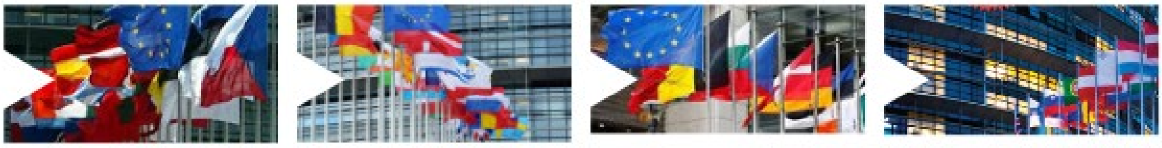
SFPE EUROPE



Q3 2020 ISSUE 19

AN OFFICIAL PUBLICATION OF SFPE

ANTHROPOMETRIC DATA AND MOVEMENT SPEEDS

By: Matthew Foley, SLS Consulting, Inc.

This paper summaries a study completed by Gales et al. It reviews the major components of the study and includes a selection of references used within the study. Readers are referred to the full study report for more information.

Introduction

The goal of the SPFE Research Roadmap is to identify future research needs to support the profession of fire protection engineering. An item identified during the inception of this program is the urgency to update the available data related to human behavior in a fire incident.

Developing an understanding of how occupants move in a building during a fire is of key importance in fire protection engineering. However, many of the egress models evaluated today use movement speeds and anthropomorphic data from research that was conducted over 40 years ago. At the time of its collection, sophisticated modeling of human behavior was heavily constrained by the limited processing power of computers at the time. As such, only rudimentary data capable of being modeled at the time was collected. The representativeness of this data has recently been subject to scrutiny from the fire protection community. In fact, authors of a widely accepted North American dataset have openly stated that their data may no longer be applicable and requested further data is collected to reflect changes in demographics.

We are now fortunate to have access to sophisticated egress modeling software capable of modeling more complex human behavior. Despite these computational advancements, the level of uncertainty associated with input data has remained largely unchanged since the early stages of the egress modeling development and analyses. Therefore, the progression of human behavior analyses is seemingly dependent on the cultivation of new, modern datasets.

Through a collaborative effort, York University and Arup led an SFPE Foundation Study with Lund University to compile specific movement and anthropomorphic data sets. This collaboration led to the development of a human factor database to complement the SFPE Handbook. This database will be available to the fire protection community to provide more applicable datasets for use in performance-based design and egress modeling. This new design tool intends to reduce the level of uncertainty in egress modeling by providing data to better represent the unique design challenges of each specific project.

Anthropometric Data and Movement Speeds

In addition to the existing compendium of movement data within the SFPE handbook, a number of universities and researchers have collected movement data. As part of this project, this includes York University and Arup who have been collecting movement data to support consultancy projects since 2015. Rather than focus exclusively on data collected through laboratory studies, researchers began to evaluate field studies of real infrastructure, including security footage and hand recordings. The findings of this SFPE Foundation study were published in "Anthropometric Data and Movement Speeds" in May 2020.

As part of the study, the research team improved upon an automated tracking technology methodology. Most of the data in this study was collected through high-resolution video taken from carefully selected vantage points. Data was extracted from this footage using open-access software, called Kinovea, originally designed to measure kinesthetic movements during a sporting event. The software was further modified by York researchers and then applied. Part of the analysis was to create a perspective grid that recognizes occupants as they walk between markers.

Figure 1: Movement Data Extraction Example using Automated Software

One of the more comprehensive studies in this report was completed at York University Stadium. Every summer, this stadium is host to several professional tennis tournaments. The stadium includes a pedestrian village that features restaurants, shops, and isolated events. The research team has been granted exclusive access to this stadium for research purposes since 2018.

The ethical considerations of studies involving human subjects are critical. In the York University Stadium study, each patron ticket for the tennis tournaments includes a written explanation of the study and disclosed that images of the attendees may be used for publication and research purposes. However, the university did not allow the research team to manipulate ground conditions or invoke emergency conditions of egress.

The primary areas of focus in this study included (1) general circulation, (2) movement on stairs, (3) accessibility, and (4) egress with urgency.

The study identified different age demographics in their evaluation of movement speeds for general circulation. The demographic categories included children, young adults, adults, and the elderly. In general, the occupants in this study traveled with a faster movement speed than the values typically used in egress modeling. The data also found a significant difference between demographic categories. For example, elderly occupants traveled as much as 19 percent slower than the average adult. These findings are compared with the standard Fruin Commuter Movement profiles in Table 1

		Speed (m/s)				
Agent Profile	**Sample Size**	**Min**	**Max**	**Mean**	**Median**	**SD**
Child	52	0.34	5.04	1.45	1.30	0.75
Young Adult	50	0.71	3.92	1.61	1.52	0.58
Adult	51	0.67	3.53	1.64	1.65	0.59
Elderly	50	0.40	2.52	1.32	1.23	0.48
Fruin	-	0.65	2.05	1.35	-	0.25

Table 1: Able-Bodied Profiles for Unimpeded Movement on Level Ground

The SFPE Handbook provides guidance for movement speeds in stadium stairs. This guidance is derived from a study at a German tennis tournament and reports an average speed of 0.71 meters per second. This value is comparable to the findings of the York University Stadium study, which reports an average movement speed of 0.73 meters per second. However, the York University Stadium study refined these movement speeds to identify age demographics and whether occupants were descending or ascending the stairs. The new study found that elderly people had an average movement speed of 0.52 meters per second, representing a 30 percent reduction in movement speed compared to adults. These findings are summarized in Table 2.

		Horizontal Speed (m/s)					
Agent Profile	**Sample Size**	**Min**	**Max**	**Mean**	**Median**	**SD**	**Direction**
Adult	53	0.36	1.26	0.71	0.70	0.18	Descent
	54	0.42	1.40	0.77	0.72	0.20	Ascent
Elderly	50	0.16	0.96	0.50	0.52	0.18	Descent
	51	0.16	1.14	0.55	0.55	0.15	Ascent

Table 2: Able-Bodied Profiles for Unimpeded Stair Movement

Movement profiles were also created for occupants with accessibility needs, including disabilities and other mobility limitations. Although this demographic only represented 3.7 percent of the total occupants, a sample size of 2,430 mobility profiles have been collected since 2018. Overall, the average movement speed of people with accessibility needs was 33 percent slower than those without accessibility needs. These findings are summarized in Table 3.

		Speed (m/s)				
Agent Profile	**Sample Size**	**Min**	**Max**	**Mean**	**Median**	**SD**
Cane	62	0.21	1.68	0.91	0.88	0.28
Crutches	5	0.35	1.22	0.68	0.66	0.34
Mobility Scooter	23	0.57	2.71	1.39	1.47	0.45
Person Req. Assist	61	0.16	2.02	0.98	0.95	0.41
Walker (Rollator)	15	0.21	2.02	1.07	0.98	0.59
Walking Stick	23	0.14	1.68	1.01	1.04	0.41
Wheelchair (Electric)	17	0.06	1.76	1.08	1.01	0.46
Wheelchair (Manual)	54	0.06	3.54	1.17	1.10	0.50
Total	260	0.06	3.54	1.05	1.02	0.44

Table 3: Mobility-Limiting Impairment Profiles for Unimpeded Movement on Level Ground

As previously mentioned, the university prohibited the use of a simulated fire scenario to evaluate movement speeds during an emergency. In lieu of an emergency, researchers sought to collect movement speeds in a situation that may be considered high urgency. A rare data collection opportunity presented itself when a torrential downpour of rain began during a filming event. Researchers filmed the egress of nearly 2,000 people during the stadium evacuation. The footage identified areas of crowd congestion, observed the decision making of occupants, and recorded a total egress time of 2.5 minutes with an average travel distance of 43 meters. Whilst a fire scenario would be localized and only likely affect those in the immediate vicinity, the event may be considered more akin to a terrorist event or a bomb threat.

In addition to the York University Stadium study, "Anthropometric Data and Movement Speeds" includes movement profiles for occupants in inter-city railway stations, museums, and retirement homes. Pending peer-review, the data recorded in these studies will eventually be featured in the new SFPE Database and made available to the fire protection engineering community for use in egress modeling.

Determining Evacuation Capability with Biomechanical Data

Current design guides typically use a basic flow rate for a single uniform population, which has not changed since the regulation of door and passageway sizes in the mid-20th century. The loss of confidence in the current data is due to a recognition of the ever-increasing proportions of elderly, obese and mobility impaired in society. These proportions have increased significantly since the original observations were made of the egress and circulation 'flows' of office workers and commuters between the 1950s and the 1980s. Despite the recognition of the potential dangers of using the original datasets, there has been no fundamental research carried out to study the effect of changing population demographics, or the nature and causes of the observed flow behaviours and associated parameters. Demographic changes have now provided the impetus and have reinforced the need to consider a "first-principles" approach to understand pedestrian movement in populated spaces.

In order to avoid increasing design and life safety implications, a fundamental change needs to be made to the pre-established approach to modelling occupant movement in populated spaces as uniform flows. As part of the SFPE Foundation study, York University sub-contracted Lund University to explore anthropometric datasets that can be used in future data collection methodologies. Rather than collect data about human movement through traditional experiments, "Determining Evacuation Capability with Biomechanical Data" focuses on the development of a biomechanical model linked to the characteristics of each individual. This new model is intended to enable the movement of a single file crowd to be derived from these demographics and biomechanical characteristics of the people in it.

The model focuses on the unimpeded normal walking speed of an occupant and its reduction due to the persons' intention to avoid collisions with other occupants around them. Additional biomechanical variables considered in this study include:

- Demographics parameters: including preferred walking speed, height, foot length, and body sway
- Gait Parameters: Factors including step length and step extent
- Contact Buffer: The distance between potential points of contact between the individual and the occupant in front of them
- Movement Adaption Time: The time needed for an occupant to recognize a change in movement conditions and adjust their walking speed as needed

Some of these basic principles are illustrated in Figure 3.

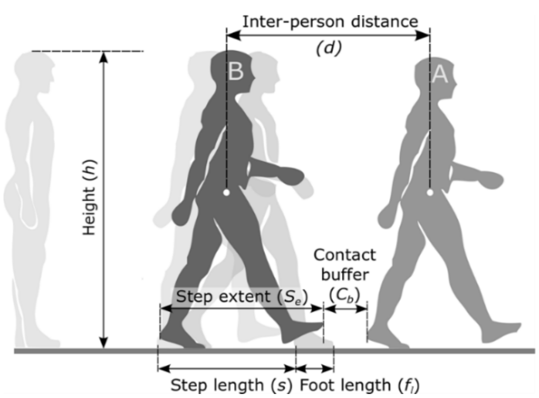


Figure 3: Components of Pedestrian Movement in a Congested Space

Basically, the model consists of the preferred speed of a person and their intention to avoid collisions with other pedestrians based on their physical and cognitive abilities. It can currently be used to predict walking speeds and single file flow and is based on the equations, presented in the report, in a spread sheet program. The “contact buffer” is the manifestation of the individual’s desire to avoid colliding with the person in front, where a person leaves enough space to allow for a potential sudden stop or change in walking speed of the person in front. This “contact buffer” also has a minimum value representing a comfortable “queue spacing” between individuals. In the project, some of the variables were quantified based on observations from a set of experiments.

All subjects in the experiments in the study were young, healthy students of Lund University. However, the results of this study were compared to available experimental data. Data produced by Cao (Cao et. al, 2016) was used for the elderly and young adults, while data produced by Wang (Wang et. al, 2018) was used for children. The results of this predictive model and the experimental data are compared in Table 4.

Parameters & calculated predictions	Lund Students	Elderly	Young	Children
Height (m)	1.80	1.62	1.64	1.42
Preferred Unimpeded Walking Speed (m/s)	1.29	0.95	1.23	1.29
Max Density (p/m)	3.28	2.58	3.40	4.34
Adaption Time (s)	0.37	0.68	0.37	0.37
Foot Length (m)	0.29	0.28	0.28	0.22
Step Extent Factor (at vu)	0.92	0.92	0.92	0.92
Peak Single-File Flow [p/s]	1.03	0.71	1.06	1.23
Percentage of Lund students flow rate	100%	69%	103%	119%
Difference from Lund students flow rate	0%	-31%	-3%	19%

Table 4: Summary of Predictions from the Movement Adaption Model Based on Parameters from Cao (2016) and Wang (2018)

While this study provides valuable data related to the movement speed of young adults, it also provides a framework to relate demographics and biomechanical information to movement speed. In the study, the results are basically considering single file movement and the model needs to be complemented with data from larger crowds. This initial step of deriving a predictive model for single-file flow analysis from the base principles of demographics, biomechanics and contact-avoidance shows remarkably good alignment with other overall published data on pedestrian movement. The mathematical model can potentially be used by fire protection engineers to derive suitable flow rates from the anticipated demographics of the population of the building. Further work will study flows across multiple lanes, using the same principles in order to build up a set of predictive calculations for a wider set of scenarios in different buildings with different occupancies (mixed ability, different elderly demographics, schoolchildren etc.).

SFPE Database

This SFPE Foundation study represents an important step in the development of a searchable database for the occupant characteristics used in egress models. While this searchable database will eventually be populated with data from new research, this database will initially be configured with the existing datasets found in the fifth edition of the SFPE Handbook.

The transition of the database and legal framework is still underway. It is anticipated that future research, through a collaboration with York University and SFPE Conseil St-Laurent, Québec will focus on buildings with limited availability of data, including airport and railway data. Additionally, a comprehensive validation exercise is being developed to support the introduction of these datasets into egress models.

Conclusion

A majority of the data related to human behavior in fire events is based on research completed over 40 years ago. As a result, many of the egress models completed today are evaluated with occupant movement speeds that were intentionally limited to facilitate limited computing power. New technologies, including developments in artificial intelligence and automated tracking software, are capable of recording new datasets that are more representative of changing demographics. As these datasets become increasingly available, the SFPE Digital Database will serve as a means for the fire protection community to share data in a standardized format and continue to evolve the practice of egress modeling. In addition, the data collected in future studies will also consider demographical and biomechanical data in order to base models on a first principle approach, this to consider anticipated changes in the population characteristics.

Download the Full Report

https://cdn.ymaws.com/www.sfpe.org/resource/resmgr/foundation/research/gales_report.pdf

References

[1] Gales, J. (2020) Anthropomorphic Data and Movement Speeds. *SFPE Scientific and Educational Foundation, Inc.*

[2] Thompson, P. (2020) Determining Evacuation Capability with Biomechanical Data. *Division of Fire Safety Engineering, Faculty of Engineering, Lund University.*