PROCEEDINGS, Fire and Evacuation Modeling Technical Conference (FEMTC) 2018
Gaithersburg, Maryland, October 1-3, 2018

Bridging the Pre-Movement and Movement Data Gap through Non-FPE Studies

Mohammed A. Saeefan

Saudi Arabian Oil Company
Dhahran, Saudi Arabia
Email: mohammed.saeefan@aramco.com

ABSTRACT

The lack of available data that can be used when conducting an evacuation analysis has been highlighted by a number of researchers over the past years. This has generated interest in bridging this gap by collecting pre-movement and movement times for impaired occupants, various occupancies and cultures. There have been limited efforts in examining existing data available in other scientific disciplines such medical journals. This paper provides a brief description of the current situations, data gaps and examples of available data collected from medical journals. It will also include a Pathfinder comparative analysis using data from non-FPE studies and the SFPE Handbook.

INTRODUCTION

The study of human behavior and movement speeds is very important for fire protection engineers with the increasing challenges associated with building design and egress analysis. According to the SFPE Handbook 5th Edition, in relation to fires, it shall be taken into consideration that the data available on human behavior is not sufficiently supported.[1] Therefore, the Fire Protection Engineer shall take into consideration the actual scenario he is designing for and selecting the appropriate data that is most suitable for it. To replicate actual real-life scenarios and the number and types of humans and buildings, this presents a major challenge for those trying to simulate human behavior in computer model simulations.

To study humans in real-life, the variables are massive. For example, age (young vs. old), health (able-bodied vs. disabled), size and weight, and culture effects. In addition to the human characteristics, there are also factors related to buildings and the environment such as the geometry effects, design of egress paths, and weather.

Existing Human Behavior Data

According to the SFPE Handbook 5th Edition, data related to human behavior was obtained using data collection techniques and through several research studies.[1] The handbook also states the importance of understanding how the data was obtained and under what circumstances. All this information has a great influence on the validity of the data and the computer simulation results.

Data used by fire protection engineer (FPE) designers is usually obtained through several sources, but mainly from the SFPE Handbook, NFPA Handbooks, and FPE journals. Furthermore, many FPE researchers have placed a great effort into studying human behavior with as many variables as they can. There are a lot of issues FPEs are facing in regard to all these data as they are not enough and don't cover the vast range of parameters for humans and buildings.

Issues FPEs are facing in regard to existing data.

- Many of the data available are very old and outdated, some dated back to 1971 from a study performed by Fruin.[1]
- Many of these studies are done by studying people who are homogeneous. This means without mixing different types of people when conducting the study. In reality, people are heterogeneous.
- Lack of data in pre-movement and movement stages for people.

OTHER NON-FPE DISCIPLINES

Although a lot of great efforts have been done by FPE researchers, this paper examines studies and research done by non-FPE disciplines. These disciplines are civil engineering, traffic engineering, and medical science. Each study will be analyzed to determine the quality of the results and how it may benefit FPEs.

Civil Engineering Studies

Utah State University-Civil Engineering Department Study[2]

A thorough study conducted by the Utah State University Civil Engineering Department studied the behavior of homogeneous and heterogeneous crowds, by having disabled and normal people in the same crowd and studying the impact on crowd movement. They built a 3,000 ft^2 circuit that included different geometries and tested 202 people, including 20 people with different disabilities. In addition, they did speed tests on stairs for 100 people, including 20 disabled. Types of disability were represented by actual percentage data (2.1% had visual impairment and 6.8% with ambulatory disability).[2] The test circuit was fitted with advanced automated video identification and tracking technology for data collection that can track up to 512 identifiable markers in a camera field at once. Figure 1 below illustrates the facility and the automated video identification usage.

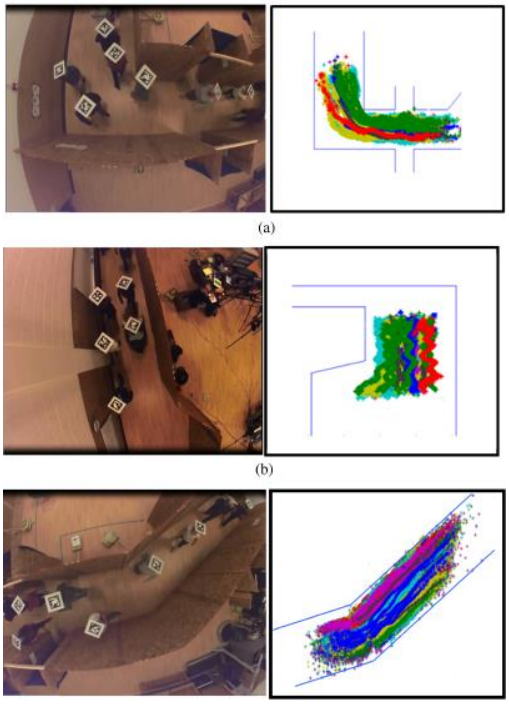

Figure 1: Trajectories at different facilities and example of automated video identification.[2]

Figure 2 shows the mean walking speeds of homogeneous and heterogeneous populations in different walking environments.[2] A significant reduction of the mean speed in heterogeneous populations is shown and this information can be very beneficial to FPEs in addition to showing the effect of geometry on walking speed.

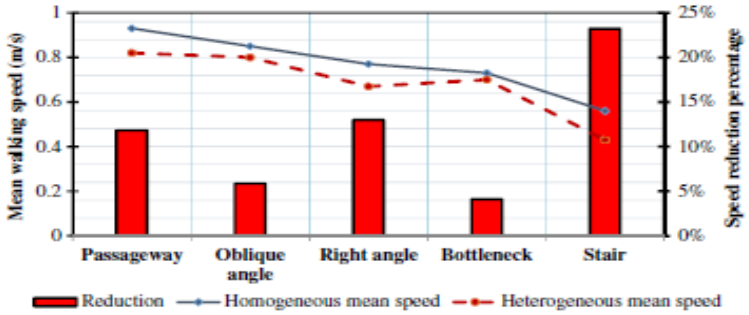

Figure 2: Mean walking speeds of homogeneous and heterogeneous populations in different walking environments.[2]

The research shows the mean speed of different disability types, such as visual and motorized, as presented in Figure 3.[2] All these data are very useful as they provide several variables and parameters that can be studied further by FPEs

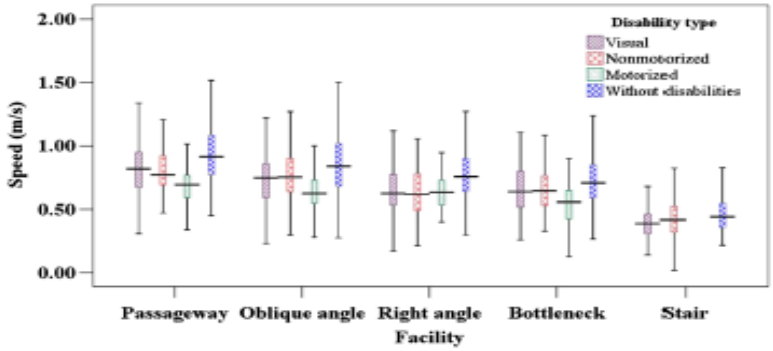

Figure 3: Walking speed statistics for different pedestrian groups and walking environments.[2]

University College of London, Study by Civil Engineers through the Center for Transport.[3]

This study focused on walking speeds of pedestrians on stairs and how the speeds compared to his/her characteristics and the stair gradient. In their study, the researchers compared the results with those from the study by Fruin (1971). They studied 18 elderly people (age 50+) and 15 young people (age 30-50). Their results were tabulated for different stair gradients and showed that walking speeds identified by Fruin were slower than those identified in their tests.

Table1: Comparison of results with Fruin (1971).[3]

	Stair gradient	Ascending				Descending			
		Elderly		Young		Elderly		Young	
		Male	Female	Male	Female	Male	Female	Male	Female
This study	38.8	0.41	0.46	0.50	0.47	0.46	0.48	0.61	0.57
	35.0	0.50	0.53	0.57	0.56	0.60	0.57	0.62	0.67
	30.5	0.56	0.60	0.65	0.62	0.64	0.64	0.72	0.76
	24.6	0.68	0.76	0.77	0.75	0.80	0.80	0.82	0.91
Fruin (1971)	32	0.43	0.39	0.69	0.51	0.57	0.47	0.69	0.51
	27	0.41	0.45	0.81	0.65	0.60	0.56	0.81	0.65

Horizontal walking speeds (m/s)
(Stair-gradient: (degree))
Data of Fruin: Data of pedestrians aged more than 50 is applied into "Elderly"
Data of pedestrians aged from 30 to 50 is applied into "Young"

The researchers indicated in the study that the differences between the two studies may be due to their tests being conducted in labs and for individuals, while Fruin conducted actual real-world test results, and the possibility of people walking together had an effect on the results.[3] From this study, FPEs can use stair walking speed data such as age difference, culture difference, and individual vs. group effect.

***Technical University of Denmark, Department of Civil Engineering*[4]**

Research was performed at the Technical University of Denmark to study the following three objectives: horizontal and stairs walking speeds, the relationship between density and walking speeds, and human behavior during evacuation exercises. The research has focused on people with visual impairments as it is estimated that 1 out of 6 people suffers from visual impairment.[4] These visually impaired people suffer when emergencies happen.[4]

This research included several studies on the evacuation speeds of blind and visually impaired people in case of fires. They have tested 57 people with different visual impairment levels, between the ages of 10-79, and conducted multiple tests of single and group evacuations to study the difference of group behavior. They have done the tests in Denmark and then in the United States for horizontal and stair walking speeds, and compared those with Nelson & Mowrer data from the SFPE Handbook[1] as shown in Table 2 below:

Table 2: Mean Walking Speeds for Danish vs. USA vs. SFPE.[4]

	Mean Speed (m/s) Horizontal	Mean Speed (m/s) Descending Stairs
Danish	0.98 (σ=0.36)	0.78 (σ=0.17)
USA	1.23 (σ=0.48)	0.54 (σ=0.21)
SFPE	1.19	0.85-1.05

This study also showed the effect of having good lighting conditions on improving evacuation speeds and the importance of handrails for visually impaired people, and how it is important to have color and texture differences to direct visually impaired people to exit quickly.[4] All these data and parameters are very useful for FPEs, especially because the study focused on evacuations during fire emergencies.

<u>Traffic Engineering Studies</u>[5]

A study was conducted on the simulation of pedestrian crowds in normal and evacuation situations by researchers from three universities, which are Dresden University of Technology, Germany; Eötvös Loránd University, Hungary; and Clark Atlanta University, USA.[5] This study related pedestrian movement to fluid dynamics and developed a theoretical microscopic simulation on pedestrian streams. Using force models, which they have developed, they managed to replicate real-life human

behavior in normal and panic situations.[5] The phenomena reproduced in normal situations are lane formations, oscillations at bottlenecks, and dynamics at intersections. See below Figure 4 illustrating these phenomena:

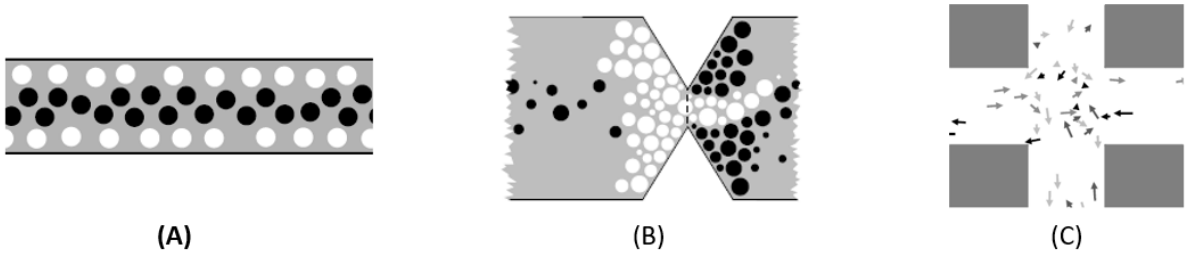

Figure 4: (A) Lane Formation, (B) Oscillations at bottlenecks, (C) Dynamics at intersections.[5]

The phenomena reproduced in panic situations are freezing by heating, transition to incoordination due to clogging, faster is slower effect, phantom panics, and ignorance of available exits due to herding.[5] See Figure 5 below, illustrating these phenomena.

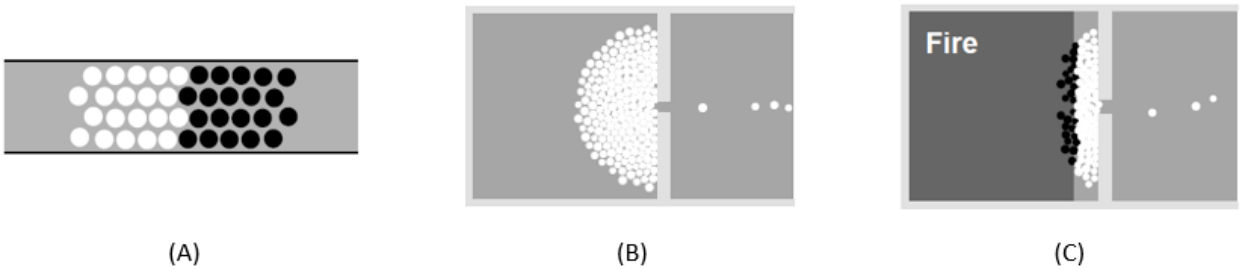

Figure 5: (A) Freezing by heating, (B) transition into coordination due to clogging, (C) faster is a slower effect.[5]

This study is very useful to FPEs for improving the evacuation models such as PYROSIM and Pathfinder, and understanding human behavior more.

Medical Science Studies

The University of Queensland, Australia, Medical Science.[6]

Researchers from Queensland, Australia, reviewed data from 4646 studies to ensure the data were of high quality. They narrowed down the number of studies to 48 that meet their selection process. These 48 studies included 7000 participants over the age of 70 in hospital inpatient and outpatient settings.[6]

They specifically studied the speed of gait, a type of movement people engage in to get from one point to another, over 15 m along straight horizontal walkways under uniform conditions.[6] "Gait speed" is a ''reliable measure of functional capacity with well-documented predictive value for health-related outcomes''[6]. The results from this study generated usual pace and maximum pace data for both settings (inpatient and outpatient) and for different age groups above 70+ and for different sexes. The estimates were 0.58 m/s for usual pace, 0.89 m/s for max pace, 0.46 m/s for acute care, and 0.74 m/s for outpatient usual pace.[6] This study compared these results with walking speeds for adults older than 70 years of age in normal community-dwelling and found that these results are slower.[6] FPEs can build on this extensive data and potentially use them for the specific conditions given in hospitals. They can benefit from the different culture these data are from and the different parameters they include.

University of Madrid, Department of Health and Human Performance Study.[7]

Researchers from the Department of Health and Human Performance at the University of Madrid, Spain, have studied the reaction time (RT) to visual stimuli in athletes with and without hearing impairment. 79 athletes with a mean age of 22.6 years and without hearing impairment and 44 athletes with a mean age of 25.6 years that had hearing impairment issues participated in this experiment. Results were found to be that the RT for athletes with hearing impairment was significantly shorter to visual stimuli, especially in males.[7] Therefore, FPEs can use this study as a starting point to pre-movement data for hearing impaired people. The data also provide parameters for different cultures and different genders.

DATA COMPARISON BETWEEN SFPE AND NON-FPE DATA THROUGH PATHFINDER

To test one of the above non-FPE studies and compare it with data points from the SFPE Handbook[1], this paper will use Pathfinder evacuation simulation model software to show the different results achieved.

Pathfinder Software[8]

Pathfinder is a computer software developed by Thunderhead Engineering Consultants to simulate human evacuation in any structure.[8] The user can understand and evaluate pedestrian egress and congestion hazards for fire protection and safety or even urban planning. It can import AutoCAD drawings and convert them immediately into ready-to-use models where you just need to enter occupant number and details. Pathfinder includes an integrated user interface and animated 3D results.

Building Description

The building used in this comparison is a 13 story office building at Saudi Arabian Oil Company in Saudi Arabia. It consists of two wings in each floor with a center core area containing a conference room. The building capacity is 4200 occupants but the average number of people is 3000 employees.

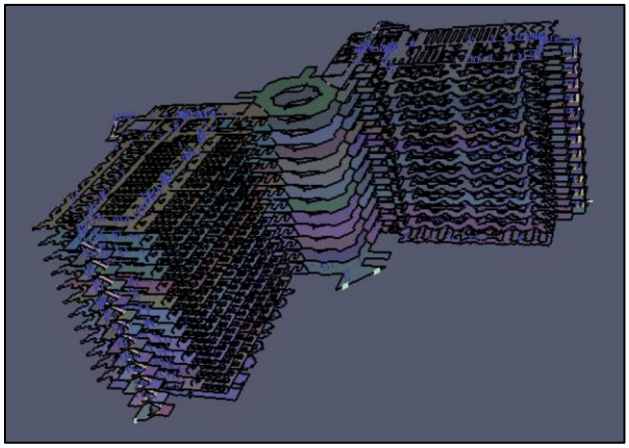

Figure 6: 3D model of the building used in this study using Pathfinder software.

Input Data Used

The number of occupants (adults, all able-bodied) used in the simulation model was 4069, with 156 occupants in the east wing, and 157 occupants in the west wing in each floor. The walking speeds chosen for this comparison are the shown in Table 3, for SFPE data, and Table 4, for the non-FPE study, shown below.

Table 3: Walking speed sample data from SFPE Handbook 5th edition.[1]

Lee and Lam [136]	L: Hong Kong, China N: C –3 × 2 h peak periods over 5 days SC: two underground stations P: commuters mixed age and gender V: movement rates in uncongested conditions	Video (time-lapse photography)	1232	Uncongested	0.31–1.4* *Extracted from graph for uncongested conditions

Table 4: Walking speeds sample data from Utah State University Civil Eng. Department Study.[2]

Mean Speed	0.93 m/s
Min. Speed	0.71 m/s
Max Speed	1.15 m/s
Standard Deviation	0.22 m/s

One thing to note, the walking speed in the SFPE run was set to Uniform and the walking speed in USU run was set to Normal. The distribution of occupants was equal for both runs.

Observations and Recommendations

The evacuation time for the SFPE run was 2081 seconds and for the non-FPE run it was 1691 seconds. The actual evacuation time for the building was actually closer to the non-FPE run. Many factors have affected this result. For example, the uniform vs. normal walking speed, the method used to collect the data, the quality of both data, and the location and culture of the data taken.

It is important to conduct more detailed analysis to determine the independent variable with significant effects. Each designer shall build up his own database suitable for the location he is designing for. Data reporting should be standardized. As mentioned previously, there are a lot of variables and it is important to make sure the quality of this data is met before recording any of them. In addition, more studies shall be conducted on heterogeneous groups as they represent real-life scenarios and in every crowd and group of people, not all of them will be able-bodied.

CONCLUSION

It is important to utilize and benefit from other studies to bridge knowledge gaps and encourage knowledge transfer between different disciplines. Several researchers from the fire protection field have conducting many such studies but many studies still need to be done in order to improve our prediction of human behavior during fires. FPEs must first localize the many great studies performed in its field to simplify data collection and act as a great build-on point for new researchers to start.

REFERENCES

1. Hurley, M.J. & Gottuk, D & J.R., Jr, Hall, & Harada, K & Kuligowski, E & Puchovsky, M & Torero, J & J.M., Jr, Watts, & Wieczorek, C. (2016). *SFPE handbook of fire protection engineering, fifth edition*. 10.1007/978-1-4939-2565-0.
2. Sharifi, M., Stuart, D., Christensen, K., Chen, A., Kim, Y., Chen, Y., (2015), "*Analysis of Walking Speeds Involving Individuals with Disabilities in Different Indoor Walking Environments*", *Journal of Urban Planning and Development*, American Society of Civil Engineers, doi: 10.1061/ (ASCE)UP. 1943-5444.0000288. Available from: http://www.researchgate.net/publication/281189721_Analysis_of_Walking_Speeds_Involving_Individuals_with_Disabilities_in_Different_Indoor_Walking_Environments
3. Fujiyama, T., Tyler, N., "*Explicit Study on Walking Speeds of Pedestrians on Stairs,*" Center for Transport Studies, University College London. Available from: http://discovery.ucl.ac.uk/1243/1/2004_21.pdf
4. Sorensen, J., (2014), "*Can Blind and Visually Impaired People Evacuate Safely in Case of Fire?*" Technical University of Denmark - Department of Civil Engineering, Available from: http://www.vigilfuoco.it/aspx/download_file.aspx?id=17319
5. Helbing, D., Farkas, I., Molnar, P., Vicsek, T., "*Simulation of Pedestrian Crowds in Normal and Evacuation Situations,*" available from: http://www.pmcorp.com/Portals/5/_Downloads/Simulation%20of%20Pedestrian%20Crowds%20in%20normal%20and%20evacuation.pdf
6. Peel, N., Kuys, S., Klein, K., "*Gait Speed as a Measure in Geriatric Assessment in Clinical Settings: A Systematic Review.*" *J Gerontol A Biol. Sci. Med. Sci.* Oxford University Press. 2012 January;68(1):39–46 doi:10.1093/gerona/gls174, Available from: http://biomedgerontology.oxfordjournals.org/content/68/1/39.full
7. Soto-Rey, Javier & Pérez-Tejero, Javier & J Rojo-González, Jesús & Reina, Raul. (2014). "Study of reaction time to visual stimuli in athletes with and without a hearing impairment." Perceptual and motor skills. 119. 123-132. 10.2466/22.15.PMS.119c18z9. Available from: https://www.researchgate.net/publication/265055315_Study_of_reaction_time_to_visual_stimuli_in_athletes_with_and_without_a_hearing_impairment
8. Thunderhead Engineering Consultants, (2018), available from: https://www.thunderheadeng.com/