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A Study on Human Evacuation Behavior Involving Individuals with Disabilities in a Building

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A STUDY ON HUMAN EVACUATION BEHAVIOR INVOLVING INDIVIDUALS
WITH DISABILITIES IN A BUILDING

by

Nirdosh Gaire

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ABSTRACT

A Study on Human Evacuation Behavior Involving Individuals with Disabilities in a Building

by

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Pedestrian evacuation studies are critical in getting information about evacuation scenarios and preparing to face the challenges of actual evacuations in the future. One of the most important aspects of evacuation studies is the exit choice of evacuees. The exit doors in the facility represent crucial factors to be studied in evacuation scenarios. Many studies in literature have examined the evacuation studies, exit choice modeling, and evacuation curve analysis. Although some studies have addressed the evacuation behavior of individuals with disabilities, this important aspect of this issue seems to be missing from effects to model the exit choice in most of the studies. This is surprising, as individuals with disabilities comprise a significant percentage of the population in the United States. This study focuses on the evacuation behavior of heterogeneous (both individuals with and without disabilities) population group. 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. In this study, the evacuation behavior of a heterogeneous population has been studied based on the revealed preference survey method, where actual evacuation scenarios are employed in the analysis. The purpose of this study is to provide information about the effects of evacuation behavior on both individuals with and without disabilities. The first part of the study presents the evacuation curve analysis for the different evacuation scenarios and discusses the effects of the availability of exit doors on the evacuation time. The second part of the study focuses on the discrete choice model for the exit choice in the room for both individuals with and without disabilities. The effect of the presence of individuals with disabilities in the exit choice for the evacuees has been modeled. The results demonstrate that the availability of exit doors plays a very important role in the evacuation time. Additionally, the presence of individuals with disabilities in the group certainly plays a crucial role in the exit choice for the evacuees (both individuals with and without disabilities).

(73 pages)

PUBLIC ABSTRACT

The individuals with disabilities are disproportionately vulnerable to hazards. However, there is very little research inquiry focused on evacuation environments and the behavior of individuals with disabilities. The most widely applied computational method used to study how effective the built environment facilities emergency evacuations in individuals-based modeling. Current pedestrian evacuation models rarely include individuals with disabilities in their simulated populations due to there being very few empirical studies of the evacuation behavior of individuals with disabilities. As a result, the models do not replicate accurate patterns of pedestrian or evacuation behavior of a heterogeneous population, which results in the evacuation needs of individuals with disabilities being generally overlooked.

To begin addressing this limitation, our research group at Utah State University (USU) has performed empirical research to observe the microscopic evacuation behavior of individuals with disabilities in heterogeneous population contexts. The purpose of this research was to: (1) develop and analyze evacuation curves to understand and assess evacuation strategies for heterogeneous populations, and (2) analyze the microscopic behavior of evacuees at exit doors necessary for developing credible and valid pedestrian and evacuation models. Doing so will contribute to evacuation models which replicate accurate patterns of pedestrian and evacuation behavior of heterogeneous populations, leading to the consideration of the evacuation needs of individuals with disabilities.

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CHAPTER 1

INTRODUCTION

Pedestrians' evacuation studies have gained much attention in recent years as a result of major hazardous events where people lose their lives during an evacuation, such as the Fukushima Daiichi nuclear disaster in 2011 (Tanigawa et al., 2012) and the 2015 earthquake in Nepal. The evacuation process must be properly planned to avoid stampedes during emergency evacuation at public facilities. Exit door availability at the facility makes an enormous difference in the evacuation pattern of individuals. Many studies on evacuation models can be found in the literature. However, empirical studies on evacuations involving people with disabilities are scant, even though people with disabilities comprise a significant percentage of the population in the United States. For example, people with disabilities represented 12.6 % of the total U.S. population in 2014 (Kraus, 2015). Generally, evacuation studies are conducted using either revealed preference or stated preference surveys (Lovreglio et al., 2016a; Lovreglio et al., 2016b; Ortuzar and Willumsen, 2011; Train, 2003; Ehtamo et al., 2010). Revealed preference is a survey method in which the preference of the evacuees is observed in an actual experiment, whereas, stated preference is a survey method in which participants are asked to choose the exit from a description, and there is no real experiment. Many studies in the literature are based on the stated preference survey method. However, participants exhibit different behavior that differs from that stated as a preference in real life during actual evacuation scenarios (Galama et al., 2017). Conducting an actual evacuation experiment can produce actual behavior, and as a result, it is thought to more closely represent the actual choices of the participants. Hence, this study's analysis is based on an actual experiment conducted with 47 participants who took part in evacuation experiments under different scenarios.

Many studies on the evacuation of the people in groups have been conducted through formulation of mathematical models (Helbing and Johansson, 2009; Klupfel et al. 2005; Abdelghany et al., 2010). Pedestrian flow cannot be easily determined and studied under certain scenarios, such as panic and emergency conditions (Guo and Huang, 2010). The major variable that accounts for the evacuation process in a closed facility is the choice of exits. This critical decision-making process can be influenced by several factors. Hence, it is important to understand the different factors that account for the choice of exit during the evacuation process. Some researchers have concluded that evacuees choose the nearest exit during the evacuation process (Kirchner and Schadschneider, 2002; Thompson and Marchant, 1995). Although various exit choice models have been studied, individuals with disabilities have received little attention in the literature. Hence, this study aims to model the exit choice and study the evacuation choices for the data sets consisting of individuals with disabilities.

This thesis is structured as follows: the next section contains detailed information about the literature related to evacuation studies on individuals both with and without disabilities. Studies on stated preferences and related preferences are briefly explained. Additionally, the section addresses how little attention has been given to the study of the evacuation behavior of the individuals with disabilities. The section is then followed by a description of the experiments conducted for the study as well as data collection techniques employed. This section focuses primarily on a description of the recruitment of participants and the radio frequency identification (RFID) technology used for tracking in the experiment. This is followed by data analysis, which primarily addresses procedures for the extraction and analysis of the data obtained from the experiment. The RFID data was used for the extraction of the trajectories of evacuees in the building. The analysis of the data was then conducted in the next section, which also addresses the evacuation behavior model. This section primarily addresses two key aspects of the study: evacuation curve analysis and the exit choice model. Evacuation curves derived from different scenarios were examined to observe different behaviors in the scenarios. The exit choice model was calibrated and validated to observe the different factors that are considered in determining the exit choice of evacuees. The different models were built for individuals with and without disabilities to identify different parameters in these two population groups. Finally, discussions based upon the above-referenced analysis are described in the next section. Results obtained from the analyses are discussed, and comparisons are drawn between the present policies for the evacuation and the results obtained from this study.

CHAPTER 2

LITERATURE REVIEW

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 (Huang and Guo, 2008). Modeling the evacuation behavior of pedestrians during evacuation is a widely popular subject of study (Helbig et al, 2000; Song et al., 2006; Duives and Mahmassani, 2012; Fu and Lo, 2016; Lovreglio et al., 2016; Lovreglio et al., 2016; Weng et al., 2007). 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 (Helbig et al., 2000). An evacuation model was built to understand the effects of fast flows of evacuees and interactions among individuals on evacuation time (Song et al., 2006). Varas et al. (2007) 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. (2003) 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. (2004) performed an experimental study to evaluate the evacuation process using students, which also revealed that jamming of the exit doors affect the exit time. Their research concluded that such studies are necessary to plan safe evacuations from buildings. Shi et al. (2015) 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 (Proulx et al., 2001; Proulx et al., 2008). If pedestrians make exit choices rationally rather than panicking, there should be many factors that influence exit choice in the 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 (Huang and Guo, 2008; Ronchi et al., 2014). Exit choice is influenced by the familiarity of the exits (Huang et al., 2008; Guo et al., 2010; Nilsson et al., 2008; Chen et al., 2013; Shields et al., 2000). Pedestrians tend to choose the exit that is nearest to them in most of the scenarios (Lovreglio et al., 2016a; Liu et al., 2009; Haghani et al., 2014; Lovreglio et al., 2014; Zhu and Shi, 2016; Fang et al., 2010). Density of pedestrians around the exit also plays a significant role in exit choice selection (Lovreglio et al., 2016b; Shields and Boyce, 2000; Liu et al., 2009; Haghani et al., 2014; Fang et al., 2010; Sobhani et al., 2014; Sorensen and Dederichs, 2013). If the exits are of different widths, the width of an exit also influences exit choice (Nilsson et al., 2008). Additional information like green flash lights (Nilsson et al., 2008), lights above the exits (Lovreglio et al., 2016a) and availability of staff to help evacuees (Shields et al., 2000) are also considered in the choice of exit, and this acts as a positive influence on the evacuation, resulting in less evacuation time. It is necessary 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 (Fu et al., 2016). The tendency to follow other individuals while making the exit choice (Haghani et al., 2014) 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 (Lovreglio et al., 2014). The authors of the study found that group dynamics influences 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 (Lovreglio et al., 2016b). 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 (Heliövaara et al., 2012). The questionnaire method of an experimental study was employed by Chen et al., (2017). In this study, children were asked different questions about exit choice in a classroom. This 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: individuals with disabilities. This is surprising, as individuals with disabilities 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 (Kraus, 2015). 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 (Sorensen and Dederichs, 2014). An experimental study on the evacuation behavior of the visually impaired revealed mixed behavior (Sorensen and Dederichs, 2013). 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 individuals with disabilities (Kuligowski et al., 2005). Some studies have been based on the speed of individuals with disabilities in navigating evacuation routes (Rudabari et al., 1997; Wrigbt et al., 1999). Some of the researchers have been found to be focused on the walking behavior of the pedestrians in an indoor walking facility rather than evacuation behavior (Sharifi et al., 2015a; Christensen et al., 2016; Sharifi et al., 2014; Sharifi et al., 2015b; Stuart et al., 2015; Sharifi et al., 2016a). Previous studies have found that individuals with disabilities show very different characteristics than individuals without disabilities during walking (Sharifi et al., 2015c; Sharifi et al., 2015d; Sharifi et al., 2016b; Sharifi et al., 2017; Gaire et al., 2017).

Because group dynamics were found to be a factor in the exit behavior of individuals, it was necessary to understand the effect of heterogeneity in the population. Heterogeneity can be defined as the mixture of different types of individuals, such as individuals with and without disabilities. The impacts of visibility and gender were used in the performance of the heterogeneous population study in experiments performed by Shen et al. (2014). Their study concluded that the reduction in the visibility of the room's features will result in lower walking speeds of the population in an evacuation, which in turn results in the clogging of exit doors. Christensen et al. (2013) evaluated the effectiveness of the built environment on the accommodation of the needs of individuals with disabilities in emergency evacuations. The difference in time to egress between homogeneous and heterogeneous population groups was explored using agent-based simulations. Christensen et al. (2014) conducted a literature review focused on studies related to the ability of individuals with disabilities to egress in the built environment and found only a few studies regarding individuals with disabilities in the built environment. Manley et al. (2011) proposed an agent-based mode model, which was used to estimate the evacuation performance of a heterogeneous population in airports. The model presented by their study could be used for the engineering design and management of emergency evacuations. Their study suggested that individuals with lower stamina and individuals using wheelchairs are at greatest risk during an evacuation. Koo et al. (2012) analyzed the trend of evacuations of the two population scenarios: homogeneous and heterogeneous residents. Results revealed that the heterogeneous group required more time to evacuate than the homogeneous group because of the congestion caused by individuals with disabilities. Table 1 provides information about the studies regarding the models for evacuation, along with the variables considered in the analysis of model.

Table 1. Studies conducted on exit choice behavior during emergency evacuation.

Author	Method of study	Factors considered for the exit choice						Relevant findings
		DE	D	RI	F	IWD	HP	
Duives and Mahmassani (2012)	Multinomial logit model	√	√					Group behavior generally found in evacuation scenarios.
Fu et al. (2016)	Discrete evacuation model	√		√				Phenomenon such as arching, clogging and irregular outflow seen during simulation.
Lovreglio et al. (2016)	Mixed-logit model	√	√	√	√			Density and distance had negative effects on the exit choice, whereas flow and room information had a positive effect on exit choice.
Guo and Huang (2008)	Logit based model			√				Information on exit has major role in exit choice.
Liu et al. (2009)	Simulation	√	√	√				Density plays an important role in exit choice. Unfamiliarity with the room's features makes it difficult to make exit choice.
Nilsson et al. (2008)	Unannounced evacuation experiment			√				Information such as green flashing lights can have a positive influence on exit choice.

Note: DE = Distance to Exit; D = Density around exit; RI = Room Information; F = Flow at exit; IWD = Individuals with Disabilities; HP = Heterogeneous Population

Table 1(contd.). Studies conducted on exit choice behavior during emergency evacuation.

Author	Method of study	Factors considered for the exit choice						Relevant findings
		DE	D	RI	F	IWD	HP	
Sørensen and Dederichs (2013)	Experimental study					√		Different patterns such as walking against the wall, lower walking speed, group dynamics among visually impaired people and negative effect of mobility stick during evacuation discussed.
Sørensen and Dederichs (2014)	Experimental study					√	√	Egress time for mixed group of populations twice that of able-bodied group. Flow is affected by mobility impaired participants.
Haghani et al. (2014)	Multinomial logit and mixed logit models	√	√	√				Distance, density and room information had a positive effect on exit choice behavior.
Fang et al. (2010)	Experimental study	√	√		√			During low density conditions around exits, shortest exit chosen. During congestion, farthest exit chosen to avoid wasting time.

Note: DE = Distance to Exit; D = Density around exit; RI = Room Information; F = Flow at exit; IWD = Individuals with Disabilities; HP = Heterogeneous Population

CHAPTER 3

DATA COLLECTION

The purpose of this chapter is to provide an overview of a controlled experiment on the evacuation behavior of a crowd involving individuals with disabilities. This study focused on measuring and studying the behaviors of crowds involving individuals with disabilities by experimentally observing and measuring key behaviors in controlled built environments. The data collected was used to establish the trajectories of individuals, which were then studied. Microscopic data was collected using new radio frequency identification (RFID) tracking technology complemented by video tracking methods.

3.1 Experiment Settings

The experiments were performed in the Agricultural Sciences (Ag Science) building at Utah State University. 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)/ADA Standards for Accessible Design accessible means of egress, including typical areas of rescue assistance. 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).

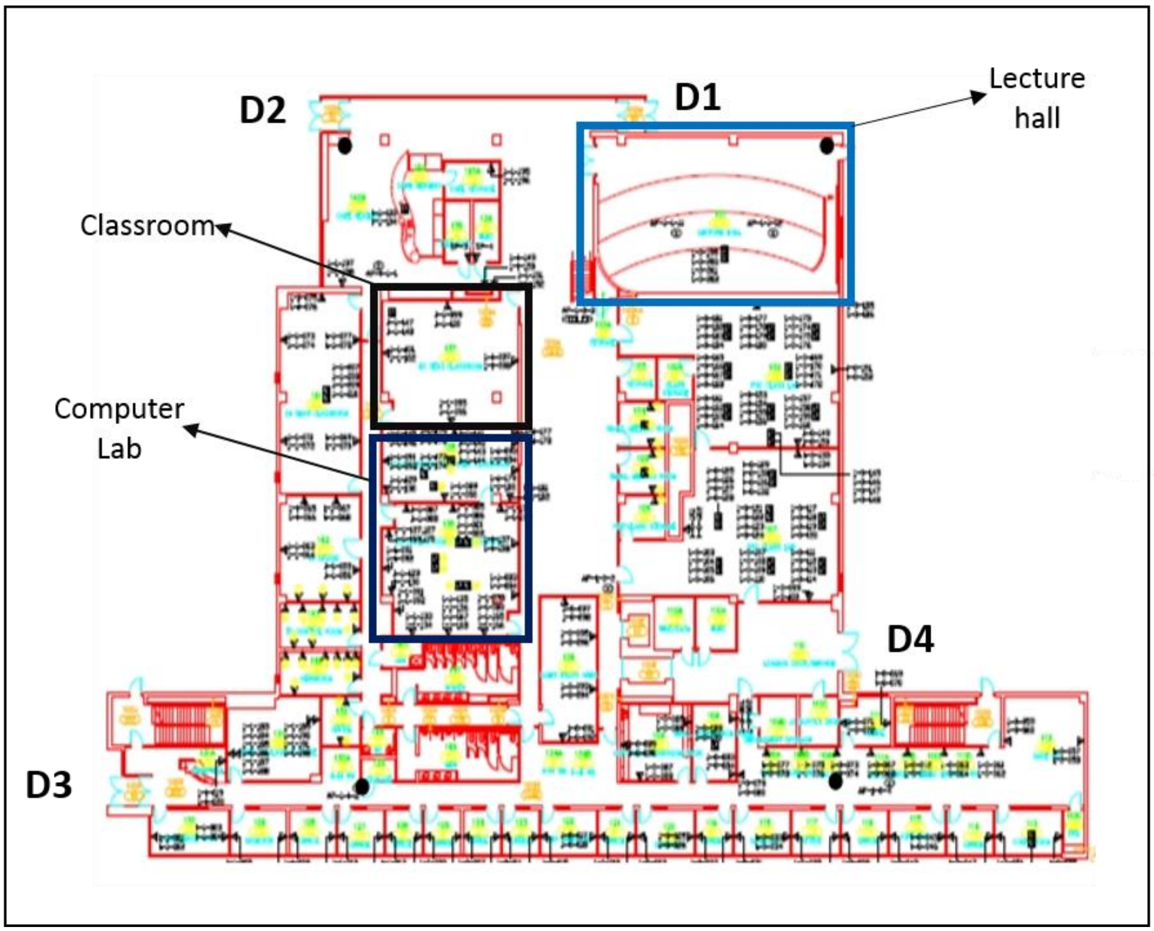

Figure 1. Layout of the building with different components.

Figure 2. Exit doors used during the evacuation experiments.

Four doors on the ground floor were used as the exit doors, as they were accessible to all individuals, regardless of disability. In different evacuation scenarios, the availability of doors was regulated to study exit patterns. Figure 2 shows the four doors that were used as exit doors during the evacuation experiments.

3.2 Radio Frequency Identification (RFID) Tracking

RFID is an automatic identification system that consists of two components: a reader and tags. 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, which makes it very important to the inventory systems (Lin et al., 2008). RFID can be used to efficiently track moving objects efficiently (Wilson et al., 2007). Although RFIDs can store information, they have some limitations. They cannot perform calculations and cannot be read beyond a distance of about 10 feet. Although RFID tags have limitations and cannot provide information about the exact location of objects, they are very efficient in tracking objects inside a facility (Lin et al., 2008). Additionally, RFID tracking of individuals was complemented by video tracking method to achieve higher accuracy than is possible when exclusively employing RFID. We used video cameras at the exit doors of the building to track the time individuals existed the building (Figure 3).

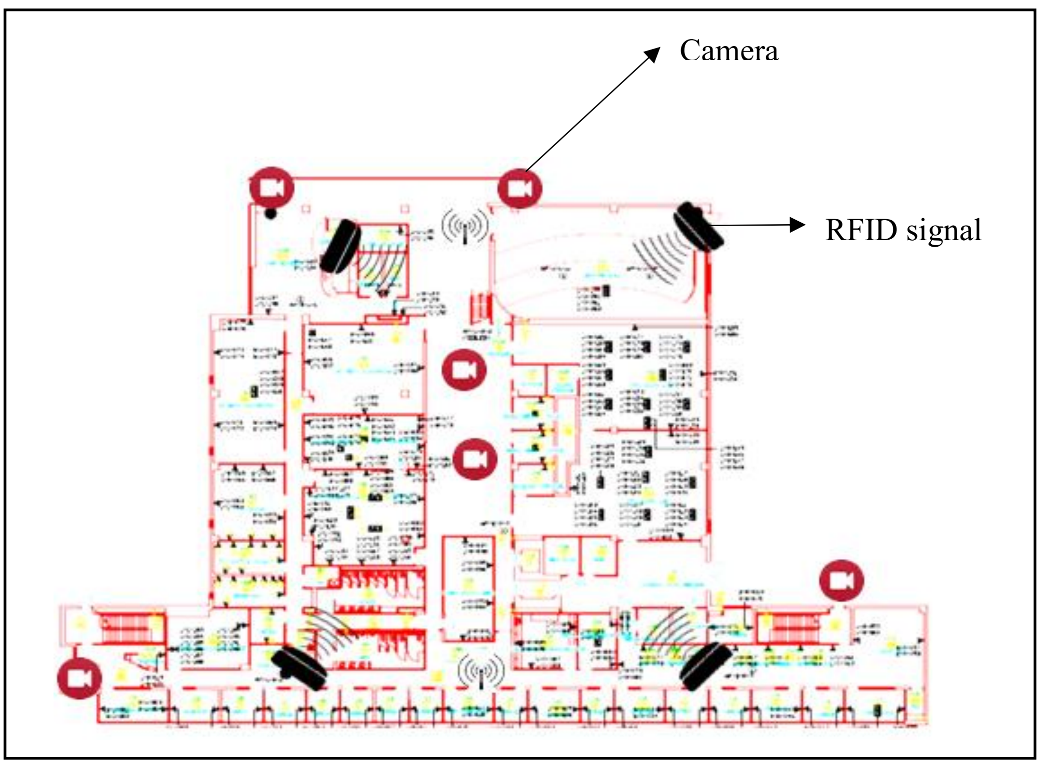

Figure 3. Approximate location of RFID and camera systems on the ground floor.

Figure 4. Participants wear markers on their heads and RFID tags with lanyards.

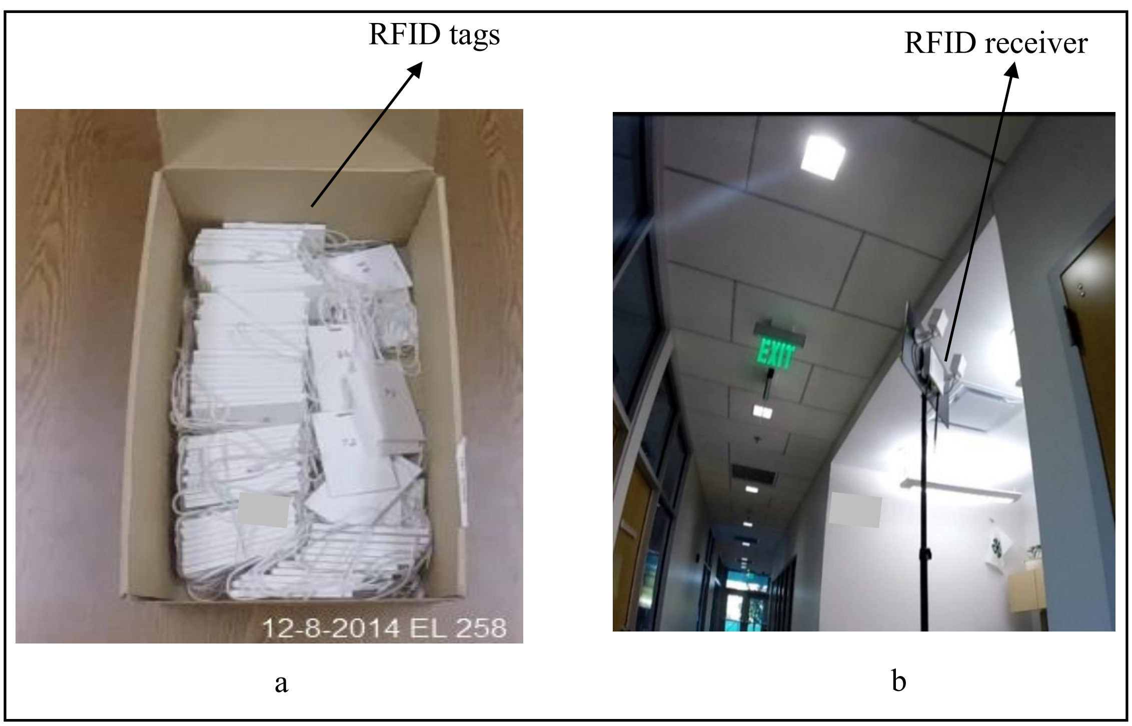

Figure 5. (a) RFID tags used for the experiment; (b) RFID receiver mounted in a stand to receive signals from the RFID tags.

Figure 3 shows the approximate location of the RFID signals and the camera locations used in the experiments. Figure 4 shows the participants wearing RFID tags and lanyards. Figure 5 shows the RFID tags and the RFID receiver used for the experiment. Camera systems were used in areas where it was desired to collect more accurate trajectories. Those desired areas were exit areas and other possible congested areas (Figure 3).

3.3 Participants in the Study

Forty-seven participants, including 13 individuals with disabilities (12 individuals with visual impairments and 1 with a wheelchair), took part in the experiments (Figure 6). Route choice, exit choice and interactions with individuals with disabilities (approaching speed, spacing, etc.) were examined using different evacuation scenarios. The following variables changed in each evacuation scenario:

- Participant distribution
- Exit door availability
- Evacuation strategy

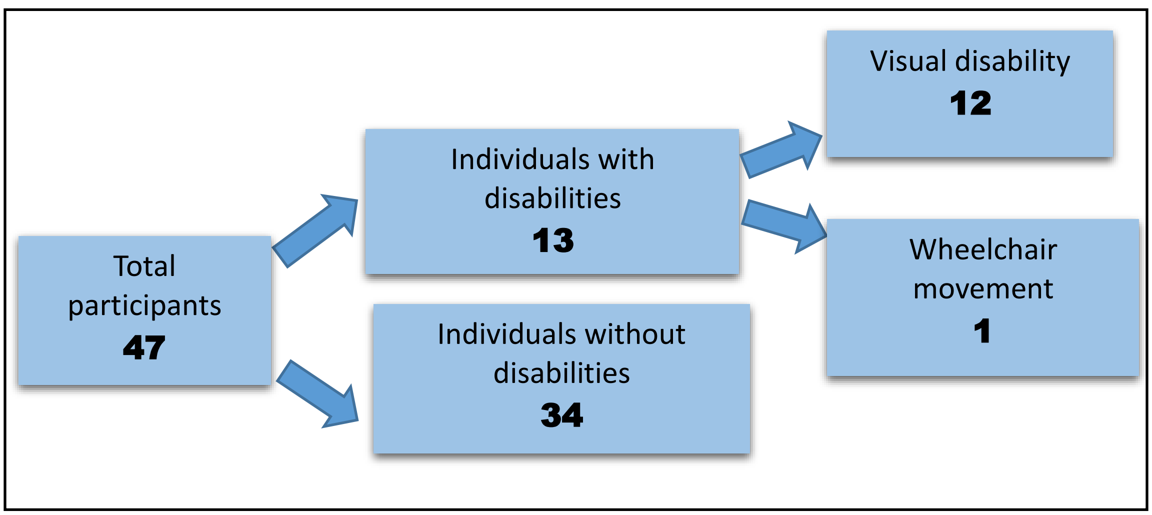

Figure 6. Distribution of the individuals in the experiments.

Table 2. Evacuation scenarios with description of IDs.

Run	Location	Total IDs	Number of IWDs
1	Class	40	7
2	Class	37	6
3	Class	40	8
4	Class	37	7
5	Computer Lab	41	8
6	Computer Lab	42	9
7	Computer Lab	43	10
8	Both	44	11
9	Both	40	9
10	Both	44	11
11	Class	41	7
12	Lecture hall	43	11
13	Lecture hall	31	4
14	Lecture hall	45	11
15	Computer lab	41	9
16	All places	41	11

IWDs = Individuals with disabilities.

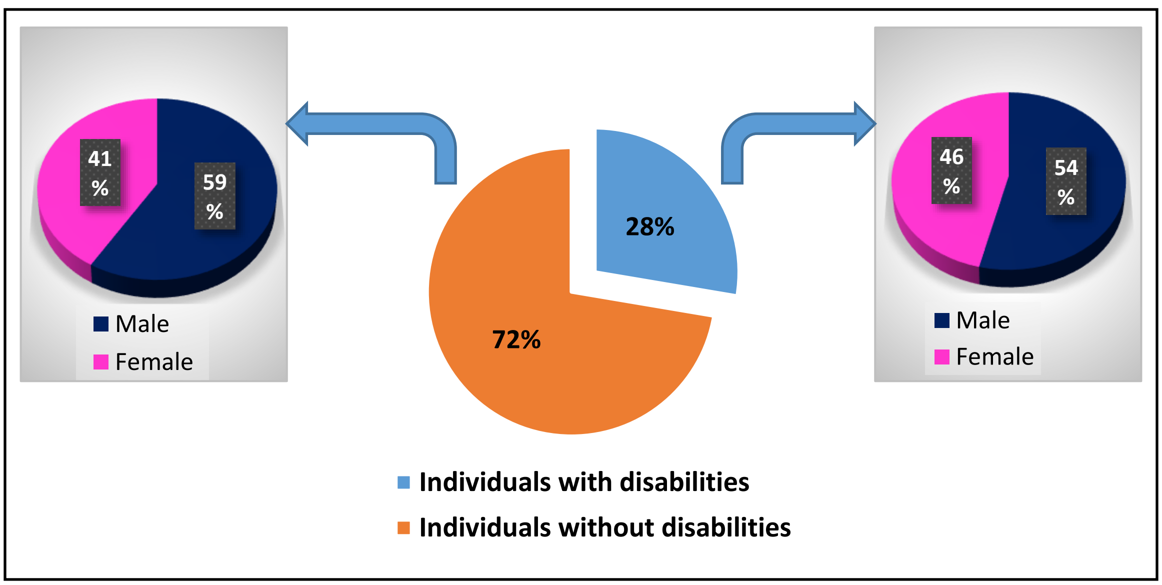

Figure 7. Distribution of participants based on gender.

CHAPTER 4

DATA ANALYSIS

This study describes the analyses completed using data obtained from the different experiment scenarios. The data extracted after the experiment shows the movement of each ID at every two-second interval. Sixteen different scenarios were conducted, each consisting of: individuals with disabilities and individuals without disabilities. Differences in evacuation scenarios were based on changes in participant distribution, exit door availability, and evacuation strategy in each scenario (Table 3). The evacuation scenarios are given as:

Table 3. Evacuation scenarios.

Run	Location	Controlled	Available doors
1	Class	No	D1, D2
2	Class	No	D1
3	Class	No	D2
4	Class	Yes	D1, D2
5	Computer Lab	No	D1, D2
6	Computer Lab	No	D3, D4
7	Computer Lab	No	D4
8	Both	No	All doors
9	Both	No	D1, D2, D4
10	Both	No	D2, D4
11	Class	Yes	D3, D4
12	Lecture hall	No	D2
13	Lecture hall	No	D1, D2
14	Lecture hall	No	D3, D4
15	Computer Lab	Yes	All doors
16	All place	No	All doors

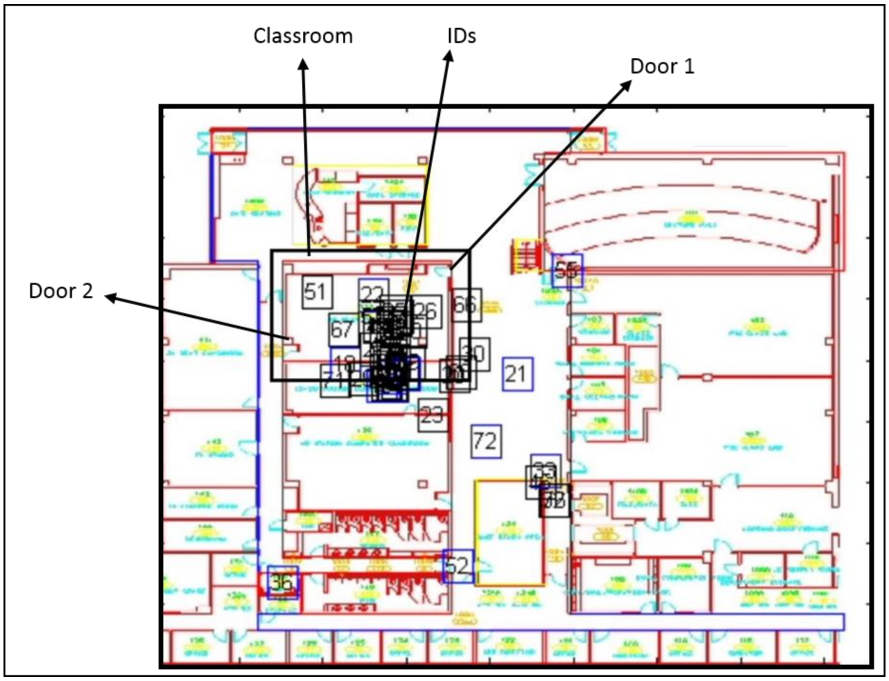

Figure 8. RFID tracking of IDs leaving a classroom.

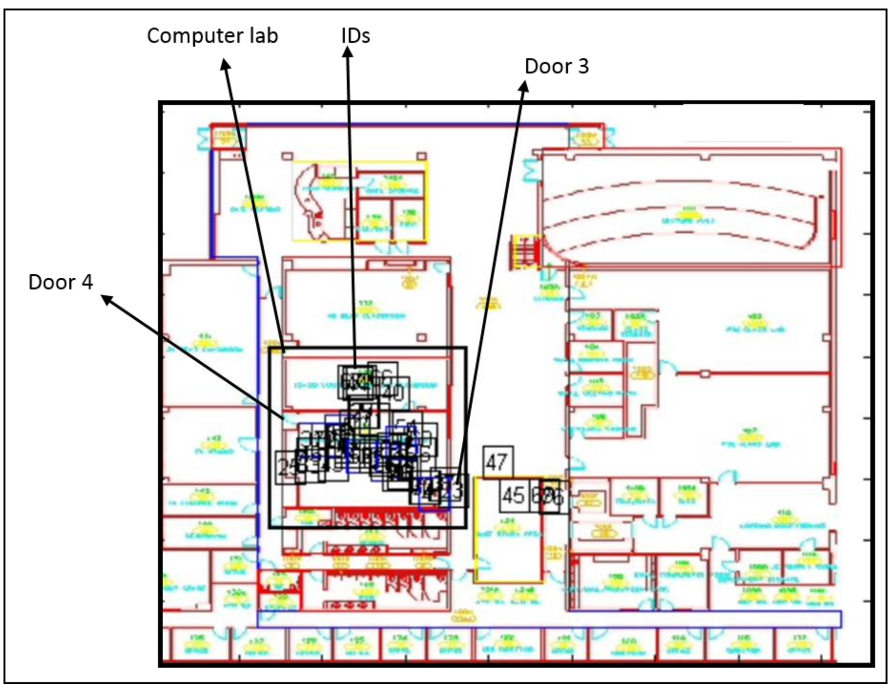

Figure 9. RFID tracking of IDs leaving a computer lab.

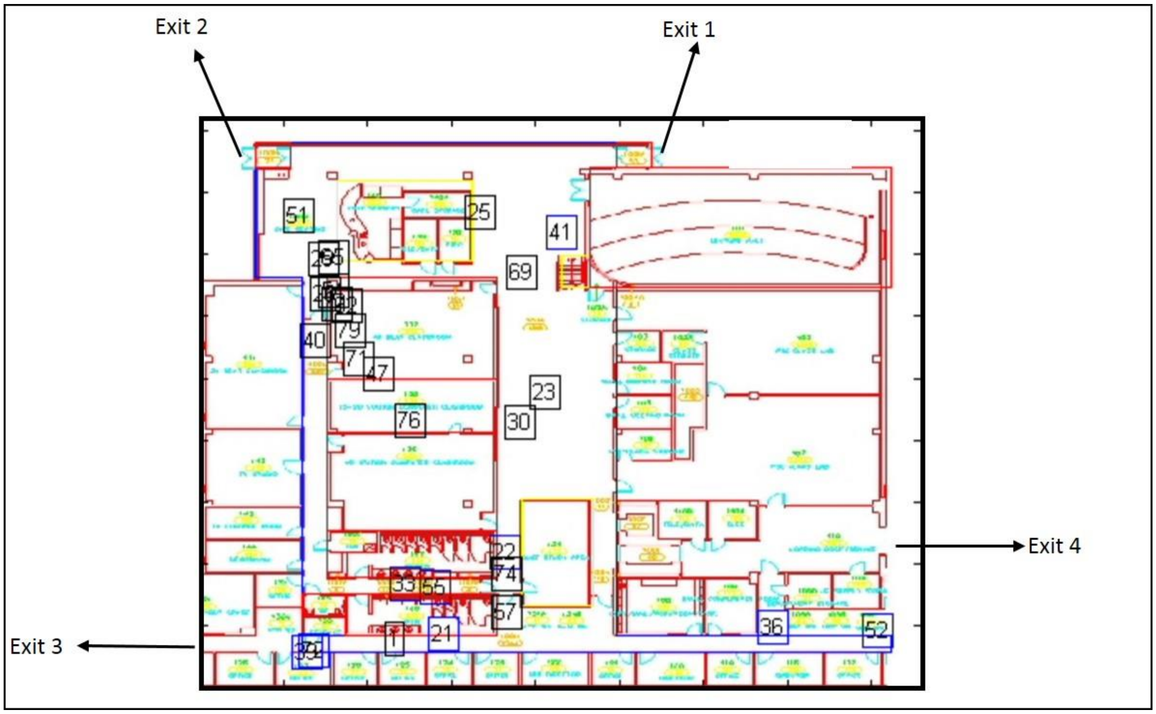

Figure 10. RFID tracking of IDs exiting the building.

Figure 8 shows the location of IDs in the classroom two seconds after the start of the experiment. Figure 9 shows the location of IDs in the computer lab two seconds after the start of the experiment. To analyze the exit choice, calculations of the distance of individuals from the exit doors in the class and the computer lab, as well as exit door positions in the classroom and the computer lab, were necessary. The positions of the exit doors in the classroom and the computer lab were manually located by analyzing trajectories of the individuals exiting the room. As seen from the experiment data exit time recorded for individuals, the results demonstrate that exit time represents the time that an individual left the building (Figure 10).

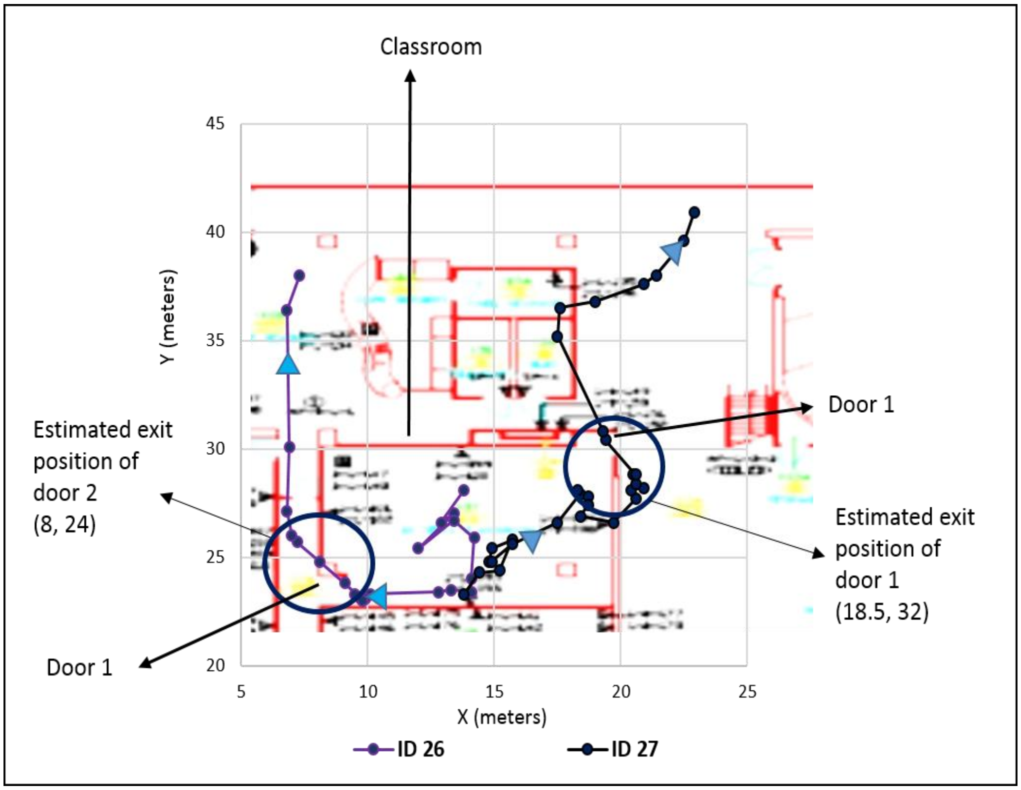

Figure 11. Estimated exit positions of the doors in the classroom.

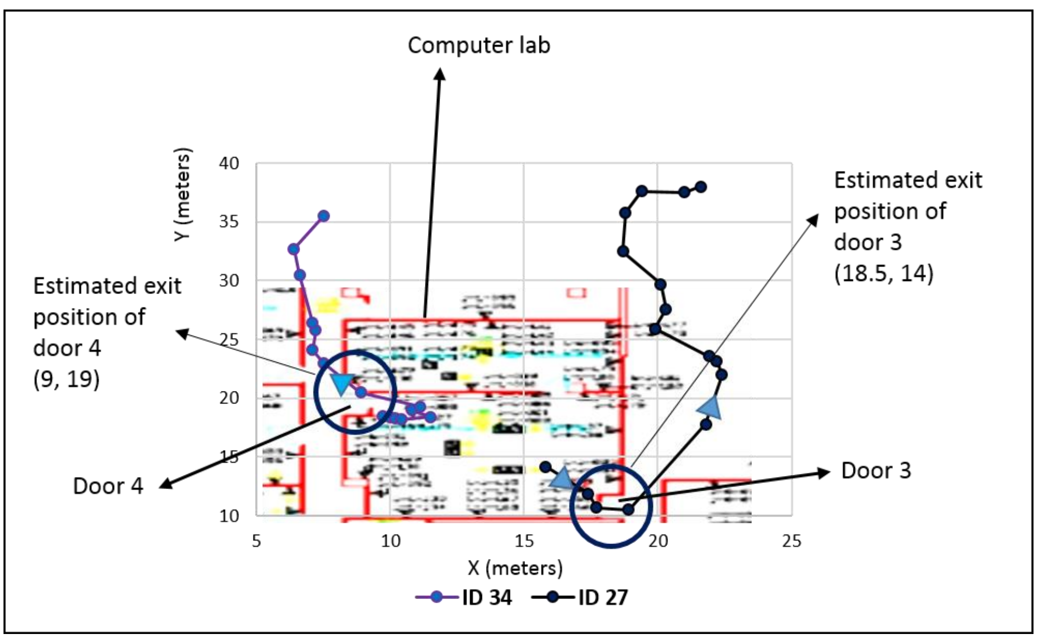

Figure 12. Estimated exit positions of the doors in the computer lab.

Hence, it was necessary to determine exit times and exit positions of individuals at the doors of the room. The exit positions of the doors in the room and the exit times of individuals from that room were estimated based on an analysis of the trajectory of all individuals in scenario 1 for the classroom (Figure 11) and scenario 5 for the computer lab (Figure 12). The exit positions and exit times of individuals from the classroom and the computer lab were manually extracted using the trajectories of individuals in both scenarios.

Table 4. Manual estimation of exit times of IDs from the room under scenario 1.

ID	Bldg. exit time (seconds)	Exit choice	Room exit time (seconds)	ID	Bldg. exit time (seconds)	Exit choice	Room exit time (seconds)
6	53.453	1	2	57	40.39	2	18
68	58.674	2	2	20	55.663	1	22
69	56.01	2	2	26	49.74	2	22
52	93.606	1	4	32	42.015	2	22
71	51.791	2	4	40	45.234	2	22
47	42.6	2	4	53	51.487	1	24
51	19.82	1	6	23	46.336	2	24
21	60.925	2	6	66	44.558	1	26
24	46.021	1	10	65	48.377	2	28
30	25.507	2	10	74	48.958	2	30
41	54.253	1	10	62	47.752	1	30
31	25.32	1	12	29	50.656	1	32
36	103.89	1	12	44	52.183	1	32
46	42.746	2	14	54	50.775	2	32
18	53.978	1	14	37	64.106	1	32
33	37.616	2	14	43	55.319	2	32
27	53.374	1	16	60	65.394	2	34
25	51.154	1	18	76	45.615	1	36
45	62.47	1	18	67	57.805	2	36
55	38.854	2	18	35	57.139	1	38

The data extracted following the experiment was used to calculate exit time information of individuals from the room, as well as their exit choice by examining their trajectory (Table 4). The trajectories of the individuals were then individually analyzed under all of the scenarios to observe their actual exit choice and their exit time from the room. Figures below demonstrate that individuals chose different exits (Figure 13 & Figure 14). After the exit choice was ascertained from the trajectory, it was possible to extract the exit times of individuals.

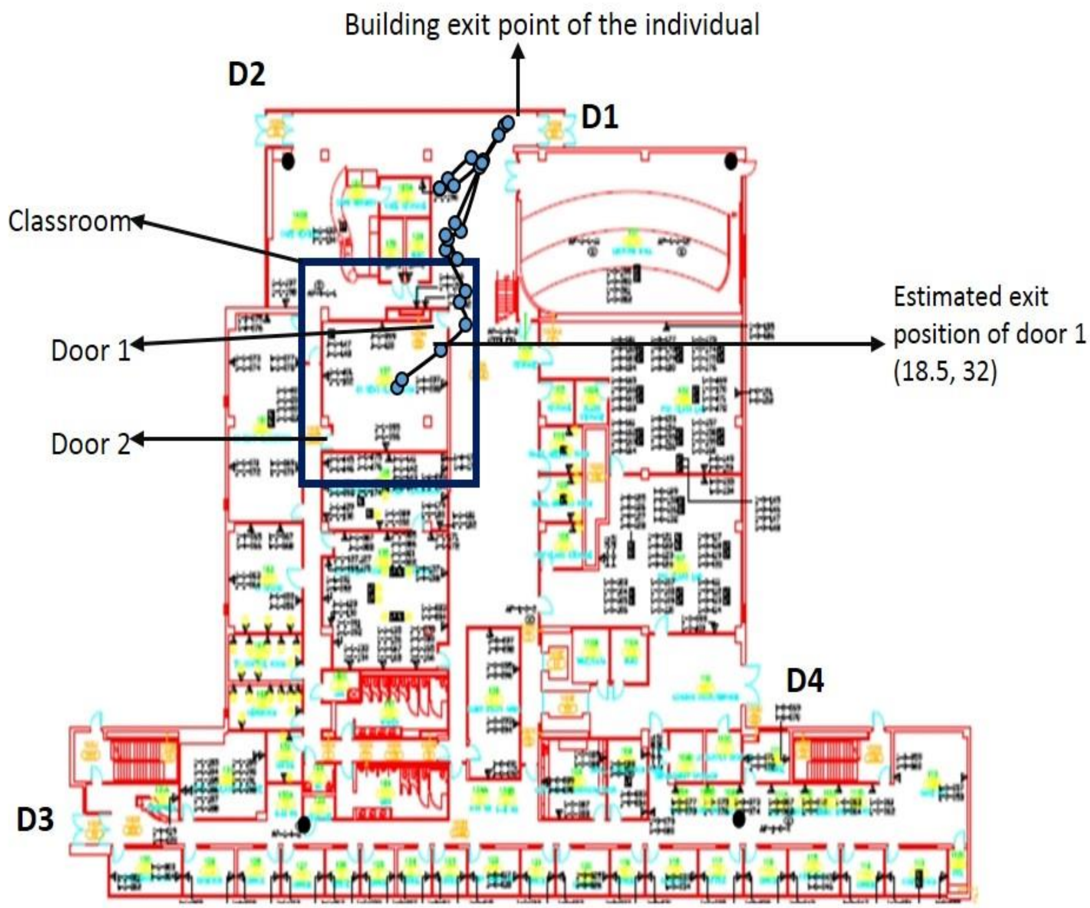

Figure 13. Layout of the AG Science Building with trajectory of an individual leaving the classroom.

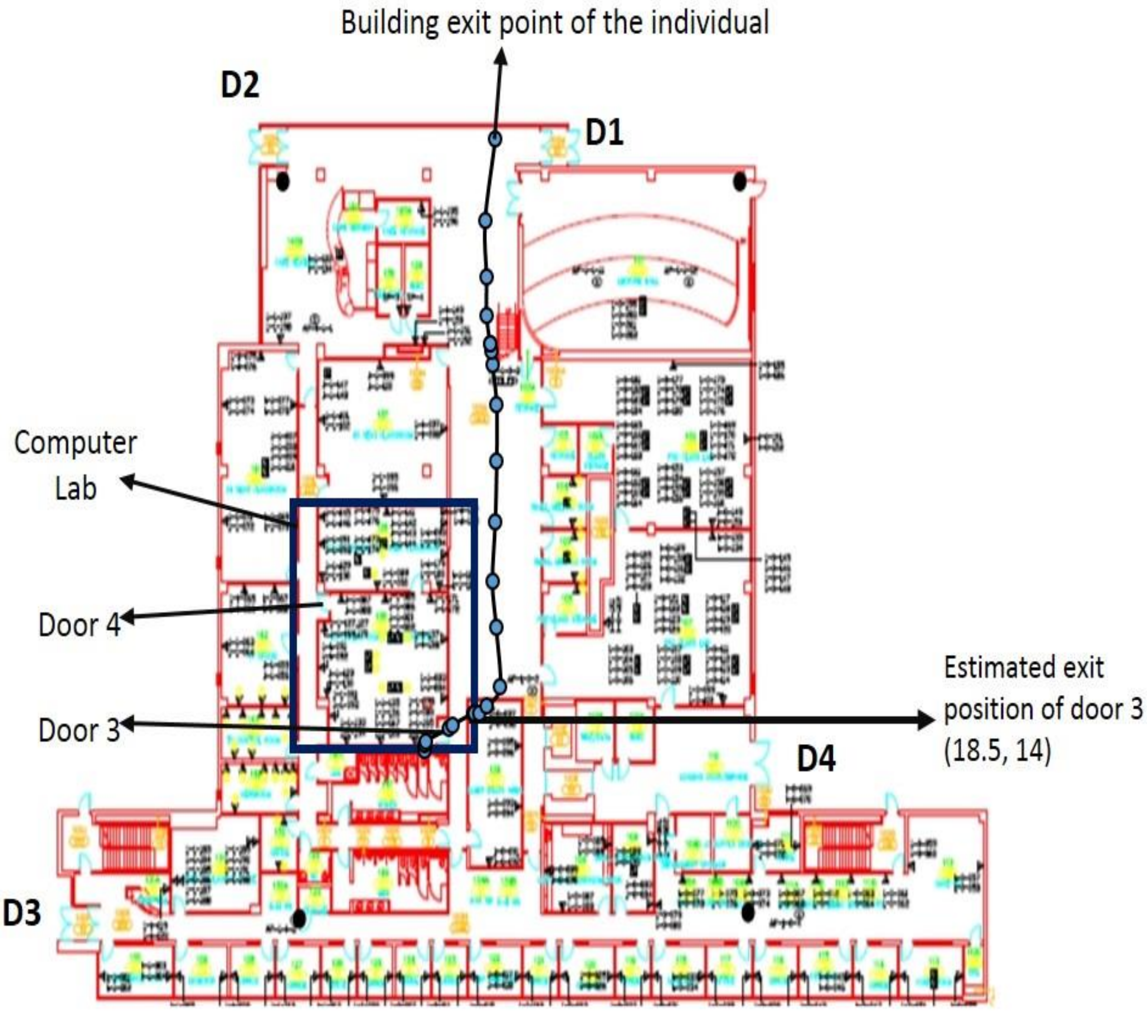

Figure 14. Layout of the AG Science Building with trajectory of an individual leaving the computer lab.

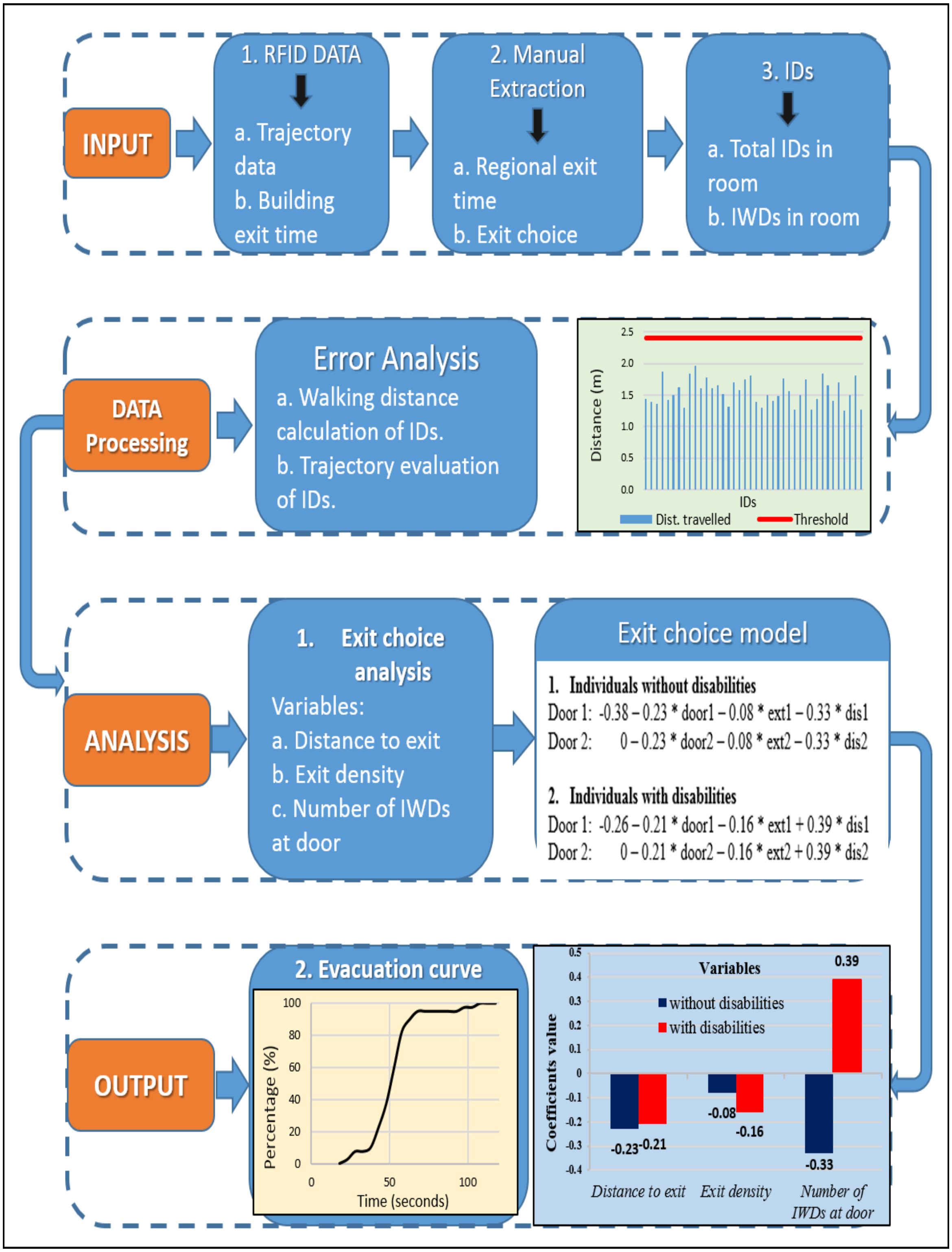

Figure 15. Diagram showing the RFID data analysis.

CHAPTER 5

EVACUATION BEHAVIOR MODEL

The RFID data was studied, and the analysis was conducted under two different topics. First, the evacuation analysis was done based on the evacuation curve. Evacuation curves for different scenarios were analyzed to observe the exit patterns of individuals. This analysis was done using data from the four cameras at four different exit doors: D1, D2, D3 and D4. The exit times of individuals from the building were recorded, and this data was used in the analysis of evacuation curves under different scenarios. The evacuation curve is the curve that provides information regarding the number or percentage of the individuals evacuating versus the exit time of individuals from a certain facility. Secondly, 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. This study may be useful in obtaining information about the evacuation process, and the results may also affect policies implemented to manage evacuations.

Additionally, the primary focus of this study was to understand the characteristics of different pedestrians group types (homogeneous versus heterogeneous). The homogeneous populations in this study is exclusively comprised of individuals without any disabilities, and while the heterogeneous population contains people both with and without disabilities. This study was conducted to examine how different parameters have distinct roles in the selection of exit doors for heterogeneous populations. Many studies have been conducted on the evacuation behavior of homogeneous populations, but far less studies regarding the evacuation behavior of heterogeneous populations are found in the extant literature. It is important to understand the differences in characteristics of heterogeneous populations. The effect of the parameters for exit door selection might be different for individuals with and without disabilities. It is necessary to understand how the introduction of people with disabilities affects the behavior of pedestrians' evacuation choices.

5.1 Evacuation Curve

The evacuation curve is defined as the number of evacuees with respect to the time of the evacuation. It provides detailed information regarding the start and the end times of the evacuation. The start time is the time at which the first individual exits the facility. The end time is the time at which all of the individuals have exited the facility. Examining the curve, one is able to ascertain the number of evacuees exiting the building at any time. The sample of the evacuation curve is provided below in Figure 16.

The start time for the evacuation according to Figure 16 is 19 seconds, whereas the end time is 110 seconds (Figure 16). Figure 17 shows the evacuation curve for all of the 16 different evacuation scenarios. The difference in the evacuation curve for different scenarios can be seen in Figure 17. The exit patterns for the different scenarios differ in terms of the start time and the exit time. This is because of differences in the availability of the exit doors in the different scenarios.

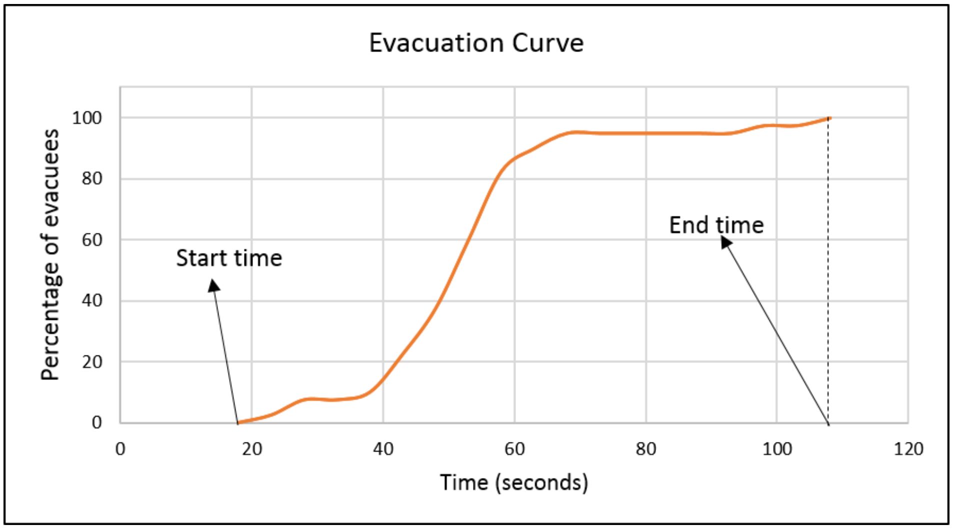

Figure 16. Evacuation curve for a scenario.

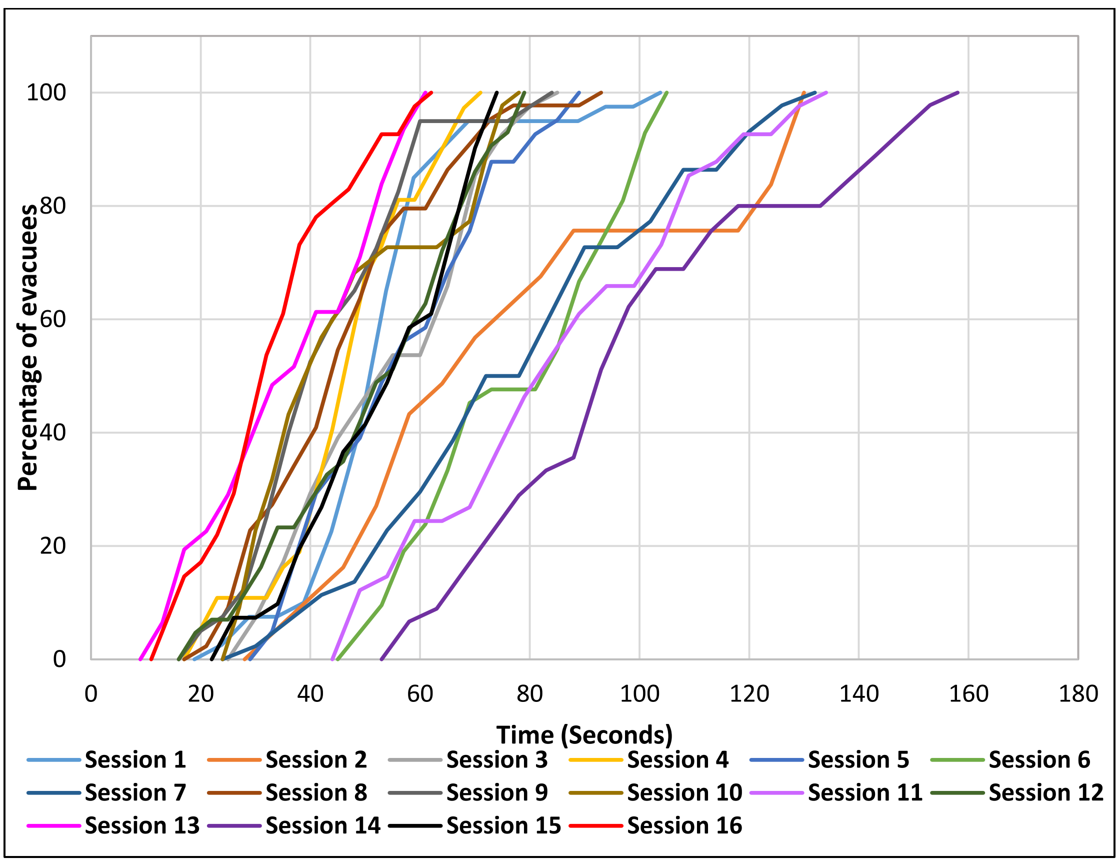

Figure 17. Evacuation curve of all 16 scenarios combined.

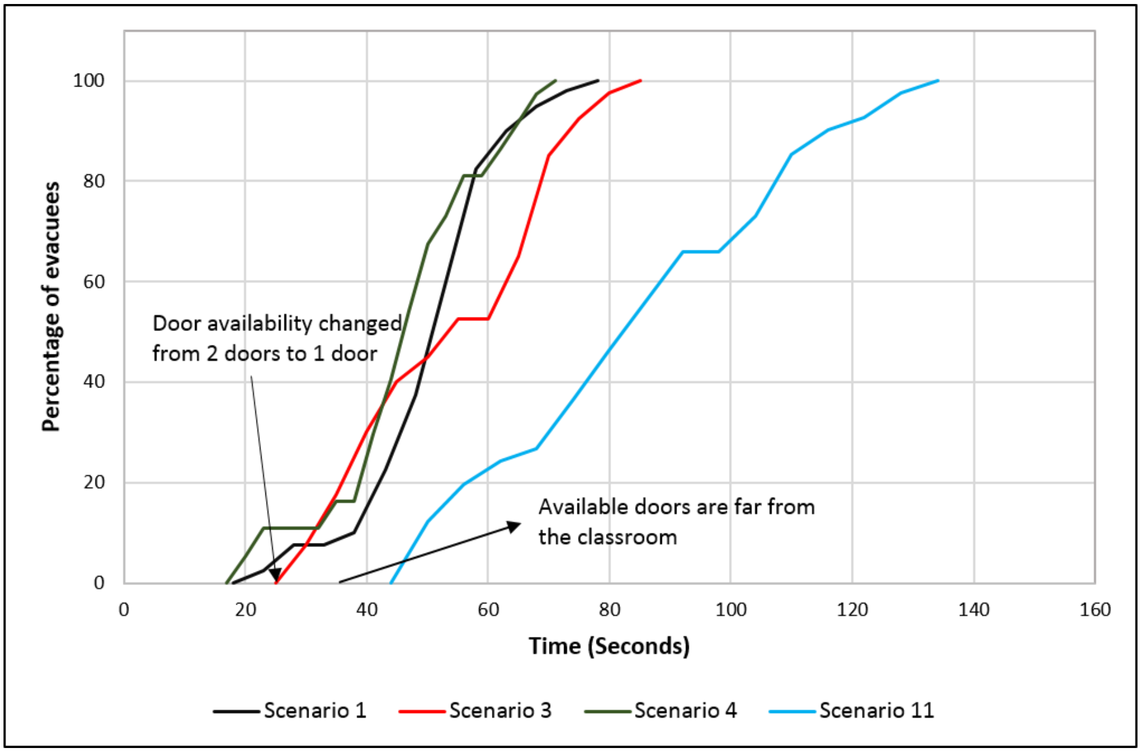

Figure 18. Evacuation curves for the scenarios in the classroom.

Figure 18 shows the evacuation curve for the four scenarios in the classroom. For scenarios 1, 3 and 4, the doors available for exiting the building are near the classroom. Hence, the start times for all three scenarios are relatively similar to the start time for scenario 11. Scenario 1 and scenario 4 have the same door availability (i.e., D1 and D2). Hence, start times and end times for these scenarios appear to be similar. Scenarios 3 has just one available door (i.e., D2). Hence, the start time for this scenario is greater than scenario 1 and scenario 4 by a noticeable degree (Figure 18). This causes lagging in the evacuation curve and this effect can be seen in Figure 18 above. This demonstrates that door availability in the building has a direct impact on the evacuation curve.

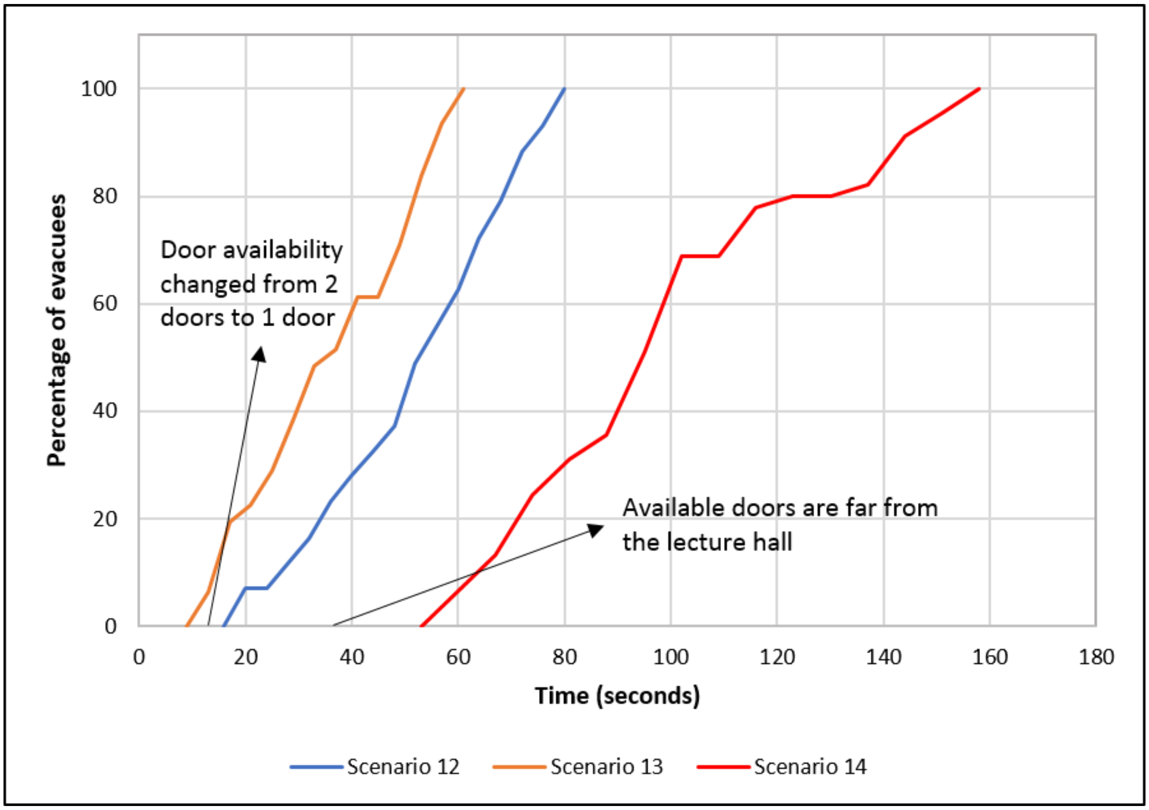

Figure 19. Evacuation curves for scenarios in the lecture hall.

In examining evacuation scenarios in the lecture hall, the pattern was noted to be much like those in the classroom (Figure 19). Scenario 12 and scenario 13 have similar patterns, as seen in Figure 19, in terms of the slope of the curves. They have distinct patterns in terms of the start time and the end time of the curves. The start time in scenario 12 is greater than that in scenario 13. This can be justified by the availability of the exit doors in the building. Scenario 13 has two doors available, while scenario 12 has only one door available for evacuation from the building. This availability of doors is directly reflected in the start time of the evacuation curves in the two scenarios. This has a direct effect on the end time in the evacuation of the scenarios.

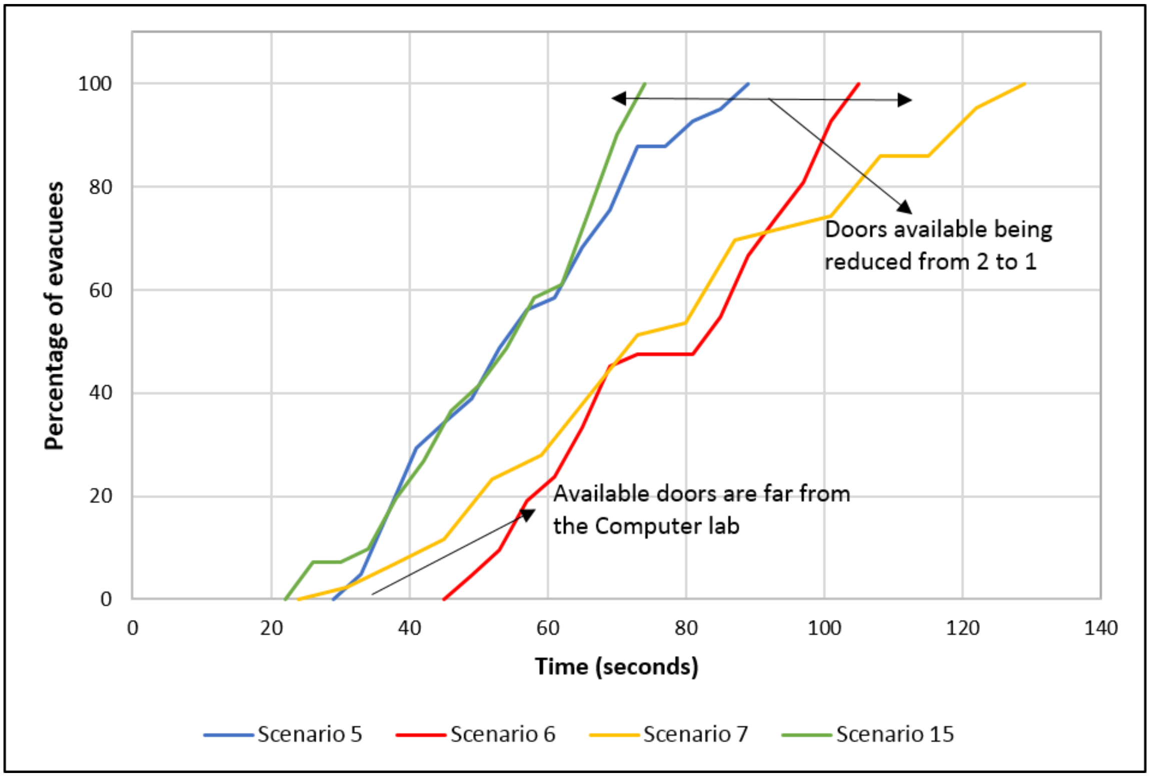

Figure 20. Evacuation curves for the scenarios in the computer lab.

However, if we look at the evacuation curve in scenario 14, we can observe there is quite a long gap in the start time of the evacuation from the building. This is because the exit doors, although two are available, are far from the lecture hall. The evacuation curves shown in Figure 20 clearly demonstrates the difference in evacuation times of the scenarios with the varying availability of the number of doors in the building.

Hence, analyzing these scenarios from the classroom, the computer lab and the lecture hall, we can determine that the availability of doors plays a major role in the evacuation time from the building.

5.2 Exit Choice

Exit choice is a crucial factor that affects the quality of evacuation. 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. "BIOGEME" was chosen as the tool for estimating the logit model. Figure 21 lists s brief description of the variables considered during evacuation by evacuees in a closed room.

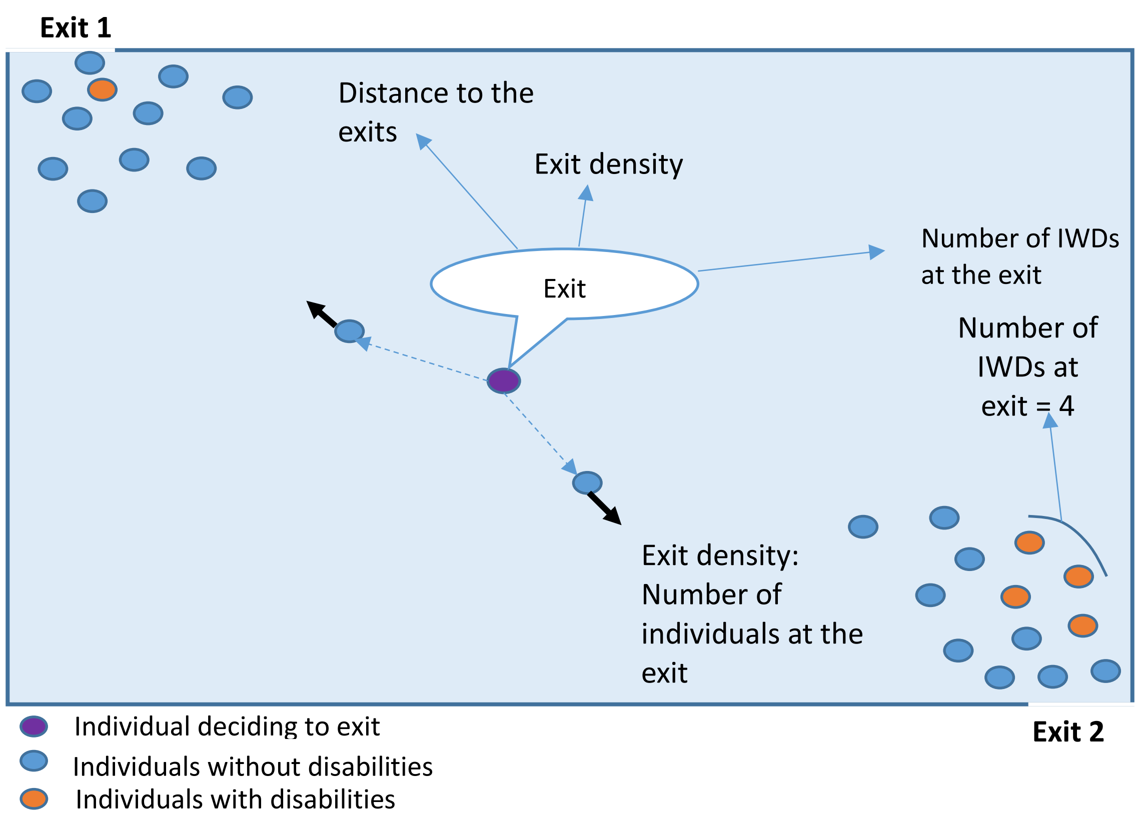

Figure 21. Exit choices in a room with two exits.

5.2.1 Discrete Choice Model

Discrete choice models are used to predict the choice or the outcomes from two or more alternatives to a problem (McFadden, 1980). The prediction of the mode of transportation of an individual when faced with different choices exemplifies discrete choice modeling. Some other examples where discrete choice models can be used include route selection between different alternative routes, such as four-lane arterial roads, two-lane highways or four-lane highways; which type of transit service to use among finite alternatives; where to go to college; and many more. Discrete choice models tie the choice made by an individual based on different statistical parameters to the different 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 (McFadden & Train, 2000). This is because of the fact that although we strive to define attributes for the alternatives, we can never incorporate all of the attributes for the choice of alternatives. This is why 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 have an effect on the selection of the alternative. These are often called the variables for the discrete choice models. The variables include dependent variables and independent variables (McFadden, 1973; Ben-Akiva et al., 1985; Swait et al., 1987; Ben-Akiva et al., 1999). The alternatives are evaluated based on utility, which is measured by defining utility function. Utility function is the function that determines the discrete outcome 'i' among 'j' different alternatives. Individuals will make a selection 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 U_i. The general representation of the utility function is then given by:

$$U_i = V_i + e_i$$

Where,

U_i = total utility of alternative 'i'.

V_i = deterministic component of alternative 'i'.

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.

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

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 ‘j’, or different alternatives, is given by:

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

5.2.2 Binary Choice Model

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. Let the utility that determines the outcome ‘i’ be represented by U_i. 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:

$$\mathbf{V_{door1}} = \text{CONS1} * \text{one} + \text{BETA1} * D_{d1} + \text{BETA2} * K_{e1} + \text{BETA3} * N_{d1}$$

$$\mathbf{V_{door2}} = \text{CONS2} * \text{zero} + \text{BETA1} * D_{d2} + \text{BETA2} * K_{e2} + \text{BETA3} * N_{d2}$$

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 & CONS2 = constants of the two equations (intercepts).

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

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

Scenario 1, 2, 3, 4, 5, 6, 7, 11 and 15 were analyzed in the evaluation of the exit choice model. The doors available were door1 and door2. 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 individuals. The binary logit model was built for exit choice evaluation. The variables used for the logit model were:

1. 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. However, the exit position of the doors was found based on the analysis of the trajectory of all individuals at each session. The cameras were attached at the four exit doors, D1, D2, D3 and D4. These cameras were used to identify the time at which the individuals left the building. The exit times of the individuals recorded from these cameras only provided information about when the individuals left the building, not the internal features, such as the trajectory of individuals in the classroom, or the computer labs. The RFID data of the individuals was examined to determine the exit door positions in the classroom and the computer lab, as there was no information about the exit coordinates of these doors and the time of exit when individuals left those rooms.

For calculation of the distance, initial and the exit coordinates of the doors were used. Distance was calculated based on the initial position of individuals and the exit coordinates of the doors. Basically, the distance calculation assumes of shortest distance between two pints, 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.

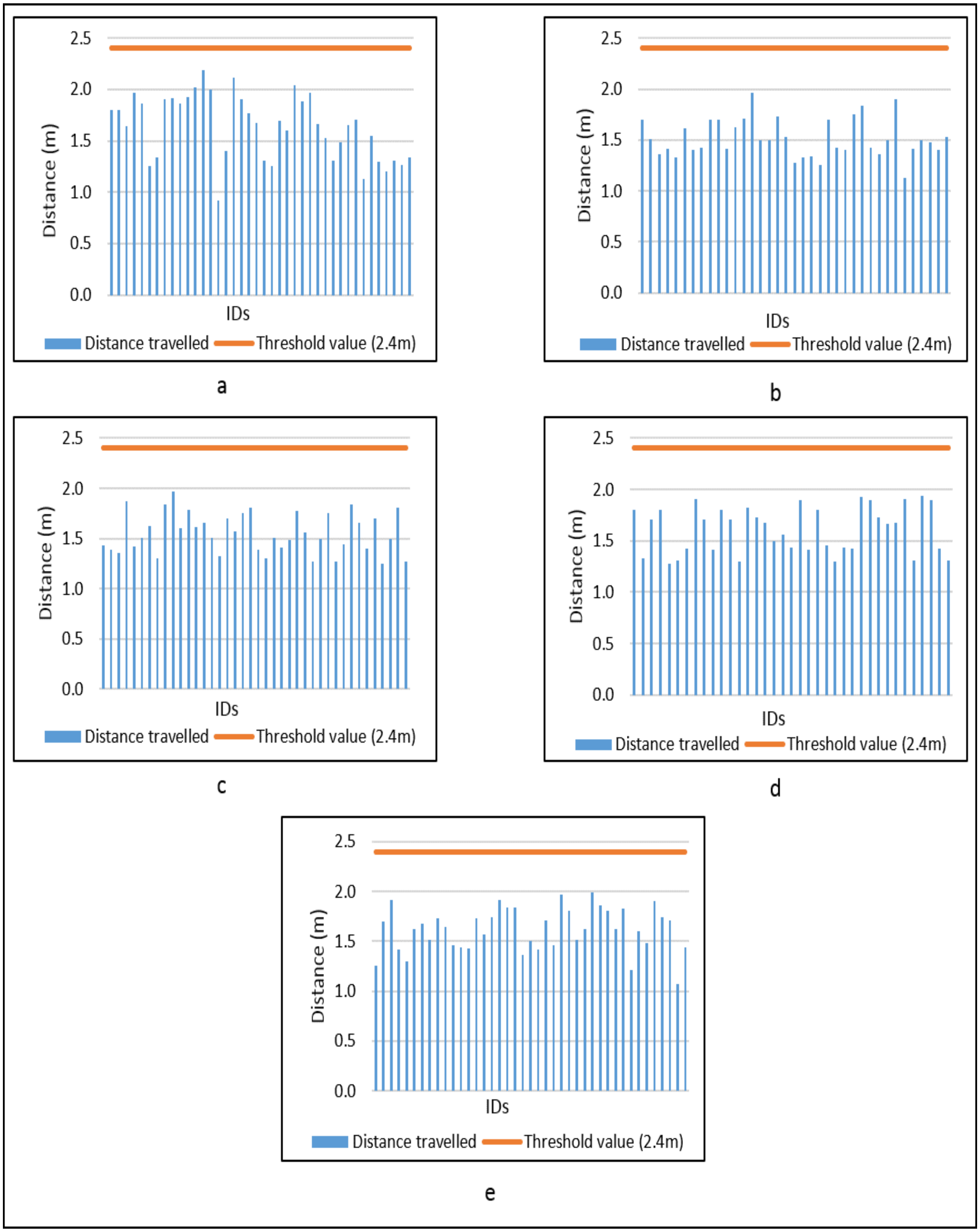

Figure 22. Average distance traveled by IDs in two seconds: (a) scenario 1; (b) scenario 2; (c) scenario 3; (d) scenario 4; (e) scenario 11.

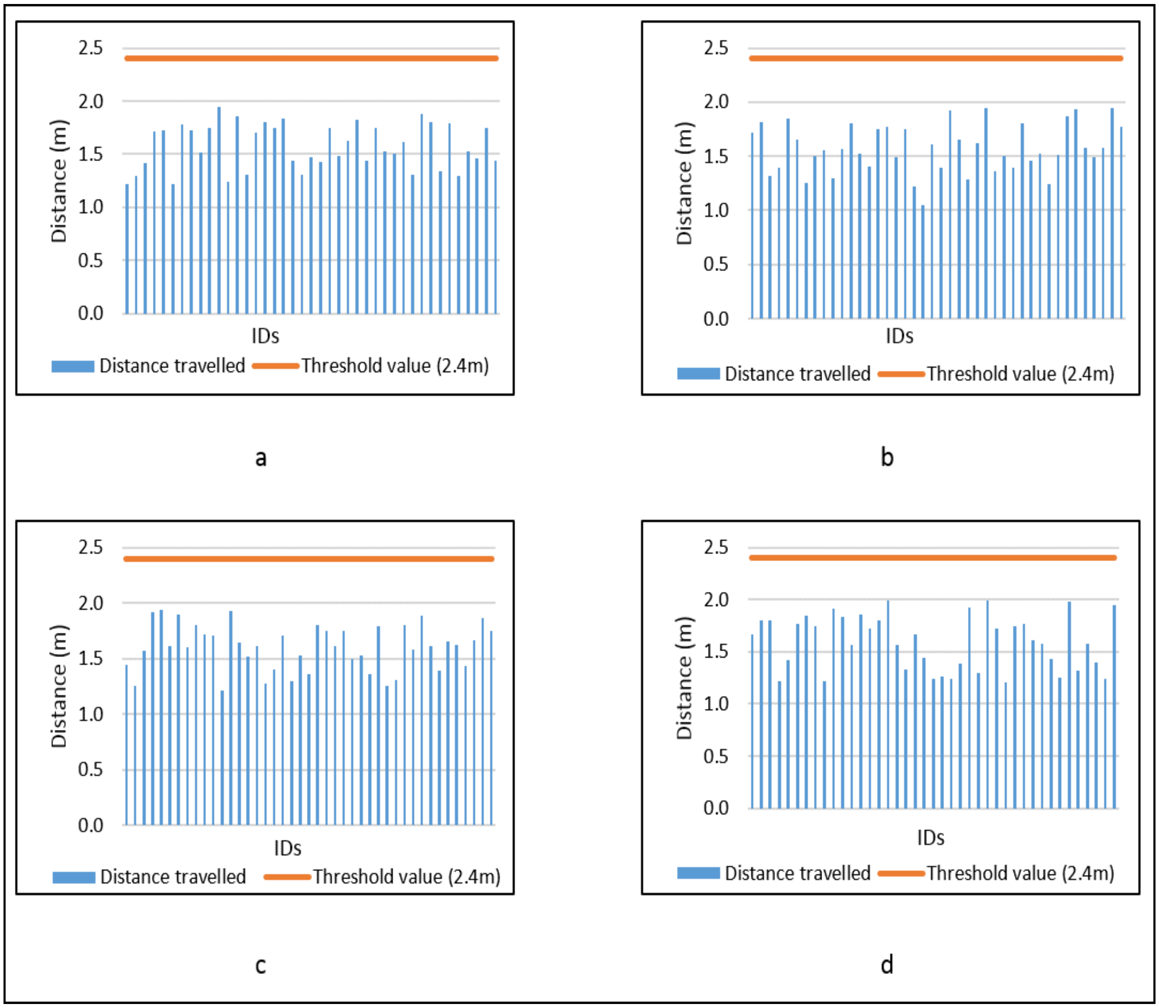

Figure 23. Average distance traveled by IDs in two seconds: (a) scenario 5; (b) scenario 6; (c) scenario 7; (d) scenario 15.

Hence, the distance traveled by an individual for the first four seconds was calculated to determine whether there was too much error in the data sets. The mean walking speed of an individual is taken as about 1.2 m/s. Hence, the individual should not have traveled more than 2.4 meters in two seconds. The distance calculated for the first four seconds in consecutive two-second intervals was found to be within the desired value (less than 2.4 meters) (Figure 22, Figure 23).

2. Total density at exits.

The population density at each exit during exiting of the rooms also appears to play a greater role during exit choice 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 easily 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. Calculation of density: 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 is determined by:

$$Density\ (k) = \ N\ \ ped/\ m$$

Where,

N = the number of people leaving the exit door at a specified time.

k = density.

In this case, the exit doors were the specified section. Because the number of people leaving the room were counted for a certain time interval, 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. Figure 8 and Figure 9 show the density patterns of individuals leaving the room for five-second and ten-second time intervals, respectively. The exit density pattern was found to be irregular when the time interval was taken as five seconds as shown in figure 24 while the pattern was found to be smooth when the time interval was taken as 10 seconds, as shown in Figure 25. The time interval of 15 seconds was also studied, but only two time intervals were identified for the density calculations. Hence, a time interval of ten seconds was used to count the number of individuals leaving the room and the exit density was then determined (Figure 26, Figure 27).

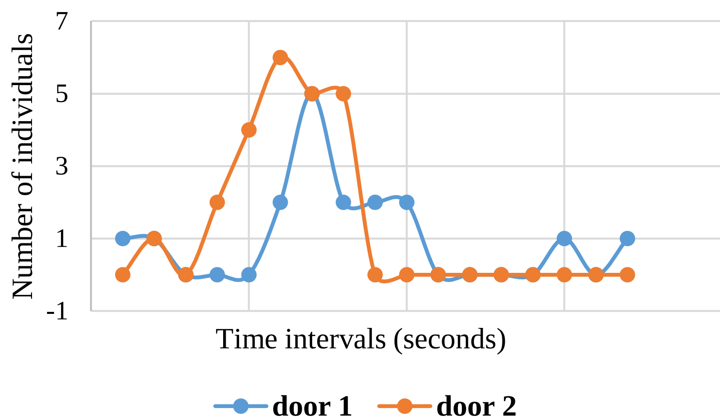

Figure 24. Exit density of individuals from two doors for five-second time interval.

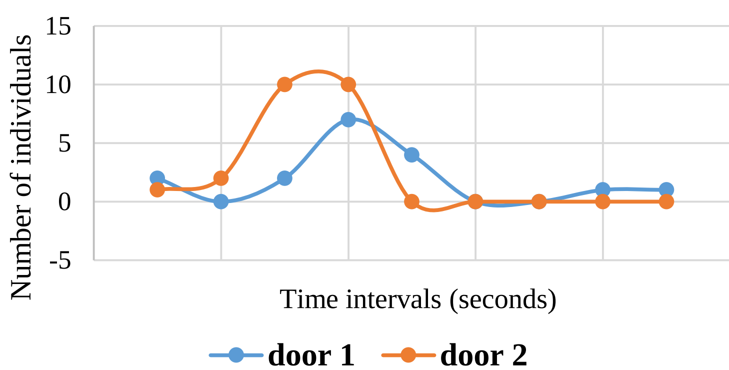

Figure 25. Exit density of individuals from two doors for ten-second time interval.

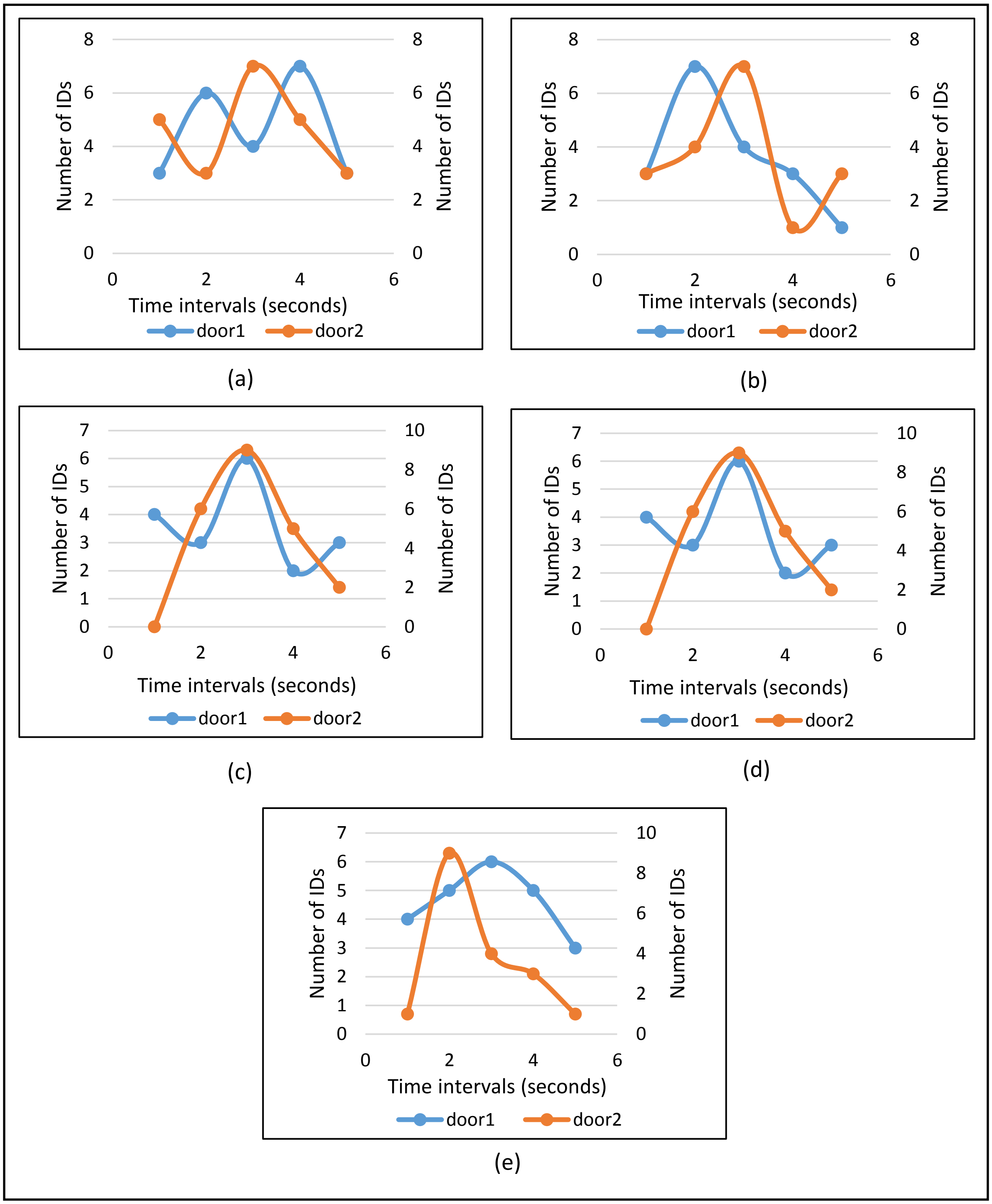

Figure 26. Exit density for individuals in the classroom: (a) scenario 1; (b) scenario 2; (c) scenario 3; (d) scenario 4; (e) scenario 11.

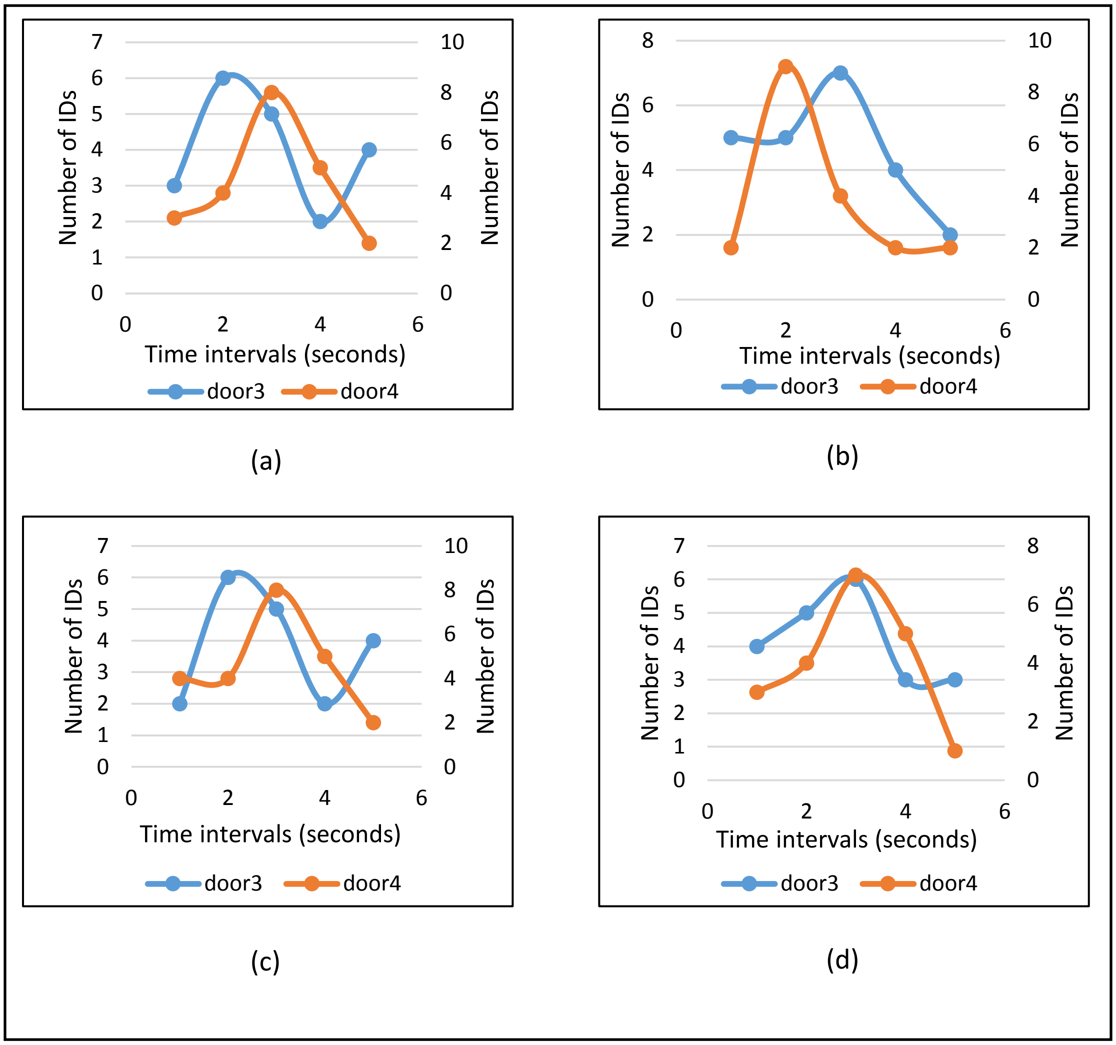

Figure 27. Exit density for individuals in the computer lab: (a) scenario 5; (b) scenario 6; (c) scenario 7; (d) scenario 15.

3. 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 individuals without disabilities. The counting was done at ten-second intervals, as there were only few individuals with disabilities (thirteen individuals with disabilities) out of total forty-seven 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 (Table 5).

Table 5. Number of IWDs at the exit doors.

Time interval (seconds)	Number of individuals	
	door 1	door 2
0-10	2	1
10-20	4	0
20-30	0	1
30-40	0	0

When analyzed at the density of individuals at the current time slot (based on ten-second intervals) and the number of individuals with disabilities at the exit just before the current time slot, it was noted that individuals tend to choose the exit which has a lower number of individuals with disabilities, and vice-versa (Figure 28). As the total number of individuals from current time intervals was compared to the number of individuals with disabilities from previous time intervals, out of four different time intervals, only the second and third had data for visualization.

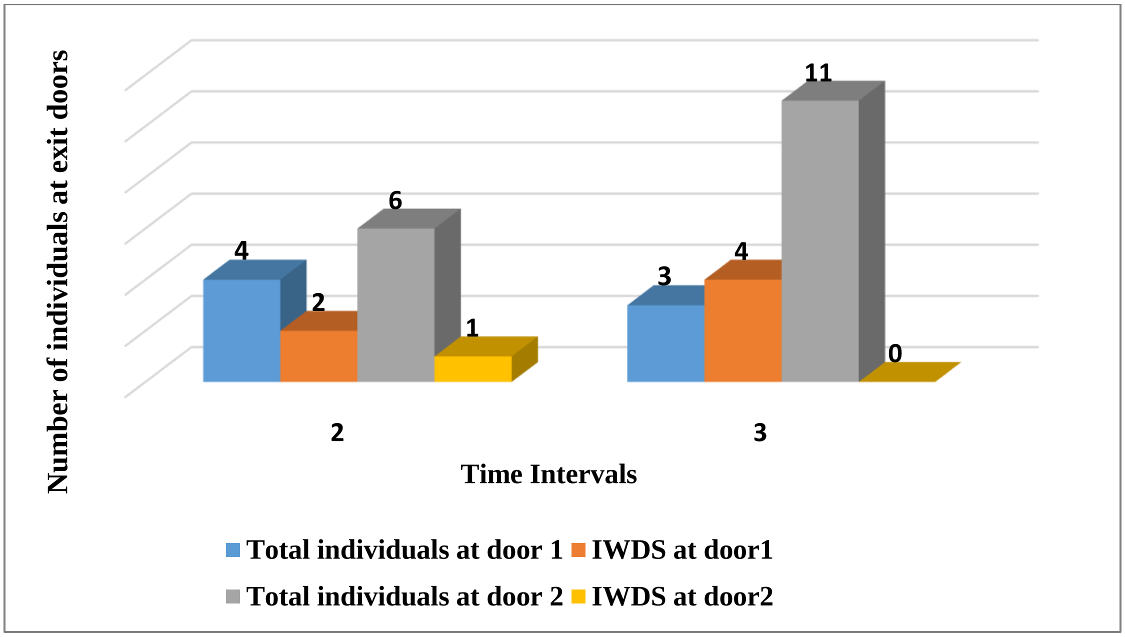

Figure 28. Number of individuals at exit doors at time interval numbers 2 and 3 for a given scenario.

We could observe from the figures that at the second-time interval, the number of IWDs at exit 1 was greater, which resulted in more individuals at the other exit. The case for the third interval proved similar. For the fourth interval time slot, there were no IWDs left in the room to make the comparison.

5.2.3 Model Analysis

Hence, after determining the variables for the scenarios, binary logit modeling was done. The model was analyzed using the program called "Biogeme". The input files were constructed, and the model was analyzed. Two different utility functions were created for individuals with and without disabilities.

5.2.3.1 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". The utility functions for the two doors are as follows:

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

$$\mathbf{V_{door2}} = CONS2 * zero + BETA1 * D_{d2} + BETA2 * K_{e2} + BETA3 * N_{d2}$$

The results from the BIOGEME were as follows:

Table 6. Statistical parameters from the model.

Variable description	value	Std error	t-test	p-value	Variable importance
Distance	-0.23	0.0321	**-7.14**	0.00	Good t-score
Exit density	-0.08	0.0554	**-1.33**	0.18	Good t-score
Number of IWDs at door	-0.33	0.08	**-4.1**	0.00	Good t- score
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		

Hence, based on the t-test scores for the variables, the model was:

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

$$\textbf{Door 2:} \quad 0 - 0.23 * D_{d2} - 0.08 * K_{e2} - 0.33 * N_{d2}$$

The model demonstrates that the exit choice has less relevance in exit density than other variables. 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 has an effect on the exit choice. The model was then validated with the remaining 10% of the data sets (Table 7). The model was determined to be valid for 87% of the validation data sets. This value is large enough. Hence, the model was valid.

Table 7. Validation of the binary logit model for individuals without disabilities.

ID	**U_{D1}**	**U_{D2}**	**EXP (U_{D1})**	**EXP (U_{D2})**	**PROBABILITY**		**ACTUAL CHOICE**	**VALIDATION**
					DOOR 1	**DOOR 2**		
25	-2.93	-2.41	0.05	0.09	0.37	0.63	1	YES
55	-3.09	-1.80	0.05	0.17	0.22	0.78	2	YES
57	-3.23	-1.74	0.04	0.17	0.18	0.82	2	YES
26	-2.97	-2.18	0.05	0.11	0.31	0.69	2	YES
32	-5.20	-4.63	0.01	0.01	0.36	0.64	2	YES
40	-3.45	-1.44	0.03	0.24	0.12	0.88	2	YES
79	-0.70	-2.58	0.50	0.08	0.87	0.13	2	NO
25	-3.25	-0.83	0.04	0.44	0.08	0.92	2	YES
37	-1.88	-2.21	0.15	0.11	0.58	0.42	1	YES
24	-2.69	-3.77	0.07	0.02	0.75	0.25	1	YES
45	-2.69	-3.77	0.07	0.02	0.75	0.25	1	YES
20	-2.11	-3.52	0.12	0.03	0.80	0.20	1	YES
24	-2.38	-1.76	0.09	0.17	0.35	0.65	1	NO
27	-2.79	-4.46	0.06	0.01	0.84	0.16	1	YES
51	-2.44	-3.19	0.09	0.04	0.68	0.32	1	YES
20	-0.64	-2.24	0.53	0.11	0.83	0.17	2	NO
6	-3.01	-2.62	0.05	0.07	0.40	0.60	2	YES
26	-1.79	-3.86	0.17	0.02	0.89	0.11	1	YES
68	-2.36	-5.65	0.09	0.00	0.96	0.04	1	YES
40	-3.55	-3.57	0.03	0.03	0.51	0.49	1	YES
65	-3.27	-3.56	0.04	0.03	0.57	0.43	1	YES
65	-2.63	-1.85	0.07	0.16	0.32	0.68	2	YES
29	-2.02	-2.65	0.13	0.07	0.65	0.35	1	YES
6	-0.84	-1.92	0.43	0.15	0.75	0.25	1	YES
68	-2.06	-0.75	0.13	0.47	0.21	0.79	2	YES
69	-1.74	-1.20	0.18	0.30	0.37	0.63	2	YES
66	-3.70	-1.57	0.02	0.21	0.11	0.89	1	NO
71	-1.76	-1.17	0.17	0.31	0.36	0.64	2	YES
66	-4.01	-4.86	0.02	0.01	0.70	0.30	1	YES

5.2.3.2 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.

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

$$\mathbf{V_{door2}} = CONS2 * zero + BETA1 * D_{d2} + BETA2 * K_{e2} + BETA3 * N_{d2}$$

The results from the BIOGEME were as follows:

Table 8. Statistical parameters from the model (IWD).

Variable description	value	Std error	t-test	p-value	Variable importance
Distance	-0.21	0.0585	**-3.65**	0.00	Good t-score
Exit density	-0.16	0.131	**-1.21**	0.2	Good t-score
Number of IWDs at door	0.39	0.181	**2.14**	0.03	Good t- score
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				

Hence, based on the t-test scores for the variables, the model was as follows:

Door 1: $\mathbf{-0.26 - 0.21 * D_{d1} - 0.16 * K_{e1} + 0.39 * N_{d1}}$

Door 2: $\mathbf{0 - 0.21 * D_{d2} - 0.16 * K_{e2} + 0.39 * N_{d2}}$

The model demonstrates that the exit choice has less relevance in the determination of exit density than other variables. Validation of the model was done by using the remaining 10% of the data sets (Table 9). The model was found to be 100% valid with the validation data sets (Table 9). The dependence of the exit choice was found to be somewhat 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 9. 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

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.

CHAPTER 6

DISCUSSION

The experiment conducted was employed to derive different evacuation curves based on the different scenarios, and a binary logit model was built to predict the exit choice of the participants. The model calibrated and validated clearly shows that there are different factors that are considered while selecting an exit. The analysis was done based on the revealed preference data sets. A large-scale experiment conducted with the inclusion of individuals with disabilities was used for extraction of the data for the analysis. This data set may reveal the influence of different parameters during the evacuation, including individuals with disabilities. Comparing to the literature as discussed above, our study is important because of the revealed preference data sets, in conjunction with the inclusion of individuals with disabilities. The study was capable of providing enough information regarding how evacuees make actual choices during the real-time scenario and in predicting the exit choice based on different parameters.

6.1 Evacuation Curve

The analysis of the evacuation curves for different scenarios revealed that the availability of more exit doors is directly related to the evacuation time from the building. There were sixteen different scenarios where the evacuation time was recorded and analyzed. All of the scenarios included different availability regarding exit doors. Sixteen different scenarios were studied under three different criteria in this study to observe the evacuation curve in the three different rooms: the classroom, the computer lab and the lecture hall (Figure 29).

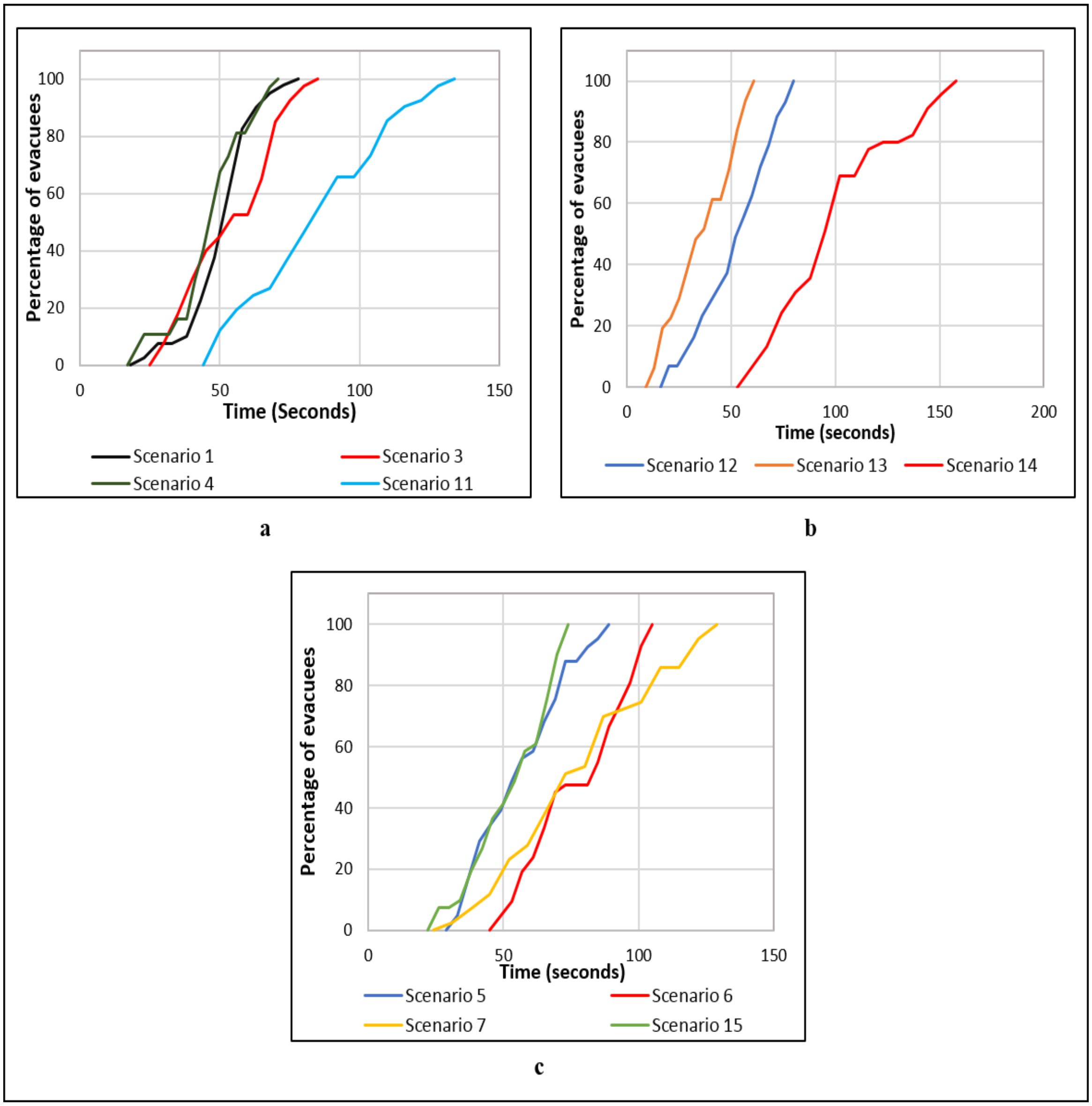

Figure 29. Evacuation curve for three different rooms.

Previous studies (Varas et al., 2007) have also identified decreases in evacuation times corresponding to the increases in the number of exit doors. This study also demonstrates the same results. An increase in the availability of exit doors from one to two doors reduces the evacuation time and the end time of the evacuation (Figure 29). The evacuation curves shown in the Figure 29 clearly demonstrates the differences in the evacuation time of the scenarios based upon varying availability of the number of doors in the building. Hence, analyzing these scenarios in the classroom, the computer lab and the lecture hall, we can observe that availability of doors plays a major role in the evacuation time from the building.

6.2 Exit Choice

The results of the logit model for the exit choice for both individuals with and without disabilities are presented as below:

6.2.1 Individuals Without Disabilities

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

Door 2: $0 - 0.23 * D_{d2} - 0.08 * K_{e2} - 0.33 * N_{d2}$

6.2.1 Individuals With Disabilities

Door 1: $-0.26 - 0.21 * D_{d1} - 0.16 * K_{e1} + 0.39 * N_{d1}$

Door 2: $0 - 0.21 * D_{d2} - 0.16 * K_{e2} + 0.39 * N_{d2}$

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.

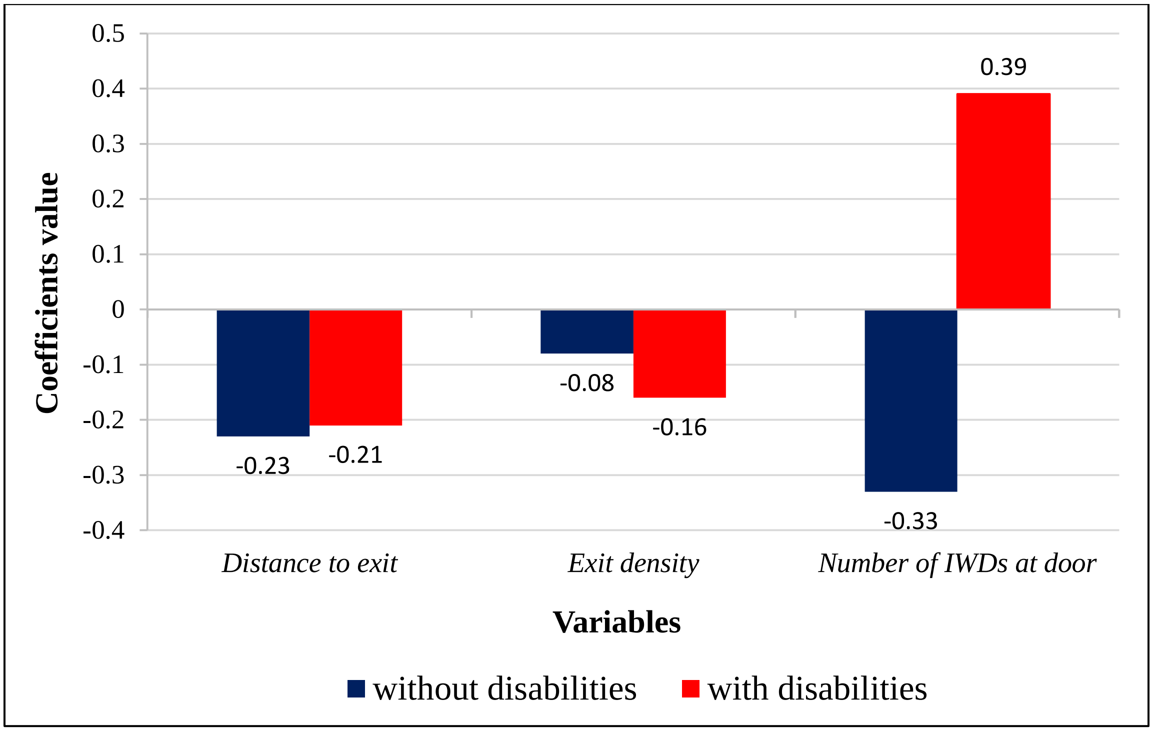

Figure 30. Comparison of the coefficients of the variables in the logit model for individuals with and without disabilities.

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. Their dependence on other individuals with disabilities could also be described as their trust for other individuals with disabilities.

Figure 30 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.

The results from the model suggest that individuals with disabilities and individuals without disabilities differ in their exit choice based on the presence of IWDs at the exit doors. Individuals without disabilities may choose the exit where there are none or less (compared to other exits) IWDs at the exit door, and likely they make this decision- because they might think the slow walking speed of individuals with disabilities could impede their exit from the room (California Employment Law 2011, 2011). Based upon the results, it was determined that individuals with disabilities trust other individuals with disabilities, which compels them to choose the same exit as other individuals with disabilities. Although the Americans with Disabilities Act Accessibility guidelines (ADAAG) (2006), the International Building Codes (IBC) (ICC, 2012) and ADA Standards for Accessible Design (2010) identify signage requirements at the exit doors for egress, these signs are not as useful as they should be to individuals with disabilities, because individuals with disabilities follow other individuals with disabilities during an emergency exit. The signage requirements as provided by the codes (ADAAG, 2006; ICC, 2012; ADA Standards for Accessible Design, 2010) requires the exit doors to feature the visual signs. IBC (ICC, 2012) 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 invention 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 disabilities to make the exit choice. Although the emergency egress is critical for all types of individuals, the codes are primarily focused on the path-finding process based on visual means (Rutherford and Withington, 1998). The policies of all three codes focus on the visual signage, and individuals with visual disabilities tend to have difficulty finding the exit doors and must trust each other to find the exit. 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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