THE INFLUENCE OF CALIBRATED MOVEMENT DATA ON MOVEMENT EGRESS TIMES IN COMPUTATIONAL SIMULATION MODELING

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ABSTRACT

This presentation quantifies the egress movement time error introduced by the use of default settings for occupant physical parameters in the Pathfinder egress modeling software. By using calibrated physical occupant inputs for Speed, Diameter, Reduction Factor, and Personal Distance taken from a large airport located within the United States [2], a comparative analysis determined the most influential physical occupant variable on calculated egress movement times. In conjunction, egress movement times were compared between Pathfinder simulations that utilized default occupant physical parameter values and simulations that utilized calibrated physical occupant data. The analysis found that egress movement times calculated using calibrated occupant data were up to 100% longer than egress movement times calculated using default settings. This difference in egress movement times is an item of significant safety importance in the traditional Required Safe Egress Time (RSET) calculation.

Additionally, calibrated physical occupant parameters for identified user groups were compared between two large geographically disparate airports located within the United States. The analysis found that even similar user groups from different geographic locations could produce egress movement times that vary up to 18%. Therefore, it was concluded that an occupant population is unique to both geographic location and types of occupancy user groups. Ultimately, an engineer not using calibrated occupant data for computational egress modeling can obtain results that are fundamentally unreliable and potentially reduce safety by margins of between 20% and over 100%.

INTRODUCTION

The use of performance-based design has become widely utilized and accepted throughout the Fire Protection Engineering community for its ability to quantify the safety levels associated with a design scenario [3]. A popular performance-based design analysis tool is the Available Safe Egress Time (ASET) vs. Required Safe Egress Time (RSET) comparative analysis. Safe egress from a fire event is said to be achieved when the calculated RSET is shorter than the calculated ASET [4]. See *Figure 1* for a graphical representation of the traditional ASET vs. RSET analysis.

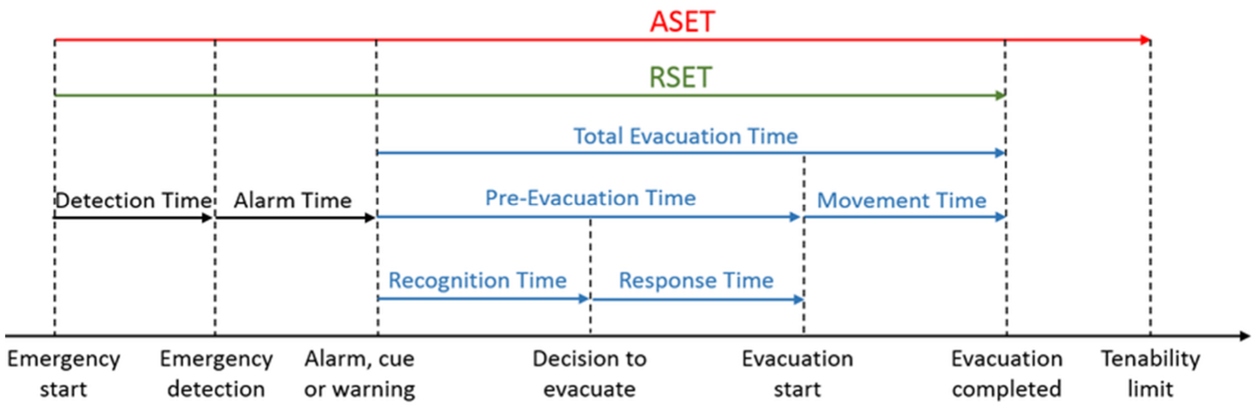

Figure 1: Available Safe Egress Time (ASET) vs. Required Safe Egress Time (RSET) [1]

A major component in the RSET calculation is the determination of egress movement time. Egress movement time is the time required for occupants to move through escape routes and reach a point of safety [3] [5]. To calculate egress movement times, the engineer may choose from a variety of techniques including empirical calculations, manual engineering calculations, or computational simulation modeling [6].

Computational simulation modeling is typically performed using computer simulation egress modeling software. There are multiple movement calculation methodologies among the available computer simulation modeling software packages. These various modeling predictions are based on a set of initial [default] conditions, algorithms, and values that are set by the developer and describe the behavioral and physical characteristics of the occupants being simulated [6] [3]. For some egress models, the default settings will address a narrow range of parameters specific to a certain area of analysis; in other models, the default settings may relate to a more general range of parameters that could apply to a range of different scenarios [7]. Ultimately, default values are provided in egress models to allow for ease of use of the model at initial setup. As stated in the Pathfinder Disclaimer, “Pathfinder is intended only to supplement the informed judgment of the qualified user.” [8]. The use of default settings is, by the very nature of the definition of *default*, an item that requires exploration and modification by the informed judgment of a qualified user.

In computer egress modeling, the building’s occupants are required to be populated by the user. The SFPE Guide to Human Behavior in Fire states that among other attributes, at a minimum, the number of occupants, their distribution throughout the building, and their characteristics and movement abilities (e.g., age, gender, impairment, achievable speeds, flow/density relationship, etc.) are required [6]. Using default values in egress models can represent optimistic and even unrealistic evacuation conditions or occupant behavior, which can lead to inappropriate and overly optimistic egress movement time results [3]. Therefore, the Engineering Guide for Human Behavior in Fire has stated that the user should never blindly adopt default values, but instead be informed about the assumptions on which they are based and the scenarios to which they might apply [6].

To better understand the impact of default values, the analysis presented herein quantified the potential calculated egress movement time error introduced by the use of pre-set, default physical occupant characteristics. The four physical occupant parameters studied were: Speed, Diameter, Reduction Factor, and Personal Distance. A comparative analysis was also performed between default and calibrated physical occupant user data to determine the most influential physical characteristic parameter in determining more accurate egress movement times.

This research also compared sets of calibrated occupant data from two large geographically disparate airports located within the United States. The aim was to demonstrate and understand the impact of geographic location on empirical physical occupant parameters for similar user groups. The impact on egress movement times was determined for each geographic user group studied on identical physical buildings.

OBSERVATIONS

A previously published research paper created a table of calibrated user group data for various physical characteristics based on observation made in a large Eastern United States airport [2]. The authors of this paper observed that the physical characteristics recorded in the study varied from the default values found within the Pathfinder egress modeling software. For example, referencing Table 1 below, the default Pathfinder mean walking speed was up to 18% faster than calibrated walking speeds for the observed 'group/family' user group. Additionally, the shoulder widths across all user groups were larger than the default Pathfinder value. It is noted that these increased shoulder widths were likely due to the presence of luggage, backpacks, and similar items associated with airport occupants. This claim adds to the statement that egress modeler users should not adopt default values, but instead use informed assumptions for the building type and user population being modeled.

Table 1: Default Pathfinder Values vs. Calibrated Eastern United States Airport Occupant Data (Select User Group Profiles)

PROFILE	SPEED (m/sec)		% CHANGE FROM DEFAULT	SHOULDER WIDTH (m)	% CHANGE FROM DEFAULT	REDUCTION FACTOR	% CHANGE FROM DEFAULT	PERSONAL DISTANCE (m)	% CHANGE FROM DEFAULT
DEFAULT	Constant:	1.19		0.46	-	0.70	-	0.08	-
Single with Roller Bag	Min:	0.80	-33%						
	Max:	3.35	182%						
	Mean:	1.28	8%						
	StdDev:	0.32	-	0.91	98%	0.70	0%	0.91	1038%
Single w/o Roller Bag	Min:	0.76	-36%						
	Max:	1.46	23%						
	Mean:	1.23	3%						
	StdDev:	0.27	-	0.61	33%	0.50	-29%	0.91	1038%
Group / Family	Min:	0.47	-60%						
	Max:	1.47	24%						
	Mean:	0.98	-18%						
	StdDev:	0.20	-	0.61	33%	1.00	43%	0.46	475%
Mobility Impaired - Self-Propelled	Min:	1.27	7%						
	Max:	1.83	54%						
	Mean:	1.49	25%						
	StdDev:	0.24	-	0.91	98%	1.00	43%	0.91	1038%

Where the authors of the initial airport study, referenced above, outline a single airport population comparison against the default settings, the study outlined herein expands the study group to include multiple geographic and facility designs in comparison to default settings. Additionally, this study compared the user groups observed between two large, geographically disparate airports.

Table 2 provides the user group distribution that was observed between an airport located in the Eastern United States and an airport located in the Western United States. A higher percentage of mobility impaired occupants were observed at the Eastern United States airport, while more groups and families were observed in the Western United States Airport.

Table 2: User Group Population Distribution Comparison – Western vs. Eastern United States Airport

OCCUPANT PROFILES	WESTERN UNITED STATES AIRPORT	EASTERN UNITED STATES AIRPORT
SINGLE OCCUPANTS	57.4%	64.2%
GROUPS AND FAMILIES	38.8%	23.0%
MOBILITY IMPAIRED	3.9%	12.8%

Table 3 provides a comparison between physical occupant parameters recorded for different user groups at each airport located in the United States. Based on the disparately between similar user groups (i.e., airport occupants), it was hypothesized that an occupant population is unique to each location and obtaining calibrated population data for the specific user and geographic location being studied is essential when performing an egress movement time analysis as part of an overall performance-based ASET vs. RSET analysis.

Table 3: User Group Characteristics Comparison – Western vs. Eastern United States Airport

Profile	Single with Roller Bag				Single w/o Roller Bag				Mobility Impaired - Self Propelled			
Western US Speed (m/sec)	Min:	Max:	Mean:	StdDev:	Min:	Max:	Mean:	StdDev:	Min:	Max:	Mean:	StdDev:
	0.55	1.91	1.19	0.27	0.53	3.28	1.16	0.28	0.70	1.53	1.07	0.43
Eastern US Speed (m/sec)	Min:	Max:	Mean:	StdDev:	Min:	Max:	Mean:	StdDev:	Min:	Max:	Mean:	StdDev:
	0.80	3.35	1.28	0.32	0.76	1.46	1.23	0.27	1.27	1.83	1.49	0.24
% Difference	-37%	-55%	-8%	-16%	-36%	77%	-6%	4%	-58%	-18%	-33%	56%
Western US Shoulder Width (m)	0.69				0.50				0.49			
Eastern US Shoulder Width (m)	0.91				0.61				0.91			
% Difference	-27%				-21%				-60%			
Western US Reduction Factor	1.00				1.00				1.00			
Eastern US Reduction Factor	0.70				0.50				1.00			

Profile	Single with Roller Bag	Single w/o Roller Bag	Mobility Impaired - Self Propelled
% Difference	35%	66%	0%
Western US PERSONAL DISTANCE (m)	0.62	0.70	0.76
Eastern US PERSONAL DISTANCE (m)	0.91	0.91	0.91
% Difference	-37%	-27%	-18%

Based on the observations above, this study aimed to answer the following questions:

1) What is the effect of using default physical occupant parameters on calculated egress movement time compared to calibrated occupant user data?

2) Which of the four identified physical parameters has the most influence on calculated egress movement times?

3) What effect does using calibrated data from similar user groups with a different geographic location have on calculated egress movement times?

METHODOLOGY

The computational simulation modeling software chosen for this research was Pathfinder developed by Thunderhead Engineering Consultants, Inc. Pathfinder is an agent-based egress and human movement simulator and was chosen due to its simple graphical user interface and robust human behavior modeling capability. Egress movement times can be computed using one of two available modes. The first, "SPFE Mode", is a flow-based egress modeling mode that computes flows through doors and stairs depending on their widths, and agents (i.e., occupants) are allowed to overlap and collide. The second, "Steering Mode", is a movement simulation mode that aims to emulate human behavior and movement as much as possible. Pathfinder's steering mode allows more complex behavior to naturally emerge as a byproduct of the movement algorithms, thereby eliminating the need for explicit door queues and density calculations [8]. Due to this higher degree of realism, the Steering Mode was chosen for this analysis.

The research was conducted in two phases. In Phase 1, a comparative analysis was performed to identify the influence that each physical occupant characteristic inputs for Speed, Diameter (i.e., shoulder width), Reduction Factor, and Personal Distance has on total egress movement times. Additionally, Phase 1 aimed to determine the most influential physical occupant input parameter in calculated egress movement times. Phase 2 compared and contrasted calibrated user physical parameter data sets from two large geometrically disparate airports located within the United States. The overall goal of Phase 1 and Phase 2 was to quantify the effect that using default occupant physical parameters has on the calculated egress movement time when compared to calibrated occupant user data.

Phase 1 – Influence of Default vs. Calibrated Physical Occupant Parameters

In Phase 1, an Eastern United States airport tenant space was used as the representative geometry for the Pathfinder simulations. The occupant profiles chosen for the comparative analysis were based on previous research [2]. A total of eight (8) user profiles were identified with calibrated physical characteristics for Speed, Diameter (i.e., shoulder width), Reduction Factor, and Personal Distance (previously known as comfort distance). These calibrated user groups were distributed throughout the Pathfinder model based on the identified percentages during the calibration process (Refer to Table 2). See *Figure 2* for the Pathfinder geometry layout of the Phase 1 analysis.

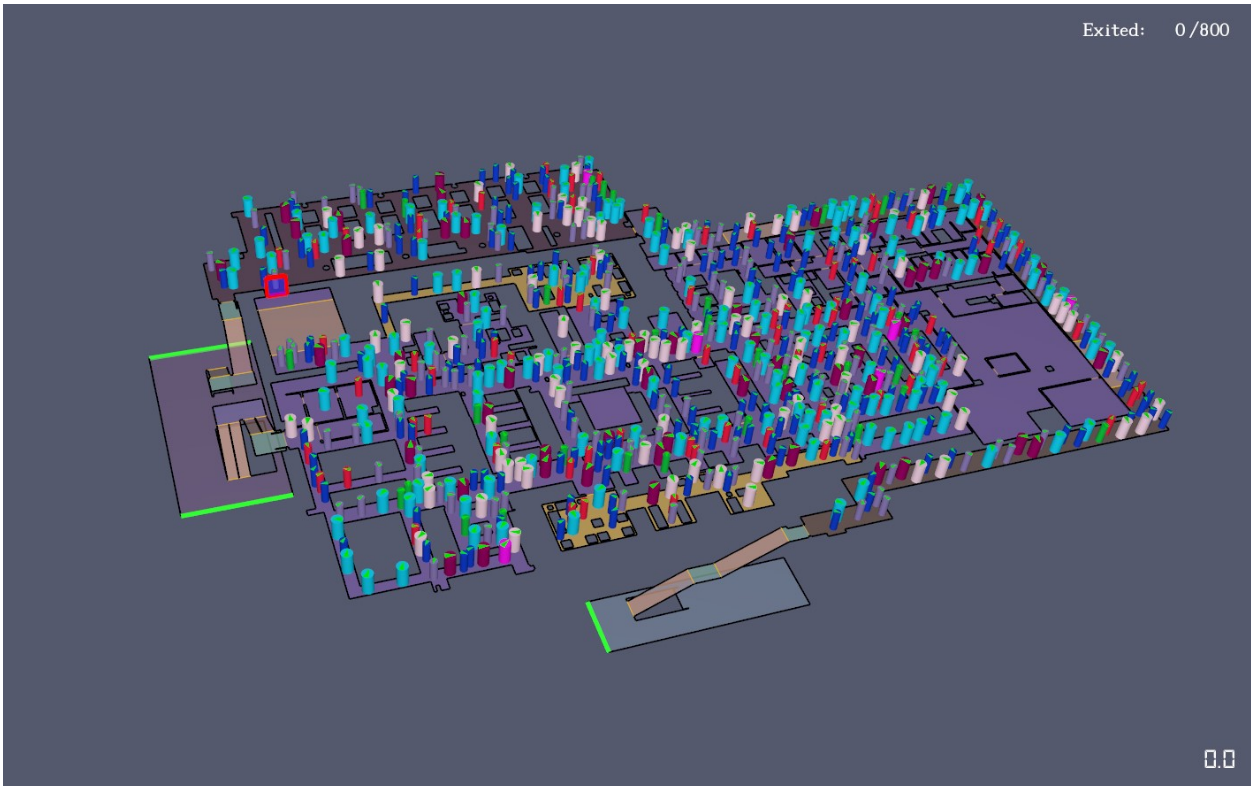

Figure 2: Pathfinder Model Geometry and Occupant Loading for Phase 1 (Eastern United States)

The comparative analysis was performed for each of the four (4) physical parameters by systematically changing one physical parameter at a time across all user groups. A total of 20 Pathfinder simulations were conducted. See Table 4 below for a description and summary of the simulations modeled for Phase 1. Simulation #1 correlated to a simulation using all default values for the physical characteristics while Simulation #18 represented a fully calibrated simulation in terms of the physical characteristics identified for each user group. Simulations #2 and #19 utilized an additional option for 'reduction factor', which was to disable the parameter's effect within the simulation. Simulation #20 also correlated to a fully calibrated simulation that utilized the mean value for speed as opposed to the normal distribution that was chosen for the remaining calibrated speed simulations.

Table 4: Phase 1 Pathfinder Simulation Summary (Eastern United States Airport Geometry and Eastern United States Airport Geometry Occupant User Group Data)

Simulation	Profile	Speed	Diameter (Shoulder Width)	Reduction Factor	Personal Distance	Notes
1	Default	Default	Default	Default	Default	Baseline Default Run
2	Default	Default	Default	Off	Default	
3	Calibrated	Default	Default	Default	Default	
4	Calibrated	Default	Default	Default	Calibrated	
5	Calibrated	Default	Default	Calibrated	Default	
6	Calibrated	Default	Default	Calibrated	Calibrated	
7	Calibrated	Default	Calibrated	Default	Default	
8	Calibrated	Default	Calibrated	Default	Calibrated	
9	Calibrated	Default	Calibrated	Calibrated	Default	
10	Calibrated	Default	Calibrated	Calibrated	Calibrated	
11	Calibrated	Calibrated	Default	Default	Default	
12	Calibrated	Calibrated	Default	Default	Calibrated	
13	Calibrated	Calibrated	Default	Calibrated	Default	
14	Calibrated	Calibrated	Default	Calibrated	Calibrated	
15	Calibrated	Calibrated	Calibrated	Default	Default	
16	Calibrated	Calibrated	Calibrated	Default	Calibrated	
17	Calibrated	Calibrated	Calibrated	Calibrated	Default	
18	Calibrated	Calibrated	Calibrated	Calibrated	Calibrated	Baseline Calibrated Run
19	Calibrated	Calibrated	Calibrated	Off	Calibrated	
20	Calibrated	Mean	Calibrated	Calibrated	Calibrated	

Phase 2 – Influence of Occupant Geographic Location

Phase 2 aimed to understand the impact of specific building user data by comparing sets of calibrated occupant data from two large geographically disparate airports located within the United States. The calibrated Eastern United States airport data, identified in Phase 1, was compared to ten (10) calibrated user groups observed for an airport located in the Western United States. Each group of airport calibrated data was simulated in its respective airport geometry to achieve a baseline egress movement time. This baseline egress movement time was then compared to egress movement times calculated from using calibrated airport user group data from the other geographic disparate airport. See *Figure 3* below for the Pathfinder geometry layout of the Phase 2 analysis runs that utilized the entire Western United States airport geometry. The Eastern United States geometry was similar to Phase 1 (Refer to *Figure 2*).

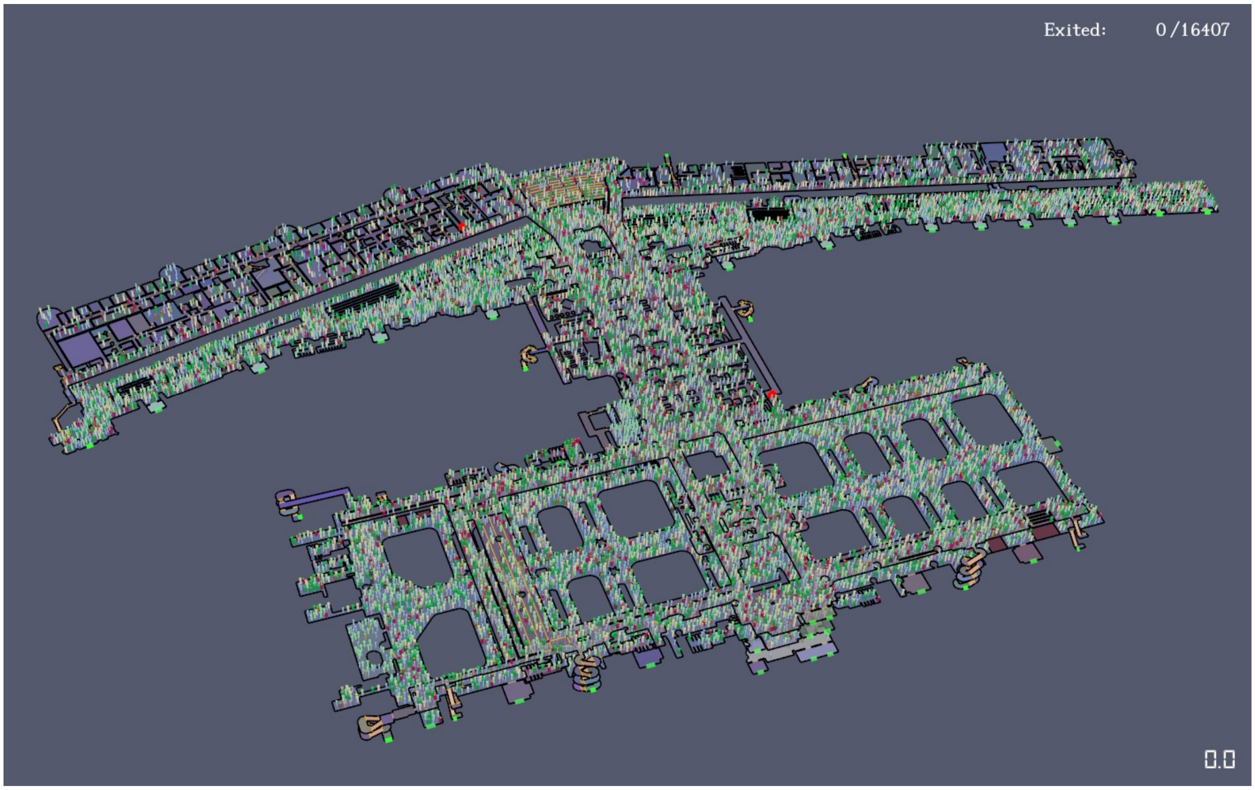

Figure 3: Pathfinder Model Geometry for Phase 2 (Western United States)

The summary of simulations for Phase 2 can be found in Table 5. Simulation #1 and Simulation #5 would generate the baseline egress movement times for the calibrated user data for the respective airport being assessed. Simulation #3 and Simulation #7 would help determine the impact that similar user groups (e.g., airport users) with different geographic locations (e.g., Western vs. Eastern United States) can have on egress movement times. These calibrated Pathfinder simulations were also compared to Pathfinder simulations that utilized all default occupant physical parameter settings, similar to Phase 1, for Simulations #2, #4, #6, and #8.

Table 5: Phase 2 Pathfinder Simulation Summary (Eastern vs. Western United States Airport User Group Comparative Analysis)

Simulation	Geometry (United States)	Occupant Profiles	Speed	Diameter (Shoulder Width)	Reduction Factor	Personal Distance	Simulation Notes
1	Western	Western	Western	Western	Western	Western	Baseline Western US Run
2	Western	Default	Default	Default	Default	Default	Default with Initial Occupant Position as Run #1
3	Western	Eastern	Eastern	Eastern	Eastern	Eastern	Eastern US Occupant Data
4	Western	Default	Default	Default	Default	Default	Default with Initial Occupant Position as Run #3

Simulation	Geometry (United States)	Occupant Profiles	Speed	Diameter (Shoulder Width)	Reduction Factor	Personal Distance	Simulation Notes
5	Eastern	Eastern	Eastern	Eastern	Eastern	Eastern	Baseline Eastern US Run
6	Eastern	Default	Default	Default	Default	Default	Default with Initial Occupant Position as Run #5
7	Eastern	Western	Western	Western	Western	Western	Western US Occupant Data
8	Eastern	Default	Default	Default	Default	Default	Default with Initial Occupant Position as Run #7

RESULTS

Phase 1 – Results

Figure 4 graphs the egress movement times for the twenty Pathfinder simulations conducted for Phase 1 using the geometry of the Eastern United States Airport. As noted, simulation #1 was the default run and produced a total egress movement time of 6:02. The calibrated simulation, #18, produced a total egress movement time of 12:11, which was 102% greater than the default simulation #1. Based on the results, using calibrated physical occupant data within the simulation resulted in an egress movement time two times (2x) greater than the simulation that utilized default physical occupant settings.

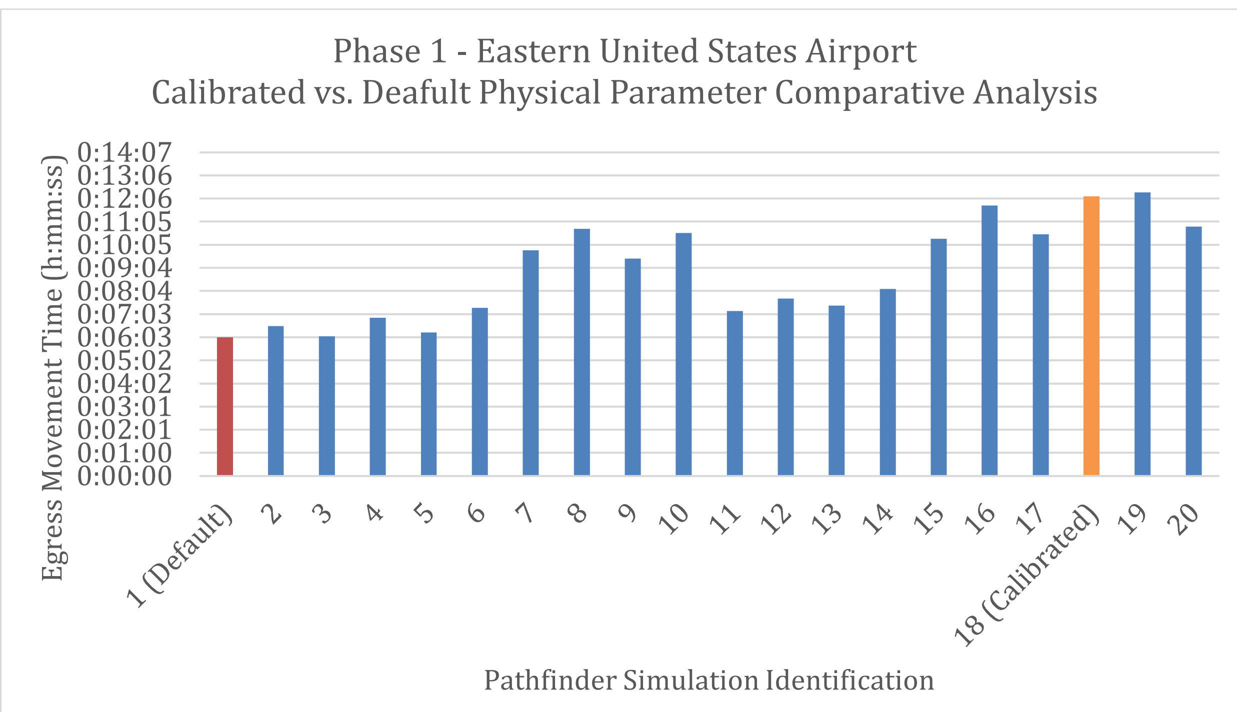

Figure 4: Phase 1 Results Preview – Egress Movement Time Comparison Graph

Table 6 provides a tabulated view of the egress movement times with percent changes from the baseline default simulation. The rightmost column states the percent change from the default run as various physical characteristics were changed in each simulation. Based on the data, simulations #7, #8, #9, and #10 produced egress times over 50% longer than the baseline default simulation. This equates to egress movement times being one and a half times (1.5x) greater than the baseline default simulation All four of these simulations included calibrated occupant diameters (i.e., shoulder widths) which was attributed to the increased egress movement times.

Additionally, simulations #15, #16, #17, #19, and #20 produced egress times over 70% longer than the baseline default simulation. This equates to egress movement times being 1.7 times (1.7x) greater than the baseline default simulation. These increased times were attributed to the increased number of calibrated physical parameter inputs used for each user group within the Pathfinder simulation. The results for Simulation #19, which produced the longest egress time, indicated that Reduction Factor being turned off produced the most conservative results.

Table 6: Phase 1 Results – Distribution of Varying Default Physical Occupant Parameters on Egress Movement Times

Pathfinder Simulation	Egress Time (h:mm:ss)	Percent Change from Simulation #1 (Default)
1 (Default)	**0:06:02**	**-**
2	0:06:32	8%
3	0:06:05	1%
4	0:06:54	14%
5	0:06:15	4%
6	0:07:20	21%
7	0:09:50	63%
8	0:10:46	79%
9	0:09:28	57%
10	0:10:35	75%
11	0:07:11	19%
12	0:07:44	28%
13	0:07:26	23%
14	0:08:09	35%
15	0:10:21	71%
16	0:11:47	95%
17	0:10:32	75%
18 (Calibrated)	**0:12:11**	**102%**
19	0:12:22	105%
20	0:10:52	80%

From the trends identified in Table 6, the four (4) physical occupant parameter inputs were able to be ranked from the most influential, value of 1, to the least influential, value of 4, on the calculated egress movement time. Table 7 provides that ranking and identified that "Diameter" had the greatest impact on overall egress movement times calculated within the Pathfinder simulations. Egress movement times in simulations that included calibrated shoulder widths were on average 80% longer (1.8 times greater) than the default baseline simulation. The second most influential parameter was Personal Distance with 64%, then Speed with 63% and lastly Reduction Factor with 53% longer average movement times compared to the baseline default simulation.

Table 7: Phase 1 Results – Influence of Physical Occupant Parameters Ranked (1 = Most Influence, 4 = Least Influence)

Speed	Diameter (Shoulder Width)	Reduction factor	Personal distance
3	1	4	2

<u>Phase 2 – Results</u>

Figure 5 shows the egress movement time for the Western United States Airport geometry with two different calibrated airport user groups, Western and Eastern United States. As seen in the figure, the egress movement time calculated for the Western United States airport user groups was 11:08 compared to the longer 13:11 egress movement time calculated for the same Pathfinder geometry that utilized Eastern United States airport user group data. This difference in similar user groups, but disparate locations, resulted in the Eastern United States user group simulation being 18% (1.18x) more conservative than the Western United States user group simulation.

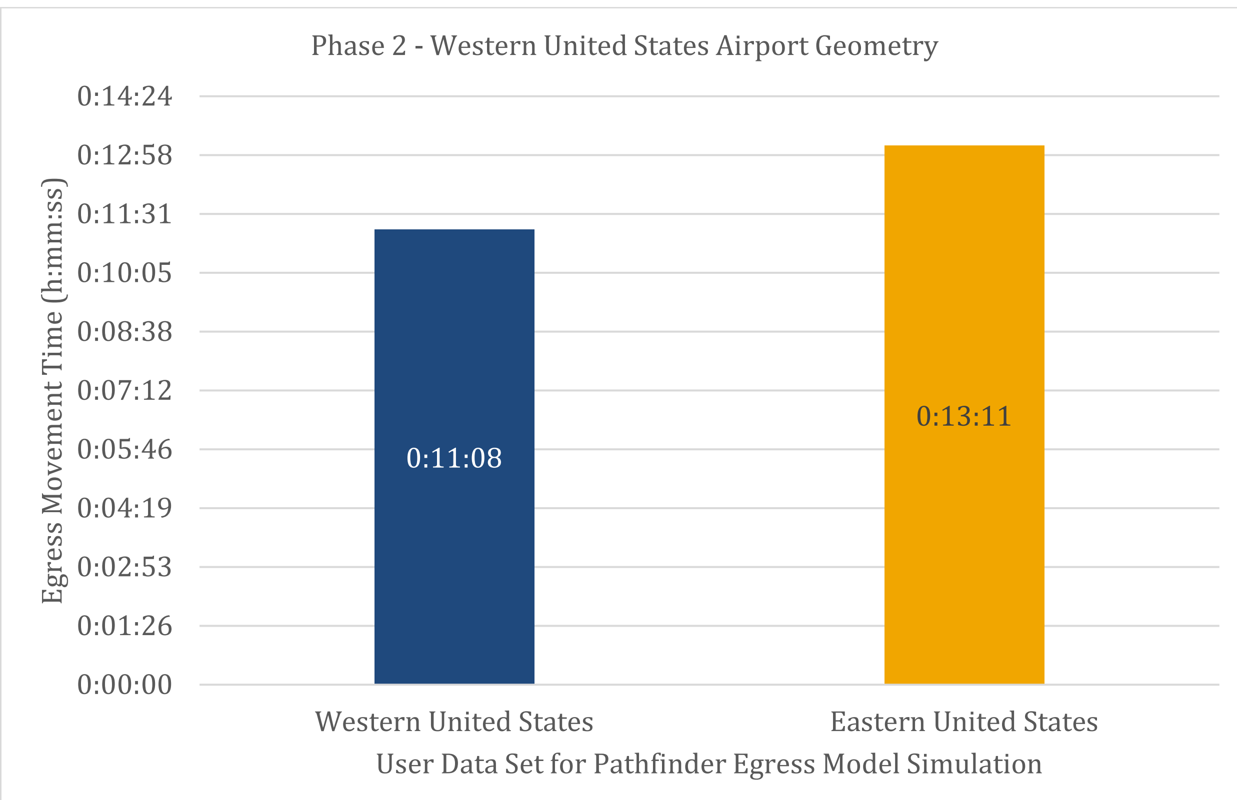

Figure 5: Phase 2 Results – Western United States Airport Geometry Egress Movement Time Comparison Graph

Figure 6 shows the egress movement time for the Eastern United States Airport geometry with two different calibrated airport user groups, Western and Eastern United States. As seen in the figure, the egress movement time calculated for the Eastern United States airport user groups was 12:11 compared to the faster 10:02 egress movement time calculated for the same Pathfinder geometry that utilized Western United States airport user group data. This difference in user groups resulted in the Western United States user group simulation being 15% (0.85x) less conservative than the Eastern United States user group simulation.

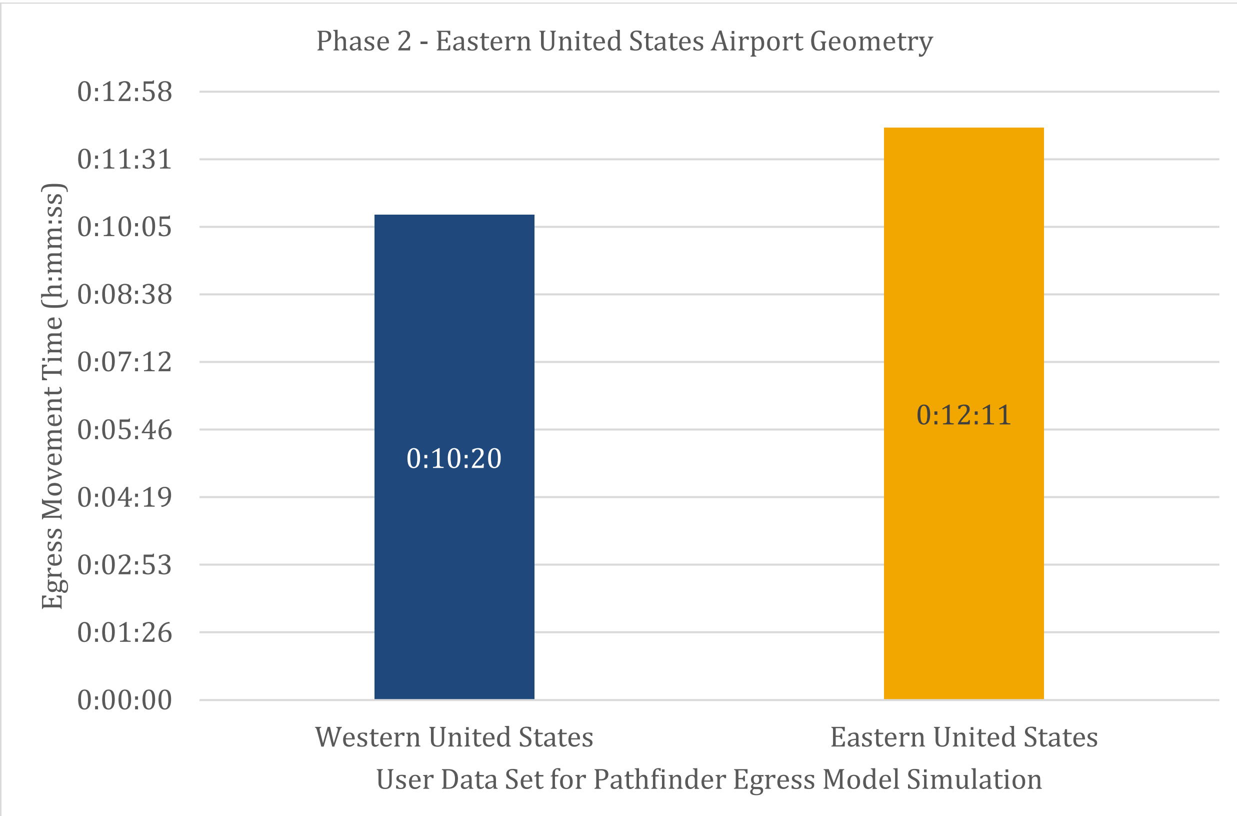

Figure 6: Phase 2 Results – Eastern United States Airport Geometry Egress Movement Time Comparison Graph

SUMMARY

To summarize, the results of the analysis provided the following answers to the original questions posed by the author:

1) What is the effect of using default physical occupant parameters on calculated egress movement time compared to calibrated occupant user data?

   Egress movement times calculated using calibrated occupant physical parameters were **up to 100% longer** than egress movement times calculated using default settings. This means egress movement times using calibrated occupant physical parameters can be twice as long (2x) than egress movement times simulated using default occupant physical parameter settings. Refer to Table 6.

2) Which of the four identified physical parameters has the most influence on calculated egress movement times?

Based on the four physical occupant parameters analyzed, **Shoulder Width had the most influence** on calculated egress movement times. Egress movement times in simulations that included calibrated shoulder widths were on average 80% longer (1.8x) than the default baseline simulation. Personal Distance and Speed were also important physical parameters with 64% and 63% longer egress movement times, respectively. Therefore, if any one of these calibrated physical parameters is missing, calculated egress movement times can be up to 1.8 times less conservative. Refer to Table 7.

3) What effect does using calibrated data from similar user groups with a different geographic location have on calculated egress movement times?

   Egress movement times varied up to 18% between egress simulations that utilized the same building geometry but different sets of calibrated occupant data from different geographic locations within the United States. This egress movement time variation confirms the import for collecting empirical calibrated data for every use case based on the geographic location and anticipated user groups being studied. Refer to Figure 5.

CONCLUSION

When employing computational simulation modeling, it has been shown that the user should not assume that the default settings employed are applicable to the project at hand [7]. The research presented has shown that default settings can only be used to confirm a working model and will not provide usable or reliable egress/REST data for an engineer to use. Therefore, the use of specified occupant data related to the project at hand is paramount in obtaining reliable egress simulation results.

Goodhead and Strege [2] identified that specifying specific facility data was shown to aid in the efficiency of analysis and provided more accurate data from which to make design assumptions and decisions. This statement is reinforced by the results of Phase 2, which showed that using calibrated data that does not align with the building being studied can produce a less conservative egress movement time of up to 15%. In conclusion, the results of this study identified:

1) Calibrated, geographically accurate, occupant data must be obtained for every anticipated user type when performing egress modeling in an RSET or performance-based design analysis. Calibrated occupant data is essential to ensure an accurate representation of the likely users for the facility/site in question.

2) That accounting for building geographic location and type of occupants present within a building are important for accurately describing the overall occupant population for a computational egress model.

3) That a building's occupant population is unique to each location, and an engineer not using calibrated population data for computational egress modeling can obtain results that potentially negatively impact the safety of the overall design.

4) The use of default settings or parametric analyses from default settings are unlikely to come close to the actual user group settings for a building/site; and therefore, can introduce errors of up to 100% (2x) in the final calculation of egress movement times.

The author of this research acknowledges that the exact influence of the variables studied herein are dependent upon the modeling software chosen for the analysis, the modeling approaches adopted, and the specific building's population and user groups being studied. The author also acknowledges that the results are pertinent to the user populations studied where occupants frequently travel in groups, have luggage and backpacks, and where large number of mobility impairments are recognized. Therefore, the results of this analysis should be considered as indicative rather than definitive as to the impact of the modeling parameters outlined in this presentation. As previously stated in research, any egress model is merely a simplified representation of reality that involves a combination of the model's representation of current theory, data, and the user's knowledge and judgment [3]. The author of this paper agrees that defaults should be minimized whenever possible and the selected physical occupant parameters should represent the population intended based on calibrated field research data points. To conclude, the findings of this analysis reinforce the need for calibration of egress model input parameters for the specific population being studied to avoid the potentially unsafe practice of using default occupant data and/or non-specific calibrated data in computational egress modeling.

LIMITATIONS AND FUTURE RESEARCH

The focus of this research paper was limited to four objective physical occupant characteristics calibrated across a specific user group set. This was in part due to the nature of physical characteristics in that they are easily measured and quantified, making consistent calibration efforts easier as a whole. There are also other important input parameters to determine and calibrate in egress modeling such as behavioral values for Pre-Movement, Route-Usage, Door Choice, Route-Availability and Flow-Conditions; however, behavioral characteristics are objective, not easily quantifiable or measurable, and require a greater level of sensitivity analysis to finalize.

A challenge presented for this analysis is the lack of available validation data for the identified field data points for different airport user groups. Airports are typically high-secure facilities, with multiple secure checkpoints, which makes performing full-scale evacuations a major security risk and impractical. Additionally, the user group data for the analysis was recorded via film assessments of people's movement within the respective airports. There is a level of objectivity and human error within those measurements that could be addressed and minimized by future more advanced AI and light detection and ranging (lidar) software. Once these tools become more available and commercialized, the hope for this research is to expand the collection of calibrated data for user groups in other airports as well as other occupancy types.

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