Developing Standard Pedestrian-Equivalent Factors

Passenger Car–Equivalent Approach for Dealing with Pedestrian Diversity

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Similar to vehicular traffic, pedestrians, despite having diverse capabilities and body sizes, can be classified as heterogeneous. The use of vehicular traffic resolves the diversity issue with a conversion of heterogeneous vehicle flow into an equivalent flow with the use of passenger car–equivalent (PCE) factors. Analysis of pedestrian flow has yet to incorporate pedestrian diversity analysis implicitly into the design of pedestrian facilities, although some form of adjustment has been suggested. This paper introduces the concept of PCE-type factors for mixed pedestrian traffic called standard pedestrian-equivalent (SPE) factors. Estimates of SPE factors are made relative to the average commuter. The equivalent total travel time approach for PCE estimation was adapted to consider the effects of the differences in physical and operational characteristics of pedestrians, particularly walking speed and body size. Microsimulation of pedestrians was employed to evaluate hypothetical pedestrian proportions so as to generate corresponding flow relationships. Walking speeds and body sizes were varied across different flow conditions, walkway widths, and proportions of other pedestrian types. The first part of this paper explores how the two pedestrian characteristics (walking speed and body size) influence estimated SPE factors. The second part is a case study in which field-collected data illustrate SPE factors calculated for older adults, obese pedestrians, and their combination. An application of SPE factors demonstrates the robustness of the methodology in bridging the gap between pedestrian compositions and planning practice.

Vehicle traffic does not consist entirely of passenger cars but also recreational vehicles (RVs), buses, and trucks. To address the problem in capacity analysis, passenger car–equivalent (PCE) factors were introduced. Use of PCE started in the 1965 *Highway Capacity Manual* (HCM) with the purpose of converting heterogeneous vehicle flow into an equivalent passenger car flow (*1*). PCE takes into account the differences in size and operational characteristics of vehicles for various traffic flow and environmental conditions. Pedestrian traffic, similarly, can be qualified as heterogeneous.

A considerable amount of research focuses on pedestrian behavior and flow. Most of this effort has put more emphasis on cultural differences (*2*), age (*3*), gender (*4*), travel purpose (*3, 5, 6*), and social groups (*7–11*). The last category deals with how people form groups while walking and the proportions of these groups. This paper deals with different pedestrian types segregated according to well-established pedestrian categories (e.g., commuters, older adults), although focus is more on how they are handled in design. It has been established that the introduction of other pedestrian types (e.g., older adults) in commuter-only traffic shifts the level of service (LOS) in the design guidelines (*12, 13*) such that assumed LOS might not represent the actual pedestrian experience within the facility. Contemporary analysis of pedestrian capacity has yet to mature to account implicitly for the effect of the heterogeneity in pedestrian traffic, although some form of adjustment factor has been suggested. Only a few studies have recommended a means for considering diversity in the design of pedestrian facilities (*14–17*). Nevertheless, no consensus or standard procedure for tackling pedestrian diversity has been proposed. This paper introduces the concept of standard pedestrian-equivalent (SPE) factors, with the aim of presenting a standard methodology.

This paper is organized as follows. The next section briefly discusses the research objectives. Past work on PCE estimation and comparison of vehicle and pedestrian traffic and the details of the proposed SPE methodology are described in two sections that follow. The results of the sensitivity analysis and case study are then presented, and those are followed by an illustration of the application of this study. The paper ends with the presentation of relevant findings and recommendations for future investigations.

RESEARCH OBJECTIVES

This paper introduces the concept of SPE factors with the aim of presenting a standard methodology for dealing with heterogeneity in pedestrian flow as the PCE methodology does in the HCM. The *Transit Capacity and Quality of Service Manual* (*18*) is the transit counterpart to HCM 2010 (*19*). The manual contains quantitative techniques for calculating passenger circulation, and LOS in transit stations or terminals are primarily founded on Fruin (*20*). This is the reason for using Fruin's data in this paper: to investigate the effects of operational and physical factors in the walkway design process. The manual recommends an adjustment factor to account for pedestrians who use additional space, although limited guidance on the factor to use is provided. This research has three specific objectives: (*a*) to evaluate PCE methodologies to be adapted for SPE estimation, (*b*) to test the methodology by varying pedestrian walking speed and body size inputs through microsimulation; and

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(*c*) to use field-collected pedestrian walking speeds and body sizes for the case study to estimate SPE.

PAST WORK

This section summarizes past effort on PCE estimation and physical and operational differences between vehicle and pedestrian traffic with the aim of adapting a suitable methodology for estimating SPE factors in heterogeneous pedestrian traffic.

Estimation of PCEs

PCE factors are generally employed to convert traffic volumes containing a mix of vehicle types into an equivalent flow of passenger cars experiencing similar conditions. This conversion is essential because heavy vehicles take up more space and have lower performance, especially on grades, and therefore result in a reduction of throughput. The calculation is relevant to capacity and LOS determination, lane requirements, and the determination of the effect of traffic on highway operations. Factors that affect PCEs on basic freeway segments considered in the HCM 2000 (*17*) include percent and length of grade, and proportion of heavy vehicles. 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. Most PCE methodologies are classified on the basis of the performance measure employed in relating uniform and mixed vehicular traffic. Two of the earliest methods were based on the relative number of passenger car passings of trucks (Walker method) and the relative delay caused by trucks (*1*). Other methods used volume-to-capacity ratio, speed, headways, density, flows, and travel time. More-comprehensive reviews of these PCE estimation methodologies can be found in Elefteriadou et al. (*21*) and Ingle (*22*).

Vehicle Traffic Versus Pedestrian Traffic

Because of the inherent physical and operational differences between vehicles and pedestrians, not all PCE methodologies may be adaptable for estimating pedestrian-equivalent factors. Vehicles come in many sizes that depend on the number of axles. Although pedestrians also come in different body sizes (aside from the personal articles they carry or have on), pedestrians are significantly smaller. Pedestrians can basically move laterally in any direction, while vehicles can only veer forward (with limited backward movement). Pedestrians can easily reverse their direction and exit a system where they enter (*23*), whereas automobiles are confined to lanes on the roadway. Pedestrian flows can be unidirectional, bidirectional, or in cross-flows in intersections, while vehicle traffic is mostly unidirectional. Vehicle traffic is ideally separated in time when using shared roadway areas (e.g., intersections) so as to avoid conflicts. Pedestrians share walking areas with others moving in different directions all the time. Pedestrians' collective effects, such as density waves, are similar to stop-and-go movement in vehicular traffic, but pedestrian traffic also exhibits some form of lane formation and self-organization (*24*). Pedestrians may be considered similar to vehicular traffic when they are constrained to footpaths, stairs, road lanes, or corridors. In that case, network capacity can be defined, demand measured or predicted, operational levels calculated, and areas of congestion and hazards identified (*25*).

PCE methodologies can be summarized on the basis of the performance measures employed, examples of which are headways, delays, platoon formations, speed, and travel time (*21*), in addition to the number of passing maneuvers (*1*). The number of passing maneuvers is difficult to measure among pedestrians 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. PCEs based on speed are estimated from relative rates of speed reduction for each vehicle type (*21*). 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. This measure is deemed the most appropriate for pedestrian traffic because it can easily be measured for all pedestrian types. The time occupancy of base pedestrians and the comparison of that with mixed pedestrian traffic form the basis for the methodology for estimating SPE factors. The method is discussed in detail next, as this was employed in determining SPE factors.

METHODOLOGY

After an extensive review of PCE methodologies, the approach proposed by Huber (*26*) for the case in which a traffic stream contains passengers cars and only one type of truck was further investigated. For multiple types of vehicles, a revision of Huber's method by Demarchi and Setti (*27*) was also adapted. The performance measure employed for flow equivalency computation was total travel time.

Proposed SPE Methodology

Huber (*26*) quantified the effect of trucks on PCEs by relating them to traffic flows for the same LOS. Different types of pedestrians, because of variations in their characteristics, expend differing numbers of pedestrian minutes in using a particular walking facility. Older adults, for example, are slower than the average commuter and require a greater number of pedestrian minutes to make the same trip than a commuter. In addition, a slower pedestrian causes other pedestrians to walk slower. A relationship between flow and total travel time could be employed to relate the equivalent pedestrian traffic flows at equal pedestrian minute values for the base and mixed conditions. The typical commuter has been used as the unit value for SPE (*20*). The measure of equal total travel time would cut across the two flow curves where the equivalency can be derived, as shown in Figure 1.

Because any two points on a horizontal line in Figure 1 have equal LOS, the sum of the products of corresponding flows and SPEs is constant. It can thus be stated that

$$E_C(1)q_B = E_C(1-p)q_S + E_S p q_S \qquad (1)$$

where

E_C = 1 = SPE value of base pedestrian type (commuters, by definition),
E_S = SPE value of other pedestrian type,
p = proportion of other pedestrian type subtracted from commuter-only base pedestrian flow,
q_B = base pedestrian flow rate, and
q_S = equivalent flow with other pedestrians.

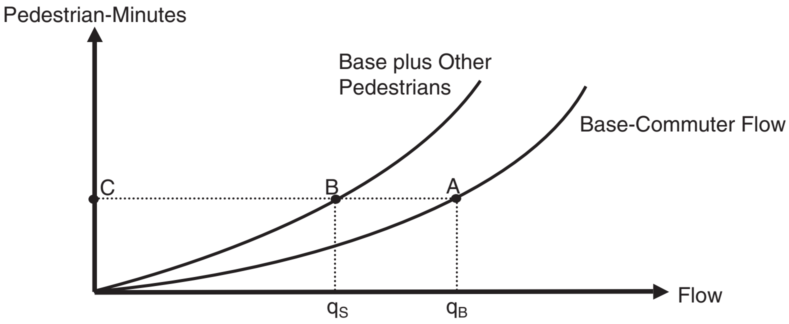

FIGURE 1 Pedestrian total travel time as function of flow.

Because, by definition, E_C is unity

$$E_S = \frac{1}{p}\left(\frac{q_B}{q_S} - 1\right) + 1 \tag{2}$$

The procedure for the determination of the flow rates q_B and q_S and of E_S can be summarized in four steps, as adapted from Demarchi and Setti (*27*):

1. Establish the relationship between the total travel time and the unit flow rate for the base stream containing commuters only and ideal conditions.
2. Establish a similar relationship (as in Step 1) for the mixed stream, containing $(1 - p)$ commuters and p other pedestrians.
3. Find equivalent flow rates q_B and q_S for the same total travel time by using linear interpolation.
4. Calculate the SPE equivalence factor E_S with Equation 2.

For multiple types of trucks, Demarchi and Setti (*27*) formulated an equation to avoid errors associated with calculating individual PCE, with an aggregate PCE formulated as

$$E_S = \frac{1}{\sum_{i}^{n} P_i}\left[\frac{q_B}{q_M} - 1\right] + 1 \tag{3}$$

where

P_i = proportion of trucks of type i of all trucks n in the mixed-traffic flow,
q_B = base flow rate (passenger cars only), and
q_M = mixed flow rate.

This equation is basically Equation 2 as proposed by Huber and modified for multiple types of trucks in the mixed-traffic stream. This approach, using an aggregate PCE, was adopted in the 1994, 1997, and 2000 editions of the HCM (*22*). Equation 3 can be employed in the same way as Equation 2 for multiple types of pedestrians.

Estimating SPE with Microsimulation

Ideally, PCE factors (as well as the proposed SPE factors) are derived from field-collected data on flow relationships that cover various possible scenarios. In recent years, though, microsimulation has been widely used in lieu of traditional analytical procedures (*21, 22, 28–30*). Microsimulation of pedestrian traffic offers an innovative approach to evaluating hypothetical pedestrian situations. Making use of simulation models is a practical way of undertaking a study without the risk of injury to pedestrian subjects. In addition, privacy issues make video collection of pedestrian data more difficult. If the SPEs were to be developed by using field data, sites with desired traffic flow rates and pedestrian compositions would have to be located. With the current state of the art in collection of pedestrian data, use of detailed pedestrian data for computation of SPE factors could soon be realized. For the purpose of this study, microsimulation will suffice.

The widely used VISSIM microsimulation model was employed to evaluate the effects of pedestrian diversity, particularly the increase in the proportion of older adults and obese people in the traffic stream for SPE estimation. VISSIM employs the social force model introduced by Helbing and Molnar (*31*) and designed to represent the stochastic behavior of pedestrian movements. This pedestrian behavior model has been validated by researchers (*32, 33*). Microsimulation software was used to generate data to build the relationships similar to Figure 1.

Microsimulation Setup

Three flat walkway test beds were considered for the microsimulation modeling scenarios. The first walkway measured 10 × 1.5 m (called Model 1); the second, 10 × 3 m (Model 2); and the third, 10 × 4.5 m. The type of flow considered for SPE estimation is unidirectional. A snapshot of the simulation setup that illustrates the three models described earlier is shown in Figure 2.

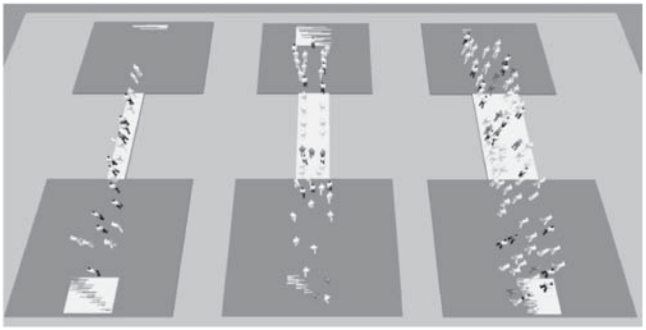

FIGURE 2 Pedestrian microsimulation setups across walkway widths.

TABLE 1 Simulation Scenarios

Part	Scenario Name	Model Input Affected	Body Width Input (m)	Average Speed Input (m/s)
Sensitivity analysis	10% lower speed	Speed	0.46 base, 0.46 others	1.40 base, 1.26 others
	20% lower speed	Speed	0.46 base, 0.46 others	1.40 base, 1.12 others
	Plus 10 cm body width	Body width	0.46 base, 0.56 others	1.40 base, 1.40 others
	Plus 20 cm body width	Body width	0.46 base, 0.66 others	1.40 base, 1.40 others
Case studies	Commuters and older adults	Speed	0.46 commuters, 0.46 older adults	1.50 commuters, 1.09 older adults
	Commuters and obese	Speed and body width	0.46 commuters, 0.61 obese	1.50 commuters, 1.24 obese
	Multiple pedestrians	Speed and body width	0.46 commuters, 0.46 older adults, 0.61 obese	1.50 commuters, 1.09 older adults, 1.24 obese

The study reported here was divided into two parts: the sensitivity analysis using well-established pedestrian characteristics from Fruin (*20*) and the use of purpose-specific data collected on pedestrian characteristics as input to the simulation models. Details of the investigated scenarios are shown in Table 1. The sensitivity analysis evaluated the effects of lower speed [10% and 20% in relation to the speed established by Fruin (*20*)] and bigger body size [+10 cm and +20 cm of body width in relation to that established by Buchmueller and Weidmann (*34*)]. For the lower-speed scenarios, a separate group of pedestrians having both lower speeds (relative to the Fruin function for the probability distribution of walking speed) and the same body sizes were introduced so that their effect could be evaluated. For the scenario with bigger body size, a group of pedestrians having bigger girths were introduced while their walking speed distribution was made similar. And for the case study scenarios, field-collected speeds of commuters, older adults, and obese pedestrians were used as input. These data were collected in field studies in pedestrian facilities in Brisbane, Australia. Body sizes were collected from anthropometric data from the literature (*16, 34*). In VISSIM, the different types of pedestrians were organized into pedestrian categories having their corresponding physical and operational characteristics. These characteristics were recorded as probability distribution functions. For this study, normal walking speed and body size were considered, although it was recognized that other factors may affect SPE results.

SPEs were evaluated across traffic volumes, walkway widths, and proportion of subject pedestrians for both the sensitivity analysis and the case study. Table 2 is a list of factors considered in the microsimulation. For each of the four scenarios in the sensitivity analysis, 108 combinations (12 flows × 3 widths × 3% pedestrians) with 50 runs resulted in 5,400 trials. In addition, 5,400 trials were run for the combinations of commuters with older adults and with obese pedestrians in the case study scenarios. And for the case of multiple pedestrians, proportions of 80% commuters, 10% older adults, and 10% obese persons were evaluated, yielding 1,800 trials. As a rule, multiple runs are made in simulation studies to account for the stochastic nature of models.

TABLE 2 Traffic Variables Considered

Traffic Variable	Combinations
Unit flow rate (ped/m/min)	6, 12, 18, 23, 28, 33, 41, 49, 57, 66, 74, 82
Walkway widths (m)	1.5, 3.0, 4.5
Other pedestrians (%)	10, 20, 30

NOTE: ped = pedestrians.

SENSITIVITY ANALYSIS

Model Comparison

With microsimulation, one must be certain that the developed model produces output that reflects field-collected data. Figure 3*a* is a graph of the relationship of pedestrian flow to space using Fruin's model (*20*). The simulation models clearly represent that relationship. The speed–density relationship also accurately replicates the model, as shown in Figure 3*b*. Paired-sample *t*-tests were conducted for the data in Figure 3. The comparison between each model (predicted) and Fruin for both walking speed and unit flow values shows no significant difference at the 95% confidence level. High Pearson correlation values of .996 and .999 were also computed for walking speed and unit flow, respectively. These results are highly achievable because the input of the speed profile for the microsimulation came from Fruin, and body sizes were kept uniform.

SPE and Speed Difference

Microsimulation modeling was used to quantify the relationship between flow and total travel time for SPE computation. Two scenarios for walking speeds were evaluated, namely, decreases of 10% and 20% while body sizes remained constant.

Logically, as flow rate increases, total pedestrian travel time increases. As Figure 4*a* shows, this trend can be observed for Model 1 (1.5-m width) across different scenarios. The total travel time–flow relationship strongly reflects the average delays across flows. The same trend was observed for Models 2 and 3.

More specifically, only a slight increase in total travel time was observed with the introduction of pedestrians having 10% slower walking speed. For a 20% speed difference, the increase was more significant, especially for high flow rates. Nevertheless, increases in total travel time across both cases were still observed. In both scenarios, increased overall travel times were prevalent and SPE values calculated. The higher total travel time for the 20% speed difference relative to the base scenario yielded higher SPE factors than did the 10% difference, as shown in Figure 4*b*. The same observation is true for similar flows, widths, and proportions. This trend corroborates observations in the 1965 HCM (*1*) that, as the difference in speed between trucks and passenger cars increases, the PCE value increases.

SPE and Body Size

For body size, two scenarios were tested, namely, an additional 10- and 20-cm increase in body width. Walking speeds were kept constant. Figure 5*a* shows that, at low flow rates, the total travel

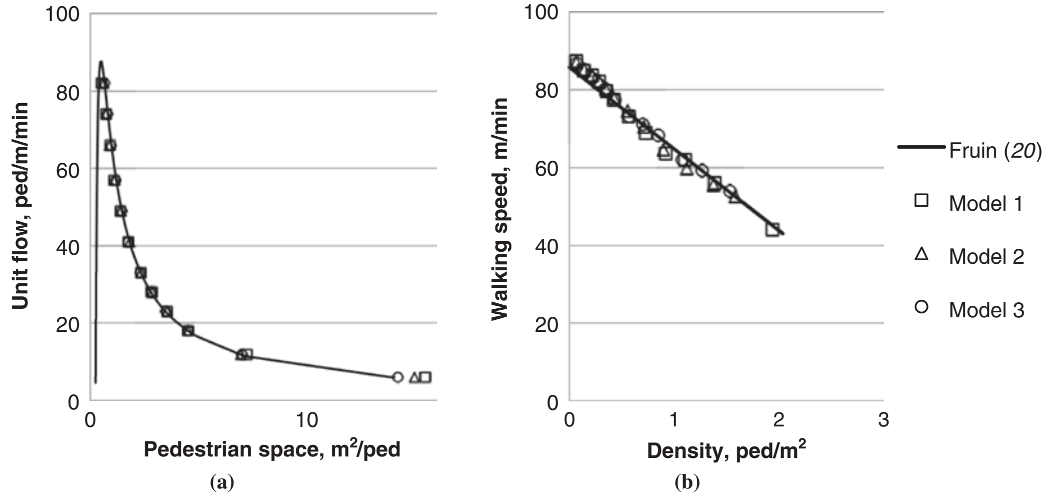

FIGURE 3 Relationships and model results for (*a*) flow–space and (*b*) speed–density.

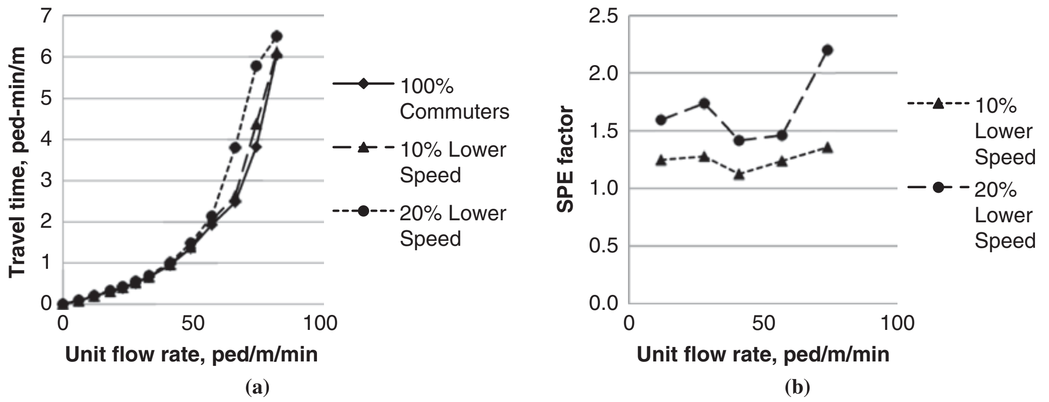

FIGURE 4 Model 1: (*a*) travel time–flow relationships and (*b*) SPE factors for 10% and 20% lower speeds.

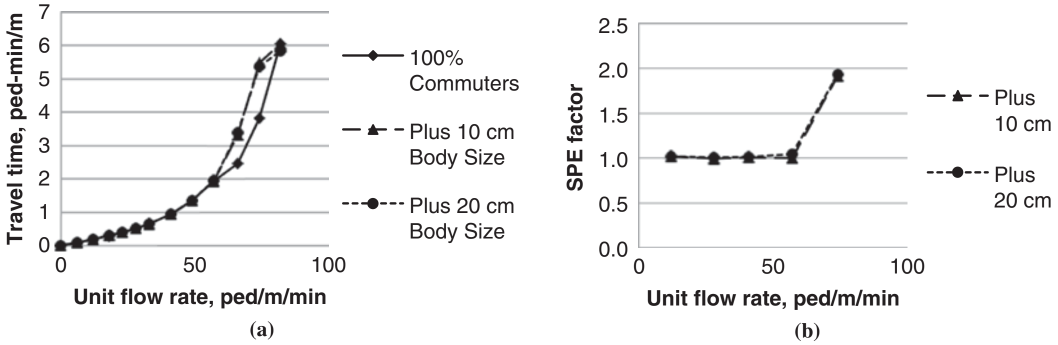

FIGURE 5 Model 1: (*a*) travel time–flow relationships and (*b*) SPE factors for bigger body widths.

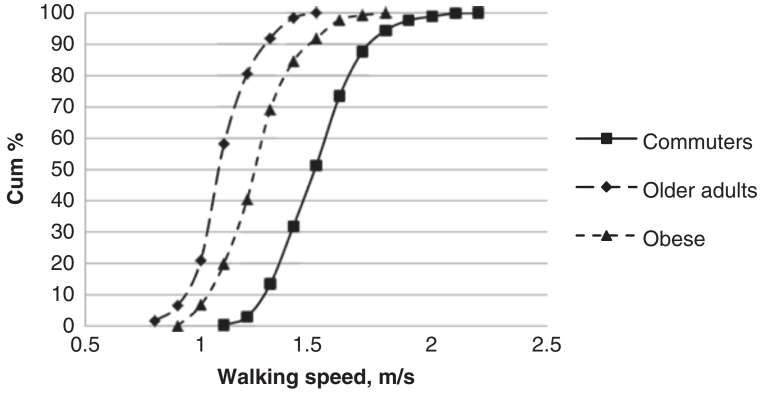

FIGURE 6 Percentage cumulative frequency graphs of walking speeds.

times were quite similar to the base scenario (same body sizes). However, at higher flows, total travel times for both the +10 and +20 cm were significantly higher.

The effect of body size on SPE is more pronounced in the higher flow rates, as shown in Figure 5*b* for Model 1. The increase in body size (with respect to base body size) yielded SPEs only slightly higher than unity. This observation is sensible because of the temporal nature of the measure used in estimating equivalency (total travel time) with pedestrians having the same speed profile. As the flow becomes more congested, the effect of increased body width becomes apparent and results in SPE values that are higher than unity. The same results were obtained for the other models and proportions.

CASE STUDY

Field-collected data were used as model input for the case study. Combinations of commuters with older adults and obese pedestrians were evaluated to estimate the SPE factors.

For the difference in walking speeds to be investigated further, a comparison of data collected for commuters, older adults, and obese was conducted. The average normal walking speed was found to be 1.50 m/s for commuters, 1.09 m/s for older adults, and 1.24 m/s for obese travelers. The values for commuters and older adults agree with the field study results of Fitzpatrick et al. (*4*). The cumulative distribution of walking speeds of the three groups is shown in Figure 6. A one-way analysis of variance test was also conducted to show whether the difference in walking speeds between commuters, older adults, and obese pedestrians was significant (95% confidence level). The results in Figure 6 show a significant difference across the three groups.

Figure 7 shows a sample of the total travel time–flow relationship for samples with 100% commuters, 10% obese, and 10% older adults for Model 1. The introduction of older adults yielded higher total travel time than a similar proportion of obese pedestrians. This finding resulted in higher values of SPE from Equation 2, as shown in Table 3. The combined effects of lower walking speed (17% relative to the commuters) and bigger body width (+15 cm) for the commuter–obese combination on SPE were lower compared with the significantly lower walking speed only (27% of commuters) of older adults. This result reinforces the findings above that higher speed differences will result in higher SPE values. For the multiple pedestrians (80% commuters, 10% older adults, 10% obese), aggregate SPE values, computed from corresponding total travel time–flow relationships by using Equation 3, are also presented in Table 3. All estimated SPE values for the case of multiple pedestrians (80% commuters and 20% others) lie between the 20% older adults and 20% obese across all flows and walkway widths. This conclusion is a logical one because the combined effects of 10% older adults and 10% obese should be between the other two cases.

The SPE factors in Table 3 can be used to convert older adults and obese pedestrians in mixed flow. For example, if a walkway

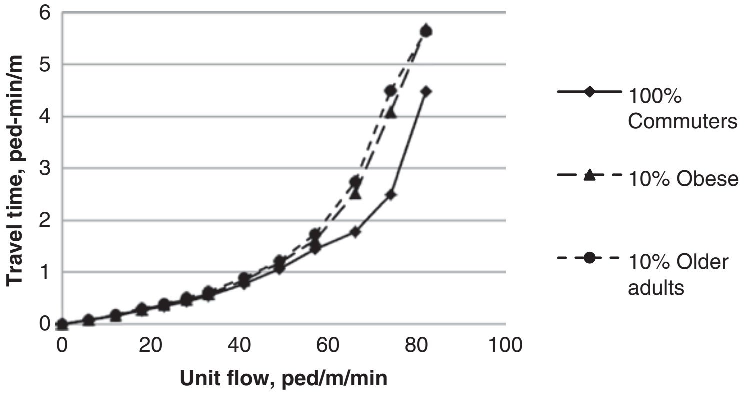

FIGURE 7 Example of travel time–flow relationship for case study, Model 1.

TABLE 3 SPE Factors for Older Adults, Obese, and Multiple Pedestrians

Model and Percentage of Pedestrians	SPE by Unit Flow Rate (ped/m/min)				
	12 (LOS A)	28 (LOS B)	41 (LOS C)	57 (LOS D)	74 (LOS E)
Older Adults					
1 (1.5 m)					
10%	1.7	2.1	1.9	1.8	2.6
20%	2.0	2.0	1.8	1.8	2.2
30%	1.9	2.0	1.8	1.8	2.0
2 (3.0 m)					
10%	1.9	1.9	2.0	2.1	1.7
20%	2.0	2.0	1.9	2.0	1.8
30%	1.9	1.9	1.8	1.8	1.8
3 (4.5 m)					
10%	1.8	2.0	1.7	2.2	2.3
20%	1.9	2.0	1.7	2.1	2.1
30%	1.9	2.0	1.8	2.0	2.0
Obese					
1 (1.5 m)					
10%	1.6	1.7	1.5	1.6	2.2
20%	1.5	1.6	1.5	1.6	1.9
30%	1.5	1.6	1.5	1.5	1.8
2 (3.0 m)					
10%	1.3	1.6	1.5	1.4	1.7
20%	1.5	1.6	1.4	1.5	1.6
30%	1.5	1.6	1.5	1.6	1.6
3 (4.5 m)					
10%	1.4	1.7	1.6	1.7	1.7
20%	1.5	1.5	1.4	1.6	1.7
30%	1.5	1.6	1.5	1.6	1.6
Multiple Pedestrians (80% Commuters, 10% Older Adults, 10% Obese)					
1 (1.5 m)	1.7	1.9	1.7	1.6	2.0
2 (3.0 m)	1.6	1.8	1.8	1.9	1.6
3 (4.5 m)	1.7	1.8	1.7	2.0	1.8

is experiencing a unit flow of 12 pedestrians per meter per minute composed of 10% older adults (and 90% commuters), each older adult is equivalent to 1.7 times a commuter, while for a unit flow of 12 pedestrians per meter per minute with 10% obese pedestrians (and 90% commuters), one obese person is equivalent to 1.6 commuters. And for multiple types of pedestrians with, for example, 10% older adults and 10% obese pedestrians (and 80% commuters) and a unit flow of 12 pedestrians per meter per minute, an aggregate SPE of 1.7 can be employed.

APPLICATION

In analysis of vehicle capacity, the PCE is used to compute the heavy vehicle factor so as to estimate a reduced lane capacity for the prevailing traffic condition. For analysis of pedestrian capacity, the width of the walkway is estimated on the basis of the desired operating LOS and prevailing pedestrian condition. The SPE factors computed above can be used to determine the appropriate width of a corridor when traffic is composed of a mix of commuters, older adults, and obese pedestrians having similar conditions. The following hypothetical pedestrian scenarios illustrate the possible application of SPEs.

For a hypothetical walkway, the desired operating LOS is C. For example, in an assumed uniform flow arrival of 4,000 pedestrians, 20% are older adults. If flow is unadjusted, the flow per unit width is 66.7 pedestrians per meter per minute, which translates to a walkway width of 1.6 m for LOS C (unit flow rate = 41 pedestrians per meter per minute in Table 3). Conversely, when older adults are considered, along with a corresponding SPE factor of 1.8 (shaded cell in Table 3) and LOS C, the flow will be computed at 77.3 pedestrians per meter per minute. A resulting walkway width of 1.9 m will be required for this scenario. This means that, with the given mix and LOS, the effective walkway width is almost 20% greater than that for a group consisting entirely of commuters. The 0.3-m difference is more than half an additional pedestrian width and can mean the difference between being able to walk with or without difficulty. As a final step to the dimensioning process, a buffer on each side of the computed effective walkway width is added if the walkway boundary condition allows.

CONCLUSIONS AND RECOMMENDATIONS

This paper introduced the concept of SPE factors to convert heterogeneous pedestrian flow into a uniform commuter flow. This approach used simulation modeling to develop the relationships between time occupancy and flow adapted from PCE methodologies. Ideally, the flow relationships for SPE computation should be derived from field data (by using the state of the art in the collection of pedestrian data) that considers possible pedestrian traffic conditions. An application of SPE factors demonstrates the robustness of the methodology in bridging the gap between prevailing pedestrian compositions and planning practice.

Further research with field-collected data is recommended to calibrate and to validate the findings reported in this study. Four major undertakings are also recommended:

1. Conduct a validation study of the SPE values estimated in this research with data collected in the field under similar conditions.
2. Use state of the art in the collection of pedestrian data to consider more factors (physical, operational, and behavioral) that may affect SPE values.
3. Investigate the effects of facility type, ramps and stairs, bidirectional and cross-flows, and other pedestrian types.
4. Use a more robust methodology that is also sensitive to changes in the physical characteristics of pedestrians (e.g., time–space concept).

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