A Crucial Re-evaluation of Grade-Separated Pedestrian Crossing Facilities

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h I G H L I G H T S

- Inadequate accepted vehicle gaps have a significant effect on pedestrian crossing speed.
- The availability of medians decreases crossing speed change behavior.
- The pedestrian platoon sizes decreases the change in their crossing speed.
- The change in pedestrian crossing path has more probability of increase in crossing speeds.
- Significant increase in speed change with small and faster-approaching vehicles.

A R T I C L E I N F O

Keywords:
Pedestrian behavior
Crossing
Speed patterns
Mid-block
Vehicle gap

A B S T R A C T

One of the key elements in the design of a pedestrian crossing facility is the crossing speed. According to research, pedestrian attributes like age and gender as well as the amount of green time at signalised crosswalks affect how quickly people cross the street. At unprotected (un-signalized) mid-block crosswalks, the impacts of vehicular time gap and extra pedestrian behavioural traits on pedestrian crossing speed patterns have not, however, been studied. The current study examines the pedestrian crossing speed change patterns at selected unprotected mid-block crosswalk locations under mixed traffic conditions in India, taking into account the effect of vehicular time gap and pedestrian behavioural characteristics such as rolling behaviour, path change, etc. In Mumbai City, a two- to three-hour video graphic survey was done at eight randomly chosen unprotected mid-block crossing locations during fair weather. Using AVS video editor software, the data was mined and the following information was extracted: pedestrian speed, pedestrian characteristics (gender and age), pedestrian behaviour (rolling, changing the path, etc.), vehicle characteristics (type and speed of the vehicle), and traffic characteristics. A logistic regression model was created utilising vehicular gaps and other pedestrian behavioural traits as independent variables, using pedestrian crossing speed change patterns (whether or not a pedestrian is changing speed when crossing a road) as a binary variable. The findings showed that at unprotected mid-block crosswalks, pedestrian crossing speed change behaviour decreases as the size of the vehicle gap increases. At mid-block crosswalks, younger pedestrians are more likely than older pedestrians to demonstrate patterns of changing their crossing pace. Additionally, it is noted that there has been a rise in Increases in vehicle speed and heavier vehicle types are correlated with faster pedestrian crossing speeds. The way a pedestrian behaves significantly affects the pace of a crossing. The study's conclusions would be helpful to designers and decision-makers for designing pedestrian crossing facilities in situations with mixed traffic

1. Introduction

Pedestrian speed is an important parameter in transportation planning and design of pedestrian facilities. The pedestrians have more exposure to vehicular traffic at crosswalk locations. Further, pedestrian road crossing behaviour has significant effect on pedestrian-vehicle interaction particularly at unprotected crosswalk locations (Zhang et al., 2018). Studies have found that 8.3% of the pedestrian fatality in India occurred due to road accidents (National Crime Records Bureau (NCRB), 2013) and global studies have shown that over the last two decades, the number of pedestrian related road crashes have increased drastically at non-intersection locations where pedestrian trips are more than other modes of transportation (National Highway Traffic Safety Administration (NHTSA), 2013). Road crossing are often locations for such collisions because pedestrian behaviour can lead to hazardous situations (Mohan et al., 2009). Walk trips are (as compared to other modes of transportation) higher in developing countries like India (National Transport Development Policy Committee (NTDPC), 2013). However, the rapid economic growth of cities in developing countries has resulted in higher motorized traffic and poor pedestrian facilities. A lack of control over pedestrian as well as vehicular traffic results in significant interaction between pedestrians and vehicles, which leads to more pedestrian-vehicle conflicts (Dandona et al., 2006). Further, the increase in urban sprawl in cities (e.g., Mumbai City) has lengthened the duration of trips and demands more number of pedestrian facilities particularly crossing facilities to access public transportation system. During such pedestrian crossing trips, pedestrian may increase their crossing speed to access the public buses on opposite side of the road. Pedestrians' altering their crossing speed (viz., running) is common phenomenon to avoid the conflict with approaching vehicles while crossing the road (Davis et al., 2008). However, lack of research studies have led to several inadequate crossing facilities and inconsistent pedestrian crossing behaviour (Leather et al., 2011).

Most of the crosswalk facilities are away from the intersection that connect bus stops and are adjacent to land-use facilities such as residential buildings, shopping areas and retail shops. Pedestrians' usually change their speed while crossing roads, either due to non-availability of adequate gaps in traffic flow or to access the opposite side of road to reach the public transit buses. Further, these locations are unprotected mid-block crosswalks and are often simple median openings with or without markings or sign boards especially in developing countries like India. These features, along with a lack of control over vehicular flow, can result in increased pedestrian-vehicle interaction and conflicts as compared to signalized crosswalk locations. Increase in pedestrian crossing speed can cause further dilemma because of potential ambiguity in vehicular driver yield behaviour to the crossing pedestrian. Therefore, gaining knowledge about pedestrian speed while crossing the road is an important aspect to control pedestrian-vehicle conflicts. Moreover, studies on pedestrian crossing speed will be useful to enforce traffic regulations, pedestrian signal design and appropriate counter measures for effective pedestrian safety. With this background, the objective of the current study is to examine pedestrian crossing speed change behaviour at unprotected mid-block crosswalks under mixed traffic conditions. The organization of this research paper is as follows. Section 1 discusses the importance of pedestrian crossing speed. Section 2 describes the background about the pedestrian speed studies. In section 3, an overview of the site characteristics and the data collection process is presented. Section 4 presents the pedestrian crossing speed change behaviour model while crossing unprotected mid-block crosswalks and discussion related to the model results is presented. The conclusions are summarized in section 5.

2. Background of the study

One of the primary contributing factors for pedestrian facility design is pedestrian speed, which is often used to evaluate existing facilities, such as sidewalks and signalized crosswalks, for level of service (LOS) studies. Several researchers have explored pedestrian macroscopic flow characteristics to study the relationship between pedestrian speed-flow-density at different locations, such as central business district (CBD) areas, sidewalks as well as mixed traffic locations and the results show that pedestrian speed varies across the locations based on cultural and environmental factors (Lam et al., 1995; Laxman et al., 2010; TRB, 2010). Further, some of these studies have linked pedestrian LOS with pedestrian speed and flow criteria at various locations (Davis and Braaksma, 1987; Tanaboriboon and Guyano, 1989). Many research studies have explored the effect of pedestrian gender and age on pedestrian walking speed and concluded that men walk faster than women and young pedestrians' walk faster than elders (Bowman and Vecellio, 1994; Coffin and Morrall, 1995;

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Fitzpatrick et al., 2006; Holland and Hill, 2007; Koushki, 1988). Large-scale research has been carried on pedestrian walking speed and start-up times at sixteen crosswalk locations in four different urban areas and results found that younger individuals walk faster than elders, with 15th percentile speed of 1.25 and 0.97 m/s respectively (Gates et al., 2006).

The pedestrian crossing speed is quite different as compared with pedestrian speed at sidewalks. In general, pedestrians increase or decrease their speed while crossing the road due to various reasons such as roadway, environmental and traffic conditions. Research study in Malaysia have shown that pedestrians cross faster at uncontrolled intersections than at signalized intersections; however, there was no significant effect of lighting on pedestrian crossing speed (Goh et al., 2012). Researchers have explored the pedestrian road crossing behaviour with pedestrian gap acceptance at mid-block crosswalk and results found that pedestrian speed has significant effect on pedestrian gap acceptance (Sun et al., 2005; Yannis et al., 2013). Researchers have also explored factors affecting pedestrian crossing speed such as traffic volume, pedestrian platoon, type of street and parked vehicles (Knoblauch et al., 1996). Researchers have studied the pedestrian crossing speed with respect to activities and results concluded that pedestrian alter their road crossing speed during performing an activity (Mustafa et al., 2014). Tarawneh (2001) evaluated the pedestrian crossing speed in Jordan and the results concluded that pedestrian crossing wider roads will move at higher crossing speed as compared to crossing narrower streets. Comparative studies of pedestrian walking and crossing have also been carried out and results concluded that pedestrians at two-lane one way road section exhibit higher crossing speed as compared with four-lane divided roadway conditions. The results also concluded that crossing speed of pedestrians are higher as compared to their walking speed (Chandra and Bharti, 2013). In this line, researchers have also shown that pedestrian crossing speed is higher as compared to the walking speed in different weather conditions (Montufar et al., 2007). Researchers have investigated the pedestrians’ crossing speed, delay and gap perception at six signalized intersections and the results concluded that pedestrian safety margin reduces as the speed limit is increased (Onelcin and Alver, 2017). Studies have shown that the perception of elderly in terms of risk related to crossing behaviour has greater variability during road crossing (Lord et al., 2018). It is also identified that there is significant effect of number of traffic lanes and crossing stages on pedestrian crossing speed and it has been concluded that the running speed is independent of number of lanes (Almodfer et al., 2017). Researchers have shown that children have chance of running during road crossing as compared to adults (Li et al., 2013). Some studies have also explored factors such as road width, motorized vehicular volume, size of urban area and bi-directional movement of pedestrian under mixed traffic conditions (Rastogi et al., 2011).

Several studies have reported pedestrian crossing speed values for design purposes: 1.2 m/s (when elder pedestrian group is less than 20%) by the Highway Capacity Manual (TRB, 2010), 0.98 m/s by the Traffic Engineering HandBook (Dewar, 1992), 1.21 m/s by the Manual of Uniform Traffic Control Devices for Streets and Highways (FHWA, 2003), 1.2 m/s by an Australian study (Akçelik & Associates Pty Ltd, 2001) and 0.95 m/s by the Indian Road Congress (IRC) (2012). Researchers have also concluded that start-up crossing speed were higher than end-reach (curb) speed (Akçelik & Associates Pty Ltd, 2001) and that crossing speed is faster than normal walking speed in all cases (Montufar et al., 2007). Furthermore, signalized crosswalk locations with count down signals encourage faster walking speed and therefore accommodate more people (Leonard and Jukes, 2000). Nevertheless, these studies have reported about pedestrian speed with respect to gender, age and signalized location and are different from the scope of present study. At unprotected (uncontrolled or un-signalized) mid-block crosswalk locations, pedestrian crossing speed change patterns depends on vehicular gap, driver behaviour, pedestrian behaviour and roadway characteristics. Hence, the present study has been focused on pedestrian crossing speed patterns considering pedestrian behaviour, approaching vehicle gaps and roadway factors under mixed traffic conditions.

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3. Methodology

3.1. Selection of survey locations

To analyze pedestrian crossing speed change behaviour, the present study has considered eight unprotected mid-block crosswalk locations in Mumbai, India (Fig. 1). The selected crosswalks range from two-lane undivided to six-lanes divided roadways. Also, these locations have different land- use facilities, such as residential, commercial and shopping areas are connected to bus stops and are located away (120e150 m) from signalized crosswalk locations. These crosswalks do not have sign boards to regulate vehicular flow, however some of the crosswalk locations have zebra markings. The crossing process involves the arrival of pedestrian at curb or median as well as searching for suitable vehicular gap to cross the road, and during this process pedestrian may be involved in road crossing speed change behaviour depending on the surrounding environment characteristics.

3.2. Data collection

At each selected crosswalk location, known distance was marked prior to the video survey to collect vehicle speed, pedestrian speed and vehicle gaps. For pedestrian speed data collection, the length of the crosswalk was marked as the lane width. For adequate site visibility, cameras were placed at suitable height to capture the vehicular as well as pedestrian data. Three cameras were placed for data collection: two for the vehicle characteristics and one for pedestrian character- istics. Data was collected in two-to-three hour periods at each selected location based on pedestrian-vehicle demand (for example, evening time data was collected at shopping area locations).

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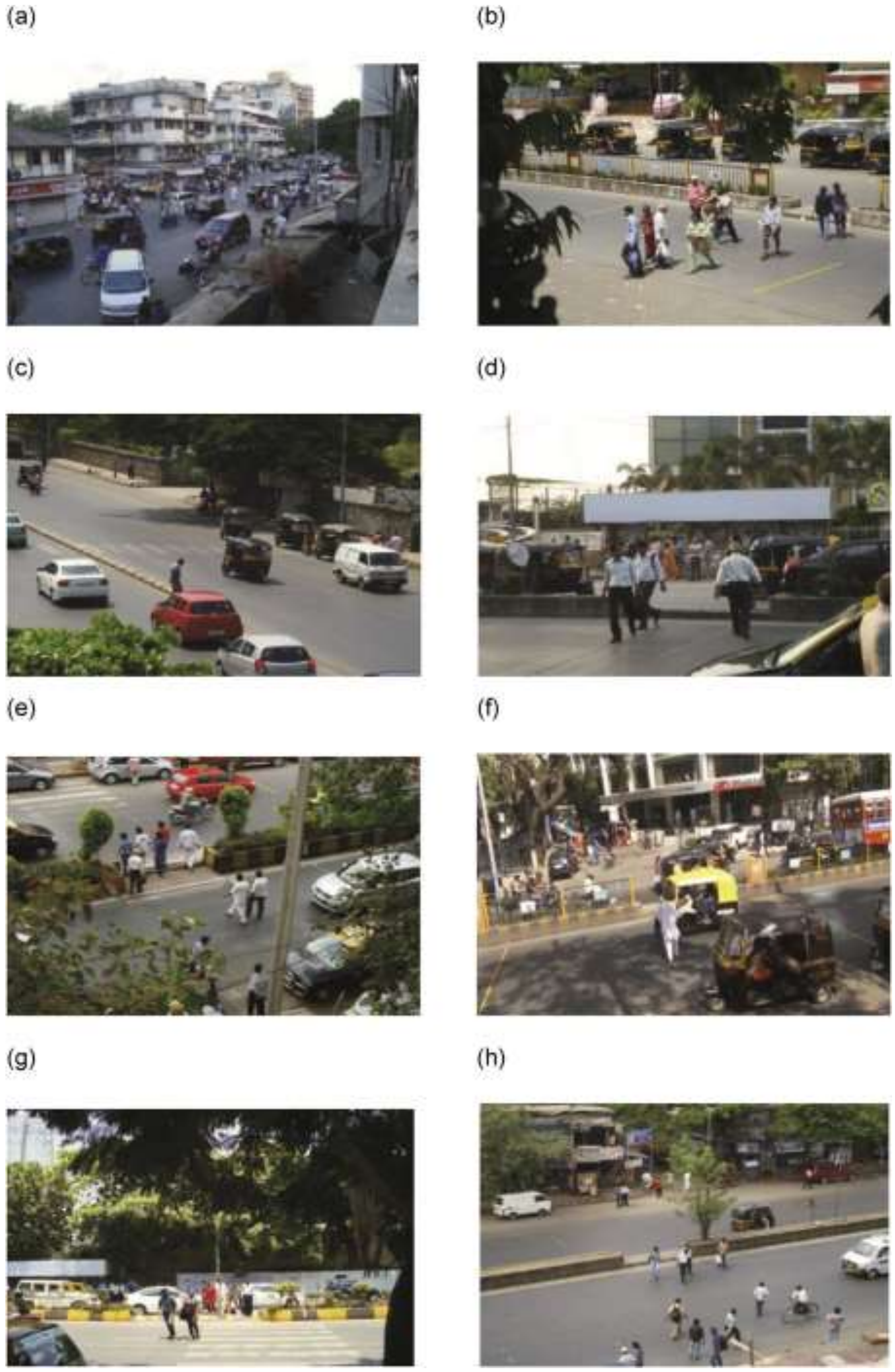

Fig. 1 e The selected unprotected crosswalk locations in Mumbai City. (a) Site 1. (b) Site 2. (c) Site 3. (d) Site 4. (e) Site 5. (f) Site 6. (g) Site 7. (h) Site 8.

3.3. Data extraction and process

All the recorded data was processed in the lab with AVS video data editor software and the relevant data (e.g., pedestrian, vehicular and traffic characteristics) were extracted. The video editor software has slow time step process of 33 ms with forward and backward click options. Hence, the pedestrian arrival at curb or median, time of

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stepping on to the road and reaching the curb has been noted down with an accuracy of 33 ms. Meanwhile, approaching vehicle time gaps were also noted considering the corresponding pedestrian crossing intersection points as the imaginary line. Vehicle speed were calculated based on the entry and leaving time of vehicles with known trap length (20 m). The extracted data consists of 5936 pedestrian speed change data points from 8 different unprotected mid-

Table 1 e Summary of roadway and traffic characteristics of selected crosswalks locations.

Site No.	Location name	Type of road	Land-use type	Total road width (m)	Number of crossing speed data points
1	Ghatkopar	Two-lane undivided	Mixed	7.0	712
2	Borivali	Four-lane divided	Mixed	12.4	922
3	Andheri Parsiwada	Four-lane divided with low curb	Mixed	15.0	280
4	Kurla	Four-lane divided	Shopping	14.0	648
5	Lower Parel	Four-lane divided	Shopping	14.0	1045
6	Malad	Four-lane divided	Residential	12.4	440
7	Prabhadevi	Six-lane divided	Residential	21.0	975
8	Chembur	Six-lane divided	Mixed	21.0	914

block crosswalks. Table 1 presents characteristics of the selected sites in this study.

The descriptions of different collected variable characteristics are explained below and the collected variables are summarized in Table 2.

3.3.1. Pedestrian individual characteristic

Pedestrian gender and age: pedestrian gender as well as age are extracted from the video, based on visual appearance.

3.3.2. Pedestrian behavioural characteristic

Pedestrian rolling behaviour: whether pedestrian rolls over the available small vehicular gaps instead of waiting for larger vehicular gaps.

Pedestrian speed change behaviour: whether a pedestrian changes speed during road crossing.

Pedestrian path change behaviour: whether a pedestrian changes crossing path while crossing the road.

Pedestrian platoon behaviour: number of pedestrians in a group while crossing the road.

Pedestrian cell-phone use: whether pedestrians are using mobile phones during road crossing.

3.3.3. Vehicular characteristic

Type of vehicle: the approaching vehicle type while pedestrian crosses the road.

Vehicle speed: the approaching vehicle speed while pedestrian crosses the road.

3.3.4. Traffic characteristic

Vehicular gap size: time gap between two vehicles with reference to pedestrian crossing path.

Pedestrian waiting time: the overall waiting time spent by pedestrian during the road crossing activity.

Pedestrian speed: the average pedestrian crossing speed in each lane.

Accepted lag or gap: whether the pedestrian is accepting the lag (first vehicular gap) or successive gaps.

Type of gap: whether the gap is close to the curb or median (viz., for four lane divided roadway close to curb lane vehicular

Table 2 e Summary of the extracted data.

Type of characteristic	Type of variable	Value (%)
Pedestrian individual	Pedestrian gender	Male (62.5), female (37.5)
	Pedestrian age	Child (5e15 years old) (3.2), young (16e30 years old) (32.3), middle (31e50 years old) (50.5), elders (more than 50 years old) (14)
Pedestrian behaviour	Rolling behaviour	Yes (26.9), no (73.1)
	Speed change behaviour	Yes (21), no (79)
	Path change behaviour	Yes (19), no (81)
	Platoon behaviour	Single (47.8), two (21.9), three or more (30.3)
	Using cell phone	Yes (5.3), no (94.7)
Vehicle	Type of vehicle	Two-wheeler (23.1), three-wheeler-auto rickshaw (27.8), car (43.4), heavy vehicle (5.7)
	Vehicle speed (km/h)	Min: 12.33, max: 78.95, standard deviation: 18.57
Traffic	Vehicular gap size (s)	Min: 1.5, max: 21.65, standard deviation: 6.44
	Pedestrian waiting time (s)	Min: 0.2, max: 298.4, standard deviation: 32.41
	Pedestrian speed (m/s)	Min: 0.6, max: 3.4, standard deviation: 0.38
	Accepted lag or gap	Lag (11.4), gap (88.6)
	Type of gap	Near (48), far 1 (48.7), far 2 (3.3)
	Number of vehicles encountered	Min: 2, max: 230, Standard deviation: 6.86
Roadway	Number of lanes	Two (5.8), four (55.6), six (38.6)
	Presence of median	Yes (83.3), No (16.7)
	Presence of marking	Yes (38.7), No (61.3)
	Land-use type	Mixed (47.6), residential (23.8), shopping (28.5)

Note: Near, far 1 and far 2 gaps were indicators that the vehicular gaps were available to the pedestrian while making crossing activity from curb to median.

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gaps are considered as near lane and close to median vehicular gaps are considered as far lane gaps) while pedestrian crosses the road curb to median.

Number of vehicles encountered: the number of vehicle encountered by pedestrian while waiting at median or curb side for suitable acceptance of vehicular gap for road crossing.

3.3.5. Roadway characteristic

Number of lanes: the number of lanes crossed by pedestrian during road crossing activity and it varies from two-lanes undivided to six-lanes divided roadway.

Presence of median: whether the median is present at selected crosswalk location or not.

Presence of marking: whether the zebra marking is present at selected crosswalk location or not.

Land-use type: it is characterized based on the adjacent land-use condition such as residential, commercial, etc., within radius of 100 m from the crosswalk location.

3.4. Classification of pedestrian speed change pattern

Pedestrian speed were extracted from each selected location and based on the combined data of eight locations a speed distribution graph was plotted. The pedestrian crossing speed change condition (yes or no) was coded as a binary variable by visually inspecting the video data. The speed change behaviour was crosschecked with extracted speed data and pedestrian speed more than the 85th percentile speed of 1.65 m/s (for combined data) was confirmed as speed change behaviour. From the authors' perspective, the 85th percentile speed could be appropriate for road crossing speed change behaviour (though pedestrian facility design will consider based on 15th percentile speed as per Indian Road Congress (IRC), 2012); and prior research has shown that pedestrian speed were higher during road crossing as compared to the normal walking speed (Leonard and Jukes, 2000; Montufar et al., 2007). Further, several research studies have reported that design speed for crosswalk ranges from 0.95 m/s to 1.2 m/s and the selected speed change condition speed (1.65 m/s) is higher than these (Akçelik & Associates Pty Ltd, 2001; FHWA, 2003; Indian Road Congress (IRC), 2012).

3.5. Model formulation

The pedestrian crossing speed change behaviour was coded as dichotomous (i.e., a binary variable) and logistic regression is a well suited model for this type of data (Peng et al., 2002). Logistic regression can be extended to assess the relationship between the dependent binary variable (speed change condition) and the different independent variables. In general, the logistic model predicts the logit of Y from different X variables, as shown in Eq. (1).

$$\ln \frac{P}{1 - P} \text{ ¼ log odds ¼ logit ¼ a þ b}X_i \qquad (1)$$

Hence

$$\text{P ¼ Probability}\,\text{ð}Y \text{ ¼ outcome of interest j}X \text{ ¼ } x\text{Þ ¼ } \frac{e^{\text{aþb}X_i}}{1 \text{ þ } e^{\text{aþb}X_i}} \qquad (2)$$

In Eq. (2), P is the outcome probability when pedestrians changing their speed, with corresponding input variables, a is the intercept value, b is the slope parameter and shows the direction of the relationship between X and the logit of Y, i ranges from 1 to 16 for the selected variables.

The essential null hypothesis for the overall model indicates that b is equal to zero; however, the null hypothesis can be rejected with at least one b value not equal to zero, which indicates that the collective variable with their coefficients (b values) better predict the outcome variable (Peng et al., 2002). The results can be interpreted with odd ratio (viz., the ratio of the probability that an event will occur versus the probability that the event will not occur) and the results can be utilized to evaluate the overall significance of model with likelihood ratio test statistics as well as significant variables with Wald test statistics. Furthermore, goodness of fit statistics are represented with Chi-square test and Nagelkerke R-square.

4. Results and discussion

4.1. Speed change behaviour model results

The speed data is extracted from the selected sites and distribution plots were drawn for different percentile speed (15th, 50th and 85th), as shown in Fig. 2. Using the Statistical Package for Social Science (SPSS), the collected categorical variables were tested with one-way Analyses of Variance (ANOVAs) to assess differences in mean crosswalk speed across groups. The results show that gender (F (1, 5934) ¼ 158.832, p < 0.000), age (F (4, 5931) ¼ 38.979, p < 0.000), rolling behaviour (F (1, 5934) ¼ 10.017, p < 0.000), platoon size (F (2, 5933) ¼ 18.566, p < 0.000), type of approaching vehicle (F (3, 5932) ¼ 18.566, p < 0.000), number of lanes (F (2, 5933) ¼ 42.782, p < 0.000) and land-use type (F (2, 5933) ¼ 80.392, p < 0.000) all significantly affected the mean crossing speed. The effects of cell phone use (F (1, 5934) ¼ 2.652, p < 0.105), path change (F (1, 5934) ¼ 0.142, p < 0.706) and presence of median (F (1, 5934) ¼ 2.397, p < 0.122) were not significant.

Further, a test of collinearity produced a variance inflation factor (VIF) of 1.343, showing no issue of collinearity with all the selected independent variables. From the correlation analysis, a negative correlation was observed between vehicle gap and speed change (r ¼ —0.294) as well as platoon size and speed change (r ¼ —0.108). Before running the actual logistic regression model, selected categorical variables were tested with cross-tabulation to check their significance in the speed change condition. It was determined that cell phone use (c^2 ¼ 1.665, p ¼ 0.165) and marking (c^2 ¼ 3.363, p ¼ 0.069) need not to be considered for the modelling due to their insignificance. The collected data set had different variables and dropping the insignificant variables did not produce a significant change in the outcome of the model.

The logistic regression was carried out using speed change condition as the dependent variable and the remaining four-

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Vol-12 Issue-07 No.03 July 2022

teen variables were considered as independent variables. Out of the total data 70% (4156 data points) was used for modelling and remaining 30% data was utilized for the validation of

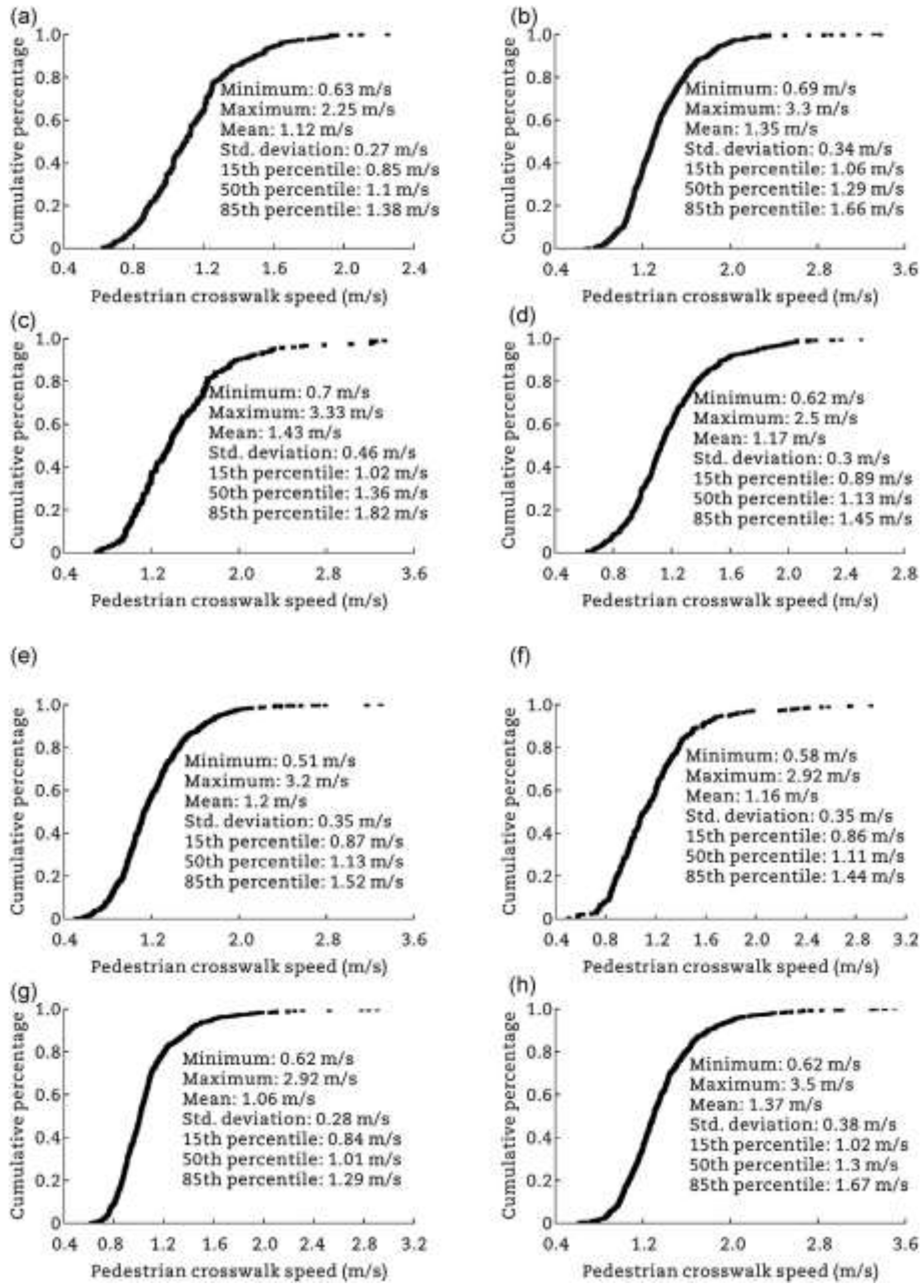

Fig. 2 e The speed distribution at selected unprotected crosswalk locations. (a) Ghatkopar. (b) Borivali. (c) Andheri Parsiwada. (d) Kurla. (e) Lower Parel. (f) Malad. (g) Prabhadevi. (h) Chembur.

model. Checking the data for the number of data points per independent variable (4156/14 ¼ 296.8), revealed no evidence for over fitting (Hosmer and Lemeshow, 1989). Also, a common rule for logistic regression is that the number of outcomes divided by the variables should be at least 10 (Peduzzi et al., 1996), a condition satisfied in this modelling process. The summary of the model results along with coefficients, standard error, Wald values and odds ratios are tabulated in Table 3. In Table 3, VGS is vehicular gap size; WT is pedestrian waiting time; PPS is pedestrian platoon size, platoon size three or more is considered as reference group; PPCC is pedestrian path change condition; VS is vehicle speed, heavy vehicle type is considered as reference group; ALG is accepted lag or gap; NOL is number of lanes; POM is presence of median; NOV is number of approaching vehicles. The model results show that the accuracy of the model for correctly predicting the speed change behaviour is 78.3%. The model R^2 values with Nagelkerke R-square score is observed as 0.143. The overall model results show that the pedestrian crossing speed change pattern is significantly affected by the collected variables (c^2 ¼ 17.892, p < 0.02). Variable selection was carried out with stepwise logistic regression analysis and showed no significant contribution of land-use type, type of gap and rolling behaviour on pedestrian speed. The validation results, based on 30% of the data indicated correct prediction with accuracy of 82.3%.

Table 3 e Summary of logistic regression model results.

Variable	Coefficient (b)	Standard error	Wald value	*p* value	Odd ratio exp (b)	95% confidence interval for exp (b)	
						Lower	Upper
VGS (s)	—0.203	0.018	135.062	0.000	0.814	0.786	0.842
WT (s)	0.008	0.003	6.539	0.011	1.008	1.002	1.013
Gender	0.470	0.092	25.995	0.000	1.600	1.336	1.917
Child	1.250	0.293	18.260	0.000	3.492	1.968	6.197
Young	0.647	0.140	21.408	0.000	1.909	1.452	2.511
Middle	0.266	0.133	3.966	0.045	1.305	0.994	1.714
Single_PPS	0.541	0.105	26.523	0.000	1.717	1.398	2.109
Two_PPS	0.242	0.121	3.985	0.046	1.274	1.004	1.616
PPCC	0.561	0.098	32.935	0.000	1.752	1.447	2.122
VS (km/h)	0.009	0.005	3.866	0.050	1.009	1.000	1.019
Two-wheeler	—1.071	0.189	32.071	0.000	0.343	0.237	0.496
Auto rickshaw	—0.832	0.182	20.857	0.000	0.435	0.304	0.622
Car	—0.718	0.175	16.800	0.000	0.488	0.346	0.688
ALG	—0.248	0.121	4.204	0.040	0.781	0.616	0.989
NOL	0.121	0.047	6.710	0.010	1.128	1.030	1.236
POM	—0.493	0.138	12.735	0.000	0.611	0.466	0.801
NOV	—0.017	0.004	22.307	0.000	0.983	0.976	0.990

4.2. Effect of gender and age

The present study results identified significant difference between males and female pedestrian speed change behaviours while crossing the road at unprotected mid-block crosswalks. The model results indicate that for every one unit increase in speed, the speed change behaviour of male pedestrians is observed with 60% higher frequency as compared to female pedestrians (Table 3). In other words, male pedestrians have more probability to increase their speed while crossing the road. The 15th and 85th percentile speeds for males were 0.93 and 1.61 m/s and for females were 0.86 and 1.41 m/s respectively. Prior research has shown that male pedestrian crossing speeds are higher than those of females (DiPietro and King, 1970; Holland and Hill, 2007), consistent with the current findings. A recent study in India found that male pedestrians had higher crossing speed than females, and the 85th percentile speed were higher for both genders (Rastogi et al., 2011).

However, other research studies have reported no difference in crossing speed across gender (Wilson and Grayson, 1980). Pedestrian age group also had a significant effect on crossing speed, such that the elderly pedestrians were less likely to increase crossing speed as compared to other age groups. The odds ratio of the child age group (reference age group is elders) is 3.492, indicating that this group was 3.492 times more likely to exhibit crossing speed change compared to the elder age group (Table 3). Likewise, young and middle-age groups were 1.909 and 1.305 times more likely to increase their crossing speed as compared to the elders. In general, earlier research studies indicate that age affects road crossing behaviour, with elders crossing more slowly than other age groups (Holland and Hill, 2007; Wilson and Grayson, 1980). The 15th and 85th percentile speed of elders were respectively 1.05 and 1.23 m/s (Bowman and Vecellio, 1994), 1.15 and 1.3 m/s (Knoblauch et al., 1996) and 1.11 and 1.4 m/s (Fitzpatrick et al., 2006) as per findings of different earlier research studies. The present study noted that 15th and 85th percentile speed, respectively for children

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are 0.88 and 1.5 m/s, young age groups are 0.95 and 1.65 m/s,middle aged group are 0.9 and 1.5 m/s and elder age group are 0.8 and 1.3 m/s. Elder age group are significantly different than other age groups.

4.3. Effect of vehicular gaps

The model results found that an increase in vehicle gap size (time gap) significantly decreases the pedestrian speed change behaviour at unprotected crosswalk locations. From Table 3, it can be observed that for one unit increase in vehicle gap size, the odds of the pedestrian speed change behaviour decreases from 1 to 0.814. Hence, if vehicle gap increases from 3.5 to 5 s, the odds of speed change behaviour decreases from 1 to 0.737 (exp (—0.203 × 1.5)). Speed change is a more common behaviour under mixed traffic conditions at unprotected mid-block crosswalk locations, where pedestrians usually increase their crossing speed because of inadequate gaps, irrespective of roadway geometry and land-use conditions. The results can also be interpreted with probabilities. For example, there is an increase in the probability of pedestrian speed change with a decrease in vehicle gap size (less than 5 s) as shown in Fig. 3. Several research efforts on pedestrian

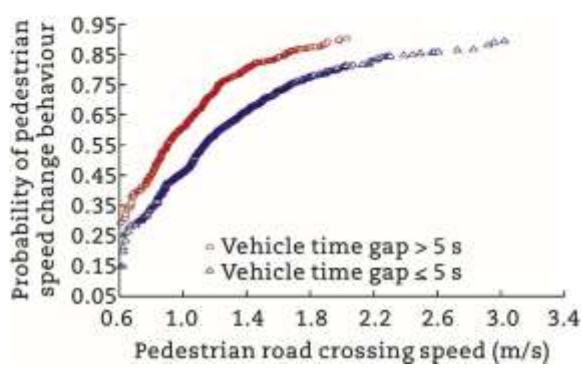

Fig. 3 e Probability of pedestrian speed change behaviour with vehicle gap size.

gap acceptance behaviour have shown that an increase in pedestrian crossing speed was observed with shorter gaps during road crossing (Das et al., 2005; DiPietro and King, 1970).

4.4. Effect of waiting time

It is observed that there is a slight effect of pedestrian waiting time on their speed change behaviour at unprotected mid-block crosswalk locations. The odds ratio of pedestrian waiting time indicates that a one unit increase in waiting time is associated with an increase in pedestrian crossing speed behaviour of only 0.8% (Table 3). Previous research shows a higher impact of waiting time on pedestrian road crossing (Das et al., 2005; Hamed, 2001), with a greater willingness to increase speed while waiting for longer time duration. However, the present study results reveal that waiting time has less impact when compared with vehicle gaps. Further, the pedestrian waiting time is associated with vehicular gaps at unprotected mid-block crosswalk. If pedestrian has experienced immediate higher vehicular gap after arrival at curb or median of unprotected mid-block crosswalks, then the waiting time of pedestrian has less effect on pedestrian speed change behaviour.

4.5. Effect of pedestrian behavioural characteristics

Pedestrian platoon size has a significant effect on pedestrian speed change behaviour: The mean crossing speed was 1.28 m/s for single pedestrian, 1.2 m/s for a two-person group and 1.15 m/s for a three or more-person group. The odds ratio of the single pedestrian group (PPS three or more is considered as a reference group) was 1.717, indicating the single pedestrian is 1.717 times more likely to increase the crossing speed and two-pedestrian group were 1.274 times more likely to increase their crossing speed while crossing road at unprotected mid-block crosswalks as compared to the three-pedestrian group. Prior research results also found that single pedestrian have higher mean speed as compared to the pedestrians in group (DiPietro and King, 1970; Gates et al., 2006). Pedestrian path change behaviour also significantly contributes to speed change behaviour at unprotected mid-block crosswalks. Results indicate that for each unit increase in path change behaviour, the odds of the pedestrian changing speed increases from 1 to 1.752. In general, pedestrians may change their crossing path due to unavailability of adequate vehicle gaps.

4.6. Effect of vehicle characteristics

The results show that there is a contribution of vehicle characteristics, such as type and speed of vehicle on pedestrian speed change behaviour. When vehicle speed was 35 km/h or less, mean pedestrian crossing speed was observed as 1.22 m/s; and when vehicle speed was more than 35 km/h, mean pedestrian crossing speed was observed as 1.29 m/s. The odds ratio of vehicle speed shows that for every one unit increase in vehicle speed, there is an increase in pedestrian crossing speed of only 0.9% (Table 3). Furthermore, pedestrian crossing mean speed were 1.16, 1.25, 1.22 and 1.30 m/s for two-wheeler, auto rickshaw, car and heavy vehicles, respectively, which reveals that there is higher probability of increase in speed with heavy vehicles as compared to the other vehicle types.

4.7. Effect of roadway characteristics

Roadway characteristics (number of lanes and presence of median) also significantly contributed to pedestrian crossing speed change patterns at unprotected mid-block crosswalk. The 15th percentile, 85th percentile and mean crossing speed for two-lane undivided, four-lane divided and six-lane divided roadways were 0.86, 1.36 and 1.12 m/s; 0.93, 1.59 and 1.25 m/s; 0.89, 1.56 and 1.25 m/s, respectively. With an increase in number of lanes, there is an increase in pedestrian crossing speed which has further impact on their crossing speed change pattern, with odds ratio of 1.128. Prior studies on the effect of vehicular lanes on pedestrian gaps found an increase in pedestrian speed with vehicle lanes having far gaps, i.e., pedestrian change their crossing speed with available gaps on third lane of six-lane divided road crossing as compared to the first lane (or) close to curb lane (Kadali and Vedagiri, 2013). Pedestrians are usually searching for vehicle gap which ranges from near to far lanes for multi-lane roadways. Due to unavailability of adequate gaps with an increase in vehicular lanes, pedestrians' change their crossing speed pattern at unprotected mid-block crosswalks under mixed traffic conditions. It is also found that availability of median for pedestrian road crossing significantly decreases pedestrian speed change crossing pattern and the odds of the pedestrian changing speed behaviour decreases from 1 to 0.611. Research studies show that pedestrian road crossing speed is lower in presence of road cross barriers as compared to the crosswalk locations without such barriers (Hine and Russel, 1993). It is also observed that the pedestrian mean, 15th and 85th percentile speed of non-median crosswalks (1.1, 1.12 and 1.45 m/s, respectively) are lower as compared to when median is present (1.02, 1.33 and 1.54 m/s respectively). It may be due to the fact that presence of median makes pedestrian road crossing possible in two stages without much change in their crossing speed. Moreover, study results found that for every one unit change in number of encountered vehicles while crossing, the odds of speed change behaviour decreases from 1 to 0.983. The present study does not draw any conclusions regarding the effect of land-use type on pedestrian crossing speed change patterns at unprotected crosswalk locations; however, other studies have shown significant effects (Rastogi et al., 2011). The present study results also do not show any significant effect of markings on pedestrian crossing speed change behaviour.

5. Conclusions

The present study used a logistic regression model to explore the effects of pedestrian behavioural, traffic, vehicle and roadway characteristics on pedestrian crossing speed change patterns with accepted vehicular gaps at unprotected mid-block crosswalk locations. Regarding pedestrian-specific factors, the study revealed that male pedestrians have higher chances of change in their crossing speed as compared to the females and young as well as middle-aged individuals have a higher chance of change in their crossing speed as compared to the elderly pedestrians at mid-block crosswalks. Additionally, higher pedestrian platoon size has less chance of change in their crossing speed patterns as compared to the individual pedestrians. Further, change in crossing path of pedestrian results in higher probability of increase in their crossing speed at mid-block crosswalks. It is concluded that inadequate accepted vehicle gaps by pedestrian results in higher probability of them exhibiting change in their crossing speed at unprotected mid-block crosswalks. The present study results also concluded that the pedestrian waiting time has less effect on pedestrian crossing speed change patterns as compared to the available vehicular gaps at unprotected crosswalk locations. The results also indicate that pedestrian crossing speed changes were observed with an increase in vehicle speed as well as for heavy vehicle type. The model results concluded that, when pedestrian crossed the road at unprotected mid-block crosswalks in presence of median, there is decrease in crossing speed change behaviour. Although the study identified significant contributing factors on pedestrian speed change behaviour, there are some limitations in this study. For example, the study could not concluded on the effects of marking, land-use type and purpose of the trip on pedestrian crossing speed change patterns at unprotected mid-block crosswalks. The present study results can also be extended with different crosswalk types, examining the effects of lighting and driver yield behaviour on pedestrian crossing speed change patterns. Despite these limitations, the present study presents a methodology which can be useful to traffic engineers for evaluation of existing unprotected mid-block crosswalk locations under mixed traffic conditions. Also, these model results may be helpful to planners for new crosswalk design to control pedestrian behaviour and to improve the pedestrian safety. For example, in design of pedestrian signal the crossing speed is one of the important parameter and the present study explored the effect of different factors on pedestrian crossing speed. Further, based on the pedestrian composition, the field engineer can select suitable average pedestrian crossing speed for signal design. Also, these results may be useful in pedestrian risk evaluation while crossing unprotected crosswalks. The increase in speed change behaviour of pedestrian is useful in design of new crosswalk facility such as signalized crosswalk locations and further implementation of regulation to vehicle drivers at unprotected crosswalk locations.

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