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A methodology for determining equivalent factors in heterogeneous pedestrian flows

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ABSTRACT

Similar to vehicle traffic, pedestrian flow can also be classified as heterogeneous. This paper introduces the concept of equivalent factors for converting heterogeneous pedestrian flow into equivalent base flow derived from vehicle traffic methodologies. The methodology computes equivalent mixed traffic flow and uniform flow for the same performance measure. To account for both temporal and spatial variations in pedestrian characteristics, time–space (TS) occupancy is the performance measure employed. This measure can deal with diversities in both walking speeds and body sizes, which are the two factors identified to test the methodology for the proof of concept. A micro-simulation approach is used to generate input data for computation of the equivalent factors in lieu of collected data. Inputs for the micro-simulation models are derived from literature for comparison between simulation and empirical results. Results show the robustness of the methodology in taking into account pedestrian walking speed and body size differences. An application of the equivalent factors illustrates the importance of considering heterogeneity in pedestrian walkway design. This methodology can be adopted to compute local pedestrian equivalent factors from field collected data.

1. Introduction

Vehicular heterogeneity in traffic flow is inherently resolved by converting larger and/or slower vehicles into equivalent passenger cars using passenger car equivalent (PCE) factors in order to have a single measure of flow. PCE takes into account the difference in size and operational characteristics of non-car vehicles for various traffic and environmental conditions. The use of PCE factors is the recognized methodology for dealing with heterogeneous vehicle traffic in the Highway Capacity Manual (HCM).

On the other hand, a similar approach is also essential for analyzing heterogeneous pedestrian traffic as a result of the aging population, 'obesity epidemic', etc. An attempt to device similar factors for luggage-laden pedestrians in airports was explored by Davis and Braaksma (1988). Only a few studies have recognized the importance of pedestrian diversity in facilities' design (Campanella, Hoogendoorn, & Daamen, 2009; Davis & Braaksma, 1988; Kittelson, 2003; Pheasant & Haslegrave, 2006; TRB, 2000). Particularly, the Transit Capacity and Quality of Service Manual (TCQSM) which is the transit counterpart to the HCM, contains quantitative techniques for calculating passenger circulation and level-of-service (LOS) in transit stations or terminals recommends an adjustment factor for diverse pedestrian flow (TRB, 2010). The LOS criteria for the TCQSM were derived primarily from commuter traffic that is why an adjustment factor is needed to account for pedestrians who use additional space, such as wheelchair users, those transporting large items and pedestrians who use service animals (Kittelson and Associates, 2003). However, no consensus or standard procedure determining these factors has been proposed. Taking the lead from vehicle traffic, a similar methodology is explored in this paper for hypothetical pedestrian traffic scenarios. This paper introduces the concept of pedestrian equivalent factors with the aim of putting forward a standard methodology for dealing with heterogeneity in pedestrian flow like the PCE methodology in vehicular traffic. Particularly, two specific objectives are identified: (1) adapt a suitable PCE methodology for pedestrian equivalent factor estimation using pedestrian micro-simulation; and (2) test the effects of varying pedestrian walking speed and body size on the factors. This preliminary work paves the way for the development of a methodology for incorporating varying physical and operational characteristics of pedestrians in facilities design.

This paper is organized as follows. The next section briefly discusses literature on the factors considered in the paper: walking speed and body size. Past work on PCE estimation and the details of the micro-simulation set-up are described in the next two sections. This is followed by the theory leading to the pedestrian

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equivalent concept and the results and discussion of the micro-simulation results. The paper concludes with an illustration of the possible application of equivalent factors and a presentation of relevant findings and recommendations for future investigations.

2. Background

To illustrate the robustness of the proposed methodology, pedestrian equivalency factors were estimated as a function of two important factors that influence walkway flow: pedestrian walking speed and body size. It is recognized that other factors contribute to pedestrian diversity however; these two factors are explored for the proof of concept. Faster pedestrians will result in higher overall throughput through a walkway section while bigger body sizes will require larger pedestrian space for maneuver. Researchers have documented that normal pedestrian walking speeds are a function of a large number of factors (besides pedestrian density): age, gender, and group size are frequently cited (Boles, 1981; Fruin, 1971; Henderson, 1971; Knoblauch, Pietrucha, & Nitzburg, 1996; Pushkarev & Zupan, 1975; Weidmann, 1993). Walking speeds have also been found to decline with age (Arango & Montufar, 2008; Fitzpatrick, Brewer, & Turner, 2006; Knoblauch et al., 1996; Weidmann, 1993). Older adults generally walk slower because of deteriorating eyesight and balance (Austroads, 1995). The increasing proportion of older adults is in the upward trend that the Highway Capacity Manual (HCM) 2000 suggests that in determining pedestrian walking speeds for street crossings, the percentage of elderly pedestrians should first be determined (TRB, 2000). If 0–20% of pedestrians are elderly, a walking speed of 1.2 m/s is recommended while a percentage more than 20% yields a walking speed of 1.0 m/s. In addition, most people of retirement age are disabled in some way (OECD, 2001). Boyce, Shields, and Silcock (1999) found the mean speed achieved by disabled participants on horizontal sections was 1.0 m/s while manually propelled wheelchair users traveled on average 0.69 m/s. In a study investigating walking speeds of older pedestrians who use walkers or canes, Arango and Montufar (2008) found normal walking speed to be 0.78 m/s for intersections and 0.75 m/s on the road segment. Walking speeds of people with disabilities are significantly lower than commuters. This is further exacerbated by the bigger area they occupy with their mobility aids. Other factors that influence pedestrian walking speed include the following: time of day, weather and temperature, gradient, trip purpose, and reaction to surrounding environment (Kittelson and Associates, 2003). In a nutshell, different pedestrians exhibit dissimilar walking speeds under different walking conditions.

Spatially, although pedestrians are essentially three-dimensional objects, in pedestrian modeling they are generally treated as two-dimensional by considering the vertical projection of the body. Body depth and shoulder width are the primary human measurements used by designers of pedestrian spaces and facilities, where shoulder breadth is the factor most affecting practical capacity. The plan view of an average adult male human body occupies an area of about 0.14 m^2 but the design envelope adopted is an ellipse 460 mm by 610 mm, of area 0.21 m^2 (Austroads, 1995). For the space related to walking, Rouphail et al. (1998) recommends a body buffer zone of 0.8 m^2 for walking which is near the upper end of the buffer zone range of 0.46 and 0.84 m^2/pedestrian provided by Pushkarev and Zupan (1975). These spaces are critical dimensions that affect the number of pedestrians able to pass through the facility (Lee & Lam, 2009). In addition to body size, the area occupied by a person is also affected by other articles carried or used. The amount of space consumed by pedestrians with various articles like bags and luggage is greater than empty-handed pedestrians. This is particularly true for pedestrian flows in arrival corridors for large airport terminals (Monteleone & Aviles, 2009). Davis and Braaksma (1988) broadly classified pedestrians based on encumbrances as standard pedestrian, pedestrian carrying on luggage and pedestrians with two luggage. On the other hand, the space needed by people with disabilities depends on the type of disability. The equipment they use and/or person escorting them adds to the area occupied while walking. Ackermann (1997 as cited in Buchmueller and Weidmann (2006)) considered people with prams as handicapped because of the walking speed restriction, difficulties in passing others, and increased area occupied. To sum up, the area occupied by a walking person is not only a function of body size but also by the article carried and mobility equipment employed.

In summary, although many other factors generally affect pedestrian flow, walking speed and body size diversity (area occupied) were identified to be significant factors in determining the equivalent factors.

3. Past work on PCE estimation

Because heavy vehicles take up more space and have lower performance especially on grades, a reduction in throughput is normally observed. Traffic volumes containing a mix of vehicle types must be converted into an equivalent flow of passenger cars using PCE factors. Factors that affect PCEs on basic freeway segments considered in the HCM 2000 (TRB, 2000) include percent and length of grade, and proportion of heavy vehicles. In addition, Arasan and Arkatkar (2010) found PCEs to significantly change with traffic volumes and roadway widths. Various methods have been used to calculate PCEs throughout the evolution of highway capacity analysis. These methods have been applied both for two lane highways and multilane highways or freeways. Two of the earliest methods were based on the relative number of passing of trucks by passenger cars (Walker method) and the relative delay caused by these vehicles was calculated using the 1965 HCM (HRB, 1965). PCE methodologies can be summarized based on the performance measures employed in developing equivalencies, examples of which are headways, delays, platoon formation, speed and travel time (Elefteriadou, Torbic, & Webster, 1997). Number of passing maneuvers is difficult to measure in pedestrian traffic because of their agility and unconstrained movement. Headways, delays and platoon formation are even more difficult to determine because pedestrians are not confined to traffic lanes. PCE based on speed are estimated from relative rates of speed reduction for each vehicle type (Elefteriadou et al., 1997). Meanwhile, total travel time pertains to the amount of time a particular space is being occupied. This measure is immediately experienced by all users and provides a clear picture of how smoothly a facility is operating. An inherent weakness of using travel time is its insensitivity to changes in vehicle physical characteristics. In order to consider both temporal and spatial characteristics, the time–space (TS) occupancy is adopted for determining pedestrian equivalent factors. TS is typically recommended for application in any facility where pedestrian activities (waiting, queuing, walking and processing) occur. Details of the TS method are discussed in Section 5.

4. Experimental micro-simulation set-up

Ideally PCE factors (as well as the proposed equivalent factors) are derived from flow relationships field collected data covering various possible scenarios. In recent years, micro-simulation has been widely used in lieu of traditional analytical procedures (Arasan & Arkatkar, 2010; Elefteriadou et al., 1997; Ingle, 2004; Patrick et al., 2008; Webster & Elefteriadou, 1999). Micro-simulation of pedestrian traffic offers an innovative approach to evaluating hypothetical pedestrian situations. Making use of simulation models is