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Differences in measurement methods for travel distance and area for estimates of occupant speed on stairs

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ABSTRACT

Many previous studies have reported that the density in the stairs affects the achievable speed of the population using them. To measure the speed, one value that needs to be known is the distance. Similarly, to measure the density, one value that needs to be known is the area used by the population. Previous studies have used different methods to calculate these values and this paper reviews some of these different methods. Comparisons are made between these methods to show the difference in results that can result simply using data and equations developed using different assumptions. Then theoretical equations are developed for the travel distance and area based on how people have previously been observed traveling along arcs while crossing landings on stairs. Finally, the effects of misusing the different methods for calculating travel distance and area are compared using data from an actual building evacuation drill. It is shown that misusing methods can lead to significantly different results for the same data.

1. Introduction

In performance based fire safety design, the available safe egress time (ASET) needs to be greater than the required safe egress time (RSET) in order for occupants to safely evacuate from a building. ASET can be determined based on fire simulations, testing, or other data that predict the amount of time until conditions become untenable, as defined by the person conducting the analysis. RSET can be determined by calculating the time from ignition until all occupants are expected to have evacuated the building. RSET includes times from ignition until detection, from detection until notification, from notification until movement to an exit path (pre-evacuation time), and while moving along the exit path.

Evacuation models used to estimate RSET values require the user to provide times for each segment of the simulated evacuation or calculate the times based on pre-set parameters. For the movement along the exit path, two pieces of information are required. The first piece is the distance to be traveled and the second piece is the movement speed. The movement speed is often determined by the density. These values can vary for various reasons including if there is a change from one component to another (i.e., from a corridor to a stair).

In a high-rise building evacuation, the stairs constitute a significant part of the exit path. For example, Life Safety Code [1] requires that the maximum travel distance to an exit in a new business occupancy that is fully sprinklered is 91 m. Assuming an approximate travel distance of 8.2 m per floor in a stair [2], travel distance in stairs is greater than the maximum travel distance to reach the stair for buildings taller than 11 stories. Even for buildings less than 11 stories, occupants located closer to the stair may travel further in the stair than outside of it depending on the nature of the structure.

Previous studies have used different measurement methods to calculate travel distances and areas on stairs. As will be shown, these differences can cause estimates of movement speeds to be significantly different regardless of any changes that could exist within the sample populations. Systematic predictions of movement speed that are too fast could lead to inadequate ASET, but speeds that are too slow could lead to expensive systems that provide far greater ASET than is required.

The purpose of this paper is to understand the differences that can arise in predicting movement speed solely due to the underlying differences between the methods used to generate the reference equation and the data it is applied to. This is accomplished by determining the methods that previous researchers have used to calculate travel distance and area, presenting equations that can be used when using different methods, and, finally, demonstrating the need to understand the methods used when making comparisons with data collected by others. While

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authors might just present an equation relating speed to density, applying that equation requires an understanding of the assumptions made to create it.

2. Previous studies

This paper highlights seven different sources that have collected data on people movement down stairs. The studies presented here are not intended to be an exhaustive review of all research that has studied movement speeds down stairs. Instead they are representative of some different methods that have been employed to calculate travel distance and area. This section is intended to show that there has not been one method consistently used by researchers in the field. While some of the sources considered a wide range of egress components, only the sections involving descending stairs are discussed here. Furthermore, while other variables were sometimes considered by the authors, only travel distance and area calculations are included in this paper.

The sources come from a variety of conditions (drills and normal use), occupancies (office buildings and public locations), geographic locations (North America and Europe), and time periods (from 1958 to 2010). Rather than focusing on the difference in results, the focus in this paper is on the difference in methods used. These different methods are shown in Table 1.

The authors of these studies have typically conducted far more studies than are included in Table 1. For example, a partial list of works by Pauls includes [10–13] and from Proulx includes [14–17]. Both of these authors have many additional works beyond these lists. Because there is no clear indication that the measurement methods changed considerably across most of their work, the works discussed here are representative of their general practice.

2.1. London Transport Board (1958)

The study by the London Transport Board [3] observed passengers in the London Metro system. In order to calculate the speed and density during peak periods, two observers stood a known distance apart and the observations were generally conducted on a single straight flight of stairs between 19 and 23 steps long (there was one stair with two sets of 12 steps). One observer moved a known distance with the crowd while a second observer counted the number of people that passed a set point until the first observer crossed that point. To calculate the areas, the entire width of the stairs (between 1 m and 2 m depending on the stair) was used, but no other dimensions or calculations for the area were provided.

2.2. Pauls (1971)

Pauls [4] observed a fire drill in a 22-story government office building. The 910 occupants used two 1.19 m-wide stairs with riser heights of 0.178 m and tread depths of 0.254 m. Speeds and densities at various points were estimated by observers. The author provided travel distance per floor measured along the centerline. This distance was along the slope of the stair. However, the method for calculating the travel distance on the landing was not provided. The area on the stair treads was the horizontal area based on the entire width of the stairs. On the landings, the author accounted for only the area used, with rounded corners to the area on the landing.

2.3. Predtechenskii and Milinskii (1978)

Predtechenskii and Milinskii [5] collected the work of several different studies in the Soviet Union to provide guidance on design and calculations. Travel distance was calculated along the slope of the stairs and the distance on the landings for one floor of travel was taken to be four times the stair width. The method for calculating the floor area to be used for the density was not provided.

2.4. Pauls (1980)

Pauls [6] compiled observations of 58 high-rise office building evacuations. The stairs varied in width from 0.91 m to 1.52 m. The buildings were typically less than 15-stories tall and the tread dimensions varied. The details of this variation were not provided. Pauls measured the distance traveled along the slope of the stair, but no mention was made of how it was measured on the landings. For the area, he used the effective, horizontal area on the treads (a "boundary layer" was subtracted from each side depending on if there were handrails and the type of walls). As with the travel distance on the landing, no mention was made of how he calculated the area on the landings.

2.5. Fruin (1987)

Fruin [7] observed two stairs that were used for normal activity. The first was an indoor stair with a riser height of 0.178 m and tread depth of 0.286 m. The second was an outdoor stair with a riser height of 0.152 m and tread depth of 0.305 m. While he did not state if he was looking at just treads or landings (for both travel distance and area), all of the figures in this source

Table 1
Study Methods.

Study	London Transport Board [3]	Pauls [4]	Predtechenskii and Milinskii [5]	Pauls [6]	Fruin [7]	Proulx et al. [8]	Peacock et al. [9]
Collection method							
Type of population	Commuters	Office Workers	Multiple	Office Workers	Commuters	Office Workers	Office Workers
Activity	Normal	Drill	Unknown	Drill	Normal	Drill	Drill
Method	Observers	Observers	Unknown	Unknown	Photographs	Videos	Videos
Travel distance							
Treads:horizontal or slope	Unknown	Slope	Slope	Slope	Horizontal	Unknown	Slope
Landings:straight lines or arcs	Not used	Unknown	Straight lines	Unknown	Unknown	Unknown	Straight lines
Area							
Components used	Treads	Both	Unknown	Unknown	Treads	Treads	Both
Treads:effective or total stair width	Total	Total	Unknown	Effective	Unknown	Unknown	Total
Treads:horizontal or slope	Unknown	Horizontal	Unknown	Horizontal	Horizontal	Horizontal	Horizontal
Landings:effective or total	Unknown	Effective	Unknown	Unknown	Unknown	Not used	Total