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Impact analysis of human factors on pedestrian traffic characteristics

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ABSTRACT

Pedestrian traffic is subject to be affected simultaneously by many factors. In order to judge which factor(*s*) should be taken into consideration when facing a specific pedestrian traffic context for fire safety analysis, it is essential to differentiate the impacts of different factors from each other. This paper aims to develop a method to separate the impacts on pedestrian traffic among different factors. Focusing on an individual pedestrian traffic indicator—walking speed, three important human factors, i.e., gender, age and luggage-carrying were selected to investigate their respective impacts on walking speed. Through video observation in a subway station in Shanghai, nearly 1000 walking speed samples were obtained. These samples include 22 combinations of different levels of age, gender and luggage-carrying. By statistical analysis the impacts of age, gender, and luggage-carrying on walking speed were revealed separately. It is found that except for older pedestrians, males walk faster than females by 5–7%. Middle-aged pedestrians walk slower than the young by 6–8%, and older pedestrians walk slower than the young by 18–24%. Compared with no luggage, small luggage only reduces mean walking speed by 2–3%. For medium luggage, large luggage and trolley cases, the decline rates of walking speeds were 5–8%, 10–14%, and 3–8%, respectively. Research results suggest that special attention and appropriate adjustments such as the modification of evacuation time, speed and capacity of pedestrian flow, should be paid for fire safety analysis in pedestrian traffic sites with noticeable amount of older pedestrians and pedestrians carrying large luggage.

1. Introduction

Pedestrian traffic flow characteristics provide quantitative relationships among pedestrian flow rate, density, and speed, which lay the foundation for technical supports to fire safety analysis during crowd evacuation. Since the 1960s significant studies have been conducted to investigate pedestrian traffic flow theories for better understanding pedestrian and evacuation dynamics [1]. Previous research has revealed that pedestrian traffic is affected by diverse factors, including human factors (gender, age, disability, and luggage-carrying), walkway attributes (slope, width, and pavement), travel purpose (commuting, shopping, and leisure) and environmental conditions (temperature, weather, and lighting) [2–5]. Moreover, many of the above factors exert influence on pedestrian traffic simultaneously. The observed pedestrian traffic phenomenon is usually from the sum of multiple factors. This has raised a challenge to pedestrian traffic study, that is, how to differentiate the impacts of different factors from each other. If one particular factor's impacts on pedestrian traffic are under investigation, the influence from other factors should be excluded. Only in this way can the effects of one factor be distinguished from others.

A clear identification of impacts among different factors is necessary because of the requirement to judge which factor(*s*) should be taken into consideration or be paid more attention to when facing a specific pedestrian traffic context for fire safety analysis. For instance, if the proportion of older or luggage-laden pedestrians is noticeably high in the study area of interest, whether the effects of age or luggage-carrying should deserve enough attention or not becomes a question to study the pedestrian evacuation safety. Nonnegligible impacts of certain factor(s) may require appropriate adjustment to crowd safety analysis compared with a situation without such impacts.

On the other hand, pedestrian traffic flow is an aggregative result of pedestrian individuals' movement, so it is rational to try to understand how the influential factors affect pedestrian traffic at individual level before those impacts are studied at aggregative level. Therefore, this paper intends to focus on the individual pedestrian traffic and develop a method to separate the impacts of different factors from each other. Additionally, as an

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autonomous form of behavior, walking is greatly influenced by human factors. For a specific pedestrian traffic site (e.g., a subway station) the external factors such as walkway attributes, travel purpose and environmental conditions are relatively fixed. Under this scenario the observed variance in pedestrian traffic characteristics are mainly subject to human factors. Hence, this paper is dedicated to the impact analysis of human factors. Consequently, one important individual pedestrian traffic indicator (walking speed) and three human factors (gender, age and luggage-carrying) are chosen for this research. By removing all other factors' influence, a method is developed to evaluate respectively the impacts of age, gender and luggage-carrying on walking speed.

From the above, the paper aims to address the need and approach to differentiating the impacts on pedestrian traffic among different factors. It is organized as follows. Section 2 reviews the relevant literature about the impacts of human factors on walking speed. The issue of the present study is deduced through literature summaries. Section 3 introduces traffic survey and data collection. Human factors definition and walking speed calculation are also explained in this section. Making use of the measured data, Section 4 develops a method to elaborately analyze the respective effects of gender, age and luggage-carrying on walking speed. Results of this research are also compared with other related research in Section 5. Finally, the conclusions are drawn together with recommendations for further studies.

2. Literature review

Significant research on pedestrian traffic and evacuation dynamics began in the 1960s. Over the past fifty years, quite a few studies have been conducted trying to reveal the impacts of human factors on pedestrian traffic, and urban crosswalks and sidewalks are typical contexts for those studies. Gates et al. [6] collected 1947 walking speed samples from 11 intersections in the U.S. They pointed out that pedestrians younger than 65 had an average 0.3 m/s higher speed than older ones (over 65 years). There was no significant difference of walking speed between males and females. Gate's findings were similar to the previous research of Knoblauch [7]. Fitzpatrick et al. [8] conducted an analysis of walking speed with 2445 samples from 42 crosswalks in the U.S. Their study determined that average speed of pedestrians younger than 60 was 0.14 m/s higher than that of older walkers (older than 60). In most cases, walking speeds of the males and females were similar. Finnis et al. [9] measured 1847 walking speed samples on thirteen sites in New Zealand. They pointed out that younger pedestrians (15 to 55 years) walked faster with an average speed 0.11 m/s higher than older ones (over 55 years). Males were found to walk significantly faster than females. No difference was found in speed of pedestrians carrying one or two bags. Arango et al. [10] investigated the walking speed of older pedestrians who used walkers or canes for mobility in Canada. They did not find significant difference between the speeds of male and female pedestrians. Tarawneh [11] collected data for nearly 3500 pedestrian crossing operations at 27 crosswalks in the Greater Amman Area. He concluded that middle-aged pedestrians (21–45 years old) were the fastest walkers relative to other age groups. They had an average 0.31 m/s higher speed than pedestrians older than 65. Males were faster than females by nearly 0.02 m/s. Laxman et al. [12] analyzed variation in speed with respect to pedestrian age, gender, and baggage in India. They stated that pedestrians in the age group of 10–15 years had the highest speed. Males moved faster than females by nearly 0.13 m/s. The speed was reduced by about 85% when pedestrians move with their baggage. Shi et al. [13] observed 1040 pedestrian speed samples at an unsignalized midblock crosswalk in China. They found that males were faster than females by nearly 0.1 m/s.

Some other studies have also been conducted in the context of transportation terminals or indoor walking environment. Young [14] observed pedestrian movements in various airport terminal corridors in the U.S. Similar to Fruin's study, he concluded that there was no significant variation found in the free-flow walking speed with any observed pedestrian characteristics including pedestrian's apparent age and the presence of baggage. But males had a significantly higher speed than females by nearly 0.12 m/s. Kholshevnikov et al. [15] described the development of pedestrian flow theory and research in Russia over the past decades. Specifically they summarized the relationship between walking speed and psychological stress level, stating that higher level of emotional state results in higher walking speed.

Despite a number of studies concerning human factors on pedestrian traffic, especially on walking speed, there were no consistent conclusions for the influence of gender, age, luggage-carrying or other factors. This may partly result from the discrepancy of the observation sites (e.g., crosswalk, sidewalk, and airport corridor). Another possibility is that some research did not exclude the mutually interferential effects between other factors and the one being studied. An example of this is the counter-intuitive phenomenon noted by Finnis [9] that pedestrians with baggage had a higher speed than those without any baggage. As Finnis [9] suggested, this was because the former were usually commuters while the latter were non-commuters. Therefore, it is imperative to control comparable observation conditions for obtaining accurate effects of one certain factor. Additionally, impacts of luggage-carrying on walking speed needs further investigation since they are especially insufficient in the available literature.

3. Data colletion and parameters extraction

3.1. Observation site

A subway station, named People's Square Station in Shanghai, China was selected as the observation site for walking speed. This station, with three subway lines interchanging, lies in the central district of Shanghai city (shown as a solid circle in Fig. 1–1). In 2009, daily passenger flow, including exchanging volumes in the station, was 580,000 person-times [1]. There are many commercial facilities, office buildings and tourist attractions around the station, which creates diverse pedestrian demographics with different ages, genders and amount of luggage carried. Thus, this station provides a favorable condition for the observation of various human factors and their impacts on walking speed.

A section of level passageway in the subway station was chosen for walking speed measurement, as shown in Fig. 1–2. The observed section is 6 m long and 4.4 m wide. The passageway is surrounded by walls along two sides. There are no disturbances, obstacles or attractions within the study area, and the pedestrian flow is smooth and continuous. The surrounding of the passageway is quite "oppressive", under which pedestrians can do nothing but walk. Since the objective of the walking speed observation in this research is to exclude influence resulting from all factors other than human factors, this passageway is a good candidate to meet that objective.

In order to accurately measure walking speed, distance marks of 60*60 cm square were adhered on the passageway floor with dark tape (Fig. 1–2). Another mark reference for distance estimation is