Design Implications of Walking Speed for Pedestrian Facilities

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Design Implications of Walking Speed for Pedestrian Facilities

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Abstract: Pedestrians walk differently on different types of facilities. Walking speeds are governed not only by the width of the facility but also by age and gender, land uses, temporal variations, cell phone usage, carrying baggage while walking, and movement in groups. This paper discusses development of adjustment factors for effective design of pedestrian facilities on the basis of pedestrian walking speeds under such influences on three types of facilities, e.g., sidewalks, wide-sidewalks, and precincts. Eighteen locations are selected in five cities in India, and data are analyzed considering the influencing parameters. Pedestrians walk faster than the population mean walking speed on sidewalks at 71.22 m/ min, whereas they walk at a speed of 63.60 m/ min on precincts. Exercise and leisure walking speeds of pedestrians are 74.57 m/ min and 62.44 m/ min, respectively. Significant difference is observed in the walking speed of pedestrians when moving alone or in a group. Pedestrians carrying baggage walk slower at 64.26 m/ min compared with the population mean walking speed. Similarly, pedestrians using cell phones walk slower at 62.82, 62.19, and 59.29 m/ min on sidewalks, wide-sidewalks, and precincts, respectively. Land use also plays a major role in determining the walking speed of pedestrians. Pedestrian speed in an educational area (85.27 m/ min) and in shopping areas (60.21 m/ min) are 28% faster and 16% slower, respectively, than the population mean walking speed. **DOI: 10.1061/(ASCE)TE.1943-5436.0000251.** *© 2011 American Society of Civil Engineers.*

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Introduction

Walking is a complete mode in itself and is a supplementary mode by which any individual accesses a personal vehicle or public transportation or reaches the final destination after using a mode. According to a modal split study of Mumbai, India, out of nearly 2.85 million trips, 52.4% are walk trips, (MMRDA 2008). African cities have a greater walking modal share than Asian and Latin-American cities. The average walking share of African, Asian, and Latin-American cities are 57, 37, and 22%, respectively (Montgomery 2006). In Beijing, China, the pedestrians were observed walking to transit station (15.1%), for recreational activities (9.8%), to work (22.7%), to school (15.2%,) and to shop (22.8%), making it 61% of the total trips (Tanaboriboon and Jing 1994). In a recent survey conducted in West Perth, Australia, 70% of all on-farm trips and 50% of shopping trips are made on foot (Curtin Univ. of Technology and Geografia 2006). Large proportion of walk trips in Asian, African, and Latin-American countries necessitate the provision of exclusive walk facilities. These may be sidewalks, pathways, shared carriageway (marked or unmarked) used with motorized or nonmotorized vehicles (especially bicycle), and dedicated spaces for walking. The widths of these facilities are usually decided on the basis of pedestrian flow (pedes/h/m), which is governed by its relationship with pedestrian speed (Kotkar et al. 2010). This relationship gets affected by factors constituting the walking environment. One of the inherent factors affecting walking speed is the purpose of the trip. Information on trip purpose can be collected through interview only. However, it can be indirectly obtained by the land-use activities of the area surrounding the pedestrian facility. The walking speed is also influenced if a pedestrian indulges in an activity during walking or is moving in a group. The personal characteristics of the pedestrian such as age and gender are additional factors which influence the walking speed. A combination of all these factors may change the pedestrian's speed and flow considerably. The design of a facility should consider all these influences to the extent possible. This paper therefore attempts to quantify the influence of various factors on pedestrian walking speeds and suggests the adjustment factors for flows that can be used in deciding the size of the facility.

Various researchers have examined the effects of influencing factors on pedestrians' walking speeds. Fruin (1971), Polus et al. (1983), Tarawneh (2001), Montufar et al. (2007), and Finnis and Walton (2008) observed that males walk faster than females, and walking speed declines with age of the pedestrian. Tarawneh (2001) and Carey (2005) found that group size of pedestrians affects the walking speed significantly. Carey (2005) and Montufar et al. (2007) found that younger pedestrians walk faster than older pedestrians and are not affected by season. Fitzpatrick et al. (2006) observed that the 15th percentile walking speed of younger pedestrians (1.15 m/s) is faster than that of older pedestrians (0.92 m/s). The 15th percentile speed is the lowest value at which 85% of pedestrians are expected to walk. Arango and Montufar (2008) compared the walking speed of older pedestrians using canes or walkers for mobility with the older pedestrians who are

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walking without these assisting devices. Older males are walking faster than older females without the assisting devices, whereas no gender difference is shown in walking speed when the assisting devices are used.

Some researchers have studied the influence of an activity performed during walking on the walking speeds. Morrall et al. (1991) observed that people carrying baggage tend to walk slower than the non-baggage-carrying pedestrians irrespective of the size and weight of the baggage. However, Young (1998) found no significant difference in the walking speed of such pedestrians. Pedestrians wearing headphones and pedestrians talking on cell phones are walking slower than those who do not indulge in these activities (New York Pedestrian Study 2006). Loeb and Clarke (2009) also found an adverse effect of cell phone usage on pedestrian's speed and safety.

The effect of land uses on pedestrian speeds has also been a subject of research. Al-Masaeid et al. (1993) found that land use of the surrounding environment is an important factor which influences the walking speed of pedestrians in developing countries. They also observed a significant difference in the walking speeds of pedestrians because of the land uses, such as business, residential, and shopping areas. Lam and Cheung (2000) observed that pedestrians walking in commercial areas are faster than those in recreational areas, and the walking speed of the pedestrian depends on the surrounding environment. Daamen and Hoogendorn (2005) observed that speed of pedestrians is influenced by walking characteristics such as the width, type of facility, and environmental factors. McDonald (2007) suggested that social environment is an important factor affecting the walking behavior of child pedestrians, and it is a major factor in short-distance walking trips. Wells and Yang (2008) found that land-use mix also affects walking, and pedestrians in nonresidential areas walk less than those in other areas. Bornstein and Bornstein (1976) and Bornstein (1979) reported that pedestrians living in cities with a large population have faster walking speeds than those living in cities with small populations, and a relationship exists between the walking speed and population size of the city.

The pedestrian speeds are also influenced by the type of facility. Polus et al. (1983) found that the average walking speed of pedestrians on sidewalks in Haifa, Israel, is 79 m/min. In Singapore, it is observed at 74 m/min (Tanaboriboon et al. 1986). Koushki (1988) found that the slowest pedestrians are in Riyadh, who walk at a speed of 65 m/min. Morrall et al. (1991) found the walking speed of pedestrians at 75 m/min in Colombo, Sri Lanka, and 84 m/min in Calgary, Canada. They suggested that for Asian countries, such as India, Sri Lanka, and China, the pedestrian planning should be based on local pedestrian characteristics rather those from cities with dissimilar cultures. Lam and Cheung (2000) compared pedestrian speeds on different facilities and found that pedestrians on indoor walkways walk slower than those on outdoor walkways. Finnis and Walton (2008) found faster walking speeds for New Zealanders compared with previously reported international studies. The pedestrian walking speed is greatly influenced by personal and locational factors. The walking speeds of pedestrians reported by the various researchers are compiled in Table 1.

Table 1. Average Walking Speed in Different Countries

Author	Year	Country	Average speed, m/min
Fruin	1971	United States	81
Bornstein and Bornstein	1976	France	90
Bornstein	1979	Republic of Ireland	76
Polus et al.	1983	Israel	79
Tanaboriboon et al.	1986	Singapore	74
Koushki	1988	Saudi Arabia	65
Morrall et al.	1991	Sri Lanka	75
Morrall et al.	1991	Canada	84
Knoblach et al.	1996	United States	86
Lam and Cheung	2000	China	74
Tarawneh	2001	Jordan	80
Finnis and Walton	2008	New Zealand	88
Kotkar et al.	2010	India	72

Methodology and Data

Data for the present study were collected on 18 locations spread over five cities in India, namely Delhi and Chandigarh in the north, and Chennai, Coimbatore, and Erode in the south. The geographical locations of the cities selected for the study are shown in Fig. 1. Study locations are categorized as "sidewalk," "wide sidewalk," and "precinct" on the basis of function and width. Sidewalks and wide sidewalks are raised spaces developed at the side of the carriageway to facilitate walking. Precinct is a wider space dedicated to walking, is free of vehicles, and is located within a specified land use such as shopping (known as shopping-precinct) or adjacent to a specific land use (e.g., tourist precinct). Example locations for sidewalks, wide sidewalks, and precincts are shown in Fig. 1 and the details are given in Table 2.

The pedestrian speed data were collected at selected locations by marking a longitudinal section of known length on the pedestrian facility and continuously recording the movement of pedestrians within this section for approximately 90 min during morning peak period (8–9:30 a.m.) and evening peak period (5–6:30 p.m.) on a typical weekday. The walking speeds of pedestrians are manually extracted from the recorded videos in the following steps:

1. A random pedestrian about to enter the trap is selected, and the time taken by the pedestrian to cross the length of the section was noted to the accuracy of 0.01 s.
2. The walking speeds of pedestrians are estimated as a ratio of the known length of the trap and the time taken by the pedestrian to cross the trap.

Personal characteristics of pedestrians, such as age and gender, and associative activities such as carrying of baggage, talking on cell phone while walking, and movements in groups of different sizes were noted from the videos. The age was judged from the face value of the pedestrian.

The advantages of the present technique are that the data can be analyzed for longer time periods covering a wider range of pedestrians; because the camera is hidden, the normal walking behavior of the pedestrians can be observed and the record of pedestrian movement and behavior is permanent.

The pedestrian walking speed is then analyzed on a pedestrian facility under the influence of various factors. The adjustment factors for influencing parameters are computed on the basis of the following assumptions:

1. When the external influence causes reduction in the walking speed of the pedestrians in relation to their mean speed on a type of facility and for a given flow condition, it starts approaching the congestion. To *neutralize* this situation, wider facility should be provided in relation to enhanced flow value.
2. When the external influence causes increase in the walking speed of the pedestrians in relation to their mean speed on

(a) Map of India showing selected cities

(b) Sidewalk (Chandigarh)

(c) Wide Sidewalk (Chennai)

(d) Tourist Precinct (Chandigarh)

Fig. 1. Study region and typical study locations (photos by the authors)

Table 2. Details of Study Locations

Category	Width	Sample size	Land use	City (locations)
Sidewalk				
1.	1.5–1.8 m	810	E and RC	2(2)
2.	9–2.1 m	3,842	M, RS, and C	3(3)
3.	12.4–2.7 m	2,349	M, RC, and C	3(4)
4.	3.0–3.3 m	1,089	C and RC	2(3)
Wide sidewalk				
1.	4.1–5.0 m	4,575	M and RC	2(2)
2.	6.1–7.0 m	3,542	C and S	1(2)
Precinct				
1.	> 9.0 m	2,076	S	1(1)
2.	> 9.0 m	1,690	RC	1(1)

Note: C = commercial; E = education; M = mixed; RC = recreational; RS = residential; and S = shopping.

a type of a facility and for a given flow condition, the improvement in efficiency can be used to *economize* the cost of facility by reducing the size of the facility.

The preceding two conditions are depicted in Fig. 2 by using the normalized values of flow and speed on a scale of 0–1. The adjustment factors and the adjusted flow values are given by Eqs. (1) and (2), respectively

$$\text{Adjustment factor} = (1/1 + 0.01r) \tag{1}$$

where r = percentage increase or decrease in pedestrian speed above or below the mean speed on a facility taken as algebraic value. Adjusted flow (q_{ad}) values are

$$q_{ad} = q \times (1/1 + 0.01r) \tag{2}$$

Walking Speeds

The whole data is considered for determining the overall mean walking speed of pedestrians and was 67.87 m/min. The mean walking speed of pedestrians on sidewalk, wide sidewalk and precinct is estimated at 71.22 m/min, 68.79 m/min, and 63.60 m/min, respectively. This shows that speed reduces as the width of the facility increases. Mean walking speeds are also estimated in relation to gender, age, grouping, land uses, and activities for different facilities, and also on the whole. These speeds are given in Table 3. It is observed that male pedestrians walk faster (by 2–5%) than female pedestrians, the difference is greater on sidewalks. Pedestrians, irrespective of their gender, walk slower on precincts than the population mean speed. Walking speeds of pedestrians categorized by age as children (< 15 years), younger adults (15–30 years), middle-aged adults (30–60 years), and older pedestrians (> 60 years) are also studied. Younger adults are the

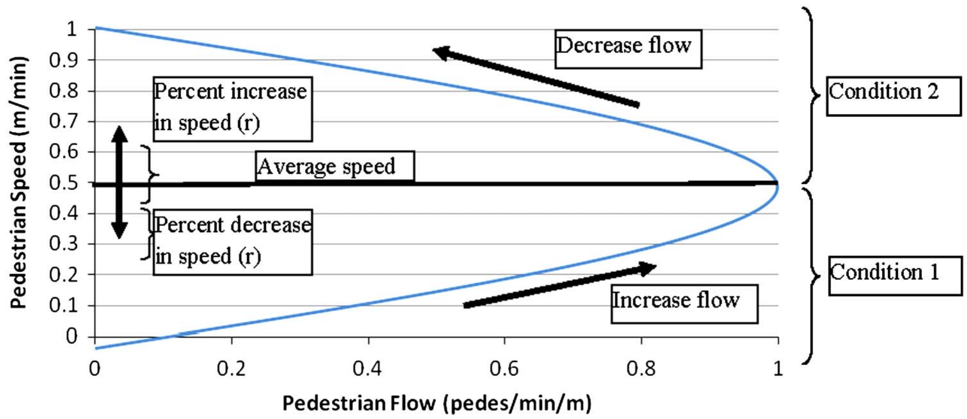

Fig. 2. Pedestrian flow—speed diagram used for adjustment factor

Table 3. Categorized Mean Walking Speeds (m/ min) of Pedestrians

	Mean walking speed (m/ min)			
Category	Sidewalks	Wide sidewalks	Precincts	Overall
Gender:				
Male	7.36	70.10	64.40	69.29
Female	69.07	67.48	62.80	66.45
Age:				
Children	73.87	72.58	64.61	70.35
Young adults	82.38	77.60	71.71	77.23
Middle-aged adults	72.44	69.40	64.34	68.73
Older pedestrians	56.19	55.59	53.73	55.17
Group size:				61.48
2 pedestrians	71.26	67.62	65.25	68.04
3 pedestrians	63.70	60.69	60.26	61.55
4 pedestrians	54.87	58.93	59.90	57.90
5 pedestrians	60.89	53.85	53.69	56.23
More than 5	59.10	—	49.56	54.33
Activity:				
With baggage	61.67	65.29	65.77	64.26
Without baggage	78.72	72.29	61.43	70.81
With cell phone	62.82	62.19	59.29	61.44
Without cell phone	78.32	75.39	67.91	73.87
Land use:				
Commercial	66.54	75.56	—	71.05
Educational	85.27	—	—	85.27
Mixed	79.95	62.95	—	71.45
Recreational	66.30	67.73	69.76	67.93
Residential	64.53	—	—	64.53
Shopping	—	65.20	55.40	60.21
Whole data	71.22	68.79	63.60	67.87[a]

[a]Population mean walking speed.

fastest (14% above population mean speed) and older pedestrians the slowest (19% below the population mean speed), whereas middle-aged adults are walking almost with population mean speed. These findings are similar to those reported by Fruin (1971), Polus et al. (1983), Tarawneh (2001), and Montufar et al. (2007). Many pedestrians walk with a speed slower than 72 m/ min, which is usually considered a normal walking speed. These are children on precincts, middle-aged adults on wide sidewalks and precincts, and older pedestrians on all types of facilities. Slow pedestrians on a facility would require wider facilities to maintain efficiency.

When group movement of pedestrians is considered, all groups on precincts and groups of three or more on the rest of the facilities under consideration are walking slower than the population mean speed. The finding that pedestrians walk slowly in groups is supported by Tarawneh (2001) and Carey (2005). The present study makes it more explicit that the group size of four or more are affected highly, whereas groups of two and three walk with speeds nearer to the mean speed. In fact, all pedestrian groups are walking at speeds less than 72 m/ min on all types of facilities. Only the pedestrians walking on sidewalk or wider sidewalk without baggage are walking at speeds greater than 72 m/ min. The reduction in the speed owing to baggage is quite high on sidewalks (22%). The walking speeds of pedestrians using cell phones are less than the population mean speed, the highest reduction is observed on precincts (13%). Difference between walking speeds without or with use of cell phone is high on sidewalk and wider sidewalks (18–20%) and medium on precincts (13%).

Furthermore, the walking speed on sidewalks in educational land use is exceptionally high (85.27 m/ min) followed by mixed land use (79.95 m/ min). The reduction in walking speed owing to the increase in width of the facility is 21% in mixed land use and 15% in shopping land use. Walking speeds of pedestrians under commercial and recreational land uses are increasing (15 and 5%, respectively) with the increase in the width of the facility. Overall mean walking speeds in recreational land use are quite near to the population mean walking speeds, but in all other land uses except educational land use, the walking speeds are less than 72 m/ min. The pedestrians in an educational area walk 26% faster, and in shopping areas pedestrians walk 11% slower than the population mean walking speeds. The walking speeds are comparable with each other and are above population mean walking speed in mixed and commercial areas.

Walking Speeds under Different Influences

Walking speeds of pedestrians are studied in relation to their personal characteristics, such as their age and gender, and the combination of both; the pedestrians moving in a group of same or different age; and for pedestrians indulged in some activity while walking. Walkings speeds were also studied in relation to purpose of walking, such as exercise walk in the morning and leisure walk in the evening by tourists and the indirect effect of purpose defined by the land use of an area under consideration. The sensitivity analysis was performed by using F-test (Downie and Heath 1970) at a confidence level of 95% to examine if a significant difference exists between the speeds observed under different influencing factors by testing the null hypothesis that group means are equal and do not differ from the population mean. The results of significance testing are given in Table 4.

Influence of Pedestrian Characteristics

Gender

Male and female pedestrians walk at different speeds (see Table 3). The difference reduces as the width of the facility increases. Compared with females, male pedestrians walk 6% faster on sidewalks, 4% faster on wide sidewalks, and 2.5% faster on precincts. Female pedestrians walk at nearly population mean speed on wide sidewalks. Approximately 14% reduction is observed in walking speed of male pedestrians on precinct in relation to that of sidewalk, whereas it is 10% in the case of female pedestrians. Speeds of both genders have increased by 8 and 2% on sidewalk, whereas it has reduced on precincts by 5 and 7%, respectively from population mean speed. It can be inferred that male walking speeds are affected more than the female walking speeds owing to change in the width of the facility. This may be a good guidance in the design of facilities that are in use by higher proportion of either male or female pedestrians.

Age

Walking speeds of pedestrians in different age groups are studied to understand the effect of age on speed (see Table 3). High variation is observed in the walking speeds of pedestrians in different age groups. Except for older pedestrians, the speed reduces by 12–15% with the increase in the width of the pedestrian facility (sidewalk to precinct). It is marginal for older pedestrians (less than 5%). The speed of younger adults is 16–11% faster (reducing with an increase in the widths), whereas speed of older pedestrians is 21–16% less than the mean speed of a facility. Similarly, when compared with overall mean walking speed, the younger adults are affected most with the change in the width of the facility. Older pedestrians walk with more or less the same speed from 53.73 to 56.19 m/min on all types of facilities. Younger adults are the fastest and older pedestrians are the slowest of all the pedestrians on all types of facilities. Older pedestrians are walking significantly different than other age groups on the facilities. Younger adults walk significantly faster than middle-aged adults on sidewalks and wide sidewalks, but this difference is not significant on precincts. Also, children walk significantly slower than younger adults only on sidewalks (see Table 4). The variation of speeds with age can help in the design of specific facilities, e.g., near schools and universities, commercial establishments, and recreational facilities.

Table 4. Hypothesis Testing Using F-test

	Sidewalk				Wide sidewalk				Precinct			
Comparison groups	F_c	F_t	p value	Hypothesis	F_c	F_t	p value	Hypothesis	F_c	F_t	p value	Hypothesis
Age	34.50	2.718	0.00	Rejected	19.59	2.87	0.00	Rejected	4.16	3.49	0.03	Rejected
Children versus younger adults	9.84	5.44	0.02	Rejected	2.51	5.74	0.13	Not rejected	1.91	6.98	0.22	Not rejected
Children versus older pedestrians	24.72	5.44	0.00	Rejected	30.66	5.74	0.00	Rejected	7.48	6.98	0.03	Rejected
Younger adults versus middle-aged adults	15.62	5.44	0.02	Rejected	7.42	5.74	0.01	Rejected	2.06	6.98	0.20	Not rejected
Younger adults versus older pedestrians	100.6	5.44	0.00	Rejected	53.51	5.74	0.00	Rejected	12.25	6.98	0.01	Rejected
Middle-aged adults versus older pedestrians	38.02	5.44	0.00	Rejected	21.08	5.74	0.00	Rejected	7.27	6.98	0.04	Rejected
Gender	0.57	4.3	0.46	Not rejected	0.69	4.105	0.41	Not rejected	0.21	4.105	0.65	Not rejected
Temporal	11.79	4.3	0.00	Rejected	3.23	4.75	0.10	Not rejected	—	—	—	—
Group size	3.01	2.71	0.03	Rejected	2.43	3.34	0.11	Not rejected	8.08	2.93	0.00	Rejected
Group size 3 mean versus population mean	9.51	5.42	0.00	Rejected	—	—	—	—	1.72	5.86	0.20	Not rejected
Group size 4 mean versus population mean	17.78	5.42	0.00	Rejected	—	—	—	—	6.03	5.86	0.02	Rejected
Group size 5 mean versus population mean	3.98	5.42	0.05	Not rejected	—	—	—	—	10.91	5.86	0.00	Rejected
Group size > 5 mean versus population mean	3.36	5.42	0.07	Not rejected	—	—	—	—	14.40	5.86	0.00	Rejected
Group size 2 versus group size 3	4.18	5.42	0.05	Not rejected	—	—	—	—	7.16	5.86	0.02	Rejected
Group size 2 versus group size 4	10.76	5.42	0.01	Rejected	—	—	—	—	12.99	5.86	0.01	Rejected
Group size 2 versus group size 5	2.63	5.42	0.13	Not Rejected	—	—	—	—	22.75	5.86	0.00	Rejected
Group size 2 versus group size > 5	2.42	5.42	0.15	Not rejected	—	—	—	—	24.96	5.86	0.00	Rejected
Group size 3 versus group size > 5	0.18	5.42	0.68	Not rejected	—	—	—	—	6.12	5.86	0.04	Rejected
Baggage (carrying)	7.80	4.3	0.01	Rejected	2.05	4.49	0.17	Not rejected	0.30	4.96	0.39	Not rejected
Cell phones	6.45	4.3	0.02	Rejected	11.67	5.32	0.01	Rejected	16.69	4.35	0.00	Rejected
With cell phones versus population mean	16.49	8.6	0.00	Rejected	8.07	10.64	0.06	Not rejected	4.86	8.7	0.35	Not rejected

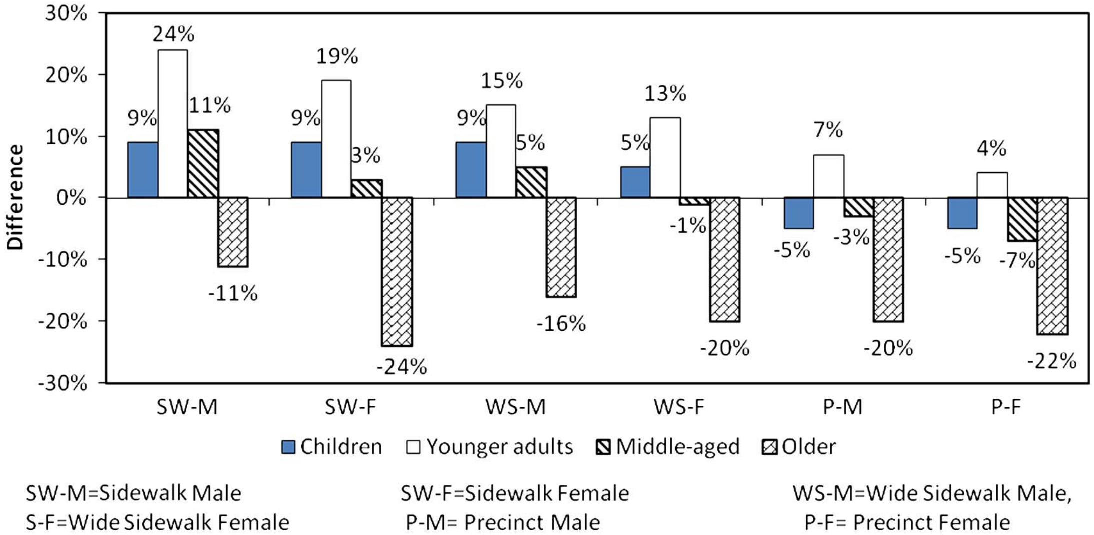

Fig. 3. Effect of age and gender

Gender and Age

The average walking speeds of female and male pedestrians in relation to age are compared across the facilities and shown in Figure 3.

Apart from the results observed in the previous two analyses, certain points are clearer in Fig. 3. In case of children, walking speeds of males are the same on sidewalk and wider sidewalk. The walking speeds of male and female children are the same on sidewalks and precincts. Younger adult pedestrians show continuous change in their walking speeds with change in the width of the pedestrian facility, although this change in relation to population mean speed is relatively higher for male pedestrians (+24 to +7%) compared with female pedestrians (+19 to +4%). It can also be inferred that compared with male pedestrians, the speeds of female pedestrians in all age groups are less affected by the type of facility and at the same time reaches a stabilized value earlier than speeds of male pedestrians.

Pedestrian Groups

Pedestrian groups are categorized by the number of pedestrians in a group as shown in Table 3. Group speed are observed to reduce with the increase in size of the group and width of the facility. Pedestrians in a group walk at an average speed and almost 73% of the observed slower pedestrians increased their speeds to match the group speed. Splitting and reorientation of larger groups because of space restrictions caused by pedestrian flow from the opposite direction was also observed in field. For example, a group of five is observed to split into two groups of two and three pedestrians walking closely in two rows. The speeds of large groups (five or more) on sidewalks have increased by approximately 10% because of this effect, whereas the walking speeds reduced by approximately 21% on wide sidewalks and 27% on precincts because this splitting-up phenomena was absent on these facilities. The reduction in walking speeds for groups of three to five is more or less the same (11–22%) on wide sidewalk and precincts. Except in the case of groups of two, the walking speeds are lower than population mean walking speed and also lower than 72 m/min, usually considered to be walking speed under normal conditions. Group speeds vary around the reported means as shown in Fig. 4.

Significant difference is observed in the mean walking speeds of pedestrians groups on sidewalks and precincts but not on wide sidewalks (see Table 4). Groups of four, five, and greater than five are walking significantly different from the population mean walking speed of pedestrians, whereas groups of two and three walk at speeds similar to the population mean walking speed. Pedestrians in a group of two walk significantly different from other groups on precincts, but only from groups of four on sidewalks.

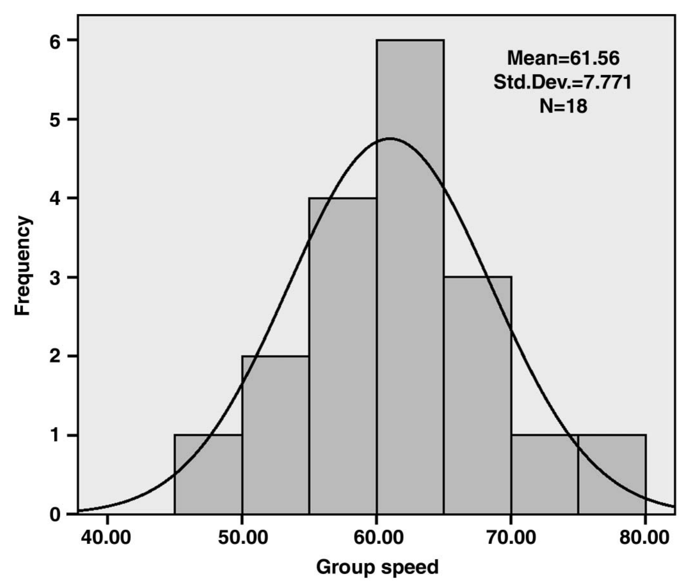

Fig. 4. Speed distribution of pedestrians walking in groups of size 3

Activity

Walking with Baggage

The walking speeds of pedestrians when carrying baggage on different pedestrian facilities are compared in Table 3. The baggage of substantial size is considered for examining its effect on the walking speeds. In general, compared with the mean walking speed of pedestrians without baggage, the speed of pedestrians carrying baggage has reduced by approximately 10% (see Table 3). Higher reduction in speed is observed on sidewalks (21%) and less on wide sidewalks (9%) and precincts (7%). The walking speed of pedestrians moving with baggage is significantly different from that of pedestrians without baggage only on sidewalks (see Table 4). The reason for this difference is that almost 78% of pedestrians carrying baggage are forced to follow the slower ones in front of them because of restricted width and heavy bidirectional flow resulting in fewer overtaking opportunities.

Cell Phone Usage and Age of the Pedestrian

Data given in Table 3 indicate that the walking speed of pedestrians reduces from 73.87 to 61.43 m/min (17% reduction) owing to the use of cell phones. The walking speeds without and with use of cell phones are ±9%, respectively, of the population mean walking speed. The speed is 15% faster than the population mean walking speed on sidewalks when walking without using a cell phone and then reduces by 13% with the increase in the width of the facility (up to precincts). When using a cell phone, the walking speed is 7% slower on sidewalk and 13% slower on precinct compared with the population mean walking speed. Within a type of facility, the reduction because of cell phone use is from 20 to 18% on sidewalk and wide sidewalk, and 13% on precinct. The walking speeds are reducing with the increase in the width of the pedestrian facility. Children (16%) are most affected on wide sidewalks whereas middle-aged adults and older pedestrians (19%) are most affected on precincts. F-test showed that walking speed of pedestrians using cell phones is significantly different on all the pedestrian facilities from those not using cell phones (see Table 4). On sidewalks, the walking speed of pedestrians using cell phones is significantly different from population mean walking speed.

Influence of Purpose of Walking

Walking with a Purpose

Two locations, one in Chandigarh (sidewalk) and another in Chennai (wide-sidewalk), are selected to examine the effect of purpose of walking speed on pedestrian speeds. Both these sites are tourist attraction locations, and are used for exercise walk in the morning by local persons and leisure walk in the evening by tourists. Data were collected during the time interval of 6–7:30 a.m. and during 5:30–7:00 p.m. No significant variation existed in the morning and evening temperatures at both cities. The average walking speed of exercise and leisure walkers was 74.57 and 62.44 m/min, respectively. This indicates that pedestrians using the facility for exercise purpose walk faster than those involved in leisure walking. Variations in these walking speeds in relation to age groups and types of facility are given in Table 5.

Table 5. Variation in Pedestrian Speed by Purpose

		Age group			
Facility	Speed	CH	YO	MA	OL
Overall	Mean walking speed	70.35	77.23	68.73	55.17
Sidewalk	Exercise walk	79.99	93.57	73.82	61.64
	Variation (%)	14	21	7	12
Wide sidewalk	Exercise walk	73.96	80.67	70.68	62.24
	Variation (%)	5	5	3	13
Sidewalk	Leisure walk	61.47	73.71	62.11	45.91
	Variation (%)	−13	−5	−10	−17
Wide sidewalk	Leisure walk	65.88	71.66	64.23	54.51
	Variation (%)	−6	−7	−7	−1

Note: CH = Children; YO = Younger adults; MA = Middle-aged adults; and OL = Older pedestrians.

When compared with the overall mean speeds, pedestrians of all age groups are walking faster on sidewalk and wide sidewalk with exercise purpose but are slow if walking with the leisure purpose. Younger adults walking for exercise purpose are very fast and older pedestrians are very slow if walking for leisure. The change in walking speed of pedestrians on sidewalks and wide sidewalks with differing purposes implies that width of the pedestrian facility is an important criterion that affects the walking speed of pedestrians. It is suggested that sidewalks that are used for multiple purposes can be operated with mechanical separators so that their widths can be changed to suit the varying flow according to speeds at a particular period of time. If at grade with a carriageway, the adjustable widths can be used for traffic flow also according to the requirements. Significant difference was found between the purpose-based walking speed of pedestrians on sidewalks but not on wide sidewalks. However, these waking speeds are not significantly different from the overall mean walking speed. (see Table 4)

Land Use

Walking speeds of pedestrians in relation to different land uses are given in Table 3 and have been discussed in the section on walking speed. Pedestrians walking in an educational area are the fastest and those in residential and shopping areas are the slowest. The walking speeds of commercial and recreational areas are increasing with the increase in the width of the facility, whereas the reverse is true for other land uses. The combined effect of gender and land use on walking speed is shown in Fig. 5.

Male pedestrians are walking faster than female pedestrians in all land uses except educational. The walking speeds in residential and shopping land uses are slower than the population mean walking speeds. The highest difference between male and female walking speed is observed in mixed land uses (9 m/min). The speeds of male pedestrians are 22% faster in educational land use and 12% slower in shopping area than their mean walking speed. The speeds of female pedestrians are 30% faster in educational land uses and 11% slower in shopping land uses compared with their mean speed. Fig. 6 compares the speed in relation to land use and age of pedestrians.

Younger adults walk faster than pedestrians in other age groups in all land uses. The walking speeds of children and middle-aged adults vary marginally in relation to each other in most of the land uses except in residential areas, in which middle-aged adults are 46% faster than children, and in recreational land uses, in which children are 8% faster than older pedestrians. The speeds of older pedestrians are quite low compared with other age groups in all the land uses except in educational land use, in which speeds are 44% faster than their mean walking speed. In an educational area, most of the older pedestrians are accompanying the children who are walking faster to their school. It forces the older pedestrians to increase their speed to match the children's speed. Speeds of older pedestrians are always less than the mean speed of the land use. Middle-aged adults are walking at nearly mean speed of a land use in educational, commercial, and recreational land uses and faster than the mean speed in the rest of the land uses.

F-test revealed that walking speed in educational land use is significantly different from that of other land uses. Pedestrian speeds in shopping areas are significantly different from those in educational, commercial, mixed, and recreational areas but are not significantly different compared with speeds in residential areas. Pedestrian speeds in mixed-type land use are significantly different from those in recreational areas.

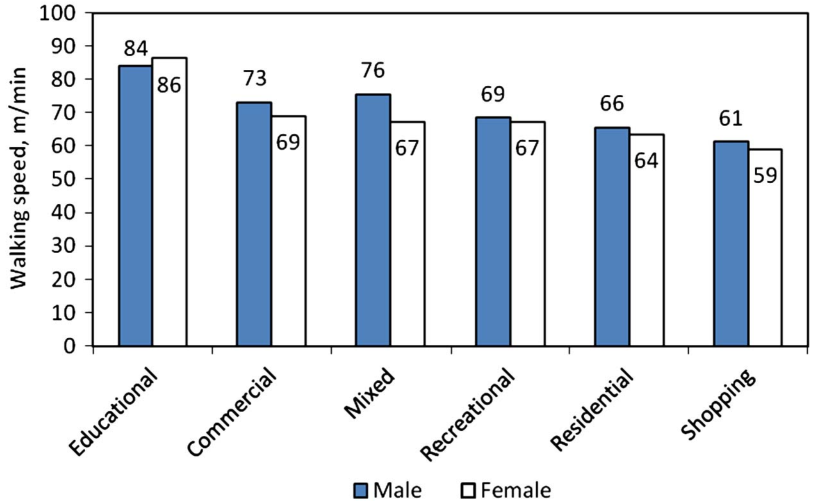

Fig. 5. Effect of land use and gender

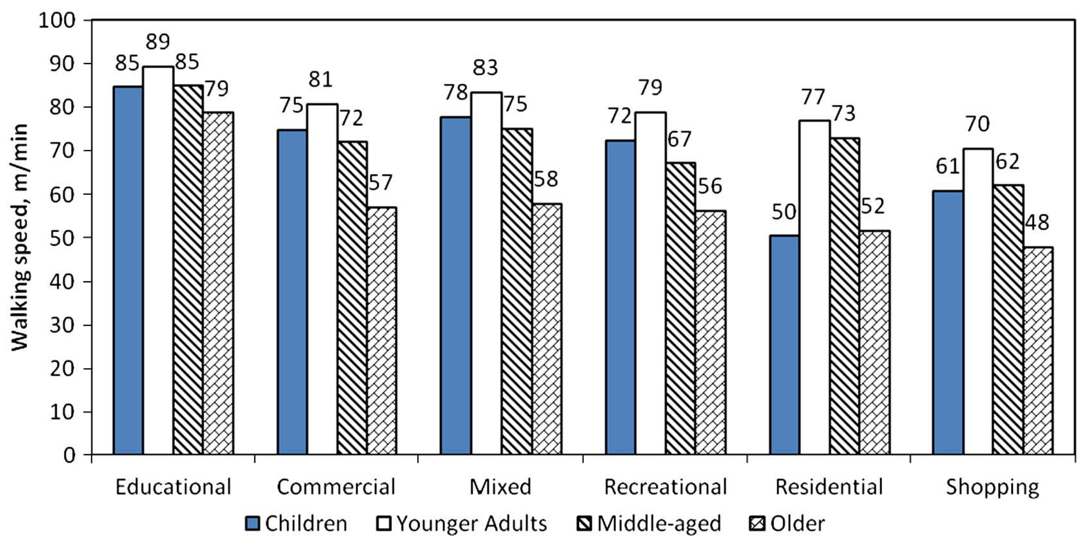

Fig. 6. Effect of land use and age

Computation of Adjustment Factors

On the basis of analyses of pedestrian walking speeds under the influence of various factors, the adjustment factors are suggested for arriving at the effective pedestrian flow with the design purpose. These are given in Table 6. The variation in the adjustment factor with the percentage change in the pedestrian speed is shown in Fig. 7.

As shown in Table 6 and Fig. 7, adjustment factors vary for different factors. Because of these adjustment factors, the adjusted flow of the particular facility should be calculated. The facility should be designed considering the adjusted flow. It can be explained by a simple example. It is observed that the speeds are lower than the population mean walking speeds at sidewalks in commercial land use. The developed adjustment factors and adjusted flow suggests that the remedial measure for these facilities is to increase the width of the facility, which would aid in greater flow of pedestrians at faster pedestrian speeds. The adjustment factors developed for different land uses will be quite useful for designing the facilities for specific purposes such as school and shopping trips.

Discussion on Results

Pedestrians in India are slow compared with those in other countries. They are nearer to their counterparts in Riyadh, Saudi Arabia (65 m/ min). This behavioral similarity is attributable to high temperatures prevailing during the daytime. Highest pedestrian speeds are observed in France (90 m/ min). General findings in relation to pedestrian age, gender, group size, and additional simultaneous activity while walking (such as carrying baggage or talking on cell phone) goes well with the available literature. The pedestrian walking speeds are decreasing with increase in age, group size, and indulgence in additional activity while walking such as carrying baggage or talking on a cell phone. The following microdetails and variations in pedestrian behavior are noticed in the present study:

1. Walking speeds are faster than population mean speeds on sidewalks and wide sidewalks but slower on precincts.
2. The difference in gender speeds reduces when the width of the facility increases. Females are less affected by change in the size of a facility, whereas younger adults and older pedestrians are the most affected.

Table 6. Adjustment Factor Suggested for Different Walking Environments

Influencing factor	Sidewalks PC[a]	Sidewalks AF	Wide sidewalks PC[a]	Wide sidewalks AF	Precincts PC[a]	Precincts AF
Gender:						
Male	8.1	0.93	3.3	0.97	−5.1	1.05
Female	1.8	0.98	−0.6	1.01	−7.5	1.08
Age:						
Children	8.8	0.92	6.9	0.94	−4.8	1.05
Young adults	21.4	0.82	14.3	0.88	5.7	0.95
Middle-aged adults	6.7	0.94	2.3	0.98	−5.2	1.05
Older pedestrians	−17.2	1.21	−18.1	1.22	−20.8	1.27
Group size:						
2 pedestrians	5.0	0.95	0.0	1.00	−3.9	1.04
3 pedestrians	−6.1	1.07	−10.6	1.12	−11.2	1.13
4 pedestrians	−19.2	1.24	−13.2	1.15	−11.7	1.13
5 pedestrians	−10.3	1.12	−20.7	1.26	−20.5	1.26
More than 5	−12.9	1.15	—	—	−27.0	1.37
Activity:						
With baggage	−10.2	1.11	−3.8	1.04	−3.1	1.03
Without baggage	16.0	0.86	6.5	0.94	0.0	1.00
With cell phone	−7.4	1.08	−8.4	1.09	−12.6	1.14
Without cell phone	15.4	0.87	11.1	0.90	0.0	1.00
Land use:						
Commercial	−2.0	1.02	11.3	0.90	—	—
Educational	25.6	0.80	—	—	—	—
Mixed	17.8	0.85	−7.2	1.08	—	—
Recreational	−2.3	1.02	0.0	1.00	2.8	0.97
Residential	−4.9	1.05	—	—	—	—
Shopping	—	—	−3.9	1.04	−18.4	1.23
On the whole	4.9	0.95	1.4	0.99	−6.3	1.07

[a]Note: PC = Percentage change in relation to population mean walking speed; and AF = adjustment factor.

3. Pedestrians in the age group 15–30 years (younger adults) are the fastest and those older than 60 years (older pedestrians) are the slowest on all the facilities. These are similar to the findings reported by Fruin (1971), Polus et al. (1983), Tarawneh (2001), and Montufar et al. (2007).
4. Speed of older pedestrians walking with exercise purpose increases abruptly on sidewalks and wide sidewalks, and also the speed of exercise walkers decreases with increase in width of the facility.
5. The effect of group size on walking speed is low for a group size up to three but quite high for groups of five or more irrespective of the facility.
6. Walking speeds of pedestrians carrying baggage are significantly different from those not carrying baggage on sidewalks. Significant difference is also found in walking speeds of pedestrians when using a cell phone on all facilities.

Land uses also affect the walking speeds of pedestrians. Among different land uses, significant increase in walking speeds is observed in educational land use and negligible change is noted in recreational land use. The speeds in shopping, mixed, and recreational land uses are significantly different from one another. Pedestrians in residential and shopping areas walk slower than the population mean speed. The walking speeds of pedestrians in recreational and commercial areas are increasing with the increase in the width of the facility, which is opposite to the behavior shown in other land uses. Universally, younger adults are the fastest and older pedestrians are the slowest in all the land uses. The existence of significant difference in the speeds of pedestrians in different land uses is similar to those reported by Al-Masaeid et al. (1993). The average speed of pedestrians at commercial (71.05 m/ min) and shopping land use (60.21 m/ min) of the present study are comparable with the findings of Lam and Cheung (2000) for commercial (74 m/ min) and shopping land use (61 m/ min) in China.

Conclusions

The present study finds that males walk generally faster than females irrespective of facility type. However, speeds of male pedestrians are more influenced by width of facility than those of females. Under varying effects, the speeds of female pedestrians stabilize faster than male pedestrians. Younger adults show continuously changing behavior with a change in the width of the facility, whereas older pedestrians show stabilizing behavior across the facilities. The effect of grouping by age is more pronounced on younger adults, and effect of the width of the facility is more pronounced on older pedestrians. Higher group sizes cause high reduction in walking speeds irrespective of type of facility. Splitting a larger group was shown to result in the increase in the walking speeds of these groups. Groups are walking slower than the individual pedestrians. These findings are similar to those reported by Tarawneh (2001) and Carey (2005). The increase in the width of a facility has,

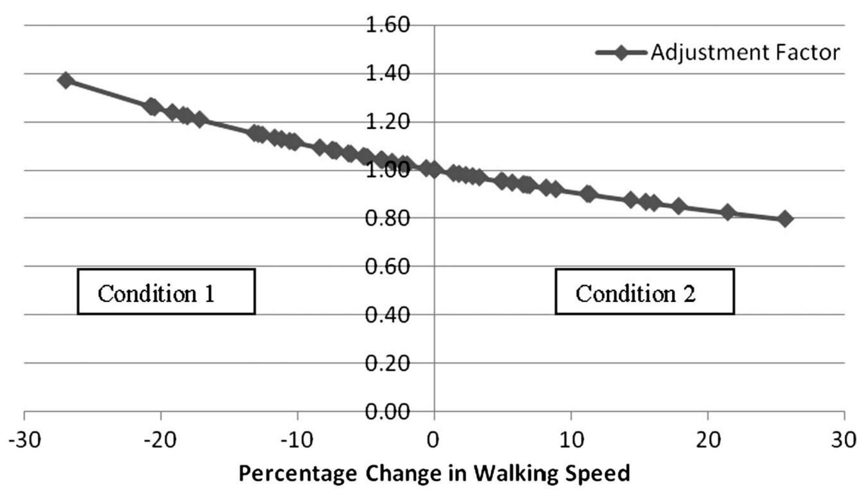

Fig. 7. Variation in adjustment factor with percent change in speed

in general, caused reduction in walking speeds, although it is the opposite case for pedestrians walking in recreational or commercial land uses. The walking speeds are purpose-specific, i.e., higher for exercise walkers than leisure walkers.

The influence of various factors on the pedestrian speed was quantified for different type of pedestrian facilities, and based on the enhancing or reducing effect of each factor, adjustment factors have been developed. The adjustment factors suggested for different walking environments on the basis of the percentage change in walking speed are indicative and can help the planners to better design walking facilities by giving consideration to efficiency and also economy in the provision of a facility. Literature suggests that a complex relationship exists between the environment and the walking behavior of the pedestrians. This study supports many of the reported observations and adds new information, which can be used in the process of designing facilities for specific pedestrian groups.

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