# The Effects of Culture-Specific Walking Speed and Pre-Movement Data on Egress Modeling in Shopping Malls- A Comparative Analysis

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## INTRODUCTION

The use of various egress analysis tools has increased in recent years through the application of performance-based design [1, 2] to demonstrate that occupants reach a point of safety before untenable conditions are reached [3]. Guidance on how to apply egress analysis can be found in various publications [4, 5], along with a detailed discussion of the different types of calculation tools, their strong points and limitations [1, 6]. Such guides can assist the user in choosing the most appropriate tool for the job. For example, when applying the hydraulic method outlined in the Society of Fire Protection Engineering (SFPE) Handbook, the user should be well aware that it assumes that people start moving instantly and that there are no delays [5].

With the increased computational capacity of modern day computers along with the low cost for purchasing such machines, the application of egress models has also increased [6]. Such models require various behavioral and movement data to be used as input parameters, which are usually collected by conducting controlled experiments, from fire incidents / drills or field observations under normal conditions [7, 8]. When examining published input data, it is clear that the majority of it is limited to western countries [8], which raises a question regarding the applicability of such data to other cultures and the results of the models using them.

When conducting an egress analysis in a conservative culture, designers need to be well aware of its traditions, especially ones that might affect building egress, such as the type of clothing worn, people familiarity and response to fire alarm signals and gender segregation in some countries.

This study compares the results of an evacuation analyses, conducted using a hypothetical shopping mall geometry and the computational model Pathfinder, using published input data from Western cultures with data collected from shopping mall in Saudi Arabia. This is part of an ongoing project to determine the effects of various cultural differences between Western countries and Saudi Arabia on human behavior during evacuation.

## CULTURAL DIFFERENCES CONSIDERED

Researchers have identified various Saudi Arabian cultural requirements that might affect occupant behavior during evacuation [8]. For this study, only the effects of clothing on walking speed, fire alarm recognition and response time, and gender segregation are considered.

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## Clothing

In the case of Saudi Arabia, studies have shown that the type of clothing donned by females can decrease their walking speeds over horizontal walkways and stairs when compared to western countries [8]. This was mainly due to the length of the "Abaya", which is a culturally required article of clothing that women have to wear when in public space and in the presence of men who are not family members [8, 9].

## Fire Alarm Recognition and Response

Studies have shown that individuals who have been previously exposed to a fire alarm through fire drills or an actual fire incident are more likely to recognize the alarm and respond to it fast than someone who has not [10], since they tend to compare the perceived cues to previous experiences [11].

Delay time to start evacuation (i.e. Pre-movement) data is scarce [12], not only for different occupancies, but also for various cultures, such as Saudi Arabia. For this reason, an online survey was developed to assess the familiarity with fire drills, alarm signals and self-reported fire alarm and recognition time during fire drills and fire emergencies in Saudi Arabia (in Arabic) and in the United States (in English). The survey contained questions regarding previous involvement in fire drills, fire incidents and participants were asked to estimate the time it took them to recognize and respond to the fire alarm signal. The US population consisted of 503 participants from the general population, of which 420 participants were involved in fire drills and reported their estimated delay time to start evacuation. On the other hand, the Saudi population consisted of only 50 participants, of which only 24 participants reported being involved in a fire drill and reported their delay times. While both surveys were distributed randomly online, Saudi participants were less likely to complete the entire survey due to its length (between 5 to 10 minutes) and there were no means to provide compensation for their participation (only 50 complete responses out of 138). On the other hand, US participants' responses were collected through a research website (SocialSci) for a fee and all participants were compensated for their participation. Though the Saudi sample is small, it can provide a rough estimate of the expect delay time for the population which can be used in this study.

## Gender Segregation

The Saudi Arabian culture has strict religious and social requirements governing gender segregation in various occupancies such as mosques, schools, university campuses, restaurants and waiting rooms in airports [8, 13]. Such segregation is mainly aimed at separating single men from families and single females. While this not usually applied to an entire shopping mall, some shopping malls were observed to have an entire floor restricted only to female shoppers. This can affect the layout of open spaces, such as a food court, as most families might feel more comfortable with the installation of partitions or dividers.

# BUILDING DISCRIPTION

The building used in this study is a hypothetical mall, comprised of three floors. The building is considered code compliant as it satisfies egress system requirements of the International Building

Code (IBC), and the newly adopted Saudi Building Code (SBC), which is largely based on the IBC.

**First Floor**

The main component of the first floor is the main lobby area, which can be used for various seasonal displays throughout the year. It is accessed by two 1.8 meter wide doors located on both the north and south entrance areas. From this area, shoppers can access 14 stores and two anchor stores. Each anchor store has 3 pairs of 1.8 meter wide exit doors leading to the exterior of the building.

Shoppers can reach the second floor by two escalators and two open stairways in the main lobby, two escalators in each anchor store and three elevators.

**Second Floor**

This floor is located at an elevation of 5 meters and consists of 16 stores and the upper level of the two anchor stores. The walkways leading to the stores are 6 meters wide, while the walkways between openings are 4 meters wide.

There are two emergency stairways which lead to the exterior of the building and only cater to second floor occupants as it cannot be accessed from other floors. From this floor, shoppers can access the third floor via two open escalators, an open stairway and an elevator located in the opening in the middle.

**Third Floor**

The third floor is situated at an elevation of 8.6 meters and contains the food court area which is comprised of two kitchens and an open area for seating.

There are two emergency stairways which lead to the exterior of the building and can only be accessed from the third floor.

**Cultural Variations**

To accommodate gender segregation cultural requirements, the Saudi model was modified where two sections in the food court seating area were partitioned and designated for family and single female dining only, where each area can be accessed by two doorways (0.9 meter wide each).

Figure 1 illustrates the location of stairways, escalators, elevators and the modifications due to cultural modifications.

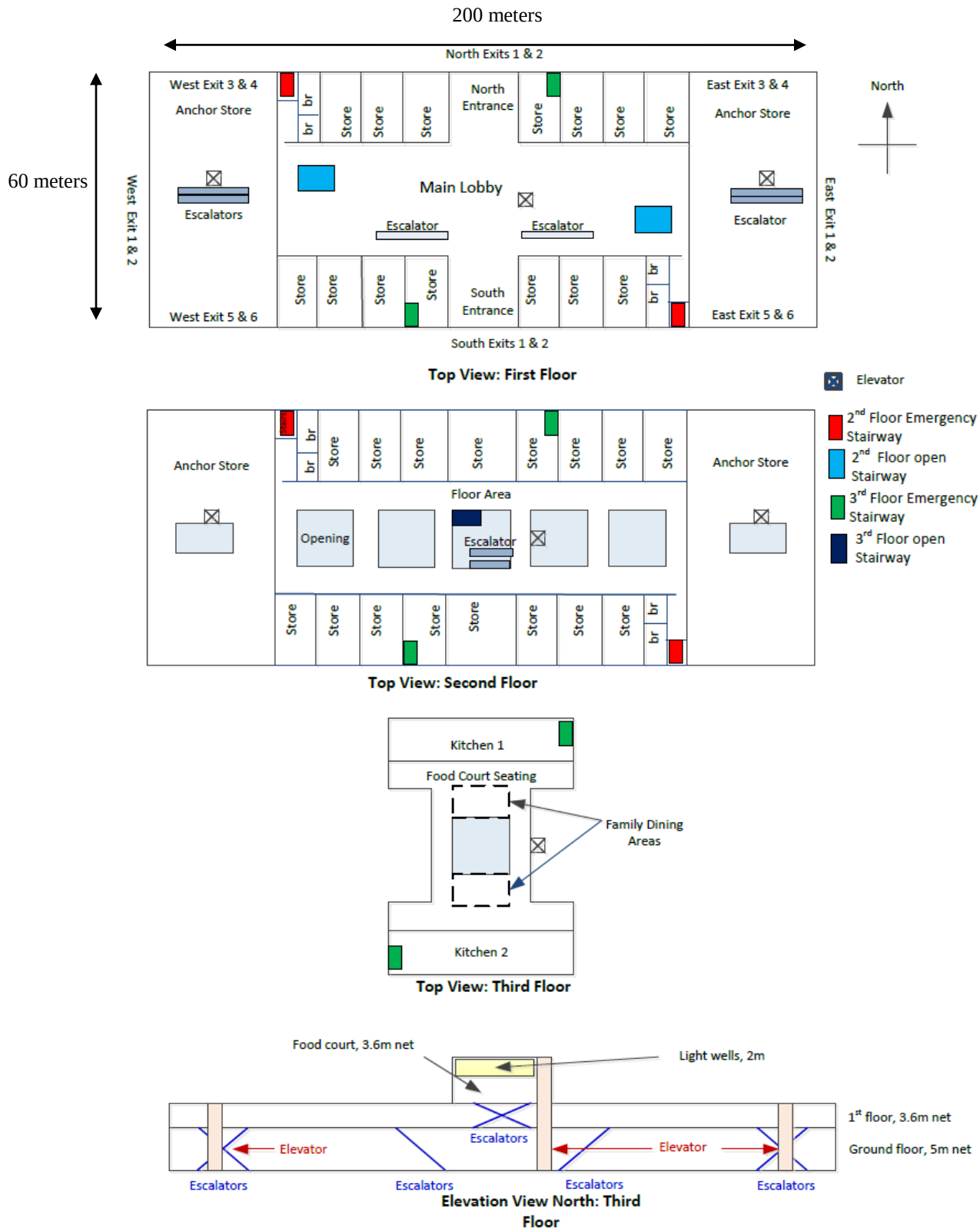


Figure 1: Shopping Mall Layout

## EGRESS MODELING

Pathfinder 2013 is an agent-based egress modeling tool developed by Thunderhead Engineering. It can be used to model occupants using either "Steering Mode", where occupants avoid obstacles and other agents, or "SFPE Mode" which utilizes the hydraulic flow method outlined in the SFPE Handbook, in which occupants to do not avoid each other and flow through exit components (e.g. doors) is the limiting factor [5, 14]. Pathfinder also provides the user with the ability to create different profiles that can be used to specify exit, target, delay time for different occupant groups and their walking speeds [14]. Real-time results are provided in 3-D while more detailed results are generated in a spreadsheet that would contain exit usage and flow at each time step after the conclusion of model's runtime [15].

To assess the effects of cultural differences on overall evacuation time, two separate Pathfinder models were developed. The first model will be used to simulate the Saudi population while the second model will represent the US population. Both models will have the same number simulations, occupant load and exits.

### Egress Model Inputs

In this study, there are four simulation inputs considered.

1. Occupant Demography: since that the current available data for Saudi Arabia covers male and female adults only, occupant age was not included in the proposed demography. Initially, the same demographic profile was going to be applied to both populations however, the corresponding data for both cultures were fairly close. For this reason and for a more realistic representation of the populations, the following demographics were used.
    a. Saudi demography: the most recent data covering Saudi Arabia indicate that the entire population is comprised of 54.6 percent males and 45.4% females [16].

    b. US demography: according to the most recent US census data, the population consists of 49.2 percent males and 50.8 percent females [17]

2. Occupant load: the occupancy load for each floor was determined using IBC and SBC table 1004.1 for the third floor and section 402 for the first and second floors. The results for each floor and population are highlighted in Table 1.

| Floor | Total Number of Occupants | Saudi Model | | US Model | |
|---|---|---|---|---|---|
| | | Male | Female | Male | Female |
| 1st | 3076 | 1679 | 1397 | 1513 | 1563 |
| 2nd | 2195 | 1198 | 997 | 1080 | 1115 |
| 3rd | 858 | 468 | 390 | 422 | 436 |

Table 1: Occupancy Load and Demography per Floor

3. Walking Speed: while there are various sources listing people, walking speed for western cultures, there were a few studies that classify walking speeds based on gender [18-20] and the majority of the data was collected more than 25+ years. On the other hand, there was only one recent study that examines the effects of traditional clothing on male and female walking speeds in Saudi Arabia [8].

    a. Saudi walking speed: the most recent study covering pedestrian walking speed based on gender indicate that females have a walking speed of 0.90 m/s when wearing the most common type of Abaya while males tend to have a walking speed of 1.05 m/s regardless of the type of clothes they are wearing [8]

    b. US walking speed: the chosen walking speeds for the US population are 1.1 m/s for females and 1.3 m/s for males [18, 20].the considered data sets reported close walking speed values even though they were collected under different environment (Fuin: transportation terminal / bus station; Polus: city street sidewalk.)

4. Delay time: the delay times used for both populations were extracted from the participants survey answers. As the majority of both populations were involved in more fire drills than fire incidents (420 US participants, 24 Saudi participants), the self-reported delay time due to fire alarm recognition and reaction for fire drills were used.

    a. Saudi delay time: survey results indicate that the mean delay time is 90 seconds, with a standard deviation of 30 seconds and responses ranged between 60 and 540 seconds. ($M$ = 90, $Min$ = 30, $Max$ = 540, $SD$ = 30 )

    b. US delay time: for the US population, survey results indicate that the mean delay time is 150 seconds, with a standard deviation of 65 seconds and responses ranged between 60 and 720 seconds. ($M$ = 150, $Min$ = 60, $Max$ = 720, $SD$ = 65 )

**Simulated Scenarios**

For this study, two egress scenarios were considered for the analysis. The first involved a full building evacuation with all emergency exits available on every floor. The second scenario involved a blocked exit on the third floor due to a fire incident at Kitchen 1.

**Simulation Results**

1. First Scenario:
    a. Saudi model: The total evacuation time estimated by the model is 859 seconds (14.31 minutes)

    b. US model: The total evacuation time estimated by the model is 773.5 seconds (12.9 minutes)

The results indicate that adjusting the input parameters to account for various cultural norms can increase the total evacuation time by up to 11 percent.

c. Observed behaviors: some second floor occupants opted to use the escalators to reach the main exits on the first floor. While escalators are not considered part of the egress system, such a behavior can be expected in actual evacuation as people tend to seek the familiar means to evacuate a space. Also, the last occupants to evacuate the building were located on the third floor. This illustrated in figures 2 and 3 where the third floor occupants in the Saudi and US models evacuated the floor at approximately 745 and 645 seconds respectively.

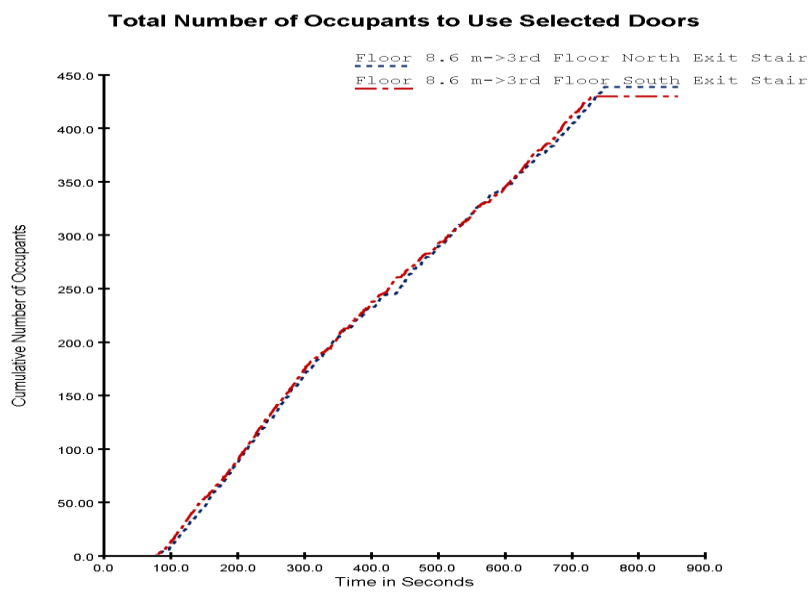


Figure 2: Scenario 1 - Thrid Floor Exit Usage Saudi Model

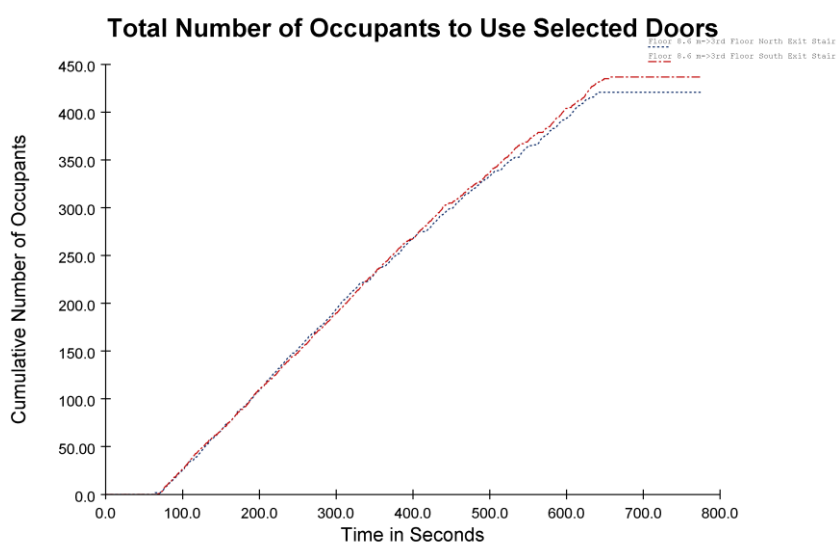


Figure 3: Scenario 1 - Thrid Floor Exit Usage US Model

2. Second Scenario: the scenario involves a fire occurring at Kitchen 1 which renders the north stairway exit inaccessible after 120 seconds.
    a. Saudi model: The total evacuation time estimated by the model is 1302 seconds (21.7 minutes).

    b. US model: The total evacuation time estimated by the model is 1169 seconds (19.5 minutes).

       As with the first scenario, the results illustrate that incorporating some of the observed cultural difference can increase the overall estimated evacuation time by 11 percent.

    c. Observed behavior: similar to the first scenario, occupants on the second floor continue to use the escalators to access the first floor's main exits. Also, third floor occupants chose to evacuate via the only available emergency exit (south exit stairway) even though the stairway and escalators were available. This may not be a realistic behavior as most people would probably choose to evacuate a building through the familiar exit [21].

## CONCLUSION

While researchers have been highlighting the importance of collecting building egress data during fire emergencies, few studies examine how different cultural norms affect the results of an egress analysis. There are various risks associated with the increased use of egress analysis and applying input parameters across culturally without examining the local cultural norms and how they might affect the estimated model results. For this reason, designers should educate themselves about the culture they are designing for and its traditions. In the case of Saudi Arabia, differences in walking speed due to clothing and the lack of familiarity with fire alarm signals increased the overall predicted evacuation time by 11 percent. This percentage can significantly increase when such differences are applied to more complex buildings with. Future publications will examine additional cultural differences such as level of fire education on fire alarm perception and personal space on exit flow.

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