access Clauses, Clause D1 Access Routes has the stated objective to:

> "**D1.1** The objective of this provision is:
> (a) Safeguard people from injury during movement into, within and out of *building*s.
> (b) Safeguard people from injury resulting from the movement of vehicles into, within and out of *building*s.
> (c) Ensure that *people with disabilities* are able to enter and carry out normal activities and functions within *building*s." (Tizard, 1992)

Therefore by omission, accessibility into buildings for people with disabilities is not explicitly extended to include movement back out of buildings, as in the case for emergency egress. However, an holistic interpretation of people would include all of the intended occupants for a building over its predicted lifetime and therefore include the diverse range of individuals that would make up the intended building occupants.

Occupant characteristics are implicitly included in the prescriptive requirements of the NZBC Acceptable Solutions for Protection from Fire (MBIE, 2013a).

Parameter values are prescribed for occupant characteristics in Part 3, Movement of People, of the C/VM2 Verification Method Framework for Fire Safety Design (C/VM2), (MBIE, 2013b) including:

- Notification time with automatic (Paragraph and 3.4, C/VM2) and manual warning systems (Paragraph 3.4, C/VM2).
- Pre-travel activity times depending on the state, familiarity, presence of trained staff and type of activity (Table, VM2).

- Travel speeds based on occupant density (Paragraph 3.2.4 and Table 3.4, C/VM2) using the correlation developed by Nelson and Mowrer (2002), with
    - Limits for maximum horizontal (1.2 m/s) and vertical (0.85 to 1.05 m/s, dependent on stair riser and tread dimensions of Table 3.4, C/VM2) travel speeds.
- Flow through choke points based on occupant density and effective choke width, where boundary layer widths for various situations is specified (Paragraph 3.2.5 and Table 3.5, C/VM2).
- Direction of opening of doors (Paragraph 3.2.6, C/VM2).

In addition, C/VM2 also has the requirement for exit doors that:

> "Where a primary entrance can be identified, the primary entrance shall be designed to egress 50% of the total occupant load of the space and the remaining occupants are evenly distributed in proportion to the number of exits. Where there is no primary entrance, the occupant load shall be distributed to the available exits with no more than 50% to one exit." (Paragraph 3.2.7, C/VM2), (MBIE, 2013b)

Therefore, if the primary entrance is accessible so that people with disabilities are able to enter, then when used as an exitway it would implicitly be similarly accessible. However, there is no explicit requirement for accessibility of an exitway for people with disabilities.

Tenability limits are prescribed in the NZBC (Tizard, 1992) for:

- Visibility as 10 m, or 5 m for rooms of < 100 m² (Clause C4.3.c).
- Thermal fractional effective dose ($FED_{thermal}$) as < 0.3 (Clause C4.3.b). This parameter is not applicable to a sprinklered firecell with less than 1000 occupants (Clause C4.4).
- Carbon dioxide fraction effective dose (FED_{CO}) as < 0.3 (Clause C4.3.a). This parameter is also not applicable to a sprinklered firecell with less than 1000 occupants (Clause C4.4).

When occupants located within an exitway or on an external escape route must egress past a window opening or glazed panel, they must not be exposed to a radiation level which will cause pain while evacuating. It is stated that the C/VM2 analysis described for calculation of radiation along this egress route is not appropriate where occupants are likely to be mobility-impaired (Paragraph 3.6.1.d, VM2). Analysis (as described in Paragraph 3.6, C/VM2) is not required where:

- There is an alternative escape route available (Paragraph 3.6.1.f, C/VM2).
- Where glazing along the escape route is insulated with a minimum fire resistance of -/30/30 (Paragraph 3.6.1.g, C/VM2).
- Where the sprinklered building has specifically-designed window wetting sprinklers on the fire side of the window (Paragraph 3.6.1.h, C/VM2).

Therefore if one of these three conditions is not part of the building design and occupants are likely to be mobility-impaired, then an alternative assessment (based on international best practice) must be used.

3.2 International standards, regulations and guidelines

It is not the intent of this scoping document to summarise prescriptive building feature requirements for accessibility (e.g. clear door widths, maximum door saddle rises, etc.).

Instead, only where metrics associated with occupant descriptions, characteristics and capabilities have been described, are they included here. This data is scarce.

As a component of design fire safety scenario, the selection of design scenarios and fires is described in ISO 16733 (2006). Along similar lines, guidance for a general methodology for selecting design fire safety scenarios for the specific fire safety objective of life safety of the occupants, design occupant behavioural scenarios and then developing the occupant behavioural scenarios for which those design fire safety scenarios are to be used to test a design is currently under development (ISO/DTS 29761). Figure 5 and Figure 6 show schematics of how an occupant scenario may be considered. If this approach was applied holistically, then naturally the full range of intended-occupant capabilities would be included in the analysis.

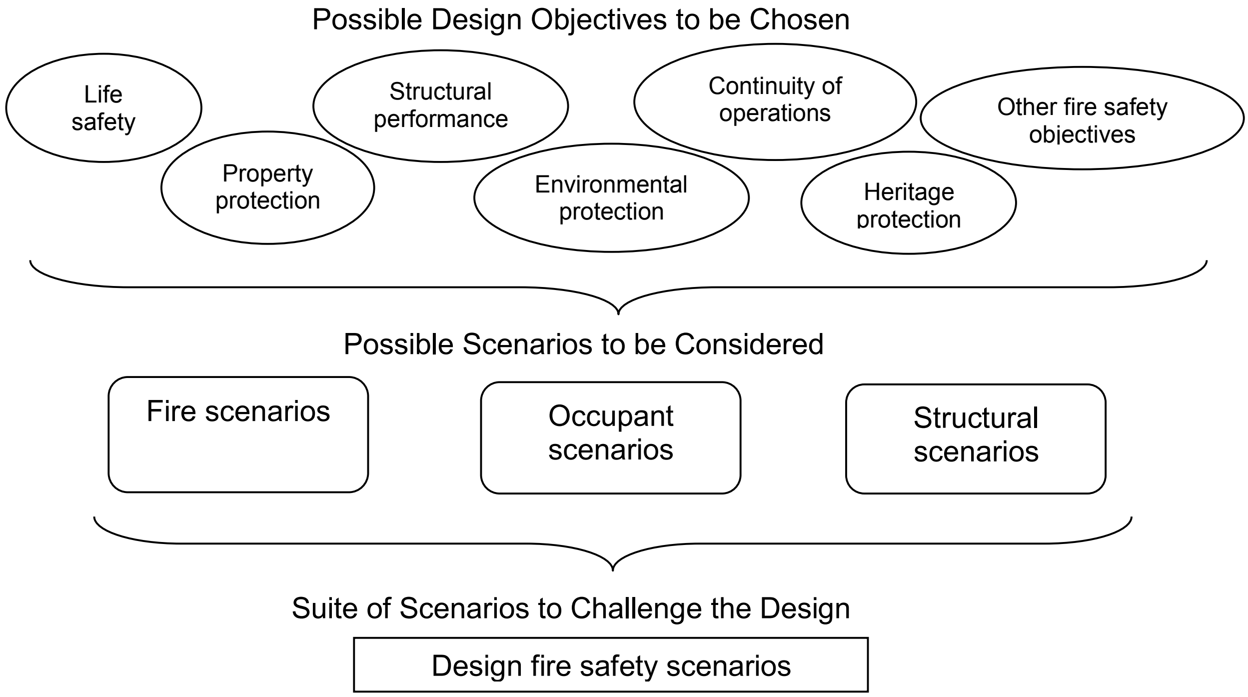

Figure 5 Schematic of the general relationship between design objectives, general scenarios and design fire safety scenarios used to challenge a design to assess the fire safety appropriateness.

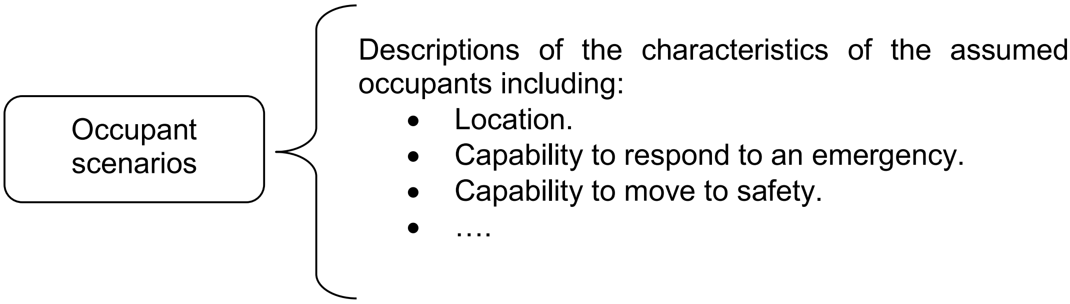

Figure 6 Schematic of the general descriptions of metrics that may be used to describe occupant scenarios.

In the US, accessibility of buildings may be addressed with ICC A117.1 (ICC, 2009) and is referenced in the International Building Code (IBC 2012). The IBC Chapter 10 (IBC, 2012) addresses theories of how to evacuate everyone out of a building in an emergency with the 2010 ADA/ABA Guidelines (ADA, 2010), Section 207.1 and 207.2, for accessible means of egress, with provisions for state, government and commercial buildings. It is acknowledged that the way into a building may not always be the way out of a building in an emergency. Performance metrics are not included in these documents.

The model National Building Code (NBC, 2012) and National Fire Code (NFC, 2012) of Canada describe the minimal fire safety requirements. Various jurisdictions implement these requirements, with or without addendums. For example, the City of Winnipeg has published its own Accessibility Design Standards (Winnipeg, 2010). This document uses areas of rescue assistance and provides prescriptive requirements for building features, such as door clear widths in exitways, etc. that are consistent with building accessibility prescriptive requirements.

Guidance documents which discuss potential design features for consideration in more holistic emergency egress design of buildings have been published by various organisations, such as the SFPE's *Engineering Guide for Designing Fire Safety in Very Tall Buildings* and occupant descriptions, such as in the SFPE's *Engineering Guide to Human Behavior in Fire*.

4. UNIVERSAL DESIGN-RELATED SOLUTION APPROACH

One approach to considering holistic emergency egress designs may be to borrow from universal design-related building solutions. It is the intention of this scoping document to bring to the fore aspects for consideration in order to holistically address emergency egress, as opposed to summarise universal design approaches that are available.

Universal design approaches may take the form of considering each type of potential occupant impairment in turn. Building design solutions that have already been developed based on this approach may be analysed and the types of solutions incorporated into performance-based design approaches or perhaps only prescriptive learnings can be drawn from them.

Impairments for consideration may include:

- Mobility, such as
    - Wheelchair and other mobility aids.
        - Influencing – location of switches, phones, surface of flooring, resting locations during egress, etc. (CAN, 2014).
- Vision, to consider aspects such as
    - Predictable and generous walkways (Downey, 2013).
- Hearing, considering communication alternatives such as
    - Tele-printer, tele-typewriter, tele-type or text telephone (TTY). The Telecommunication Device for the Deaf (TDD) is an electromechanical typewriter paired with a communication channel to enable typed communications over ordinary telephone lines. Such systems are used in the aviation industry, called AFTN and airline teletype system.
- Dexterity and strength, to consider aspects such as
    - Door opening forces and handle operation.
- Cognitive, considering
    - Interpretation and standardisation of alarms, notification and signage.

4.1 Age influence on characteristics

Age alone does not provide a direct measure of capability in terms of successful self-evacuation of a building (e.g. USFA, 1999). Disability-related classification intersects with age, but does not define age-related changes in functional reality. There are many aspects of an individual's ability to identify an incident, respond with a self-evacuation plan and execute a plan or gain assistance to escape – e.g. hearing impairments, sight impairments, etc. (FEMA, 1999a and 1999b). Also, evacuation of a building is building-specific and cannot be approached generically. Modelling evacuation is instead a way of considering the appropriateness of the fire safety design of a building.

There are several aspects to consider surrounding the selection of appropriate metrics for inclusion in performance-based design and assessment of emergency egress:

- Is the metric available as a function of individuals' ages?
- How appropriate/applicable is it to include the age of occupants in the distributions of characteristics (e.g. age versus mobility characteristics, etc.) used in describing an occupant group?
- How useful/practical is defining a design occupancy based on the age distribution of the intended occupants from a designer's point of view?

5. METRICS FOR DESIGN OCCUPANTS DESCRIPTION

The concept of "design occupants" is not new, as discussed and investigated by Horasan (2003). Design occupants are considered here as an analogous concept to a design fire (ISO, 2006). That is, a description of intended building occupants is used to challenge a particular building design with design fire safety scenarios in order to assess the appropriateness of the design's fire safety. There may be multiple design occupant characteristic descriptions based on the intended usage of the building. For example, a proposed building may contain various types of activities targeting very different subsets of the general population.

The following is a discussion of potential metrics that might be used to describe a design occupancy and thus be useful for emergency egress design. These build on the existing metrics that were summarised in Section 2.4. There is the potential to draw on and utilise data from a diverse range of professions that collect information across a wide range of population subsets for intents other than emergency building egress. It is not the intent of this report to present a collation of available data, instead the content may provide a talking point for future discussions with experts in related fields as to what data sets are already collected and how these might relate to emergency egress of building occupants, as is also planned for the next stage of this work.

5.1 Influence of source on data applicability

As has been previously discussed, for fire safety metrics, the source of the data can influence the applicability of the values in the context of emergency building egress. For example, occupant recognition time could vary greatly between countries that have vastly different familiarity with central fire alarm systems and that could make the application of data from one country inappropriate in another (ISO/DTS 29761, 2014). However, the country of origin may not be the only influencing aspect of the source, as data collected for a wide range of reasons (e.g. health-related, etc.) would potentially be considered.

5.1.1 Data from incident statistics

Another consideration that has previously been raised in the context of emergency egress, is that care must be exercised in applying emergency incident statistics. It may be necessary to demonstrate that the data is appropriate for the built environment under consideration (ISO/DTS 29761, 2014).

5.2 Potential indirect metrics

Considering there may be a direct or indirect correlation between population metrics that are collected for reasons other than emergency egress, the authors suggest there may be useful metrics already available to map to describe intended building occupant groups for the purpose of emergency egress performance.

An initial literature scan was done to identify potential metrics that might be useful when describing characteristics of building occupant groups for emergency egress design and assessment. This considered types of activities or surveys conducted by all of our population, communities or sub-groups of these, that would potentially provide a snapshot of capabilities that may indirectly influence an individual's performance during emergency egress. Identifying potential universal considerations, irrespective of capabilities, included suggestions such as:

- Having accidents
    - Slips trips and falls versus age for residential, institutional, workplace, other types of occupancy.

- Sickness/disease
    - Number of doctor visits versus age.
    - Number of hospitalisations versus age, for accidental, non-accidental incidents.
    - Medication level versus age.
    - Consider how this may be influenced by socio-economic factors and whether it could be uncoupled.
- Income
- Education level
    - Whether this influences comprehension, wayfinding during a stressful event.
    - Consider how this may be influenced by socio-economic factors and whether it could be uncoupled.
- Transport
    - Number of public transport users per year versus age.
    - Number of public transport uses per user per year versus age.
    - Number of car drivers versus age.
    - Number of driving accidents versus age.
    - Distance driven per year versus age.
    - Note – driving limits the range of demographics of the population considered, however evaluate whether there any correlations between driver-related statistics and other types of metrics.
- Native to country
    - Native versus temporary and permanent immigrants and in what ways does this influence fire safety culture and response.
    - Proportion of population with English as a first language versus age and how this may influence fire safety messages and comprehension.

5.2.1 Population size based on age

Since population distribution based on age is one of the most commonly available data sets it is summarised here so as to provide a comparison and set of data for consideration of other metrics. However, it is not proposed that age is the most appropriate metric to be used in this situation. Further investigation and consideration of the influence of age on analysis results would be needed before such conclusions could be substantiated. Therefore this summary is only to facilitate the ease of general comparison and consideration at this stage.

An estimate of the distribution of the New Zealand population based on extrapolation of Census data is summarised in Figure 7 (data extracted from SNZ, 2014). For comparison, an estimate of the distribution of the US population based on extrapolation of Census data is summarised in Figure 8 (data extracted from USCB, 2013b).

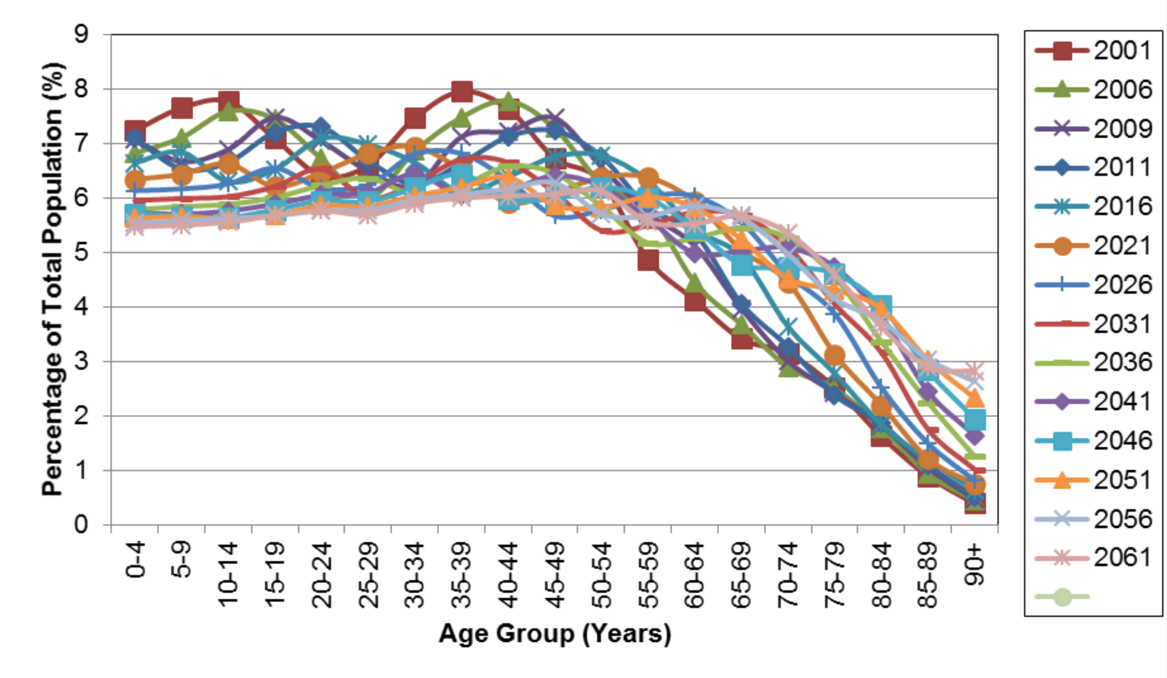

Figure 7 Estimated percentage of the total New Zealand population of each age group based on Census data. Extracted from SNZ (2014).

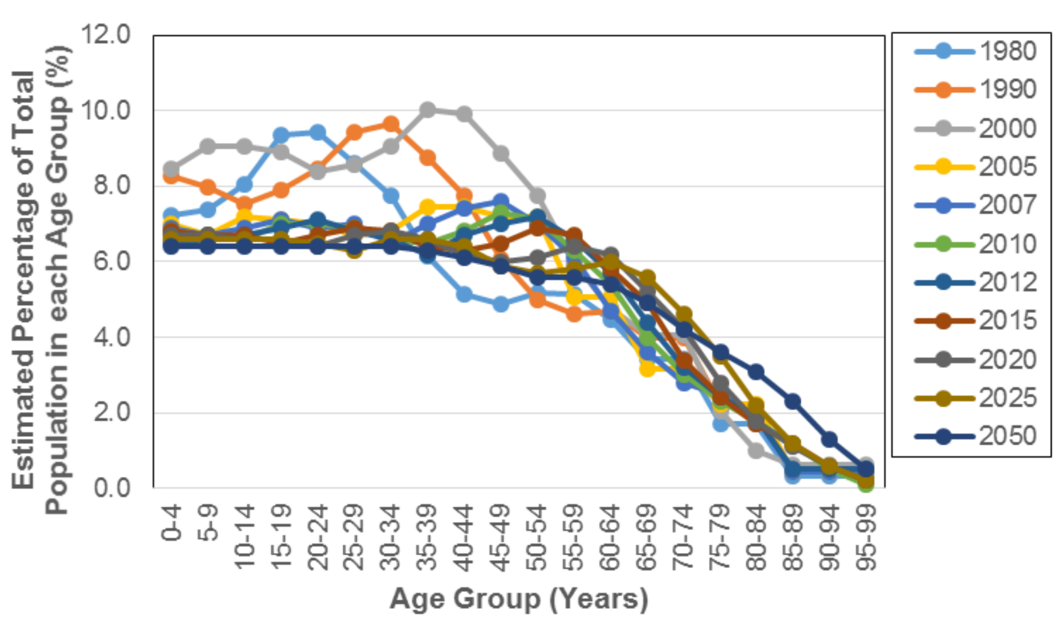

Figure 8 Estimates of the percentage of the total US population in each age group. Data extracted from USCB (2013b).

As some causes of limitations of capabilities may be associated with gender, the proportion of males to females for each of the age groups is also considered here. An estimate of the proportion of male to female distribution of the US population for age groups based on interpolation of Census data is summarised in Figure 9 (data extracted from USCB, 2013b). Similarly for New Zealand data, different proportions of males to females of the total population tend to be most obvious for ages 60 years and over.

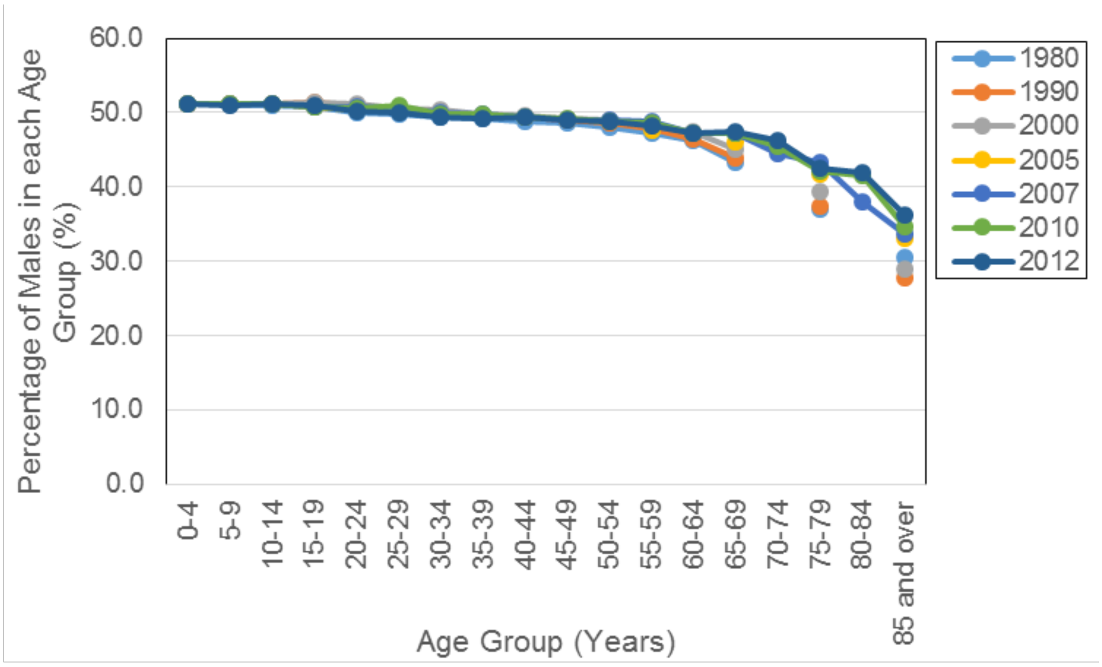

Figure 9 Proportion of males in each age group for the US population. Data extracted from USBC (2013b).

5.2.1.1 Comparative metrics other than age

Alternative metrics than age that are relatively commonly available and may prove useful for demonstrating distributions of other metrics against may include gender, household income and household size (i.e. individual or group, family or non-family structure). These metrics are typical variables that have been used to report distributions of other metrics for other data sets (e.g. SNZ, 2014; USBC, 2013b).

5.2.2 Reported disability

Another source of information about capabilities of a sub-group of the population may be from reported disability.

The (US) Centres for Disease Control and Prevention (CDC) and US Census Bureau (USCB) reported results from analysis of Survey of Income and Program Participation (SIPP) data for the prevalence and most common causes of self-reported disability among civilian non-institutionalised (e.g. persons living in nursing homes were excluded) adults (aged 18 years and older), (CDC, 2009).

In 1999, the prevalence of disability among adults in the US was reported as approximately 22.0%. In 2005, the prevalence was similar, being reported as approximately 21.8%. This related to an increase in the absolute number of adults with disability of approximately 7.7% (CDC, 2009).

Women were reported to have a significantly higher prevalence of disability (approximately 24.4% of the total female population) compared with men (approximately 19.1% of the total male population) at all ages (CDC, 2009).

Considering both sexes, the prevalence of disability reported doubled in each successive age group (CDC, 2009):

- 11% of 18-44 years of age.
- 24% of 45-64 years of age.

- 52% of ≥65 years of age.

The top seven self-reported causes of disability (for the adult population) in this survey were (CDC, 2009):

- Arthritis or rheumatism.
- Back or spine problems.
- Hearing trouble.
- Lung or respiratory problem.
- Mental or emotional problem.
- Diabetes.
- Deafness or hearing problem.

A summary of the estimated percentages and 95% confidence intervals of the total male and female population is included in Table 19 (CDC, 2009).

Estimated population percentages of individuals with a self-reported difficulty with a specific function were reported for (CDC, 2009):

- Having self-reported difficulty with at least one of the specified functions.
- Seeing letters in newsprint.
- Hearing normal conversation.
- Having their speech understood.
- Walking three city blocks.
- Climbing a flight of stairs.
- Grasping objects.

Estimated population percentages for these are summarised in Table 14 (CDC, 2009). Note that these categories are not mutually exclusive, as respondents may have indicated that they had various different difficulties.

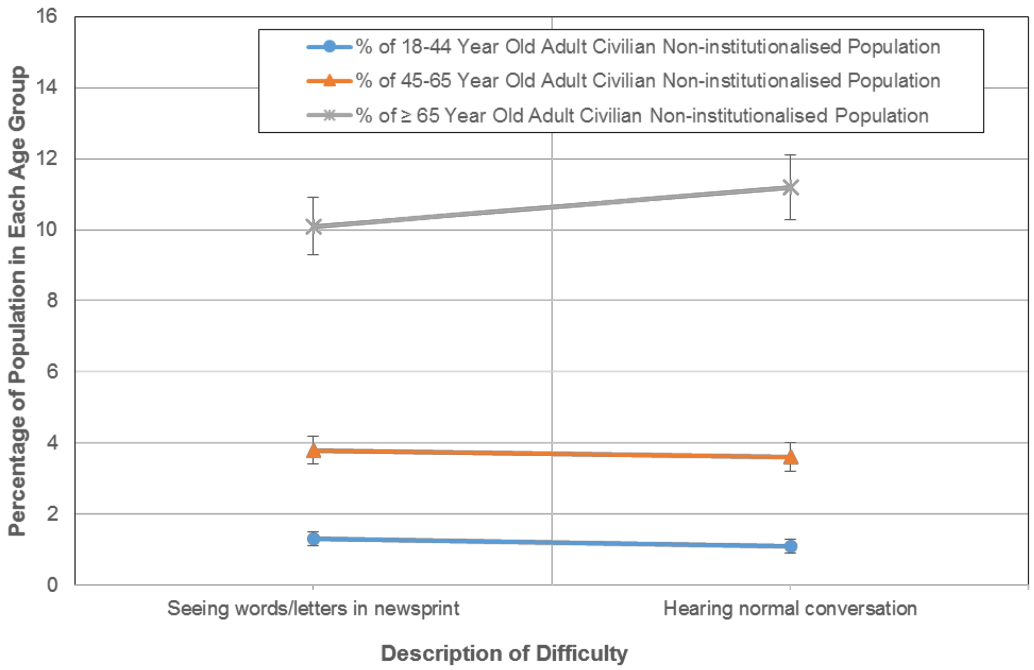

Figure 10 Estimated percentages (with a 95% confidence interval) of the adult (≥ 18 years of age) civilian non-institutionalised population for the age groups of 18-44 years, 45-64 years, ≥ 65 years and total population based on self-reported disabilities, according to data presented in CDC (2009), for difficulties that may influence the ability to be alerted by emergency alarms and notifications.

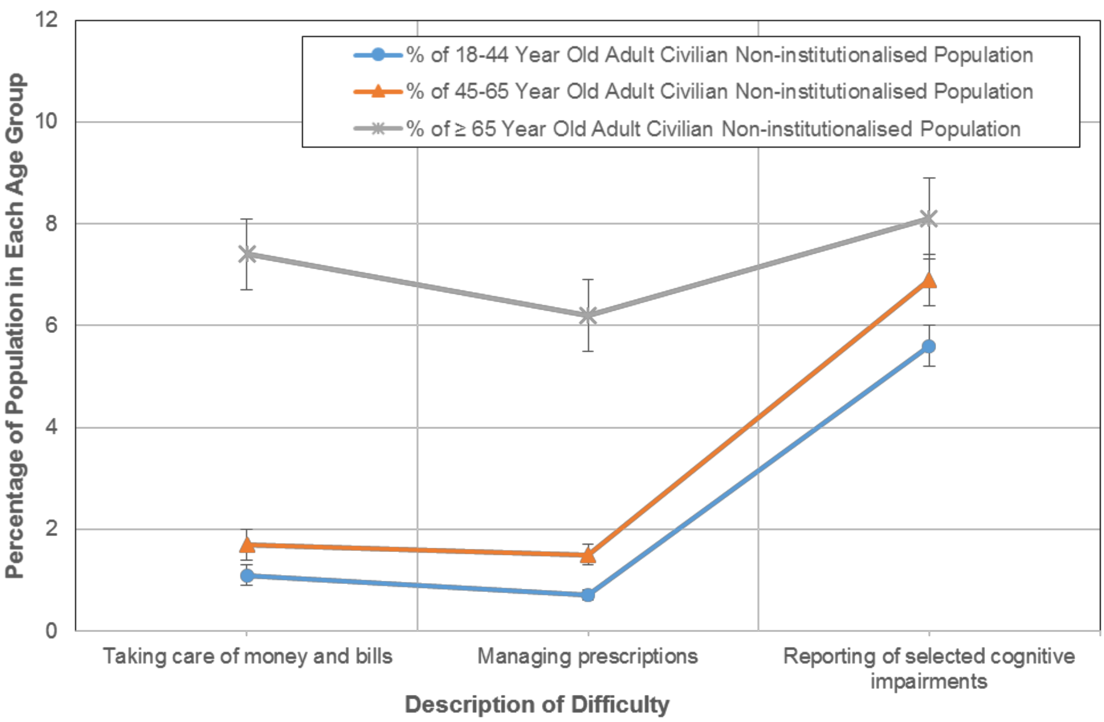

Figure 11 Estimated percentages (with a 95% confidence interval) of the adult (≥ 18 years of age) civilian non-institutionalised population for the age groups of 18-44 years, 45-64 years, ≥ 65 years and total population based on self-reported disabilities, according to data presented in CDC (2009), for difficulties that may influence the ability to understand the need to take action and which action to take.

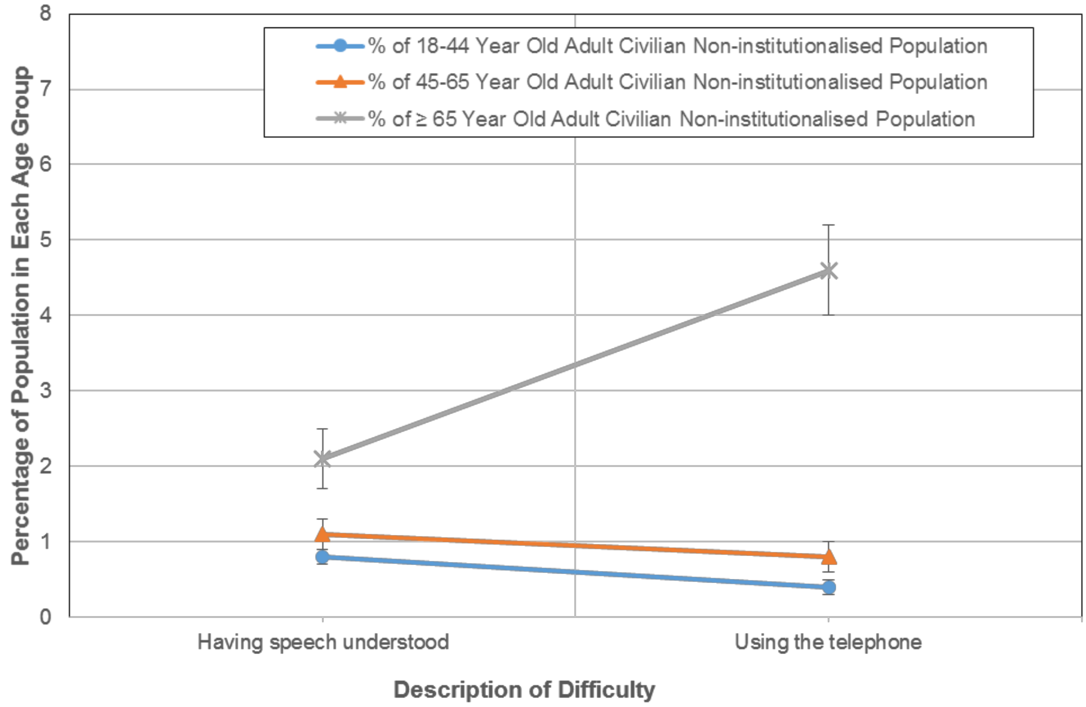

Figure 12 Estimated percentages (with a 95% confidence interval) of the adult (≥ 18 years of age) civilian non-institutionalised population for the age groups of 18-44 years, 45-64 years, ≥ 65 years and total population based on self-reported disabilities, according to data presented in CDC (2009), for difficulties that may influence the ability to raise an alarm.

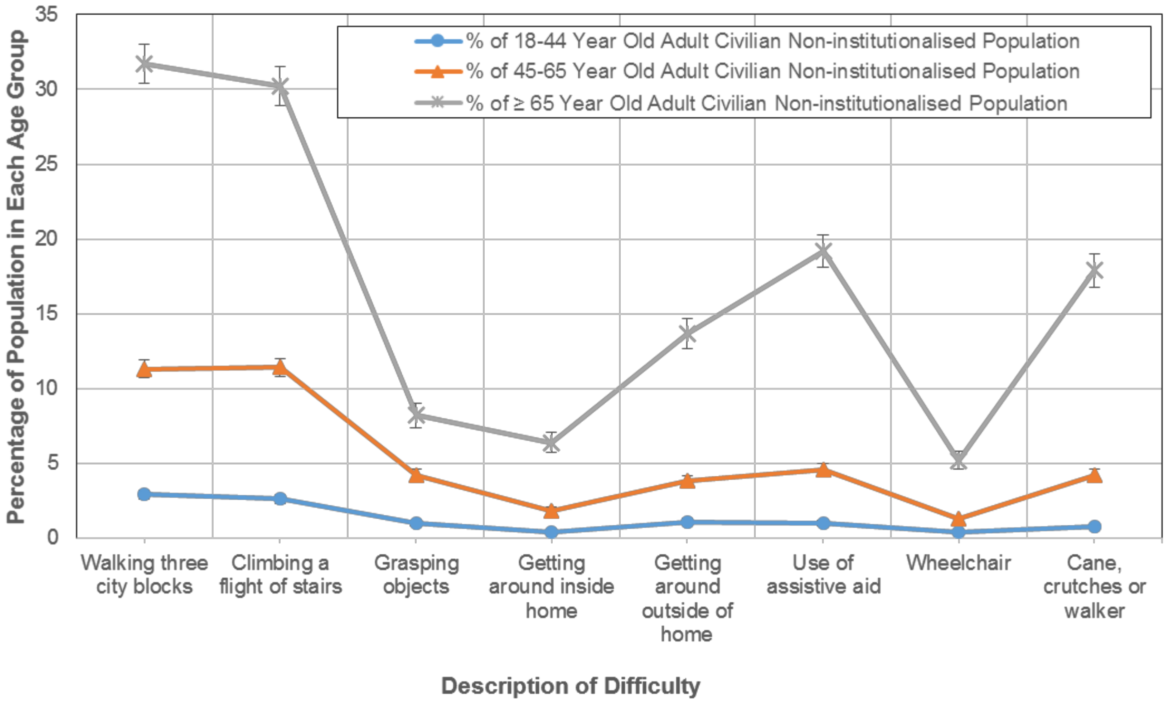

Figure 13 Estimated percentages (with a 95% confidence interval) of the adult (≥ 18 years of age) civilian non-institutionalised population for the age groups of 18-44 years, 45-64 years, ≥ 65 years and total population based on self-reported disabilities, according to data presented in CDC (2009), for difficulties that may influence the ability to move to a place of safety.

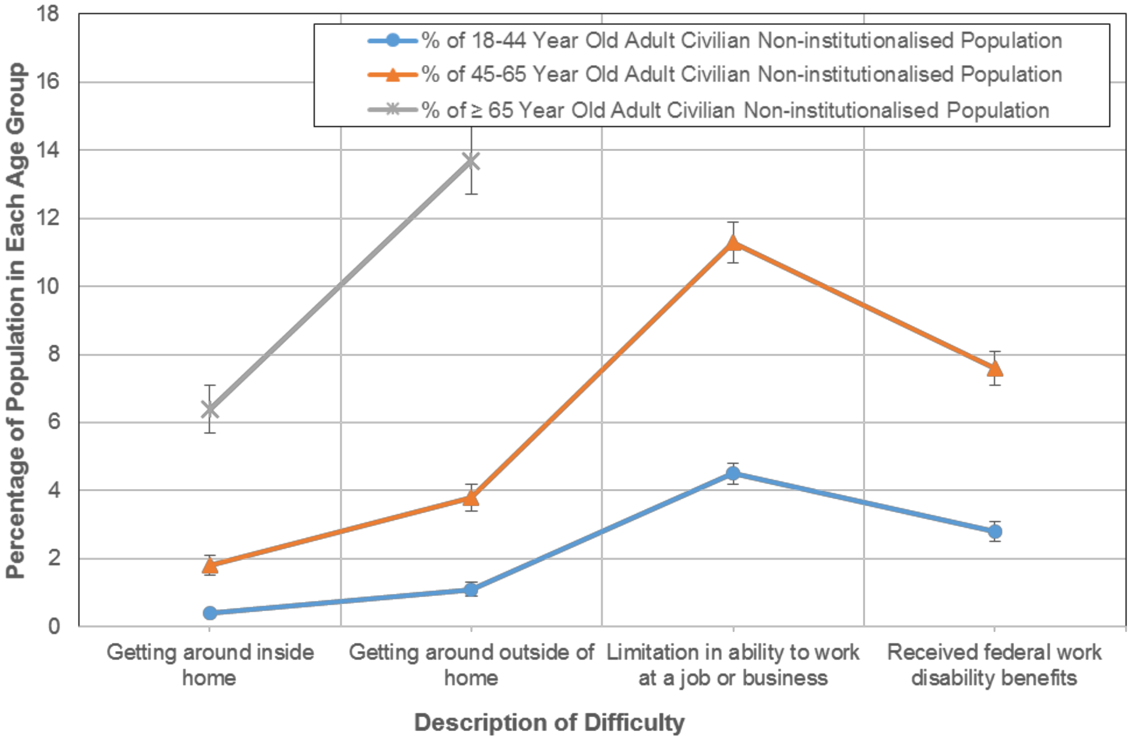

Figure 14 Estimated percentages (with a 95% confidence interval) of the adult (≥ 18 years of age) civilian non-institutionalised population for the age groups of 18-44 years, 45-64 years, ≥ 65 years and total population based on self-reported disabilities, according to data presented in CDC (2009), for difficulties that may influence the ability to self-rescue, i.e. may require assistance.

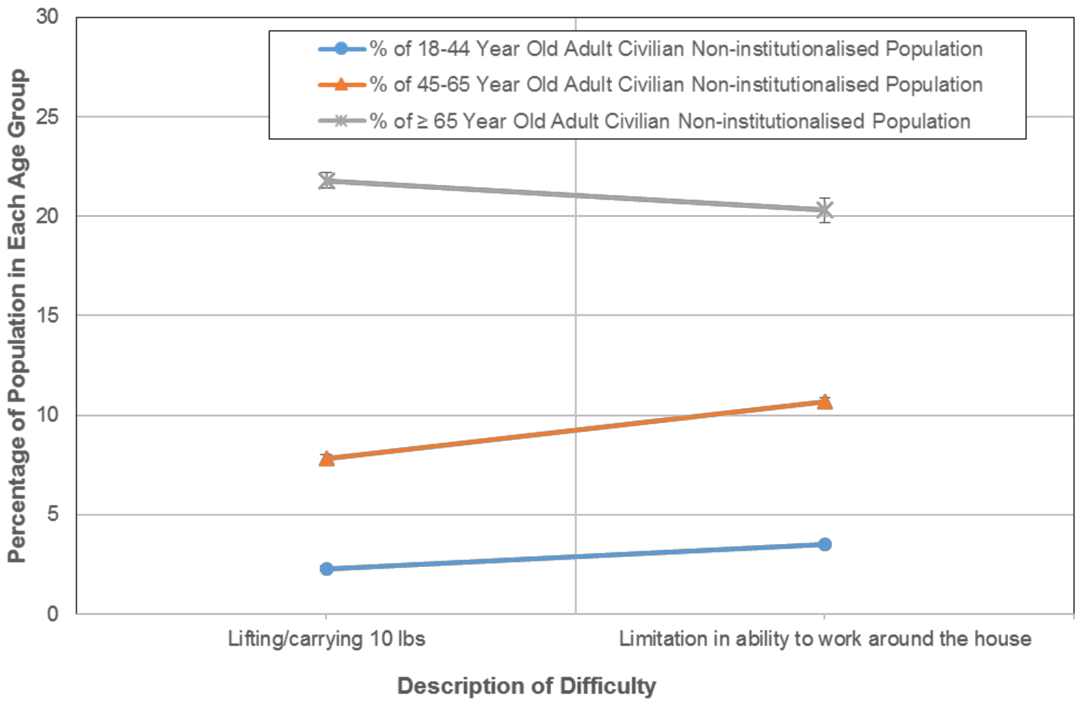

Figure 15 Estimated percentages (with 95% confidence intervals) of the adult (≥ 18 years of age) civilian non-institutionalised population for the age groups of 18-44 years, 45-64 years, ≥ 65 years and total population based on self-reported disabilities, according to data presented in CDC (2009), for difficulties that may influence the ability to assist others while egressing.

Similarly, the number of mobile disabled people by degree of mobility was reported by Boyce, Shields and Silcock (1999d) for Northern Ireland. The proportion of the total Northern Ireland mobile adult population with limited locomotion capabilities was approximately 7.6%. Additionally, those with limited dexterity totalled 3.0%, with limited sight was 2.9% of which 0.06% were blind, with limited hearing was 5.0% of which 0.1% were deaf and with mental or behavioural impairment was 2.7%.

Other metrics that may be useful and may be directly or indirectly related to reported disability might include obesity and sizes of individuals (FIFARS, 2012), hearing loss or impairment and vision loss or impairment that may be related to work considerations or other activities.

In the majority of cases, disability survey results are self-reported disability and limitations – e.g. the New Zealand 2006 Disability Survey (SNZ, 2007) etc. Self-reporting levels of capabilities means that each individual may be influenced by various combinations of social stigmas and personal scales of abilities and personal expectations. Therefore it would be useful to have a metric that utilises a common objective scale for estimating population distributions of capabilities.

5.2.3 Emergency room injuries and hospitalisations

Another potential metric that may be useful might include numbers of injuries and treatments.

Based on an analysis of US data available from 1991 to 2002, the rate of emergency room-treated injuries (associated with consumer products) per population for those 75 years and older was approximately double that of those 65 to 74 years of age, as shown in Figure 16 (CPSC, 2005). Of these, approximately 15% of the treatments of 65 to 74 year olds resulted in hospitalisation and approximately 27% of the treatments of 75 years and older resulted in hospitalisation (CPSC, 2005).

For US data available from 1997 to 2002, the rate of emergency room-treated injuries (associated with consumer products) per head of population for those aged 65 years and older was approximately a quarter more that of those 20 to 64 years of age, as shown in Figure 17 (CPSC, 2005). Similarly, statistics from 2011 indicate that approximately five per 100 seniors (65 years and over) were reported with emergency department-treated injuries of which 25% resulted in hospitalisation, while there were only three injuries per 100 adults 25 to 64 years of age with 5% resulting in hospitalisation (CPSC, 2013).

These data sets are from the (US) National Injury Surveillance System (NEISS) which is a probabilistic analysis based on a sample of 98 US hospitals with 24-hour emergency rooms with more than six beds.

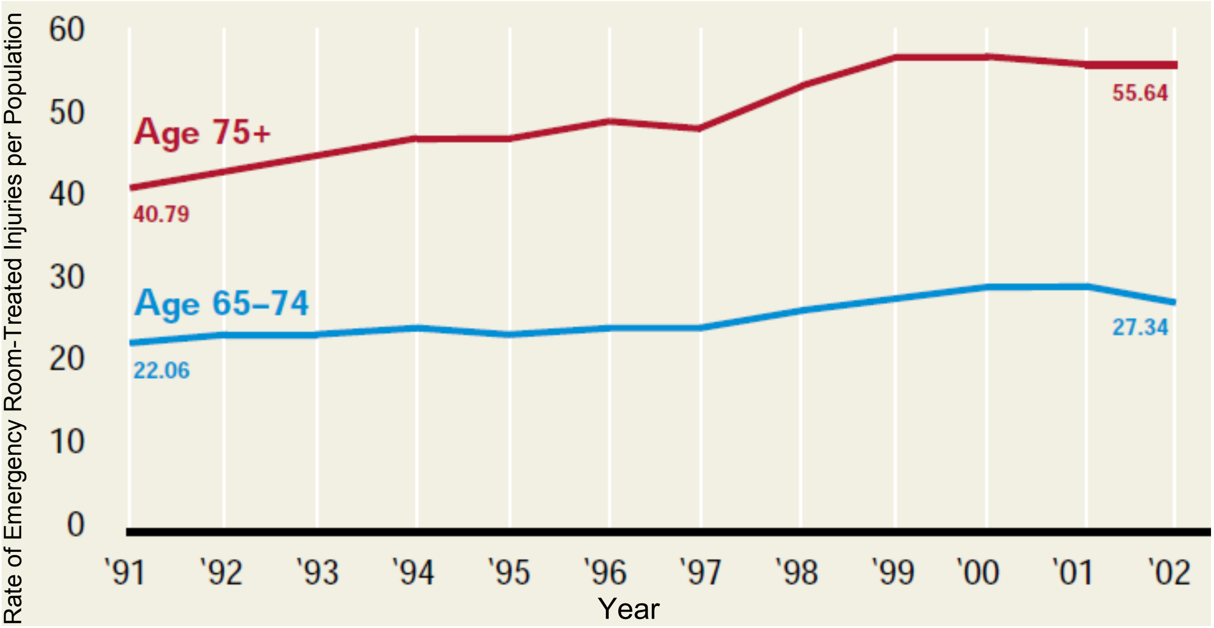

Figure 16 Rate of emergency room-treated injuries per 1000 population for 65 to 74 year olds and 75 years and over in the US between 1991 and 2002. Extracted from CPSC (2003).

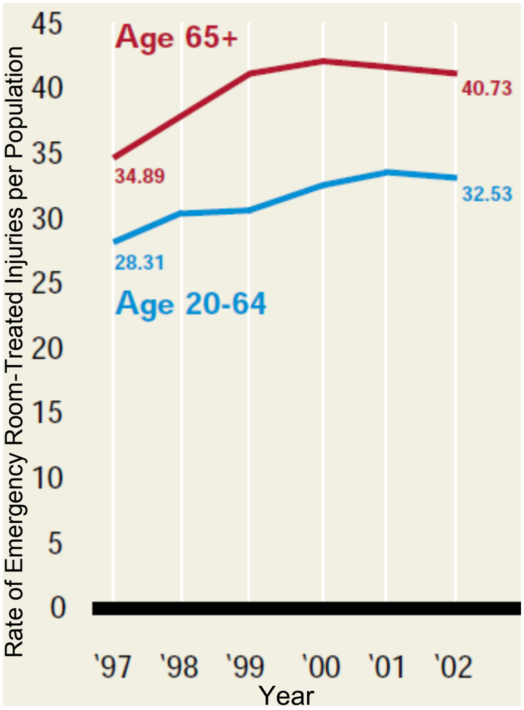

Figure 17 Rate of emergency room-treated injuries per 1000 population for 20 to 64 year olds and 65 years and over in the US between 1997 and 2002. Extracted from CPSC (2003).

5.2.4 Slips, trips and falls

A subset of injuries and treatments that may be collected by organisations other than health-focused groups would be slips, trips and falls.

Scenarios for falls recorded in injury statistics typically involve (CPSC, 2005 and 2013):

- Falls down stairs, either while ascending or descending.

- Transitioning between standing and sitting on chairs, toilets, beds, bathtubs, etc..
- Tripping over obstacles, such as loose carpet, cords, etc.
- Falling off ladders.

US data from 1991 to 2002 indicated approximately 77% of emergency room treatments related to consumer products involved slips, trips or falls. Whereas, for adults 65 to 74 years old, only 59% of treatments were attributed to falls (CPSC, 2005). Similarly, statistics from 2011 indicate that approximately 75% of the reported emergency department-treated injuries were attributed to falls for the elderly (CPSC, 2013).

6. SUMMARY

In summary, emergency building egress characteristics of the New Zealand population is not well defined in terms of distributions of metrics for emergency egress across various occupancies. Furthermore, actual emergency data is not as readily available as other data sources and less directly-related data sets are already utilised.

Metric values that are currently available in the literature are sourced from controlled experiments, with (e.g. some experiments have used irritant smoke) or without (e.g. Boyce et al, 1999) elements of a fire, announced evacuation drills (e.g. Kuligowski et al, 2012) and fire incident case studies (e.g. Averill et al, 2005). Actual emergency data is most desirable and might provide the most realistic predictor of behaviour, however it is not as readily available as evacuation drill data or controlled experiments. Potential biasing influences of the data sets must be taken into consideration when using the values in a modelling context and subsequent analysis of the results.

Variations in data sets for studies using similar types of occupant descriptions in various types of situations (e.g. announced evacuation drills, laboratory conditions, etc) have been shown for different individuals with different occupant characteristics (e.g. Kuligowski et al, 2012). Therefore the source of the data sets and influence of the potential variability of the data sets must be taken into account for each intended application.

In combination with available emergency egress characteristic data sets, there is potential to utilise a wider range of data that is already collected for our communities. Collation of this diverse data on the characteristics of our population and communities may provide a clearer description of the distribution of potential metrics related to capabilities of emergency building egress. A snapshot of related characteristics could be created from a collage of metrics collected by other professions to describe the characteristics of their interest groups.

6.1 Recommendations

Recommendations for research in alignment with the concept of utilising data sets from other focuses in our communities includes:

1. Collect and collate data sets on population mobility and comprehension, etc. from groups and organisations throughout our communities.
2. Establish levels of capability based on the combined data sets for modelling emergency egress scenarios. Identify the key metrics and combinations of metrics for more detailed consideration. Appropriateness might be assessed by
    a. Comparison of distributions, partial distributions, value ranges and average values reported from emergency egress drills or controlled experiments.
    b. Use of the combination of metric distributions in modelling of well-documented case studies.
3. Compare New Zealand values of the identified metrics to international values to assess whether there is a correlation between the identified metrics and fire incident statistics.

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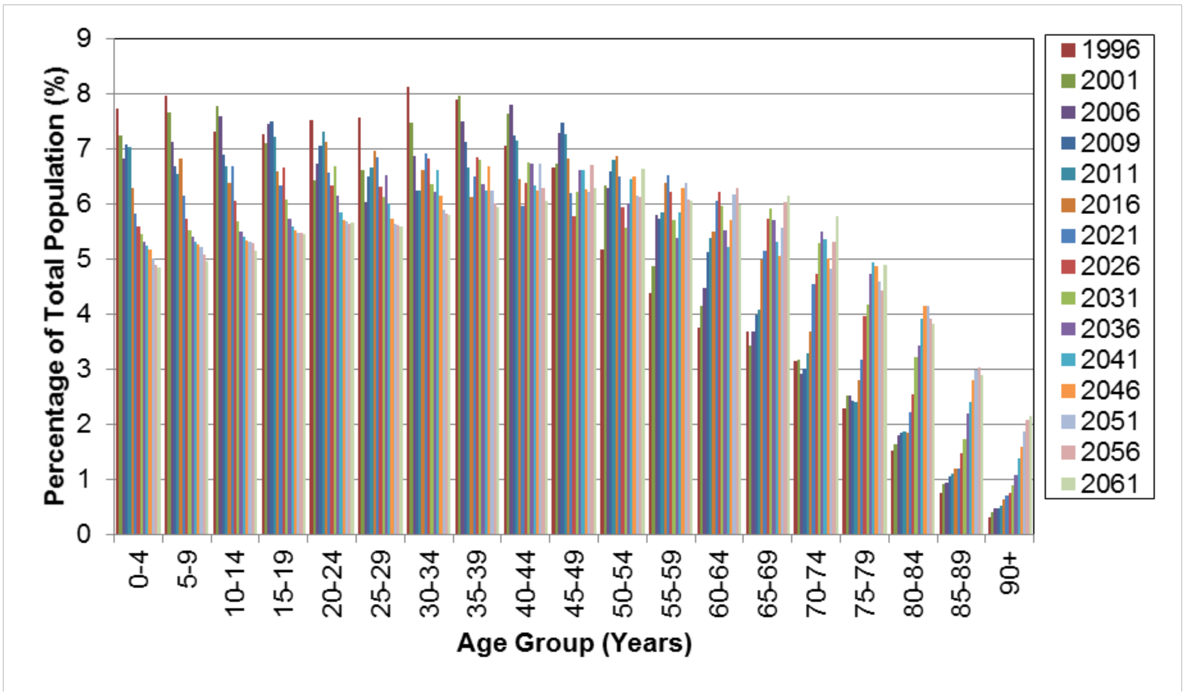
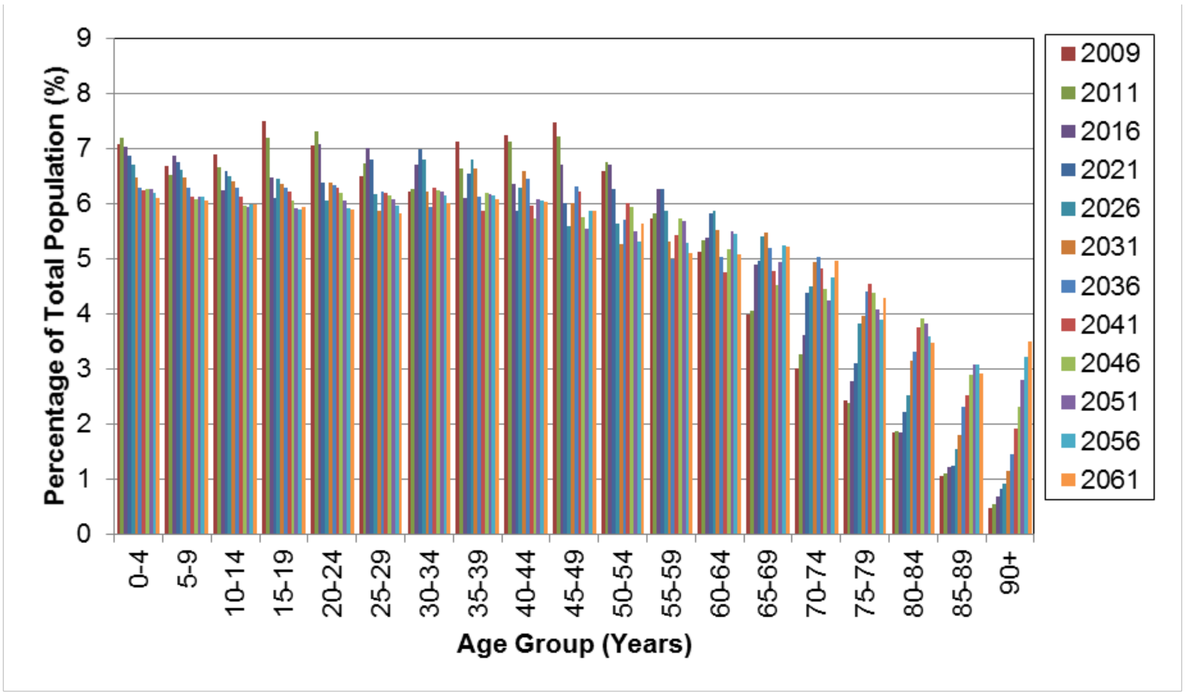
APPENDIX A POPULATION SUMMARIES FOR COMPARISON OF DATA SETS

The data summarised here is for general comparison of population distributions based on age.

A.1 New Zealand



(a)



(b)

Figure 18 The range of percentages of each age group based on Census data (for 1996 to 2006) and estimated projections for (a) minimum population size estimates and (b) maximum population size estimates. Based on data extracted from SNZ (2014).

A.2 United States of America

Intercensal estimates of the resident population by sex and age for the US, September 2011 (for the years 2002-2009) (Table 11) and annual estimates of the resident population for selected age groups by sex for the US, May 2012 (for the years 2010 and 2011) (Table 12), US Census Bureau, Population Division (CPSC, 2013).

Table 11 Estimated percentages of the US population based on age group. Extracted from USBC (2013b).

Estimated Percentages of the US Population in Each Age Group											
	Year										
Age Group	**1980**	**1990**	**2000**	**2005**	**2007**	**2010**	**2012**	**2015**	**2020**	**2025**	**2050**
0-4	7.2	8.3	8.5	7	6.9	6.8	6.5	6.8	6.7	6.6	6.4
5-9	7.4	8.0	9.1	6.7	6.7	6.7	6.6	6.7	6.7	6.6	6.4
10-14	8.1	7.5	9.1	7.2	6.9	6.6	6.7	6.7	6.6	6.6	6.4
15-19	9.3	7.9	8.9	7.1	7.1	7	6.9	6.5	6.6	6.6	6.4
20-24	9.4	8.4	8.4	7	6.9	7	7.1	6.7	6.4	6.5	6.4
25-29	8.6	9.4	8.6	6.7	7	6.9	6.8	6.9	6.7	6.3	6.4
30-34	7.8	9.6	9.1	6.8	6.5	6.6	6.6	6.8	6.8	6.6	6.4
35-39	6.2	8.8	10.0	7.45	7	6.5	6.2	6.4	6.6	6.6	6.3
40-44	5.2	7.8	9.9	7.45	7.4	6.8	6.7	6.3	6.2	6.4	6.1
45-49	4.9	6.1	8.9	7.2	7.6	7.3	7	6.5	6	5.9	5.9
50-54	5.2	5.0	7.8	7.2	7	7.1	7.2	6.9	6.1	5.7	5.6
55-59	5.1	4.6	5.9	5.05	6.1	6.3	6.6	6.7	6.4	5.8	5.6
60-64	4.5	4.7	4.8	5.05	4.7	5.4	5.7	5.8	6.2	6	5.4
65-69	3.4	4.0	4.1	3.15	3.6	4	4.4	4.9	5.2	5.6	4.9
70-74	3.4	4.0	4.1	3.2	2.8	3.0	3.2	3.4	4.2	4.6	4.2
75-79	1.7	2.2	2.0	2.3	2.5	2.3	2.4	2.4	2.8	3.5	3.6
80-84	1.7	2.2	1.0	2.3	1.9	1.8	1.9	1.7	1.8	2.2	3.1
85-89	0.3	0.4	0.6	0.4	0.4	1.2	0.5	1.2	1.1	1.2	2.3
90-94	0.3	0.4	0.6	0.4	0.4	0.5	0.5	0.6	0.6	0.6	1.3
95-99	0.3	0.4	0.6	0.4	0.4	0.1	0.5	0.2	0.2	0.2	0.5

Table 12 Estimated proportions of males per age group of the US population based on age group. Extracted from USBC (2013b).

Estimated Proportions of Males in Each Age Group of the US Population							
	Year						
Age Group	**1980**	**1990**	**2000**	**2005**	**2007**	**2010**	**2012**
0-4	51.1	51.2	51.2	51.1	51.2	51.1	51.1
5-9	51.1	51.2	51.2	51.1	51.1	51.1	51.1
10-14	51.1	51.2	51.2	51.2	51.2	51.2	51.1
15-19	50.8	51.3	51.4	50.8	50.8	50.8	51.0
20-24	50.0	50.9	51.1	50.4	50.7	50.5	50.2
25-29	49.7	50.2	50.6	50.4	50.5	50.9	49.9
30-34	49.4	49.8	50.3	49.7	49.9	49.7	49.4
35-39	49.1	49.6	49.8	49.5	49.8	49.8	49.2
40-44	48.9	49.3	49.6		49.3	49.5	49.3
45-49	48.6	49.0	49.2	49.0	49.0	49.2	49.0
50-54	48.0	48.6	48.9		49.0	48.9	48.7
55-59	47.2	47.8	48.3	47.6	48.7	48.6	48.3
60-64	46.3	46.6	47.5		47.2	47.3	47.3
65-69	43.4	43.8	45.1	46.0	47.2	47.2	47.5
70-74					44.5	45.5	46.2
75-79	37.1	37.4	39.5	41.7	43.2	42.1	42.6
80-84					38.1	41.6	41.8
85 and over	30.4	27.8	28.9	33.1	33.7	34.8	36.1

Proportions of the population with various self-reported disabilities as summarised from SIPP data (CDC, 2009) Table 13 to Table 19.

Table 13 Estimated percentages of the US adult (≥ 18 years of age) civilian non-institutionalised population for the age groups of 18-44 years, 45-64 years, ≥ 65 years and total population based on self-reported disabilities. Extracted from CDC (2009).

	Total Population		18-44 Year Old Population		45-64 Year Old Population		≥ 65 Year Old Population	
	Percentage (%)	95% Confidence Interval	Percentage (%)	95% Confidence Interval	Percentage (%)	95% Confidence Interval	Percentage (%)	95% Confidence Interval
Total	**21.8**	**(21.3-22.3)**	**11**	**(10.5-11.5)**	**23.9**	**(23.1-24.7)**	**51.8**	**(50.4-53.2)**

Table 14 Estimated percentages of the US adult (≥ 18 years of age) civilian non-institutionalised population for the age groups of 18-44 years, 45-64 years, ≥ 65 years and total population based on self-reported disabilities associated with having difficulty with specified functions. Extracted from CDC (2009).

	Total Population		18-44 Year Old Population		45-64 Year Old Population		≥ 65 Year Old Population	
	Percentage (%)	95% Confidence Interval	Percentage (%)	95% Confidence Interval	Percentage (%)	95% Confidence Interval	Percentage (%)	95% Confidence Interval
Having a difficulty with specified functional activities	**17.3**	**(16.9-17.7)**	**6.3**	**(5.9-6.7)**	**19.4**	**(18.6-20.2)**	**47.5**	**(46.1-48.9)**
Seeing words/letters in newsprint	3.5	(3.3-3.7)	1.3	(1.1-1.5)	3.8	(3.4-4.2)	10.1	(9.3-10.9)
Hearing normal conversation	3.6	(3.4-3.8)	1.1	(0.9-1.3)	3.6	(3.2-4.0)	11.2	(10.3-12.1)
Having speech understood	1.1	(1.0-1.2)	0.8	(0.7-0.9)	1.1	(0.9-1.3)	2.1	(1.7-2.5)
Walking three city blocks	10.3	(10.0-10.6)	2.9	(2.6-3.2)	11.3	(10.7-11.9)	31.7	(30.4-33.0)
Climbing a flight of stairs	10	(9.7-10.3)	2.6	(2.3-2.9)	11.4	(10.8-12.0)	30.2	(28.9-31.5)
Grasping objects	3.2	(3.0-3.4)	1	(0.8-1.2)	4.2	(3.8-4.6)	8.2	(7.4-9.0)
Lifting/carrying 10 lbs	7.3	(7.0-7.6)	2.3	(2.1-2.5)	7.8	(7.3-8.3)	21.8	(20.6-23.0)

Table 15 Estimated percentages of the US adult (≥ 18 years of age) civilian non-institutionalised population for the age groups of 18-44 years, 45-64 years, ≥ 65 years and total population based on self-reported disabilities associated with having a difficulty with instrumental activities of daily living. Extracted from CDC (2009).

	Total Population		18-44 Year Old Population		45-64 Year Old Population		≥ 65 Year Old Population	
	Percentage (%)	95% Confidence Interval	Percentage (%)	95% Confidence Interval	Percentage (%)	95% Confidence Interval	Percentage (%)	95% Confidence Interval
A difficulty with instrumental activities of daily living	**6.2**	**(5.9-6.5)**	**2.2**	**(2.0-2.4)**	**6**	**(5.5-6.5)**	**19.1**	**(18.0-20.2)**
Getting around outside of home	4	(3.8-4.2)	1.1	(0.9-1.3)	3.8	(3.4-4.2)	13.7	(12.7-14.7)
Taking care of money and bills	2.3	(2.1-2.5)	1.1	(0.9-1.3)	1.7	(1.4-2.0)	7.4	(6.7-8.1)
Managing prescriptions	1.9	(1.7-2.1)	0.7	(0.6-0.8)	1.5	(1.3-1.7)	6.2	(5.5-6.9)
Using the telephone	1.2	(1.1-1.3)	0.4	(0.3-0.5)	0.8	(0.6-1.0)	4.6	(4.0-5.2)

Table 16 Estimated percentages of the US adult (≥ 18 years of age) civilian non-institutionalised population for the age groups of 18-44 years, 45-64 years, ≥ 65 years and total population based on self-reported disabilities associated with cognitive impairments. Extracted from CDC (2009).

	Total Population		18-44 Year Old Population		45-64 Year Old Population		≥ 65 Year Old Population	
	Percentage (%)	95% Confidence Interval	Percentage (%)	95% Confidence Interval	Percentage (%)	95% Confidence Interval	Percentage (%)	95% Confidence Interval
Reporting of selected cognitive impairments	**6.4**	**(6.1-6.7)**	**5.6**	**(5.2-6.0)**	**6.9**	**(6.4-7.4)**	**8.1**	**(7.3-8.9)**
A learning disability	1.7	(1.6-1.8)	2.2	(2.0-2.4)	1.3	(1.1-1.5)	0.6	(0.4-0.8)
Mental retardation	0.5	(0.4-0.6)	0.7	(0.6-0.8)	0.4	(0.3-0.5)	0.3	(0.2-0.4)
Other developmental disability	0.3	(0.2-0.4)	0.4	(0.3-0.5)	0.2	(0.1-0.3)	0.1	(0.0-0.2)
Alzheimer's disease/senility/dementia	1	(0.9-1.1)	0.3	(0.2-0.4)	0.6	(0.4-0.8)	3.8	(3.3-4.3)
Other mental/emotional disability	4.6	(4.4-4.8)	3.5	(3.2-3.8)	5.6	(5.1-6.1)	5.6	(4.9-6.3)

Table 17 Estimated percentages of the US adult (≥ 18 years of age) civilian non-institutionalised population for the age groups of 18-44 years, 45-64 years, ≥ 65 years and total population based on self-reported disabilities associated with the use of an assistive aid for mobility. Extracted from CDC (2009).

	Total Population		18-44 Year Old Population		45-64 Year Old Population		≥ 65 Year Old Population	
	Percentage (%)	95% Confidence Interval	Percentage (%)	95% Confidence Interval	Percentage (%)	95% Confidence Interval	Percentage (%)	95% Confidence Interval
Use of assistive aid	**5.2**	**(4.9-5.5)**	**1**	**(0.8-1.2)**	**4.6**	**(4.2-5.0)**	**19.2**	**(18.1-20.3)**
Wheelchair	1.5	(1.4-1.6)	0.4	(0.3-0.5)	1.3	(1.1-1.5)	5.2	(4.6-5.8)
Cane, crutches or walker	4.7	(4.5-4.9)	0.8	(0.7-0.9)	4.2	(3.8-4.6)	17.9	(16.8-19.0)
Limitation in ability to work around the house	8.6	(8.3-8.9)	3.5	(3.2-3.8)	10.7	(10.1-11.3)	20.3	(19.2-21.4)

Table 18 Estimated percentages of the US adult (≥ 18 years of age) civilian non-institutionalised population for the age groups of 18-44 years, 45-64 years, ≥ 65 years and total population based on self-reported disabilities associated with participating in the labour force. Extracted from CDC (2009).

	Total Population		18-44 Year Old Population		45-64 Year Old Population		≥ 65 Year Old Population	
	Percentage (%)	95% Confidence Interval	Percentage (%)	95% Confidence Interval	Percentage (%)	95% Confidence Interval	Percentage (%)	95% Confidence Interval
Limitation in ability to work at a job or business	-	-	**4.5**	**(4.2-4.8)**	**11.3**	**(10.7-11.9)**	-	-
Received federal work disability benefits	-	-	**2.8**	**(2.5-3.1)**	**7.6**	**(7.1-8.1)**	-	-

Table 19 Estimated percentages of the cause of disabilities in the US adult (≥ 18 years of age) civilian non-institutionalised population for the age groups of male, female and total population based on self-reported results of survey participants. Extracted from CDC (2009).

	Total Adult Population		Male Adult Population		Female Adult Population	
	Percentage (%)	95% Confidence Interval	Percentage (%)	95% Confidence Interval	Percentage (%)	95% Confidence Interval
Arthritis or rheumatism	19	(18.0-20.0)	11.5	(10.3-12.7)	24.3	(22.9-25.7)
Back or spine problems	16.8	(15.9-17.7)	16.9	(15.5-18.3)	16.8	(15.6-18.0)
Heart trouble	6.6	(6.0-7.2)	8.4	(7.3-9.5)	5.4	(4.7-6.1)
Lung or respiratory problem	4.9	(4.4-5.4)	4.9	(4.1-5.7)	4.9	(4.2-5.6)
Mental or emotional problem	4.9	(4.4-5.4)	5.2	(4.3-6.1)	4.6	(3.9-5.3)
Diabetes	4.5	(4.0-5.0)	4.8	(4.0-5.6)	4.2	(3.5-4.9)
Deafness or hearing problem	4.2	(3.7-4.7)	6.8	(5.8-7.8)	2.4	(1.9-2.9)
Stiffness or deformity of limbs/extremities	3.6	(3.1-4.1)	3.6	(2.9-4.3)	3.7	(3.1-4.3)
Blindness or vision problem	3.2	(2.8-3.6)	3.9	(3.2-4.6)	2.8	(2.3-3.3)
Stroke	2.4	(2.0-2.8)	3.1	(2.4-3.8)	1.9	(1.5-2.3)
Cancer	2.2	(1.8-2.6)	2.4	(1.8-3.0)	2.1	(1.6-2.6)
Broken bone/fracture	2.1	(1.7-2.5)	1.9	(1.4-2.4)	2.3	(1.8-2.8)
High blood pressure	1.9	(1.6-2.2)	1.6	(1.1-2.1)	2.1	(1.6-2.6)
Mental retardation	1.5	(1.2-1.8)	1.7	(1.2-2.2)	1.3	(0.9-1.7)
Senility/dementia/Alzheimer's disease	1.2	(0.9-1.5)	1	(0.6-1.4)	1.3	(0.9-1.7)
Head or spinal cord injury	1.1	(0.8-1.4)	1.5	(1.0-2.0)	0.9	(0.6-1.2)
Learning disability	1.1	(0.8-1.4)	1.6	(1.1-2.1)	0.7	(0.4-1.0)
Kidney problems	0.9	(0.7-1.1)	1.2	(0.8-1.6)	0.7	(0.4-1.0)
Stomach/digestive problems	0.8	(0.6-1.0)	0.7	(0.4-1.0)	0.8	(0.5-1.1)
Paralysis of any kind	0.6	(0.4-0.8)	0.7	(0.4-1.0)	0.5	(0.3-0.7)
Epilepsy	0.6	(0.4-0.8)	0.6	(0.3-0.9)	0.6	(0.4-0.8)
Hernia or rupture	0.5	(0.3-0.7)	0.6	(0.3-0.9)	0.5	(0.3-0.7)
Cerebral palsy	0.5	(0.3-0.7)	0.8	(0.5-1.1)	0.3	(0.1-0.5)
Missing limbs/extremities	0.5	(0.3-0.7)	0.8	(0.4-1.2)	0.2	(0.1-0.3)
Alcohol or drug problem	0.4	(0.2-0.6)	0.8	(0.5-1.1)	0.2	(0.1-0.3)
Tumour/cyst growth	0.3	(0.2-0.4)	0.2	(0.0-0.4)	0.3	(0.1-0.5)
Thyroid problems	0.2	(0.1-0.3)	0.1	(0.0-0.2)	0.3	(0.1-0.5)
AIDS or AIDS-related condition	0.2	(0.1-0.3)	0.2	(0.0-0.4)	0.2	(0.1-0.3)
Speech disorder	0.2	(0.1-0.3)	0.1	(0.0-0.2)	0.2	(0.1-0.3)
Other	12.9	(12.1-13.7)	12.1	(10.8-13.4)	13.5	(12.4-14.6)

APPENDIX B SUMMARIES OF VARIOUS ORGANISATIONS AND COMMUNITY GROUPS

The following is a collation of various groups that may currently collect data for a multitude of situations that may be indirectly applicable to creating a snapshot of the population's capabilities, that in turn could be related to aspects that influence an individual's ability to self-rescue.

The lists are grouped by country. The order of groups is not related to any hierarchy, simply similar groupings are used to collate the information for ease of comprehension.

B.1 New Zealand

Government departments and organisations:

- Regulators – Ministry of Business, Innovation and Employment (MBIE).
- Accident Compensation Corporation (ACC).
- Human Rights Commission, Disability Commission – in particular, regarding the Canterbury rebuild for accessibility.
- MSD, Centre for Research and Development, concerning disability and aging.

Fire service:

- New Zealand Fire Service (NZFS).

Building designers:

- Lifetime Design/Universal Design.
    - Lifemark.
- Fire safety engineering design.
    - New Zealand Branch of the Society of Fire Protection Engineers (SFPE).
    - Institute of Professional Engineers New Zealand (IPENZ).

Community representatives:

- Disability groups.
- Health and disability professionals.
- Aging groups.
    - Aged Concern, Grey Power, stroke groups.

School/parent groups:

- Teachers groups (i.e. interested in the context of when they have students with a temporary or long-term disability during field trips, etc.).
- School groups (i.e. interested in the context of events etc. held at the school that may include people with temporary or long-term disabilities).
- Parent groups (i.e. interested in the context of taking their children into other buildings, e.g. museums, shopping centres, etc.).

B.2 Australia

Groups in Australia:

- Youngcare http://www.youngcare.com.au/.

B.3 United States of America

Groups in the US:

- World Institute on Disability (WID).
- United Cerebral Palsy Association, Inc. (UCPA).
- United Spinal Association.
- Paralyzed Veterans of America (PVA).
- New Mexico Governor's Commission on Disability (NMGCD).
- National Association of the Deaf (NAD).
- Administration on Aging (AOA), Department of Health and Human Services www.aoa.gov.
- Agency for Healthcare Research and Quality (AHRQ), Department of Health and Human Services www.ahrq.gov.
- Centers for Medicare and Medicaid Services (CMMS), Department of Health and Human Services www.cms.hhs.gov.
- National Center for Health Statistics (NCHS), Department of Health and Human Services www.cdc.gov/nchs.
- National Institute on Aging (NIA), Department of Health and Human Services www.nia.nih.gov.
- Office of the Assistant Secretary for Planning and Evaluation (OASPE), Department of Health and Human Services www.aspe.hhs.gov.
- Substance Abuse and Mental Health Services Administration (SAMHSA), Department of Health and Human Services www.samhsa.gov.
- Department of Housing and Urban Development (HUD) www.hud.gov.
- Bureau of Labor Statistics (BLS), Department of Labor www.bls.gov.
- Employee Benefits Security Administration, Department of Labor www.dol.gov/ebsa.
- Department of Veterans Affairs (VA) www.va.gov.
- Office of Statistical and Science Policy, Office of Management and Budget, www.whitehouse.gov/omb/inforeg_statpolicy.
- Office of Research, Evaluation, and Statistics, Social Security Administration www.ssa.gov.
- US Census Bureau, Department of Commerce www.census.gov.
    - Statistical Abstract of the United States http://www.census.gov/compendia/statab.
    - Age data http://www.census.gov/population/www/socdemo/age.html.
    - Longitudinal Employer-Household Dynamics http://lehd.did.census.gov/led/.
- US Fire Administration, Federal Emergency Management Agency.

B.4 Other countries

- Spinal Cord Injury Canada (formally Canadian Paraplegic Association) http://sci-can.ca/.