EXIT CHOICE BEHAVIOR OF PEDESTRIANS INVOLVING INDIVIDUALS WITH DISABILITIES DURING BUILDING EVACUATIONS

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ABSTRACT

Pedestrian evacuation studies are critical in getting information about evacuation scenarios and preparing to face the challenges of actual evacuations. Many studies in the literature have examined the evacuation policies, exit choice modeling, and evacuation curve analysis. Although some studies have addressed the evacuation behavior of individuals with disabilities (IWDs), this important aspect seems to be missing from modeling the exit choice in most of the studies. This is surprising, as IWDs comprise a significant percentage of the population in the United States. Additionally, in modeling of the exit choice for evacuation, many studies have been found based on the stated preference survey method, where the evacuees are asked to choose an exit based on descriptions with an actual experiment taking place. This study focuses on the discrete choice model for the exit choice in the room for both individuals with disabilities and individuals without disabilities (IWODs). The results demonstrate that the presence of IWDs in the group plays a crucial role in the exit choice for the evacuees (both individuals with and without disabilities). The results from this study clearly demonstrates that there are significant differences in the exit choice for IWDs and IWODs. Current evacuation policies are found to be more focused on the visual signs, while this study shows that these visual signs are not of much importance to individuals with visual disabilities.

Keywords: evacuation, heterogeneous population, individuals with disabilities, discrete choice model.

Abstract = 226 words (limit = 250 words)

INTRODUCTION

Emergency evacuation studies have gained much interest among researchers in recent years. Several evacuation models have been developed to estimate the evacuation time of evacuees. The danger of accidents caused by panic during an evacuation makes it difficult for researchers to observe pedestrian evacuation, which makes it almost impossible to study real evacuation behavior (*1*). Modeling the evacuation behavior of pedestrians during evacuation is a widely popular subject of study. Evacuation models are used to study the different effects on both evacuation behavior and evacuation time. The exit behavior of people, both individually and in a group, has been studied using the evacuation simulation model (*2*). An evacuation model was built to understand the effects of fast flows of evacuees and interactions among individuals on evacuation time (*3*). Varas et al. (*4*) built a cellular automaton model to study evacuation behavior in a closed room with obstacles. Their simulation considered two different situations by varying the type of exit doors from the room (single and double doors), which demonstrated that evacuation time is minimized using multiple doors rather than a single door.

Pedestrian evacuation behavior in a single room with single or multiple exits has previously been studied, and results have been drawn from both experimental studies and from modeling the exit choice. Experimental data obtained from actual experiments or online surveys have been used to model the exit choice of pedestrians from a room during emergency evacuation. For example, Helbing et al. (*5*) performed experiments in a classroom simulating the evacuation process, which revealed that escape time distribution is affected by jamming of students at the exit. Additionally, Isobe et al. (*6*) performed an experimental study to evaluate the evacuation process using students, which also revealed that jamming of the exit doors affects the exit time. Their research concluded that such studies are necessary to plan safe evacuations from buildings. Shi et al. (*7*) also performed controlled laboratory experiments to examine the safety of pedestrians at the merging angles, which suggests that the merging angles have a significant influence during the emergency evacuation of pedestrians. Pedestrians were found not to be panicking, but rather using rational knowledge and making exit choices in case of fire (*8*). If pedestrians make exit choices rationally rather than panicking, there should be many factors that influence exit choice to pedestrians.

Exit choice during emergency evacuations has been studied under different scenarios considering different factors. The selection of exits during evacuation is a stochastic process, which is defined by the behavioral uncertainty of the pedestrians (*1*). Exit choice is influenced by the familiarity of the exits (*9*). Pedestrians tend to choose the exit that is nearest to them in most of the scenarios (*10-13*). Density of pedestrians around the exit also plays a significant role in exit choice selection (*14*). If the exits are of different widths, the width of an exit also influences exit choice (*15*). Additional information, such as green flash lights (*15*), lights above the exits (*10*) and availability of staff to help evacuees (*16*), is also considered in the choice of exit, and this acts as a positive influence on the evacuation, resulting in less evacuation time. It is essential to understand that an emergency evacuation takes place in groups of people. Hence, it is necessary to study the group behavior of individuals during an evacuation. A pedestrian evacuation study that employed a simulation model from a single room revealed that phenomena, such as arching, clogging and irregular outflows, were seen at an exit for a group of pedestrians (*17*). The tendency to follow other individuals while making the exit choice (*12*) also demonstrates the group behavior of individuals during emergency evacuation. A study of exit choice with a focus on human factors, such as social influence and proximity behavior during emergency evacuation, revealed that herding behavior was found in individuals (*13*). The authors of the study found that group dynamics influence on the exit choice and should be considered during modeling of exit choice.

Herding behavior of individuals has been explained as an individual's trust of others during selection of an exit, or preferring not to be embarrassed by being the only one to select an exit (*14*). It was revealed that group behavior has a negative effect on evacuation time, as evacuation time was found to be faster if individuals egress independently rather than cooperating with others (*18*). The questionnaire method of an experimental study was employed by Chen et al. (*19*). In their study, children were asked different questions about exit choice in a classroom. The study revealed that position, congestion, group behavior and backtracking behavior play significant roles in the determination of evacuation route choice in a classroom.

Although these studies focused on exit choice during an emergency evacuation, they all seem to be missing a key factor: IWDs. This is surprising, as IWDs constitute a significant percentage of the population in the United States. The percentage of people with disabilities has increased from 11.9% in 2010 to 12.6 % in 2014 (*20*). The flow of pedestrians during evacuation has been found to be affected by mobility-impaired participants due to their slower walking speed, which has an effect on exit choice (*21*). An experimental study on the evacuation behavior of the visually impaired revealed mixed behavior (*22*). The effects of a mobility stick, a guide dog, hand rails and walls on navigation toward an exit were studied. Even though many of the evacuation models reviewed were based on consideration by the models, no study founded on the models was based on IWDs (*23*). To begin addressing this limitation, an empirical study has been performed at Utah State University (USU) to observe the evacuation behavior of individuals with disabilities in heterogeneous population contexts. The purpose of this study is to understand which parameters have effects on individual's exit door choices in evacuation situations. This paper is structured as follows: The next section contains detailed information about the experiments conducted for the study as well as data collection techniques employed. This section is followed by methods, which primarily addresses procedures for the extraction and analysis of the data obtained from the experiment. The next section presents results of model calibrations and analysis will be presented in discussion section. Finally, conclusions based upon the analysis are described in the final section.

EXPERIMENTS

The experiments were performed in the Agricultural Sciences (Ag Science) building at USU. This building possesses the necessary environmental conditions: various walkway configurations (resulting in directional changes and cross-flows), stairways, and queuing area (exits), which comprise International Building Code (IBC) (*24*), ADA Standards for Accessible Design accessible means of egress (*25*).

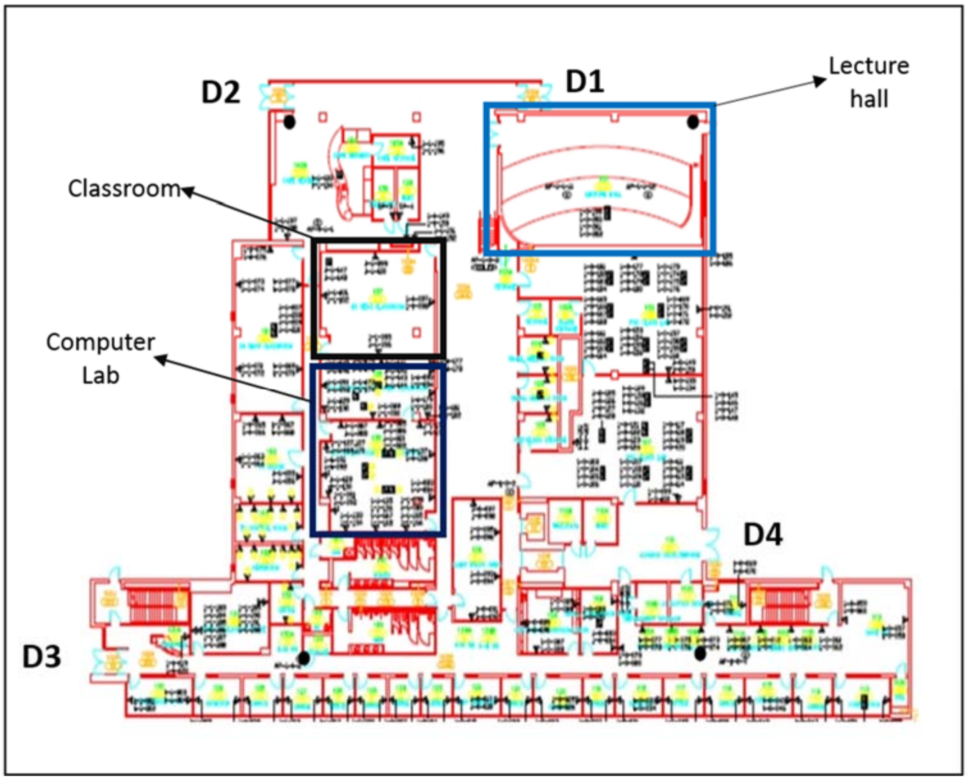
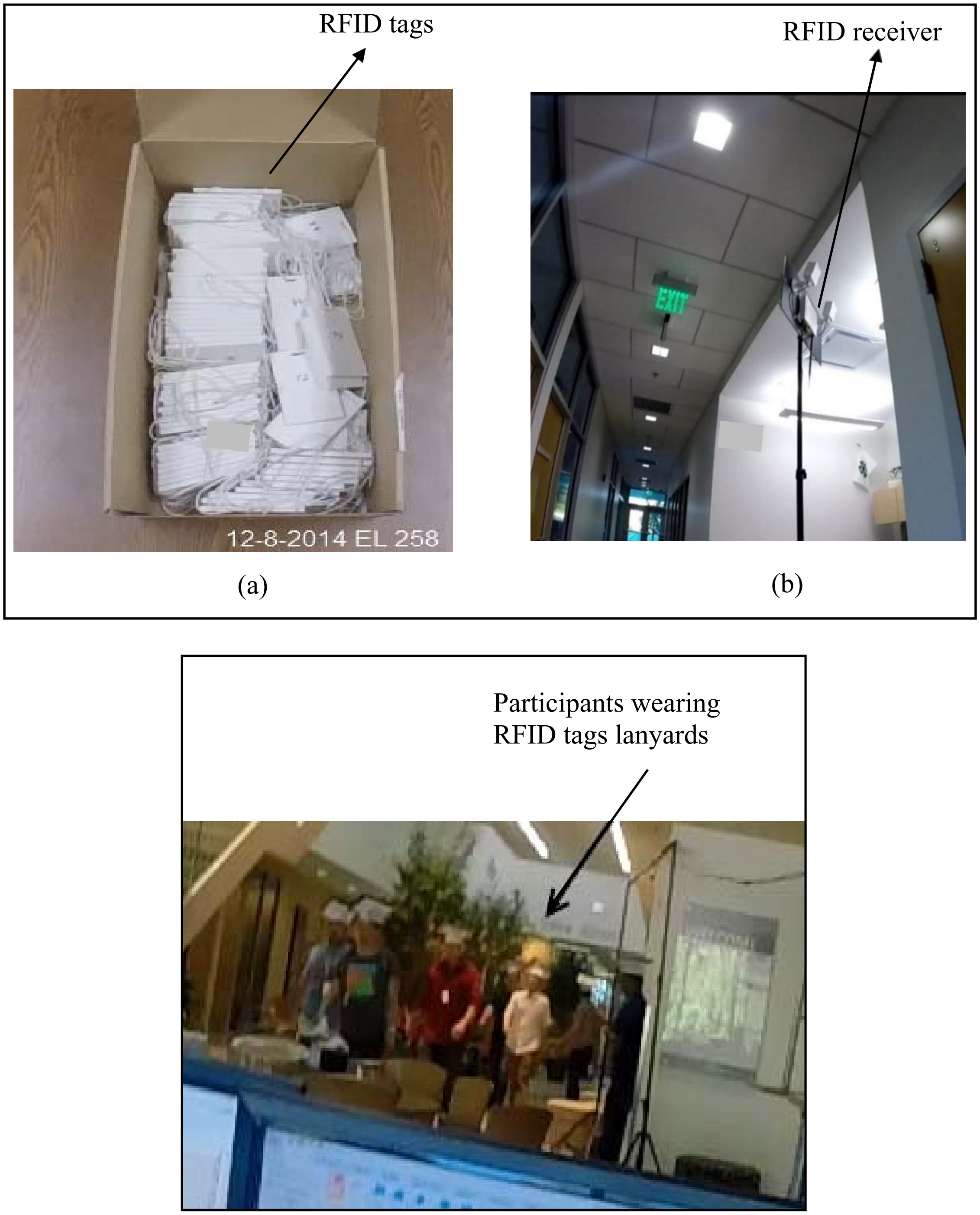


FIGURE 1 Layout of the building with different components.

The building contains a large lecture hall, wide and narrow hallways, classrooms, offices and study rooms in which participants were distributed for the experiments. There are four exits on the ground floor, which are accessible to all individuals. Three are main exits, and one is for emergencies. Figure 1 shows the layout and various components of the floor. Doors D1, D2 and D3 have similar dimensions, and they are wider than the emergency door (D4). Forty-seven individuals participated in the experiments, including 12 individuals with various mobility-related disabilities, including physical (requiring use of wheelchair) and sensory (visually impaired) disabilities. Participants were positioned throughout the Ag Science building and when prompted by an alarm were asked to evacuate the building through an exit of their choice at their maximum comfortable speed. Sixteen evacuation experiments were conducted, with participant distribution, exit door availability and evacuation strategy modified in each scenario. Participants' evacuation behavior was recorded using RFID tracking technology, supplemented by video tracking where desirable to verify the accuracy of the collected data (exits and congested areas). RFID is an automatic identification system that consists of two components: a reader and tags (Figure 2). An RFID reader can recognize tags at high speed and send data within various distances. It is cost effective, small in size, and capable of storing more than enough information.



(c)

FIGURE 2 (a) RFID tags used for the experiment; (b) RFID receiver mounted in a stand to receive signals from the RFID tags; (c) Participants wear markers on their heads and RFID tags with lanyards.

METHODS

The RFID data was studied, and the analysis was conducted on the exit choice model. The exit choice pattern was examined by developing a binary logit model for the exit choices of the scenarios in the classroom and the computer lab. For modeling purposes, out of all the scenarios, there were nine similar scenarios (five in a classroom and four in a computer lab) in which two doors were available for evacuees to exit from the room. Exit choice analysis was conducted to observe how different parameters affect methods of exit door selection. Prior to model calibration, it is necessary to extract potential variables, which can effect individuals' exit choices. These variables include distance to exit door, pedestrian density at exit doors, and number of IWDs at exit doors.

Distance to the exits

The distance of individuals from the exit doors can be calculated based on the start position and the exit door position. Based on the RFID data trajectory of the individuals, it was possible to determine the start position of the individuals in the room. Distance was calculated based on the initial position of individuals and the exit coordinates of the doors. Basically, the distance calculation assumes the shortest distance between two points, which is given by a distance formula.

$$\text{Distance (D)} = \sqrt[2]{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

Where (x_1, y_1) = initial position (start coordinates) of the individual.

(x_2, y_2) = position (coordinates) of the doors.

Total density at exits

The population density at each exit during exiting of the rooms also appears to play a greater role than reflected in existing exit choice models, as explained in the literature review. The density of individuals at the exit simply determines the number of individuals at the exit at a certain period of time. By intuition, it can be understood that individuals will try to avoid an exit that has a higher exit density than an alternative. The higher the number of individuals at the exit, the lower the probability of choosing that exit. The density was calculated at the exits by counting the number of individuals exiting the room. The calculation was done by simply counting the number of individuals leaving the exit within a certain time period. Traffic flow properties were taken as analogous to define the density of individuals leaving the exits. Density is defined as the number of people present at a given specified section for a certain interval of time. It was necessary to define the time interval. Different time intervals were analyzed to observe the density pattern in conjunction with elapsed time. Different time intervals, such as five and ten seconds, were analyzed to generate the density graph. The density pattern was then analyzed to determine whether the pattern was smooth. Analysis showed that the pattern was found to be smooth when the time interval was taken as 10 seconds.

Number of IWDs at exits

Because some individuals with disabilities might walk slowly, which results in congestion at the exits, this might affect the exit choice behavior of other individuals with or without disabilities. The counting was done at ten-second intervals, as there were 12 individuals with disabilities out of 47 total individuals in the room. This variable was considered to determine whether the presence of individuals with disabilities at the exit doors had any effect on the exit choice analysis. Our experiment included 12 individuals with disabilities, out of which 11 had visual disabilities. The walking speed of individuals with disabilities has been found to be lower than that of individuals without disabilities in previous studies. Hence, this factor may lead to heightened congestion at the exit doors, which might have an effect on the exit choice of individuals without disabilities. This variable was analyzed by counting the number of individuals with disabilities at the exit doors for ten-second intervals, as we did in the calculation of the exit density to identify whether their presence makes any difference in the selection of that a particular exit.

Exit Choice

Exit choice is a crucial factor that affects the quality of evacuation (Figure 3). In the experiment, different exit choices were available for evacuation under different scenarios. Discrete choice modeling was proposed for the exit choice analysis. Discrete choice models can be used to analyze and predict a decision maker's choice of one alternative from a finite number of alternatives. The variables to be considered for the exit choice are believed to have certain connections to individuals with disabilities. The primary focus of this study was individuals with disabilities and the heterogeneity of the population. Based on the data available regarding exit time information and movement of individuals at every two-second interval, we found the exit coordinates of every individual. The binary logit model was built for exit choice evaluation. The variables used for the logit model were distance to the exits, exit density and number of IWDs at the exit (Figure 3).

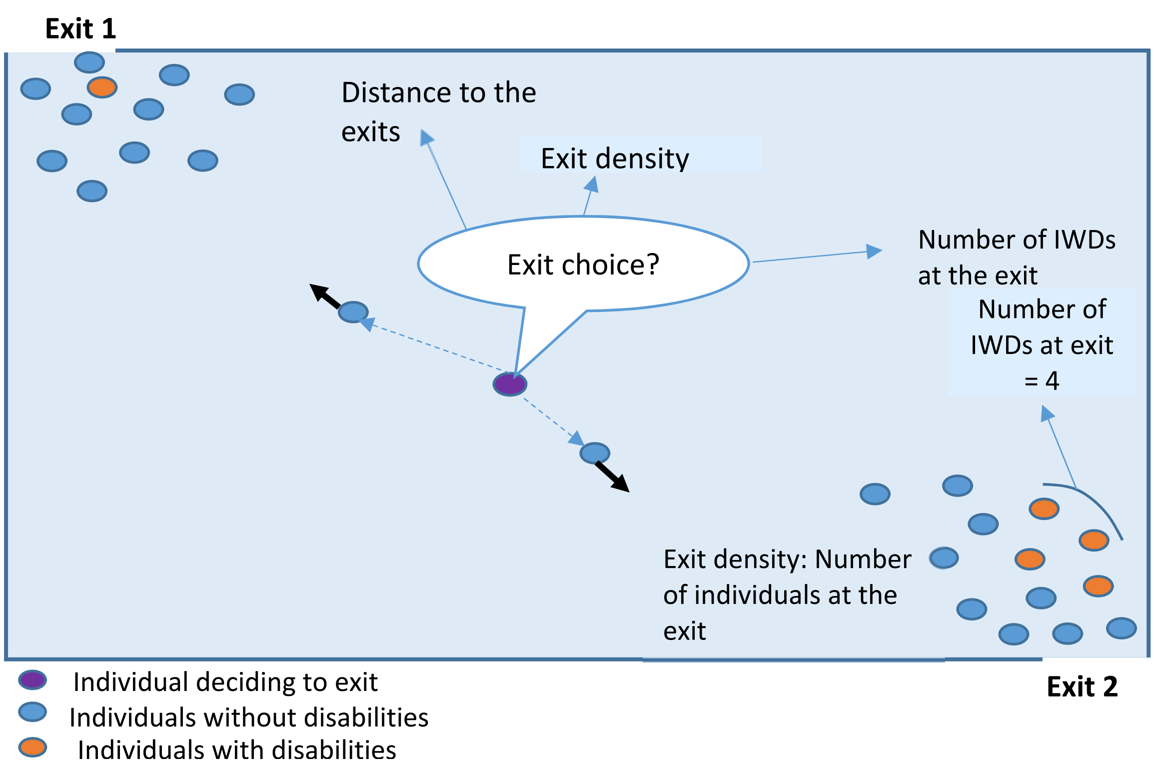


FIGURE 3 Exit choices in a room with two exits.

Discrete choice models are the choice made by an individual based on different statistical parameters of the attributes that could relate to the alternatives and the decision maker. The approach used for the determination of the choice is based entirely on probability (*26*). This is because although we strive to define attributes for the alternatives, we can never incorporate all the attributes for the choice of alternatives. Therefore, the discrete choice models rely on stochastic assumptions. First and foremost, the problem is defined in the modeling process, which is generally a situation in which a choice must be made. The situation is then provided with a finite set of alternatives (which may be two or more than two). Every alternative is examined properly, and a set of attributes are defined, which will influence the selection of the alternative. Individuals will select based on utility function: the higher the utility for an alternative, the probability of selecting that alternative is higher than other alternatives. Let the utility that determines the outcome k be represented by $\mathrm{U_i}$. The general representation of the utility function is then given by:

$$\mathrm{U_i} = \mathrm{V_i} + \mathrm{e_i}$$

Where,
$\mathrm{U_i}$ = total utility of alternative 'i'.
$\mathrm{V_i}$ = deterministic component of alternative 'i'.
$\mathrm{e_i}$ = stochastic component (non-measurable component) of alternative 'i'.

The deterministic component of the utility function is the sum of different attributes that affect choice among the alternatives multiplied by parameters that will define the weight of the attributes based on the importance of the attributes.

$$\mathrm{V_i} = \sum_{i=1}^{k} \beta_i X_i$$

Where,
k = the number of attributes used for the utility function.
β_i = the parameter that will define the weight of the attribute.
X_i = the attribute for selection.

Let 'A' define the set of all of the alternatives for the discrete choice model. Another assumption of discrete choice modeling is the assumption of error distribution. The stochastic component (non-measurable component), which is often referred to as the error term, is assumed to be distributed as a Gumbel distribution. The probability that an individual will choose discrete alternative 'i' among 'l', or different alternatives, is given by:

$$\mathrm{P_i} = \frac{\exp(\mathrm{V_i})}{\sum_{l \in A} \exp(\mathrm{V_l})}$$

The binary choice model is a discrete choice model in which an individual must choose between only two alternatives. For the analysis of the exit choice in our case, two doors were available as alternatives for any individual. Hence, it was possible to use the binary logit model to model exit choice. The two alternatives were door1 and door2 for the different scenarios. A total of nine scenarios were noted to have two doors as alternatives for individuals to make exit choices. Other scenarios consisted of the lecture hall as the experiment area, which had only one exit door. Hence, they were avoided for the analysis and nine scenarios were chosen for the analysis. Utility function was defined for the two alternatives with different attributes that could have an impact on selection of a particular exit.

Two different utility functions were created for individuals with and without disabilities. The deterministic components for the exit doors were constructed using three different variables, as described above. The deterministic components (V_i) for the two doors were as follows:

$$\mathbf{V_{door1}} = CONS1 + BETA1 * D_{d1} + BETA2 * K_{e1} + BETA3 * N_{d1}$$
$$\mathbf{V_{door2}} = BETA1 * D_{d2} + BETA2 * K_{e2} + BETA3 * N_{d2}$$

Where,

D_{d1} & D_{d2} = distance of the individual's initial position from the doors (meters).

K_{e1} & K_{e2} = exit density at the two doors.

N_{d1} & N_{d2} = number of individual with disabilities at doors at different time intervals.

BETA1, BETA2 & BETA3 = coefficients of the variable distances, exit density and number of IWDs, respectively, at exit doors.

CONS1 = constant.

The probability of choosing an exit among two alternatives is given by (assuming error distribution are modeled as a Gumbel distribution).

$$\mathbf{P_{door1}} = \frac{\mathbf{exp}\ (\mathbf{V_{door1}})}{\mathbf{exp}\ (\mathbf{V_{door1}}) + \mathbf{exp}\ (\mathbf{V_{door2}})}$$

MODEL CALIBRATION

Individuals without Disabilities

The data sets for nine different scenarios were combined, and the model was calibrated with 90% of the data sets and was also validated with the remaining 10% of the data sets. Calibration of the model was done using "BIOGEME" (*27*). This software is designed for estimating discrete choice models. It allows the estimation of the parameters of the various discrete choice models like logit, binary probit, nested logit, cross nested logit etc. The results from the BIOGEME were as follows:

TABLE 1 Statistical parameters from the logit model for IWODs.

Variable description	value	Std. error	t-test	p-value
Distance	-0.23	0.0321	-7.14	0.00
Exit density	-0.08	0.0554	-1.33	0.18
Number of IWDs at door	-0.33	0.08	-4.1	0.00
Constant1 (CONS1)	-0.38	0.151	-2.55	0.01
Constant 2 (CONS2)	0	0	0	1
Summary of statistics				
Final log-likelihood			-157.321	
Likelihood ratio test			90.156	
Rho-square			0.223	
Adjusted rho-square			0.198	
Number of observations			292	
Number of individuals			292	

The model demonstrates that the exit choice has less relevance in exit density than other variables (table 1). This may be due to the presence of individuals with disabilities, as not only exit density is considered, but also the presence of individuals with disabilities at the exit doors when making the decision. Variable exit density was considered for the model, although its t-score was not good as it influences the exit choice.

Individuals with Disabilities

The data sets for nine different scenarios were combined, and the model was calibrated with 90% of the data sets and was also validated with the remaining 10% of the data sets. The dependence of the exit choice was found to be similar to the exit choice model of individuals without disabilities, although a variance was found on the third variable (number of individuals with disabilities at the door) (Table 2). The logit model for individuals without disabilities had a negative impact on the exit choice due to the number of individuals with disabilities at the door. However, the logit model for individuals with disabilities had a positive impact on the exit choice due to the number of individuals with disabilities at the door. This implies that the presence of individuals with disabilities at the door renders it less likely that individuals without disabilities will choose an exit, although they appear to express an opposite opinion in the evacuation surveys conducted. On the other hand, individuals with disabilities appear to choose the same exit that is chosen by other individuals with disabilities.

TABLE 2 Statistical parameters from the logit model for IWDs.

Variable description	value	Std. error	t-test	p-value
Distance	-0.21	0.0585	-3.65	0.00
Exit density	-0.16	0.131	-1.21	0.2
Number of IWDs at door	0.39	0.181	2.14	0.03
Constant1 (CONS1)	-0.26	0.322	-0.8	0.42
Constant 2 (CONS2)	0	0	0	1
Summary of statistics				
Final log-likelihood		-34.98		
Likelihood ratio test		28.457		
Rho-square		0.29		
Adjusted rho-square		0.19		
Number of observations		71		
Number of individuals		71		

The model was then validated with the remaining 10% of the data sets. The models were found to be valid with the validation data sets. The validation process has been shown in Table 3.

TABLE 3 Validation of the binary logit model for individuals with disabilities.

ID	U_{D1}	U_{D2}	EXP (U_{D1})	EXP (U_{D2})	PROBABILITY DOOR 1	PROBABILITY DOOR 2	ACTUAL CHOICE	VALIDATION
41	-0.58	-1.68	0.56	0.19	0.75	0.25	1	YES
36	-0.25	-2.47	0.78	0.08	0.90	0.10	1	YES
18	-0.65	-1.54	0.52	0.22	0.71	0.29	1	YES
22	-0.34	-1.74	0.71	0.17	0.80	0.20	1	YES
33	0.23	-2.57	1.25	0.08	0.94	0.06	1	YES
52	-0.61	-1.56	0.54	0.21	0.72	0.28	1	YES
52	-1.87	-0.17	0.15	0.85	0.15	0.85	2	YES
23	-1.69	-0.38	0.18	0.68	0.21	0.79	2	YES
72	-1.87	-0.17	0.15	0.85	0.15	0.85	2	YES
18	-1.06	-0.05	0.35	0.95	0.27	0.73	2	YES

DISCUSSIONS

The experiment conducted was employed to derive a binary logit model and predict the exit choice of the participants. The model calibrated and validated clearly demonstrates that different factors are considered by pedestrians while selecting an exit. The results of the logit model for the exit choice for both individuals with and without disabilities are presented as below:

Individuals Without Disabilities

$$\textbf{Door 1:}\ -0.38 - 0.23 * D_{d1} - 0.08 * K_{e1} - 0.33 * N_{d1}$$

$$\textbf{Door 2:}\ - 0.23 * D_{d2} - 0.08 * K_{e2} - 0.33 * N_{d2}$$

Individuals with Disabilities

$$\textbf{Door 1}: -0.26 - 0.21 * D_{d1} - 0.16 * K_{e1} + 0.39 * N_{d1}$$
$$\textbf{Door 2}: - 0.21 * D_{d2} - 0.16 * K_{e2} + 0.39 * N_{d2}$$

The role played by distance to the exit in the selection of the exit door is found to be inversely related. This suggests that individuals tend to choose the exit that is nearest to them from their initial position. The negative sign on the coefficient of the distance variable in the logit model indicates that individuals are less likely to choose the exit if the distance to the exit from their initial position is greater. Similarly, exit density plays an inverse role in the selection of the exit door. The exit density at the doors also had a negative relationship with the selection of the exit door. However, the third variable, the number of IWDs at the exit, assumes a totally different role in the selection of the exit door in the case of individuals with and without disabilities. Presence of IWDs at the exit door has an inverse relationship with the selection of that exit for individuals without disabilities. On the other hand, presence of IWDs at the exit has a positive relationship with the selection of the particular exit for individuals with disabilities. This suggests that individuals with disabilities tend to follow other individuals with disabilities during an exit in an emergency (figure 4). Their dependence on other individuals with disabilities could also be described as their trust for other individuals with disabilities. Figure 4 shows the comparison of the coefficients of the variables in the logit models for individuals with and without disabilities. The figure clearly shows that there is a very different dependence on the exit choice based on the number of IWDs at the exit door for individuals with and without disabilities. In terms of variable distance and exit density, the dependence of the model on the variables is seen to have a similar trend, i.e., it is inversely related (figure 4).

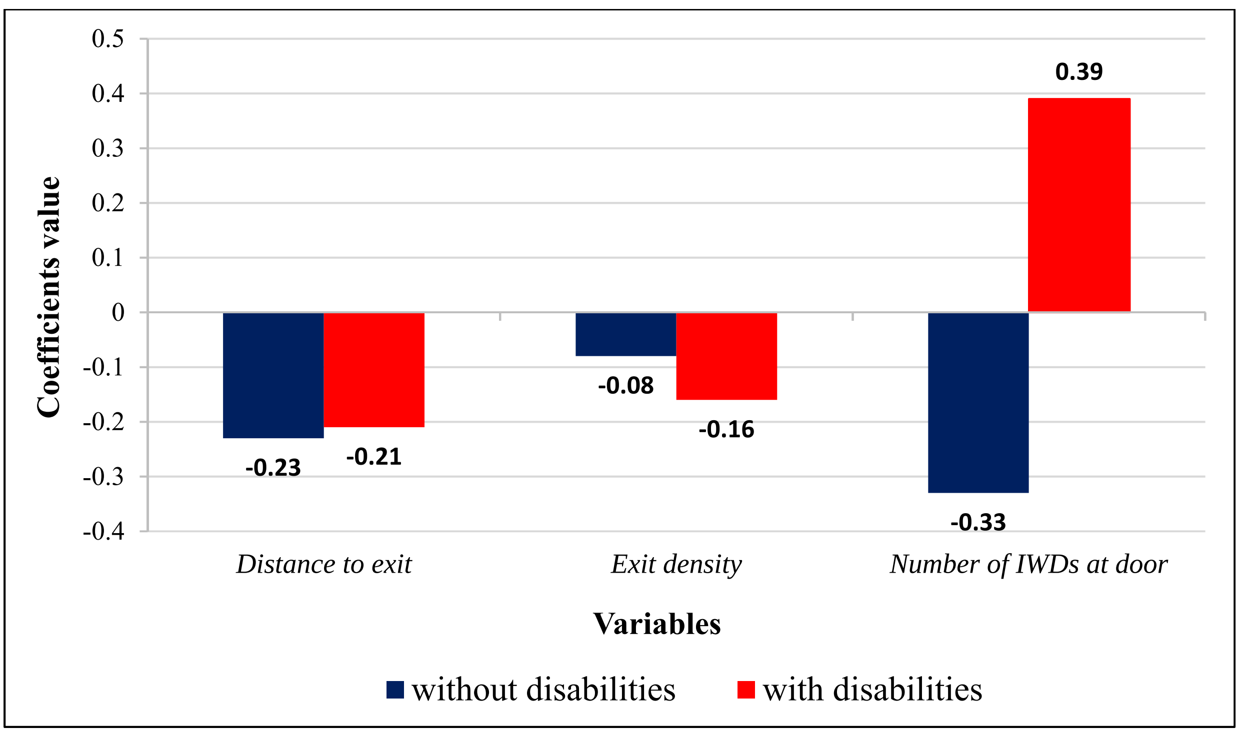


FIGURE 4 Comparison of the coefficients of the variables in the logit model for individuals with and without disabilities.

CONCLUSIONS

The results from the model suggest that IWDs and IWODs differ in their exit choice based on the presence of IWDs at the exit doors. IWODs may choose the exit where there are none or fewer (compared to other exits) IWDs at the exit door, and likely they make this decision because they might think the slow walking speed of IWDs could impede their exit from the room (*28*). Based upon the results, it was determined that IWDs trust other IWDs, which compels them to choose the same exit as other individuals with disabilities.

Although the Americans with Disabilities Act Accessibility guidelines (*29*), the International Building Codes (*24*) and ADA Standards for Accessible Design (*25*) identify signage requirements at the exit doors for egress, these signs are not as useful as they should be to individuals with visual disabilities, because individuals with visual disabilities follow other individuals with visual disabilities during an emergency exit. The signage requirements as provided by the codes (*24*-*25*, *29*) requires the exit doors to feature the visual signs. IBC (*24*) requires the signage requirements to be illuminated, and raised chartered and braille signage also to be provided. The use of braille signage is found to be decreasing these days due to the introduction of many user-friendly devices for individuals with visual disabilities. Additionally, these signs offer greater and easier exits to individuals with mobility disabilities, not individuals with visual disabilities, even though braille signage is provided. Individuals with visual disabilities will have to figure out the signage with great difficulty when compared to individuals with mobility disabilities. From this study, we found that individuals with visual disabilities do not take the exit based only on the distance to the exit and exit density, but rather trust other individuals with visual disabilities to make the exit choice. Thus, not only visual signs, but also audible indicators, if provided in the emergency egress may prove more helpful to individuals with visual disabilities. Additionally, assistance from trained personnel during an evacuation might prove more helpful to individuals with visual disabilities.

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