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Traffic Engineering
Preliminary Communication
Submitted: 20 June 2019
Accepted: 4 Oct. 2019

MODELLING THE PEDESTRIAN SPEED AT SIGNALISED INTERSECTION CROSSWALKS FOR HETEROGENEOUS TRAFFIC CONDITIONS

ABSTRACT

Pedestrian crossing speed is the key element in the design of pedestrian facilities. It depends on various attributes related to road, traffic and pedestrians. In this paper, an attempt has been made to explore the variation, examine the influencing factors and formulate a model for the pedestrian crossing speed at signalised intersection crosswalks. The data have been collected using video graphic technique at 16 signalised crosswalks of the Chandigarh city. The findings reveal that a 15th percentile crossing speed (1.11-1.31 m/s) exceeds the design crossing speed of 0.95 m/s. It is also higher than the crossing speed of 1.2 m/s, usually being prescribed and adopted in the developed countries. The statistical analysis indicates no significant difference in the percentile crossing speeds between males and females. However, the variation exists among different age groups, group sizes, and crossing patterns. The correlation analysis depicts that the pedestrian crossing speed has significant negative correlation with the crosswalk width, the crosswalk length, the width of the pedestrian island, the classification of road, average traffic flow and average pedestrian delay, whereas the availability of separate bicycle paths at intersections is positively correlated. Furthermore, the stepwise regression model with 70.1 percent accuracy reveals that the crosswalk width, the width of the pedestrian island and the average pedestrian delay play a predominant role in determining the pedestrian crossing speed. The authors propose the usage of the developed model for setting out the standards for the appropriate design crossing speed for different crosswalks having similar geometric and traffic conditions as that of the study area.

KEY WORDS

pedestrians; crossing speed; crosswalk; intersection; percentile;

1. INTRODUCTION

Pedestrian safety is the key concern while crossing at signalised intersections in the developing nations. The pedestrians face a number of conflicts with the vehicular traffic and experience maximum delays at the intersections [1]. This leads to the pedestrians' erratic crossing behaviour which results in the rise in the number of accidents. With the increase in the number of pedestrian accidents the concern of pedestrian safety has become essential [2]. Therefore, there is need for proper designing of signalised intersection crosswalks. The pedestrian crossing speed is a vital factor for the effective implementation of safety measures and designing of the crosswalks at intersections. Hence, it is essential to have adequate knowledge of the pedestrian crossing speed under heterogeneous crossing conditions. The design manuals such as the Traffic Engineering Handbook [3] propose a speed of 0.91–0.98 m/s and the Highway Capacity Manual [4] suggests 1.2 m/s as the appropriate speed for the design of pedestrian facilities (if the population of elderly people accounts for less than 20 percent of the total population). The Manual of Uniform Traffic Control Devices for Streets and Highways (MUTCD) [5] also advises a standard value of 1.21 m/s for kerb-to-kerb crossing. The average crossing speed ranges between 0.75-1.21 m/s on the basis of heterogeneous mix of pedestrians (age and gender). The Indian Roads Congress (IRC) suggests a crossing speed of 0.98 m/s for educational and recreational areas. The 15th percentile speed of 0.95 m/s should be used for the design of pedestrian crossing facilities. If elder pedestrians account for a greater proportion, the crossing speed of 0.79 m/s should be used [6].

The literature indicates that the variation in the pedestrian crossing speed limits (as prescribed by different manuals) is mainly a consequence of the difference in location, geometric site conditions and pedestrian behavioural characteristics. Numerous factors for instance, type of crosswalk, pedestrian socio-demographics (age, gender and group size) and flow characteristics (flow and conflicting flow) significantly affect the crossing speed [7-10]. Lam and Cheung [11] investigated the pedestrian flow behaviour at several crosswalks in Hong Kong and found that the pedestrians usually walk faster at crosswalks without a midblock. Similarly, the study conducted at signalised and non-signalised crosswalks in Malaysia by Goh et al. [12] inferred that pedestrians at non-signalised crosswalks have considerably faster crossing speed than at signalised crosswalks. Studies carried out at different locations reveal a variation in the crossing speed of the adults and elder pedestrians. The studies undertaken in the UK stated an average crossing speed between 1.32-1.72 m/s for younger pedestrians and between 1.11-1.16 m/s for elderly pedestrians [13-16]. In the United States, the variation in the crossing speeds of the elderly people ranges between 0.97–1.34 m/s with the margin of +0.5 percent [17-19]. In Sweden, elder pedestrians usually walk at speeds lower than 0.7 m/s [20]. The crossing speed in the Netherlands is found to be 1.24 m/s for elder pedestrians and 1.5 m/s for the younger ones [21]. Studies undertaken in India also reveal that young pedestrians cross the street at a faster pace (1.24-1.42 m/s) in comparison to middle-aged (1.15-1.24 m/s) and elder pedestrians (0.98-1.23 m/s) [22-24].

Likewise, the effect of gender on the crossing speed has been also explored by various authors. Tanaboriboon and Guyano [25] observed that men walk faster than women by 0.6 m/s at signalised intersections in Bangkok. Similarly, Tarawneh [26] conducted a study in Jordan and found that the male crossing speed (1.35 m/s) is on the higher side as compared to the female counterpart (1.33 m/s) and the speed also depends on the crosswalk width. Subramanyam and Prasanna [27] also found similar results in India and revealed that male crossing speed exceeds the female crossing speed by 0.17 m/s. Further, DiPietro and King [28] observed that the 15^{th} percentile speed is 0.76 m/s for a single pedestrian, 0.67 m/s for pedestrians in a pair and 0.61 m/s for more than two pedestrians. Gates et al. [19] also found that the pedestrian speed for crossing in groups is lower than crossing individually (1.32 m/s as opposed to 1.44 m/s). Hatfield and Murphy [29] revealed that the mobile phones do not affect the crossing speed of pedestrians but increase the tendency of hazardous road crossing behaviour. Goh and Lam [30] pointed out that the pedestrians crossing in oblique fashion with two-stage crossing have lower speed as compared to one-stage crossing. Moreover, Rastogi et al. [31] deduced that traffic volume, width of road and urban area size have positive influence on the crossing speed. The preceding discussion reveals that the socio-demographic factors (such as gender, age group size), geometric characteristics (such as road width, road classification) and flow conditions are the significant factors influencing the crossing speed of pedestrians at signalised crosswalks. It is evident from *Table 1* that over a period of time, the average pedestrian crossing speed has increased (1.24-1.43 m/s) due to the improvement in traffic conditions and infrastructure facilities [32-34]. Therefore, the present study aims to determine the factors that affect the crossing speed and to model the pedestrian crossing speed for the selected signalised intersection crosswalks in the Chandigarh city under heterogeneous traffic conditions.

2. METHODOLOGY

The present study was carried out in one of the well-planned cities of India – Chandigarh. The selected sites varied in terms of traffic volume, numbers of lanes, nature of land-use and other geometric features. The crosswalks were either four/six-lane divided or three-lane undivided carriageways. The Chandigarh city has the best urban planning and modern architecture. It also has the largest number of vehicles per capita in India, due to which non-motorised users face inconvenience in manoeuvrability on the roads especially at the time of crossing at intersections. The statistics show that during the past five years, road accidents claimed 664 lives of which 213 were pedestrians, which accounts for 32.07 percent of the total deaths [39]. This indicates a severe mistake of ignoring the non-motorised traffic in the city road designs. Hence, the data were collected at 16 signalised crosswalks (C1-C16) in Chandigarh city.

Videographic technique was used to gather the pedestrian flow data during the morning peak hour, i.e. between 9:00 a.m. to 10:00 a.m. A total of 994 samples were collected at signalised crosswalks which were further classified into different genders and age groups (less than 18, 19 to 29, 30 to 44, 45 to 59, equal to and above 60). The crossing speed of the pedestrians was computed based on the time taken by a pedestrian to cross the road between the kerb and the median. From the observed data, the average crossing speed was estimated under varying pedestrian flow conditions. The cumulative S-shaped frequency curves were used to find the percentile speeds at different crosswalks among the various genders, age groups and group sizes. The pedestrian flow, crossing time and delay, vehicular flow and speed were also

Table 1 – Comparison of pedestrian crossing speeds among different countries on the basis of socio-demographics

Chronological order	Country	Male	Female	Adult	Older	Individual	Group of two or more		Source
1967	UK			1.44[a], 1.14[b]	1.14[a], 1.04[b]				Sjostedt
1970		0.67[b]	0.58[b]	0.76[a]	–				DiPietro and King
1978				1.57	1.11				Cresswell et al.
1980		1.32	1.27	1.32	1.13				Wilson and Grayson
1984				1.47	1.16				Griffiths et al.
1988	–	1.2							MUTCD
1991	Bangkok, Thailand	1.31	1.23						Tanaboriboon and Guyano
1994	–	1.2							Robertson et al. [35]
1994	–	1.4							TRB [36]
1994	Sweden			1.45	1.03				Bowman and Vecellio
1996	United States			1.51[a] 1.25[b]	1.25[a] 0.97[b]				Knoblauch et al.
1998				1.35[a] 1[b]	0.97[a] 0.67[b]				Guerrier and Jolibois
2006		1.47	1.4	1.44[a] 1.22[b]	1.16[a] 0.92[b]				Gates et al.
2006		–	–	1.45[a] 1.17[b]	1.34[a] 0.97[b]				Fitzpatrick et al.
2015		1.45[a] 1.18[b]	1.39[a] 1.14[b]			1.44[a] 1.19[b]	1.29[a] 1.07[b]		Peters et al.
2000	–			–	1				TRB
2001	Jordan	1.35	1.33	1.47[a] 1.22[b]	1.17[a] 0.97[b]				Tarawneh
2005	China	1.33	–						Qingfeng Li [37]
2007	Netherland	–	1.18	–	1.24				Daamen and Hoogendorn
2015	Italy	1.34							Mantecchini and Paganelli
2016	Iran	1.42							Boroujerdian and Nemati
2017	Hong Kong	1.22							Xie et al.
2017	Iran	1.09[a] 0.83[b]	1.03[a] 0.78[b]			–	0.97[a] 0.74[b]		Behbahani et al. [38]
2017	Qatar	1.43							Muley et al.
2012	IRC	0.95[b]							IRC
2013	India	1.37	1.26	1.36	1.23	1.37	1.24		Marisamynathan and Vedagiri
2014	India	1.31	1.25	1.49	0.99	–	–	–	Chandra et al.
	India	1.18	1.06	1.24	1.05	–	–	–	
2016	India	1.12	0.97	1.1	0.98				Asaithambi et al.
2017	India	1.28	1.11	–	–	–	–	–	Subramanyam and Prasanna Kumar

Note: [a]Average speed, [b]15th percentile speed [m/s]

deduced from the videography. The details of the geometric features of the crosswalks were observed manually. The geometric features, pedestrian flow and traffic flow characteristics are depicted in *Table 2*.

A one-way analysis of variance (ANOVA)/F-test was applied to check the significance of the social factors or demographic factors on the pedestrian crossing speed. Thereafter, the correlation analysis was performed to check whether the factors (geometric and operational) undertaken in the present study have any relation with the crossing speed. The Pearson bivariate correlation analysis was carried out for continuous factors, Eta-squared analysis for nominal variables and Kruskal's Gamma analysis for ordinal variables. Multi-collinearity diagnostics test was also run for examining the VIF (Variance Inflation factor)

Table 2 – Geometric features, operational and flow characteristics of the study area

Site	C [s]	G [s]	W [m]	L [m]	Wp [m]	VC	CR	SBP	GR	CS	LU	P [ped/h]	T [PCU/h]	V [km/h]	Ct [s]	D [s]
C-1	112	30	3.2	35.0	11.0	3	2	2	1	2	2	131	3,868	41.3	25	5.40
C-2	112	40	3.0	27.0	8.6	3	1	2	0	2	2	43	3,195	43.9	18	7.35
C-3	112	40	3.2	27.8	14.5	3	1	2	0	2	2	191	3,086	42.8	19	7.46
C-4	112	30	3.2	35.1	9.1	3	2	2	1	2	2	96	4,071	43.6	25	7.66
C-5	135	69	2.9	34.0	6.6	3	2	2	1	2	2	35	3,879	42.8	23	7.94
C-6	135	37	2.9	26.1	8.1	2	1	1	0	1	2	34	3,094	43.9	17	9.58
C-7	135	33	3.0	26.7	6.2	2	1	1	0	1	2	36	2,099	44.6	18	9.33
C-8	135	47	3.1	33.2	7.4	3	2	2	1	2	2	36	3,432	42.1	23	8.25
C-9	146	62	3.2	29.9	7.5	3	2	2	1	2	2	102	3,422	42.6	22	11.6
C-10	146	57	3.0	22.7	8.6	0	1	1	0	0	2	58	2,966	43.1	15	7.56
C-11	146	40	2.9	21.4	6.5	1	1	1	0	1	2	48	2,877	46.7	15	9.99
C-12	146	42	3.0	30.8	7.0	3	2	2	1	2	2	99	3,613	44.9	20	6.20
C-13	125	36	3.0	21.8	20.0	2	2	0	1	1	0	29	3,445	41.3	15	7.31
C-14	125	36	3.1	15.1	15.2	0	1	0	0	0	2	18	3,050	42.1	12	12.9
C-15	125	36	2.9	12.4	25.0	0	0	0	0	0	0	20	3,069	40.6	10	11.6
C-16	125	36	3.1	22.3	18.2	2	2	0	1	1	2	38	3,280	41.3	17	9.11

Note: C – Cycle length, G – Green time for pedestrians, W – Width of crosswalk, L – Length of crosswalk, Wp – Width of pedestrian islands, VC – Visibility of cross markings (Not visible - 0, Slightly visible - 1, Moderately visible - 2, Highly visible - 3), CR – Classification of road (Three-lane undivided – 0, Four-lane divided - 1, Six-lane divided - 2), SBP – Separate bicycle path for crossing (0 - Not available, 1 - Semi operational, 2- Fully operational), GR – Presence of guard rails (No - 0, Yes - 1), CS - Crosswalk Surface Condition (Poor - 0, Fair - 1, Good - 2), LU – Nature of land use (Commercial - 0, Educational - 1, Mixed - 2, Recreational/Shopping - 3, Residential - 4), P – Average pedestrian flow, T – Average traffic flow, V – Average traffic speed, Ct – Average crossing time, D – Average pedestrian delay

values to check the collinearity among the independent variables. Dummy variables were assigned to the categorical variables for formulating the model using stepwise regression technique. The model validity was checked using the goodness-of-fit tests.

3. PARAMETRIC ANALYSIS OF THE CROSSING SPEED

The 15th percentile speed is the design speed for deciding on the pedestrian signal timings for pedestrians to cross safely. The 15th percentile speeds are found to vary between 1.11-1.31 m/s for all crosswalk locations, which is consistent with the standard value of 1.2 m/s as suggested by different manuals (HCM 2000, FHWA 2003) [4, 40], but higher than that prescribed by IRC (0.95 m/s) [6]. The 50th percentile speed fluctuates between 1.29-1.56 m/s which represents the speed at which half of the pedestrians are below and half of the pedestrians are above. The 85th percentile speed ranges between 1.54-1.85 m/s which indicates the maximum speed at which pedestrians could cross the road so as to avoid accidents. These values are higher than the values recommended by researchers in other developing countries with similar crosswalk conditions. The variation of the speed percentiles is presented in *Figure 1*. The lowest percentile speeds are observed at C-9, C-14 and C-16 locations, whereas the maximum percentile speeds are found at C-2, C-6 and C-12 locations. This may be due to the difference in the crosswalk characteristics or flow conditions which is evident from *Table 2*. The delays experienced by various pedestrians are maximum at C-9, C-14 and C-15 crosswalk locations due to which the crossing speed gets reduced.

3.1 Pedestrian socio-demographic features (gender, age group, group size)

The results of the percentile crossing speed (crosswalk-wise) with respect to gender, age-group and group size are presented in *Table 3*. *Table 3* depicts that the males and females speed do not vary significantly as indicated by F-Value (< F-Critical) (F=1.392 <2.389, p=0.289). The average crossing speed of male and female pedestrians is 1.48 and 1.47 m/s, respectively which indicate that males walk faster than females by trivial margin of 0.01 m/s. It is also noticed that 15th and 85th percentile speeds of both males and females are on the higher side as compared to the speed observed in other countries (0.83 m/s and 1.25 m/s in Iran; 1.18 m/s and 1.54 m/s in the United States) [9, 39]. Another important observation is that the crossing speed of pedestrians at all signalised crosswalk locations show significant variation (p=0.045) and decrease with the age of the pedestrians (*Table 3*). Moreover, it is found that about 80 percent of the elder pedestrians (above 60 years) and 85 percent of pedestrians in the age group of

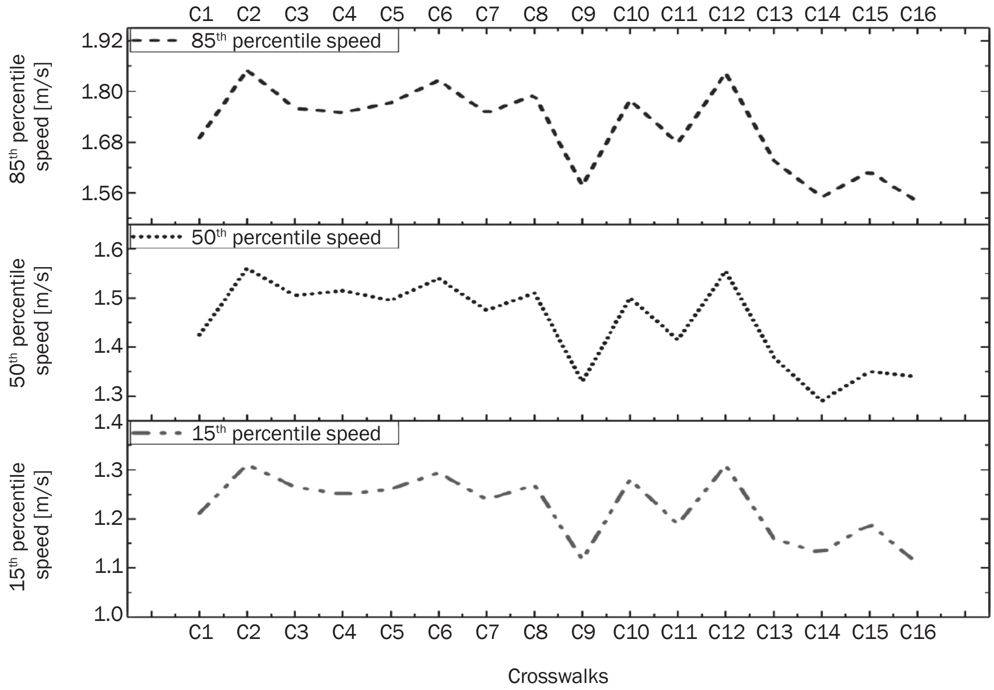

Figure 1 – Variation in percentile speeds across different locations

Table 3 – Statistical significance of variation in crossing speeds

Parameters		N	Range			Avg. crossing speed		F-Ratio statistic	F-Critical	p
			15th	50th	85th					
Gender	Male	650	1.06-1.33	1.26-1.58	1.49-1.87	1.48		1.392	2.389	0.235, Not significant
	Female	344	1.13-1.31	1.23-1.54	1.46-1.83	1.47				
Age group	<18	222	1.19-1.36	1.26-1.64	1.52-1.86	1.51		3.121	1.652	0.045*, Significant
	18-29	294	1.07-1.32	1.27-1.61	1.51-1.87	1.49				
	30-44	301	1.05-1.33	1.26-1.58	1.49-1.84	1.47				
	45-59	135	0.91-1.25	1.21-1.54	1.48-1.82	1.46				
	≥60	42	0.89-1.23	1.2-1.5	1.46-1.79	1.39				
Group size	One	623	1.18-1.35	1.29-1.59	1.53-1.79	1.52		2.124	0.954	0.032*, Significant
	Two	256	1.14-1.32	1.27-1.54	1.49-1.75	1.53				
	≥Three	115	1.15-1.33	1.24-1.52	1.48-1.77	1.52				

*Note: *Significant, if p<0.05*

18-45 years have crossing speeds higher than 1.2 m/s. This may be due to more agility in the young pedestrians and psychological tendency of the elder pedestrians to have minimum interactions with the vehicular traffic while crossing. The 15th percentile speeds of different age groups are almost in coherence with the standard crossing speed of 1.2 m/s. Correspondingly, the significant difference in the crossing speed exists among various group sizes (p=0.032). The group walking speeds varied from the speed of the individuals. The time difference between the entry of the first pedestrian and the exit of the last pedestrian of the group from the section was used to compute the group speed. The person crossing alone has higher crossing speed than those crossing in pairs or groups. The speed decreases with the increase in the size of the pedestrian group. The 15th percentile speed gets reduced by 25 percent as the group size increases above 3. The proportion of pedestrians crossing in a group of three and above are below 15 percent; therefore, the design crossing speed should range according to the speed of individuals and crossing in a pair. The observations clearly indicate that the design crossing speed needs to be revised according to the present crosswalk characteristics, geometric features and flow conditions.

3.2 Crossing pattern, baggage and mobile use

Different types of crossing patterns have been observed while using the crosswalk i.e. one-stage and two-stage crossings which could either be perpendicular, oblique, or a combination of both. The proportion of one-stage crossing (59 percent) is found to be greater compared to the two-stage crossing (41 percent). It is observed that the mean value of the crossing speed is higher in the case of one-stage crossing (1.5 m/s) as compared to the two-stage crossing (1.44 m/s). In case of a two-stage crossing, the pedestrians have to stop at the median for a while which results in an increase in the overall crossing time and reduction of the overall crossing speed.

Another interesting inference is that the pedestrians carrying baggage or using mobile phones (either speaking to someone or texting or surfing over the mobile phone) have a significant effect on the crossing speed. The speed at the time of crossing decreases if the pedestrians are carrying baggage or using mobile phones because this may divert their attention/focus towards either handling the baggage or using the mobile phones (especially texting or surfing), and as a result the crossing speed gets hindered. The mean speeds observed at different locations for pedestrians in case of carrying baggage and using mobile phones are found to be 1.42 and 1.43 m/s, respectively, which is less than the mean speed observed under normal conditions (1.48 m/s).

3.3 Geometric features, operational and flow characteristics

Along with the socio-demographic factors discussed in the preceding sections, the crossing speed also depends on the geometric features of the crosswalk such as the crosswalk width, the crosswalk length, the width of pedestrian islands, visibility of the cross-markings, the presence of guard rails, the classification of roads, the signal cycle length and the green time allocated to the pedestrians. In the present study, the correlation analysis (Pearson bivariate correlation analysis for continuous factors, Eta-squared analysis for nominal variables and Kruskal's Gamma analysis for ordinal variables) depicts that a significant correlation has been observed for seven factors only, such as the crosswalk width, the width of pedestrian islands, the crosswalk length, separate bicycle paths for crossing, classification of roads, average traffic flow and average pedestrian delay (*Table 4*). The effect of each factor on the pedestrian crossing speed has been discussed in the following paragraphs.

The correlation analysis reveals that the pedestrian crossing speed has significant negative correlation with the crosswalk width (R=-0.499, p=0.048) and the width of pedestrian islands (R=-0.625, p=0.010) (*Table 4*). This signifies the reduction in the crossing speed with the increase in the width of crosswalk and pedestrian island. Extra width of the crosswalk and the pedestrian islands (additional space available) may result in more comfortability to the pedestrians in their

Table 4 – Variation in crossing speed with respect to different attributes/factors

Type	Attributes/factors	Nature of variable	Correlation		Analysis tool
			R	p	
Operational characteristics	Cycle length	Continuous	0.089	0.742	Pearson bivariate (Continuous / Interval by interval**)
	Green time for pedestrians	Continuous	0.049	0.856	
Geometric features	Crosswalk width	Continuous	-0.499	0.048*	
	Crosswalk length	Continuous	-0.537	0.032*	
	Width of pedestrian islands	Continuous	-0.625	0.010*	
	Nature of land use	Nominal	0.394	0.131	Eta-squared (Nominal by interval)
	Presence of guard rails	Nominal	-0.118	0.664	
	Classification of road	Nominal	-0.502	0.039*	
	Visibility of cross markings	Ordinal	0.343	0.193	Kruskal's Gamma (Ordinal by interval)
	Crosswalk surface condition	Ordinal	0.58	0.452	
	Separate bicycle path	Ordinal	0.604	0.013*	
Flow characteristics	Average pedestrian flow	Continuous	0.165	0.541	Pearson bivariate
	Average traffic flow	Continuous	-0.544	0.028*	
	Average traffic speed	Continuous	0.494	0.052	
	Average crossing time	Continuous	0.388	0.138	
	Average pedestrian delay	Continuous	-0.584	0.017*	

*Note: *Significant, if p<0.05, **Crossing speed is also of continuous (interval) nature.*

crossing manoeuvres. This in turn leads to psychological no-haste condition by some of the pedestrians. The best fitted curves in both cases are found to be cubic in nature with the coefficient of determination (R-square) values of 0.412 and 0.513, respectively. Thus, the crossing speed can be suitably predicted with the help of the crosswalk width and the width of pedestrian islands with 41 percent success rate.

The study was carried out for three types of roads: three-lane undivided, four-lane divided and six-lane divided carriageway. For analysis of crossing speed, the three-lane undivided carriageway is considered same as the four-lane divided carriageway because both carriageways have somewhat similar geometric features and flow characteristics (crosswalk surface condition, separate bicycle path and traffic flow etc.). The variation in the percentile speeds for different classes of roads is shown in *Figure 2*. It is observed that the 15th percentile speed and 85th percentile speed have higher values for four-lane divided carriageways in comparison to the six-lane divided carriageways (1.24 m/s vs 1.21 m/s and 1.73 m/s vs 1.7 m/s respectively). The correlation analysis results replicate for the length of crosswalk (i.e. moderate negative correlation with the crossing speed) (R=-0.537, p= 0.032) (refer to *Table 4*). It is noted that the average crossing speed is more in case of four-lane divided carriageways as compared to the six-lane divided carriageways. The distance to be covered is more in the latter case which results in increase in time for kerb to kerb crossing. It also increases the probability of pedestrian-vehicular interaction in case of signal non-compliance either by vehicle or pedestrian. However, these results are contradictory to the results obtained by Rastogi et al. while conducting a study at midblock crosswalks in India [31]. Therefore, this also confirms that the crossing speed is also a function of the crosswalk type (signalised, unsignalised or mid-block).

Figure 3 shows the effect of traffic flow on the crossing speed of the pedestrians. The traffic flow (bi-directional) ranges between 2,099-4,071 PCU/hour with the average traffic speed of 42 km/h. *Table 4* indicates that the traffic flow has negative correlation with the crossing speed (R=0.544, p=0.028). However, according to the best fitted curve with R-square value 0.4469 predicts that the crossing speed initially increases when the traffic flow is lower (<2,750 PCU/hour), and as it increases further, the corresponding crossing speed decreases. The dip in the crossing speed with increase in traffic volume is due to the increase in the number of pedestrian-vehicular interactions while crossing, thus increasing the overall pedestrian crossing time.

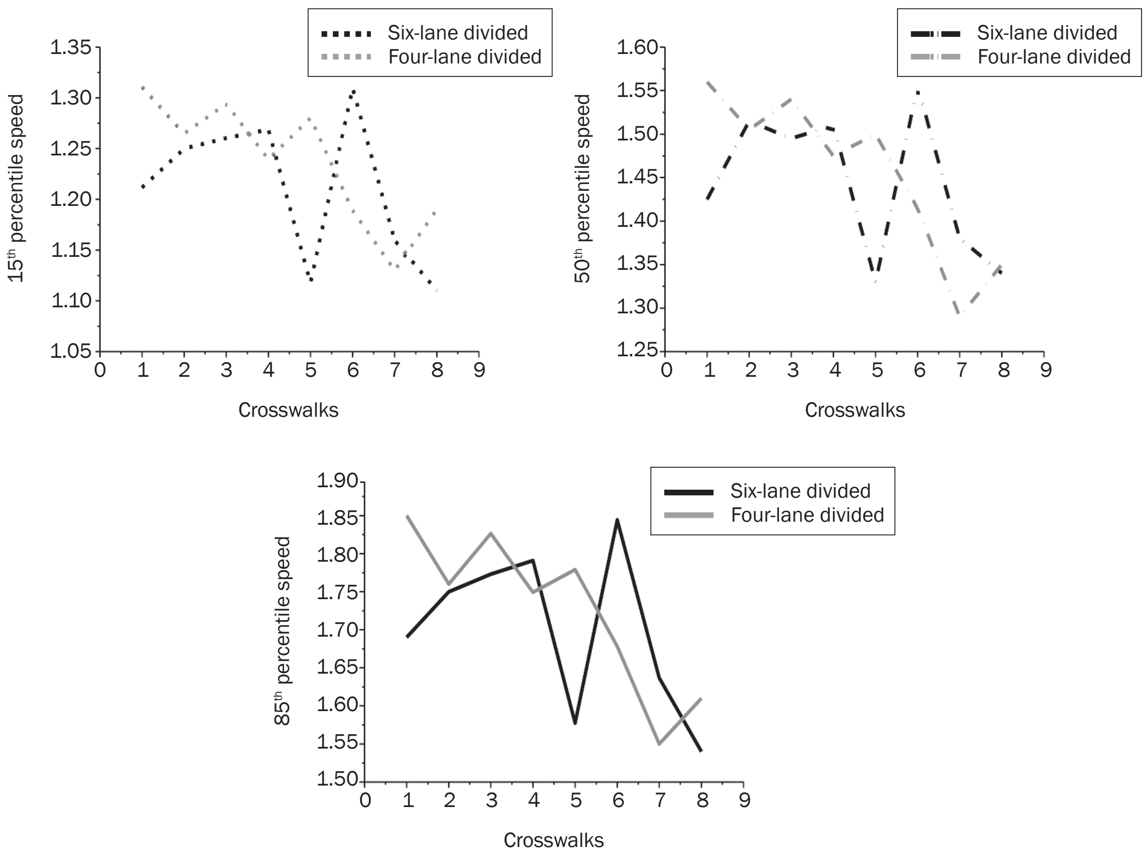

Figure 2 – Variation in percentile speeds for different carriageways

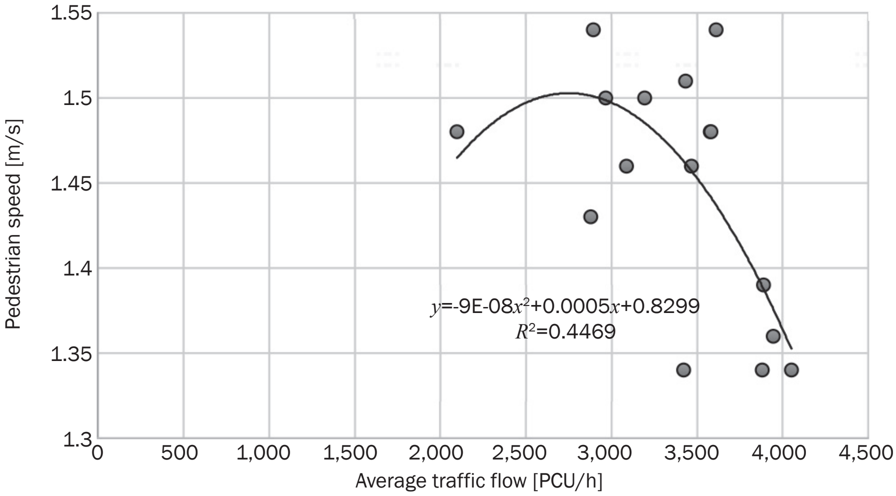

Figure 3 – Variation in crossing speed with traffic volume

Pedestrian delay is also one of the major factors that affect the crossing speed. In the present study, the delay experienced by pedestrians while crossing is only considered for examining its effect on the crossing speed. *Table 4* clearly indicates that pedestrian delay has negative correlation with the crossing speed (R=-0.584, p=0.017). However, the relation between the pedestrian delay is not linear. The cubic curve best with 47 percent accuracy rate describes the decrease in the crossing speed with the increase in pedestrian delay.

Nowadays, most of the cities are equipped with the cycle tracks solely for the use of cyclists. Chandigarh city is also equipped with the cycle tracks either running parallel to the main carriageway or at separate locations. For crossings of cyclists at the intersections, separate paths have been provided so as to avoid interaction with the pedestrians while crossing. For the present study, 50 percent of the crosswalks have fully operational separate cyclist crossings, whereas 25 percent of crosswalks are in semi-operational condition (under construction). The rest of 25 percent do not have separate cyclist crossings. The correlation analysis shows that there is positive relation between the pedestrian crossing speed and the availability of separate bicycle paths (R=0.604, p=0.013). The pedestrian crossing speed lies in the range of 1.34-1.39 m/s in the absence of separate bicycle paths, whereas the crossing speed of the pedestrian increases significantly if separate bicycle paths are present (1.41-1.54 m/s). It has been also observed that a similar green phase has been provided for both the pedestrians as well as the cyclists. The pedestrians and cyclists have to cross at the same time, thus increasing the likelihood of pedestrian-cyclist interactions. A separate path provided for cyclists ensures minimal hindrance to the pedestrians on the account of other cyclists crossing the path at the same instance.

The prior discussion elaborates the independent effect of all the significant variables on the crossing speed. No significant correlation has been found in case of cycle length, green time, nature of land use, visibility of crosswalk markings, presence of guard rails, crosswalk surface condition, average pedestrian flow, average traffic speed and average pedestrian crossing time. This may be due to the existence of similarity in the characteristics of the crosswalks or other variables being more significantly correlated.

4. STEPWISE REGRESSION MODELLING

The effect of significantly correlated variables on the pedestrian crossing speed at signalised crosswalk locations is modelled with the help of a stepwise linear regression technique. The categorical variables to be included in the model are converted into dummy variables. The categorical variable, classification of road, is converted into two separate dummy variables (Four-lane divided and Six-lane divided). Similarly, for the variable separate bicycle path for the crossing of cyclists, two dummy variables (Semi-operational cycle path and Fully-operational cycle path) have been formed. Before formulating the model, the multi-collinearity diagnostics is run to check the correlation among the selected independent variables. The Variance Inflation Factor (VIF) values less than 10 indicate that high (alarming) multi-collinearity does not exist among the variables (*Table 5*). However, the variables having values greater than 5 indicate a certain degree of multi-collinearity. Therefore, for modelling, a stepwise regression technique has been employed which could tackle this multi-collinearity issue.

After creating the dummy variables and running the correlation analysis along with the collinearity tests, nine explanatory variables (independent variables) have been recognised at 95 percent confidence interval (crosswalk width, crosswalk length, four-lane

Table 5 – Multi-collinearity diagnostics of independent variables

Model	Collinearity statistics	
	Tolerance	VIF
Crosswalk width [m]	0.604	1.656
Crosswalk length [m]	0.121	8.263
Four-lane divided	0.156	6.410
Six-lane divided	0.189	5.291
Width of pedestrian island [m]	0.718	1.393
Average pedestrian delay [s]	0.402	2.488
Average traffic flow [PCU/hour]	0.174	1.144
Semi-operational cycle path	0.152	6.590
Fully-operational cycle path	0.116	8.629

a. Dependent variable: average ped speed [m/s]

divided, six-lane divided, width of pedestrian islands, average pedestrian delay, average traffic flow, semi-operational cycle path, fully-operational cycle path) for modelling the pedestrian crossing speed. The model has been developed using the Stepwise Linear Regression (MLR) through SPSS. The estimates of the model along with the standard error, t-values, significant values and confidence intervals are summarised in *Table 6*. The model developed is given in *Equation 1*.

$$\begin{aligned} &Pedestrian\ crossing\ speed\ (Vp) = \\ &2.329 - 0.006(Wp) - 0.017(D) - 0.220(W) \end{aligned} \tag{1}$$

The model shows that the average pedestrian crossing speed gets vastly influenced by three factors such as crosswalk width, width of pedestrian island and average pedestrian delay. All the three variables have negative unstandardised coefficients revealing the inverse relation between the variables and the crossing speed. The speed of the pedestrians can be easily predicted with the help of these three variables. The model is calibrated using 80 percent data and the remaining 20 percent of data is used for the validation of the model. The calibrated R^2 value is found as 0.701 which indicates that 70.1% variation in the predicted crossing speed has been explained by the explanatory variables, or in other words, the regression line. This R-square value is higher than the independent R-square values found for each variable separately. The graph indicates that the crossing speed model developed through this study yielded results close to the observed values as shown in *Figure 4*.

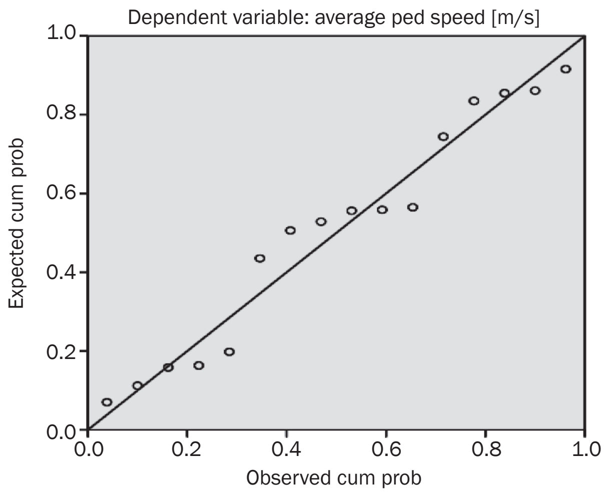

Figure 4 – Comparison between predicted and observed values

Table 6 – Model estimation and calibration results

Model	Unstandardised coefficients		Standardised coefficients	t	Sig.	95% confidence interval for B	
	B	Std. Error	Beta			Lower bound	Upper bound
(Constant)	2.329	.313	--	7.446	.000	1.648	3.011
Width of ped island (Wp)	-.006	.002	-.485	-2.963	.012	-.011	-.002
Average pedestrian delay (D)	-.017	.006	-.486	-2.959	.012	-.029	-.004
Crosswalk width (W)	-.220	.101	-.347	-2.183	.049	-.440	.000

5. DISCUSSION

A comprehensive literature survey construed that there are significant variations in pedestrian crossing speeds at different crosswalks between the developing countries (India, Thailand, etc.) and the developed countries (USA, UK, etc.). It was also noted that over the course of time, the crossing speed of the pedestrians in the developing countries (especially the Indian cities) have increased tremendously and surpassed the design standard speed limits approved by different manuals. Therefore, the factors influencing the crossing speed were studied and the modelling was carried out to predict the crossing speed at signalised intersections for heterogeneous traffic conditions.

The present study was undertaken at the selected 16 signalised intersection crosswalks in Chandigarh city (India). The 15th percentile speed was found varying between 1.11-1.31 m/s across different study locations. The statistical tests i.e. F-tests exhibited no substantial difference in the percentile speeds for different genders but varied for different age groups and group sizes. The overall 15th percentile speeds found for different genders across the studied crosswalk locations (68 percent) were much higher than the prescribed standard value of 1.2 m/s. It was also observed that the crossing speed decreases with an increase in age and group size. The pedestrians exhibiting different crossing patterns also affect the crossing speed. One-stage crossing speed was higher as compared to the two-stage crossing. Moreover, the pedestrians carrying baggage or using mobile phones had a significant effect on the crossing speed. The crossing time gets increased and the speed gets decreased if the pedestrian is carrying luggage. Based on other significant influencing factors (geometric, operational and flow characteristics) the correlation analysis found that the factors like crosswalk width, crosswalk length, width of pedestrian island, classification of road, average traffic flow and average pedestrian delay had negative correlation with the crossing speed, whereas separate bicycle path for crossing positively correlated with the crossing speed. The 15th and 85th percentile speeds were found to have higher values for the four-lane divided carriageways in comparison to the six-lane divided carriageways (1.24 m/s vs. 1.21 m/s and 1.73 m/s vs. 1.7 m/s, respectively). Reducing the number of lanes resulted in fewer interferences to the pedestrians, hence shorter crossing time and higher crossing speed. The crossing speed was found to increase till the traffic flow is less than <2,750 PCU/hour, but with further increase in the traffic flow, the crossing speed is reduced and showed a declining trend. The crosswalk locations with separate bicycle paths recorded higher pedestrian crossing speed (1.41-1.54 m/s) than the locations with no separate bicycle path (1.34-1.39 m/s).

Further, the pedestrian crossing speed was modelled using the stepwise regression technique. The model concluded that only three factors i.e. crosswalk width, width of pedestrian islands and average pedestrian delay contribute a lot in predicting the crossing speed. The coefficient of determination (R-square) was found to be 0.701 indicating 70.1 percent accurate prediction rate.

6. CONCLUSION

The present study concludes that the pedestrian crossing speed at signalised intersections has tremendously increased over the past decade due to the improvement in infrastructure, thus demanding the need for revising the prescribed speed limits. Pedestrian characteristics, Traffic factors, Geometric conditions and Operability characteristics exhibit significant effect on the crossing speed. Therefore, it has been suggested to incorporate all the factors while deciding on the pedestrian design crossing speed at signalised crosswalks. The model formulated in this paper should also be applicable to other countries of Southeast Asia where similar traffic conditions prevail.

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