Research Journal of Applied Sciences, Engineering and Technology 4(21): 4299-4304, 2012
ISSN: 2040-7467
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Submitted: February 22, 2012 Accepted: April 14, 2012 Published: November 01, 2012

Analysis of Pedestrian Free Flow Walking Speed in a Least Developing Country: A Factorial Design Study

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Abstract: The direct use of foreign design codes and unavailability of well-recognized local parameters for pedestrian facilities has been a concern in least developing countries. In this study, a study on pedestrian movements on sidewalks in the capital city of Dhaka, Bangladesh has been done to determine the free flow walking speed and to identify the effect of contributing factors. Basic data on walking speeds and the chosen factors were collected from 1,440 pedestrians by a photographic procedure of video recording. A Factorial Design with Mixed Levels was used. Results show that the free flow walking speed is greatly affected by the pedestrian age, gender and the 'walkability' of the facility. In addition, male speed is less hampered by the carrying of baggage than female speed. In general, Bangladeshi pedestrians are slower than those of Western countries, but are faster or alike compared to some Asian counterparts. Such finding does not validate the sustainability of the adoption of foreign design and parameters for pedestrian facilities in Bangladesh. The results of this analysis can be used as a guideline for developing design codes for local pedestrian facilities.

Keywords: ANOVA, free-flow speed, pedestrian, sidewalks, urban areas

INTRODUCTION

Environment is being contaminated by the increment of vehicles, particularly in Central Business Districts (CBDs) where most of the government offices and trading centers of a city are located. To reduce environmental pollution, pedestrianization has become an integral part of sustainable modern urban design. Thus, the design, arrangement and development of support infrastructures should be in favor of pedestrian movements and to popularize walking. To achieve so, pedestrian facilities should be planned and based on the concrete information on user characteristics, travelling patterns and objectives of pedestrians flow. The facilities also need to be harmonized with the ambient factors that affect the safe, convenience and secure movement of pedestrians. It is a challenging task for urban planners as they are required to ensure pedestrians against overexertion, interference by other pedestrians, and interruption by external factors like conflict with vehicles, temperature etc (Hoel, 1968; Tanaboriboon and Guyano, 1991). In fact, the real facilities have to be able to meet the requirements of pedestrians which are generated based on their physiological, psychological, socio-economic and environmental conditions (Koushki, 1988).

The smooth movement of pedestrians is affected by a number of factors including gradient or roughness of surface (Older, 1968), indoor or outdoor walkway (Lam *et al*., 1995), available space (Fruin, 1970), riser height of stairways (Tanaboriboon and Guyano, 1991), intention of pedestrians, intelligence and physical fitness of pedestrians, and topography (Robertson *et al*., 1994). For sidewalks in a dense city, important factors identified include age and gender of pedestrians, and type of walking facility (Morrall *et al*., 1991; Smith, 1995), width of the walking facility (Mitchell and MacGregor, 2001), time of day (Hoel, 1968), and density (Smith, 1995). Fruin (1971) and Young (1999) on the other hand observed that pedestrian walking speed is not affected by pedestrian baggage carrying capacity.

The term 'walkability' is recently used by urban planners which measures the degree of a walking facility or an area in terms of pedestrian-friendly. It is also related to assessing the quality of pedestrian network and facilities. Landis (2001) identified sidewalk capacity, quality of the walking environment, and individual perceptions of comfort/safety as the three main factors that influence 'walkability'.

Due to economic conditions, transportation facilities, road network, urban structure, existing facilities and

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Table 1: Physical and socioeconomic facts of Dhaka city

Area	Metropolitan area: 1,530 km^2
	Dhaka city corporation boundary: 360 km^2
Population	10.9 million-metropolitan area
	8.0 million-Dhaka city corporation area
Density	19,447 persons/km^2
Population growth rate	4.2
Per capita income	US$ 500
House holds below poverty line	48%

Dhaka City Corporation web location: http:// www. dhakacity. org/ Page/ To_know/ About/Category/2/ Id/21/Type/Quick/Info (Retrieved on 10 October 2011); Bangladesh Bureau of Statistics, Statistical Pocket Book, 2008; Asian City Development Strategies: Fukuoka Conference, 2000; City Profiles: Dhaka

cultural backgrounds, people in developing countries have to walk relatively long distances for daily activities (Koushki, 1988). However, not much have been done in the proper planning and designing of walking facilities for optimum performance and in the evaluation of the existing facilities in these countries. In least developing countries, in general, such planning, designing and evaluation are absent.

The recognized design parameters for pedestrian facilities, such as mean free flow walking speed, are mostly established on the user characteristics of developed and western countries. Consideration of pedestrian movement characteristics from developing countries, in particular, from least developing countries is by and large neglected to take into account for standard capacity parameters. Thus, the direct use of foreign design codes and unavailability of well-recognized local parameters for pedestrian facilities has been a concern in least developing countries. In addition, interaction effects of the factors influencing pedestrian movements on sidewalks were not investigated in previous studies. These apprehensions motivated the current study for a statistical analysis of pedestrian walking speeds on sidewalks in Dhaka, Bangladesh, which is considered as a typical capital city of least developing countries.

At around 15 million inhabitants, Dhaka is now the eighth-largest city in the world and is projected to become the third-largest by 2020 (World Bank, 2010). It is also one of the most densely populated cities in the world. The city is being expanded without proper planning. Table 1 shows the physical and socioeconomic facts of Dhaka. Land-use constraints and financial conditions along with energy crisis alluded to the necessity of walking for mobility. In Dhaka city, about 60% trips are on foot but the pedestrians are facing many problems while using the walkways (Rahaman *et al*., 2005). Pedestrians are the most vulnerable group in Dhaka City when it comes to road accidents, as they constitute 51% of the victims of traffic fatalities (Rahman, 2010). However, not enough attention has been paid to the planning and the designing of the infrastructure facilities for the safety of pedestrians in Dhaka.

Table 2: Physical characteristics of selected sidewalks

Location no.	Location description	Length (m)	Width (m)
1	Commissioner's Market Sidewalk, Farmgate	6.60	2.80
2	Kazi Nazrul Islam Avenue (in front of Tejgaon Govt. Girls' School)	7.00	4.20
3	Mirpur road (Science Lab Signal Right Corner, approaches to Mirpur)	6.00	2.10

In this study, we only consider pedestrians in free flow condition which is characterized by minimal traffic density and whose desired walking speeds that are not obstructed by other persons in front of her/him. The main objectives of the study are to determine the pedestrian free flow speed and to examine the influence of pedestrian age, gender, baggage carrying capacity and the 'walkability' of the facility on pedestrian speed in free flow.

DATA COLLECTION LOCATIONS AND METHODOLOGY

Study locations: The focus of this study is on pedestrian free flow walking speeds on sidewalks in the capital city of Dhaka, Bangladesh. Such walking facilities have uninterrupted foot traffic flows and are generally restricted by fence, wall, shops, or road with high traffic of vehicles. The locations of the sidewalks with its physical characteristics are given in Table 2. The selection of the locations was done in these different areas so as to have sidewalks with different grades of 'walkability', so that their contributions on pedestrian speed could be investigated. Kazi Nazrul Islam Avenue has the highest grade of 'walkability' followed by Mirpur Road with a medium grade of 'walkability' and Commissioner's Market with a low grade of 'walkability'. At each study location, observed movement of pedestrians were bi-directional with no entry from or exit to other walkways and pedestrians were assumed to have different trip objectives.

Data collection: A photographic procedure was used to collect the basic relevant data of pedestrian movements. Self adhesive masking tapes were used to prepare longitudinal pedestrian traps on sidewalks. The effective width of each walkway was constant throughout the observed length. Except at Kazi Nazrul Islam Avenue, sides of walkways were occupied by vendors. In those cases the widths were measured by excluding the space occupied by the vendors. In each study location, a handy-cam was placed on an elevated fixed position by tripod to record the pedestrian movements through the selected dimensions. Advantages of recorded videos over direct count on-location can be found in Ye *et al*. (2008).

Data on pedestrian movements at selected locations were recorded both during peak and off-peak periods on

three typical weekdays in September of 2011 under clear and dry weather condition. The recorded videos were converted to digital files and were then analyzed to yield data on pedestrians' gender, age (estimated by subjective judgment) and whether the pedestrians were carrying baggage. Walking speed of a particular pedestrian was computed by dividing the mark-off length by the travel time taken by that pedestrian. The traverse time was obtained using Adobe Premiere Pro software. In total, 1,440 pedestrian speeds were investigated at the three different walkways.

Data analysis: The independent variables age, gender, carrying baggage and location were categorized into different groups according to their levels. Age was categorized as young (15-30 years), adult (30-50 years) and elderly (≥50 years). The age group 0-15 years was not considered as they were generally escorted by their guardians and did not walk at their natural speeds. The two categories of gender were male and female. While location was categorized as 'Commissioner's Market Sidewalk', 'Kazi Nazrul Islam Ave' and 'Mirpur Rd'. Carrying baggage was categorized as 'yes' and 'no'.

Descriptive statistics for the dependent variable, mean speed, were computed and categorized according to the chosen independent variables. The Analysis of Variance (ANOVA) for Factorial Design with Mixed Levels (Montgomery, 2008) was used to analyse the influence of the chosen variables as well as their interactions on the free flow walking speeds of pedestrians. A sample of size 40 for each combination of the levels of factors was chosen to ensure the normality assumption and the orthogonality of main effects and interactions remained valid. In cases where the null hypothesis was rejected, the Least Significant Difference (LSD) method was used for pairwise comparison of level-means. All tests were done at 1 or 5% level of significance. SPSS (Statistical Package for Social Science) was used to analyse the collected data.

RESULTS AND DISCUSSION

General findings: Tables 3-6 provide the mean, standard deviation and range of pedestrian free flow walking speed in relation to age, gender, location and carrying baggage. The overall mean free flow speed of observed pedestrians was 1.15 m/sec. Table 3 shows that young pedestrian group of Bangladesh is faster than others. The speed variability among this group is also highest as this group covers teenage and matured pedestrians. It is intuitive that as a pedestrian becomes older, her/his walking capacity tends to decline. The average of low ranges of speed is 0.70. This value indicates that the design of a sidewalk facility in Dhaka should cover walking speed of 0.70 m/sec to facilitate slower pedestrians.

Table 3: Pedestrian free flow walking speed corresponding to age

			standard deviation	Range	
Age group	N	mean (m/s)	(m/s)	high	low
Young	480	1.26	0.20	2.03	0.80
Adult	480	1.16	0.17	1.80	0.71
Elderly	480	1.04	0.17	1.76	0.59
All ages	1440	1.15	0.20	2.03	0.59

Table 4: Pedestrian free flow walking speed corresponding to gender

			standard deviation	range	
Gender	N	mean (m/s)	(m/s)	high	low
Female	720	1.07	0.17	1.70	0.59
Male	720	1.24	0.20	2.03	0.63
Both	1440	1.15	0.20	2.03	0.59

Table 5: Pedestrian free flow walking speed corresponding to location

			standard deviation	range	
Location	N	mean (m/s)	(m/s)	high	low
1	480	1.10	0.18	1.90	0.59
2	480	1.20	0.21	2.03	0.68
3	480	1.17	0.20	1.76	0.72
All locations	1440	1.15	0.20	2.03	0.59

Table 6: Pedestrian free flow walking speed corresponding to baggage

			standard deviation	range	
Baggage	N	mean (m/s)	(m/s)	high	low
Yes	720	1.11	0.20	2.03	0.59
No	720	1.20	0.20	1.90	0.63
Both	1440	1.15	0.20	2.03	0.59

Table 4 shows that female pedestrians were found to be slower than male pedestrians by nearly 0.17 m/sec, while the free flow speed of female pedestrians were more consistent compared to male pedestrians. That is, male pedestrians walk faster with more variation than female pedestrians. These findings support the results of previous studies (Morrall *et al*., 1991; Tanaboriboon and Guyano, 1991).

From Table 5, it is found that the free flow walking speed of pedestrians at Kazi Nazrul Islam Avenue was faster than the other two locations. The grade of 'walkability' of Kazi Nazrul Islam Avenue is also higher than the other two locations. The higher grade of 'walkability' stems from the fact that the width of Kazi Nazrul Islam Avenue location was the widest among the three locations. That in turn has an influence on the location's capacity and hence on the location's 'walkability'. Pedestrians walking speeds at Mirpur Road was also faster than Commissioner's Market Sidewalk. Mirpur Road has better grade of 'walkability' than Commissioner's Market Sidewalk due to the better quality of walking environment found in this residential area. An individual perception of comfort/safety would be also favourable to this location. These findings coincide with the findings of earlier studies that 'walkability' of the facility has an influence on pedestrian walking speeds (Finnis and Walton, 2008).

Table 7: List of pedestrian mean speed in different countries

	Country	Author	Pedestrian mean speed (m/s)
Asia	Saudi Arabia	(Koushki, 1988)	1.08
	India	(Victor, 1989)	1.20
	China	(Lam *et al*., 1995)	1.20
	Bangladesh	----	1.20
	Thailand	(Tanaboriboon and Guyano, 1991)	1.22
	Singapore	(Tanaboriboon *et al*., 1986)	1.23
	Sri Lanka	(Morrall *et al*., 1991)	1.25
	Israel	(Polus and Schofer, 1983)	1.31
Europe	England (UK)	(Older, 1968)	1.47
	Austria	(Schmitt and Atzwanger, 1995)	1.54
North	USA	(Hoel, 1968)	1.47
America	USA	(Fruin, 1971)	1.35
	Canada	(Morrall *et al*., 1991)	1.40

Results in Table 6 shows that the speed of pedestrians who carried baggage were lower than those who did not have any baggage. However, speed variation for both categories was the same. Pedestrians of Bangladesh have the free flow mean walking speed of 1.20 m/sec (without baggage), which could be compared with similar studies from other countries. Such comparison will indicate whether there is any necessity to establish local design standard.

Pedestrian mean speeds of different countries: Pedestrian mean walking speeds from different countries (which also include the result of present study) are listed in Table 7. The mean speed of Bangladeshi pedestrians, 1.20 m/s, is equivalent to the mean speeds of Indian and Chinese pedestrians. Bangladesh is adjacent to India and linked with China by India. This finding might suggest that socioeconomic concord among the pedestrians has a great influence on walking behaviours. It also bears out that Bangladeshi pedestrians are slower than those of Western countries, but are faster or alike compared to some Asian counterparts. Such findings do not validate the sustainability of the adoption of foreign design and parameters for the pedestrian facilities in Bangladesh.

Analysis of Variance (ANOVA): In this section, the observed differences in previous section will be discussed in terms of statistical significance. Table 8 summarizes the corresponding analysis of variance. Results show that all main factors-age, gender, location (i.e., the 'walkability' of the facility), and baggage-and two interactions gender-baggage and gender-location significantly affect the walking speeds of pedestrians at 1% level of significance.

Analysis of the residuals from the fitted model showed that the underlying assumptions of normality and homogeneity were fulfilled. Since the F tests of all main factors and two interactions were significant at 5%, the multiple comparison method, LSD, was used to determine the specific differences among levels (Carmer and Swanson, 1973).

Since the interactions gender-location and gender-baggage were significant, comparison between level means of location and baggage might be obscured by these interactions. Thus, level of gender was fixed to male or female and the LSD method was applied to the speed means of the three locations. At 1% level of significance, the test indicated that for both sexes, the mean speed was statistically the same for Kazi Nazrul Islam Avenue and Mirpur Road, and that the mean speed for Commissioner's Market Sidewalk was significantly lower in comparison to the other two locations. This implies that sidewalk capacity, quality of the walking environment, and individual perceptions of comfort/safety accelerate the walking capacity of pedestrians as Kazi Nazrul Islam

Table 8: Analysis of variance for the speed data

Source of variation	Sum of squares	df	Mean square	F statistic	p value
Corrected model	29.138[a]	35	0.833	38.176	0.000[b]
Intercept	1918.889	1	1918.889	87994.796	0.000[b]
Age	12.533	2	6.266	287.357	0.000[b]
Gender	9.822	1	9.822	450.399	0.000[b]
Location	2.635	2	1.318	60.426	0.000[b]
Baggage	2.392	1	2.392	109.681	0.000[b]
Age*gender	0.049	2	0.025	1.132	0.323
Age*location	0.151	4	0.038	1.733	0.140
Age*baggage	0.028	2	0.014	0.646	0.524
Gender*location	0.240	2	0.120	5.501	0.004[b]
Gender*baggage	0.855	1	0.855	39.189	0.000[b]
Location*baggage	0.091	2	0.045	2.080	0.125
Age*gender*location	0.119	4	0.030	1.363	0.245
Age *gender*baggage	0.067	2	0.033	1.527	0.218
Age*location*baggage	0.046	4	0.011	0.525	0.717
Gender*location*baggage	0.050	2	0.025	1.150	0.317
Age*gender*location*baggage	0.060	4	0.015	0.693	0.597
Error	30.617	1404	0.022		
Total	1978.644	1440			

[a] R^2: 0.488 (Adjusted R^2 = 0.475); [b]: Significant at 1% percent level of significance

Avenue and Mirpur Road had the highest capacity and better quality of walking environment, respectively. However, baggage carrying significantly affected the mean speed of female, at 1% level of significance, but, for male this was at 5% level of significance, indicating a mild influence on speed. That is, male speed is less hampered by the carrying of baggage. The finding of the effect of baggage capacity on pedestrian walking speed is contrary to findings from other studies by Fruin (1971) and Young (1999). Females were found to walk significantly slower than males, at 1% level of significance. All age groups disclosed significant differences, at 1% level of significance.

Rearranging of speed data in relation to gender-location interaction produced 6 cells and a multiple comparison test was done accordingly. The comparison between male-Kazi Nazrul Islam Ave vs. male-Mirpur Rd and female-Kazi Nazrul Islam Ave vs. female-Mirpur Rd cells found that, even at 5% level of significance, mean speeds of these cells were statistically equal. This again confirmed that mean speed at Nazrul Islam Avenue and Mirpur Road are statistically the same. All 4 means produced by the interaction gender-baggage were significantly different at 5% level of significance. However, at 1% level, the comparison male-baggage vs. male-non-baggage was statistically insignificant. This further confirmed that male speed is less hampered by the carrying of baggage.

LIMITATIONS

There are a number of limitations of this study. First, the choice of study locations and observation of only weekdays might generate bias. Second, data on age was collected on subjective judgment. Third, women usually use handbags as a fashion in daily life. However, some observed females used comparatively big bags and it was hard to distinguish whether they carried any weighted baggage. Lastly, pedestrian free flow walking speed is not only affected by the selected variables age, sex, baggage and location 'walkability', but it may be affected by many other factors. Although the use of factorial design has facilitated the determination of effect of interactions, the model was fitted with only $R^2 = 0.488$ (Adjusted $R^2 = 0.475$). This implies the importance of the inclusion of other factors. Other factors such as weather condition, gradient or roughness of surface, intelligence and physical fitness of pedestrians, time of day, pedestrian weight, and pedestrians walking with others should be investigated to determine their influence on speed. Inclusion of all or some of these factors could produce a better model for pedestrian free flow speeds with stronger predictive power.

CONCLUSION

Urban pedestrianization is necessary and beneficial in terms of safety, health, energy savings, environment and socio-economy. To popularize walking, walking infrastructures should be constructed based on the local users' characteristics.

Pedestrian movements in Dhaka, Bangladesh have been analyzed to identify the contribution of personal and locational factors and their interactions on pedestrian free flow speed. Age, gender and location (characterized as 'walkability') significantly influence the pedestrian speed on sidewalks in Dhaka. In addition, male speed is less hampered by the carrying of baggage than female speed.

The study also shows that Bangladeshi pedestrians are slower in walking speed compared to pedestrians from western countries. Pedestrians of Bangladesh have the free flow mean walking speed of 1.20 m/s. Thus, the free-flow speed of 1.5 m/s as recommended in the Highway Capacity Manual (National Research Council (U.S.), 2000) for pedestrians on sidewalks is not appropriate to least developing countries like Bangladesh. Further, the design of a sidewalk facility in Dhaka should cover walking speed of 0.70 m/s to facilitate slower pedestrians. In conclusion, an appropriate pedestrian design standard should be developed based on the local users' characteristics. Results of this study could, in addition, be inputted into well-recognized pedestrian simulation packages to build design codes for pedestrian facilities in Dhaka, Bangladesh.

ACKNOWLEDGMENT

This study was supported by the Research University (RU) Grant Scheme, [Acct. No.: 1001/PJJAUH/811097], Universiti Sains Malaysia. Khalidur Rahman wishes to thank Universiti Sains Malaysia for the financial support (USM Fellowship).

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