A Statistical Analysis of Pedestrian Behaviour at Signalized Intersections

S Marisamynathan[1*], P Vedagiri[2]

[1]Research scholar, Transportation Systems Engineering, Department of Civil Engineering, Indian Institute of Technology Bombay, Mumbai, India
[2]Associate Professor, Indian Institute of Technology Bombay, India

Abstract

In India pedestrian crashes mostly occurs when pedestrians cross the road, especially at signalized intersections. This study examines various factors affecting pedestrian crossing behaviours at signalized intersections under mixed traffic conditions. The pedestrian crossing movements were captured throughvideographic survey conducted at selected 8 signalized intersections in Mumbai, India. The captured data consisting of around 2476 pedestrians and observed that the rate of pedestrian compliance with traffic signal was 53%. This study is oriented towards various levels of pedestrian crossing behaviour such as pedestrian arrival pattern, crossing speed, compliance behaviour and pedestrian-vehicular interaction at signalized intersections. In first level, the pedestrian arrival pattern was analysed to find best fit. In second level, the factors affecting pedestrian crossing speed were identified by suitable statistical test with respect to pedestrian and traffic characteristics. The third level involves the analysis of pedestrian compliance behaviour with respect to pedestrian gender, age, platoon, crossing type, crosswalk marking, crossing direction and crossing speed based on various statistical tests. The fourth level comprises of pedestrian-vehicular interactions in detail,based on conducted statistical test. The pedestrian-vehicular interaction was modelled by using binary logit model. Study results indicate that approaching vehicle direction and gap sizewere the highly influencing factors for interactions. Findings from this study will help to understand the pedestrian crossing behaviour at signalized intersections where the pedestrians noncompliance are predominant and recommends for adequate facilities to be provided to all pedestrians to cross the street with utmost safe, comfort and convenience.

*Keywords:*Pedestrian, signalized intersections, crossing speed, compliance, interaction

1. Introduction

Walking is one of the foremost and sustainable traffic modes in urban transportation, predominantly in developing countries like India because of the flexibility and mobility involved in it. For mixed traffic flow conditions prevailing in India, most of the cities have high rate of pedestrian crashes. Major cities like Mumbai, the latest statistics states that more than 10% of people die on roads (Ministry of Road Transport and Highway 2012). The major reasons for such accidentsare mixed traffic conditions, pedestrian

[*] Corresponding author: S Marisamynathan (marisamy@iitb.ac.in)

noncompliance behaviour, free left turning and absence of pedestrian facilities such as crosswalk marking and refuge islands at signalized intersections in Mumbai. Pedestrians-vehicular crashes mostly occur when pedestrians cross the roads without caution, especially at signalized intersections. More than 50% of pedestrians crashes in China occurred at signalized intersections (Ren et al. 2011), whereas in India it was more than 60% (Ministry of Road Transport and Highway 2012). One of the major reasons for pedestrians-vehicular interaction is pedestrian noncompliance behaviour with traffic signals at signalized intersections, which is considered in this work, for analysis. In India, during flashing green and red phases, pedestrians are forbidden to enter the crosswalk. This rule however is found to be violated by some portion of pedestrians in India. The major reasons for pedestrian noncompliance are mixed traffic conditions, low quality traffic management, personnel unavailable to manage pedestrians, pedestrian behaviour and complex traffic signal system.

Pedestrian crossing speed is one of the significant design parameter at signalized intersections. Pedestrian crossing speed varies largely from the existing manual Indian Road Congress (IRC) estimated walking speed at crosswalk of 1.2m/s (Indian Road Congress (IRC) 1985). This constant value is not applicable for dynamic traffic conditions in Indian signalized intersections because crossing speed is variable with respect to pedestrian and traffic characteristics. Another important factor to be considered for developing pedestrian facilities is pedestrian arrival pattern at signalized intersections. Existing studies were done by assuming that pedestrian arrival pattern follows uniform pattern without any statistical evidence with any field data references. These assumptions failed to estimate accurately the following factors such as pedestrian delay, level of service and pedestrians-vehicular interactions at crosswalks. The interaction between the vehicle and the pedestrian at crosswalk is thus a complex and totally dependent upon pedestrian gap acceptance, crossing speed and vehicle speed. Psychological factors and behaviours of the pedestrians, while crossing the crosswalk, determine both pedestrian safety and vehicle safety. By considering the aspects of pedestrian safety, the study described in this paper evaluates pedestrians crossing behaviours at signalized intersections which are representative of the prevailing pedestrians' situations. The results of this study can be useful to assess the performance and adequacy of existing signalized intersections, develop crosswalk design and level of service standards where the pedestrians noncompliance at signalized intersections are predominant.

2. Review of earlier studies

Studies on pedestrian behaviour analysis have great implications for transportation and urban planning policies and design practices (Laxman et al. 2010). Many of the existing studies have examined only the pedestrian characteristics in sidewalks and walkways (Yordpholet al.,1986) and analysed pedestrian flow characteristics in pedestrian walkways under mixed traffic conditions in India (Laxmanet al.,. 2002) Few studies analysed pedestrian characteristics at signalized intersections for the development of pedestrian models for evaluating walking facilities (Lamet al., 2002) and examined pedestrians crossing behaviour variation by providing count down display signal (Lipovac et al. 2013). Pedestrians compliance behaviour and arrival pattern were studied without statistical evidence for the purpose of developing pedestrian delay model at signalized intersections (Nagraj and Vedagiri 2013; Li et al. 2005). Statistical studies on pedestrian noncompliance behaviour were investigated with limited parameters like pedestrian gender, age and platoon (Ren et al. 2011). Few studies were developed on pedestrian speed flow relationship for noncompliance pedestrians and on pedestrian-vehicle conflict application aspects (Zhouet al., 2011). The existing studies were reviewed in four themes such as based on pedestrian arrival pattern, crossing speed, compliance behaviour and pedestrians-vehicular interactions.

In the first theme, the reviews were based on pedestrian arrival pattern at crosswalks. Pedestrian delay is one of the significant parameters for designing traffic signal, level of service and pedestrian facilities at signalized intersections. Existing pedestrian delay estimation methods and models are mostly derived from HCM (Highway Capacity Manual 2010) and those models are assumed pedestrian arrival pattern follows only uniform arrival pattern and fail to estimate accurate pedestrian delay (Virkler 1998; Braun and Roddin 1978). Few studies have considered that pedestrian arrival pattern is non-uniform (Li et al., 2005; Nagraj and Vedagiri, 2013), Poisson distribution (Xieet al., 2012) and negative binomial distribution (Ying-fenget al., 2009) without any statistical evidence.

In the second theme, the studies carried out in pedestrian crossing speed variations at signalized intersections. Pedestrian speed can help in determining the rate at which the facility will clear out and have great implications for transportation and urban planning policies and design practices (Laxmanet al., 2010). Existing works on pedestrian crossing speed distribution analysis were focussed in sidewalksand walkways (Daamen and Hoogendoorn, 2003; Laxmanet al., 2010; Rahmanet al., 2012). Few studies have examined pedestrian crossing speed distribution at signalized intersections and impacts of countdown display pedestrian signals were also analysed (Canbinand Ma 2010). Crossing speed seems to be follow a normal distribution irrespective of gender and age of the population using the crosswalk without statistical evidence (Canbin and Ma 2010; Gates et al. 2006). Very few studies only focussed on crossing speed variations with respect to pedestrian characteristics and determined that pedestrian crossing speed was dependent upon age and disability, traffic control condition and group size based on a multi-factor analysis of variance (Gates et al. 2006).

In the third theme, the reviews were focussed on pedestrian noncompliance behaviour. Pedestrian noncompliance with traffic signal, rather than by vehicles, is one of the main causes of traffic accidents on an at-grade intersection. Compliance studies were performed to understand pedestrian behaviour in crosswalks of signalized intersections and promote a better pedestrian crossing environment (Zhouet al., 2011). Many of the earlier studies provided theoretical support on setting pedestrian crossing parameters without considering any statistical support (Li et al., 2005; Chen et al., 2011; Zhouet al., 2011). Initially pedestrian noncompliance were considered during flashing green time only and delay models were developed (Virkler 1998) but many pedestrians started to noncomplying with signal during red phases also (Li et al. 2005). Major reasons for pedestrian noncompliance are long cycle time (Li et al. 2005), poor traffic management (Virkler 1998) and variation in pedestrian behaviours (Zhouet al., 2011). Many studies examined the patterns of compliance and noncompliance with laws but fail to consider all possible significant parameters (Zhouet al., 2011) and reasons for noncompliance (Chen et al. 2011). Logistic regression models were described for pedestrians' noncompliance as a function of their characteristics, age, gender, and crossing group size (Zhouet al.,2011).

In the fourth theme, the studies were based on pedestrians-vehicular interactions at intersections. Most of the previous research works in pedestrian-vehicular interaction at crosswalk applications are focused on pedestrian accident analysis without any detailed statistical test results (Wang and Abdel-Aty, 2008; Kuan-min et al., 2010; Linget al., 2012). During pedestrian clearance time, pedestrians are facing interaction with vehicle movement because of pedestrian crossing speed variations and also pedestrians may encounter greater risk and conflict when they cross intersections in groups (Kuan-min et al. 2010; Qi and Yuan 2012). During pedestrian non-green phases, noncompliance pedestrians are facing vehicle interaction in crosswalk (Chen et al., 2011; Zhouet al., 2011) when pedestrians select a small gap size from vehicle front to conflict point and make a yielding decision to cross the intersection (Zhouet al., 2011). Another reason for pedestrian-vehicular interaction is driver's disobeying rules and conflicts induced by driver's behaviour of not giving way to pedestrians cross the intersection during pedestrian green phase time (Kuan-min et al. 2010). At most signalized intersections in developing countries, pedestrians are released together with the parallel right-turn vehicles, which results in frequent conflicts between the pedestrians and the turning vehicles in crosswalk (Linget al., 2012). Pedestrian focus to reduce their waiting time, they alter travel path or travel speed and cause conflict with right turning vehicles (Hubbard 2009). Pedestrian conflict with left turning vehicles also occur and crash mechanisms were used to develop generalized linear model (Wang and Abdel-Aty 2008) and binary logit model (Linget al., 2012) for pedestrian crash studies with limited influencing factors.

Existing literature indicates that many researches have conducted studies on pedestrian behaviour; few of them have considered pedestrian crossing behaviours at signalized intersections in developing countries. In addition, fewer studies have focussed on the pedestrian crossing speed variation and compliance rate without identifying influencing factors based on statistical tests and there is no study related to pedestrian arrival pattern distribution and pedestrian-vehicular interactions at signalized intersections. It is indicating that there is a need for analysis of pedestrian crossing behaviour that incorporates pedestrian arrival pattern, crossing speed, compliance behaviour and pedestrian-vehicular interaction with statistical investigation by considering all possible parameters under mixed traffic conditions in India. This study is an attempt in this direction.

3. Research objectives

The overall objective of this research is to study pedestrian crossing behaviours at signalized intersections under mixed traffic conditions. The specific objectives of the study are as follows: (a) examine the pedestrian arrival pattern and identify best fitting distribution with statistical performance evaluation; (b) investigate the factors affecting pedestrian crossing speed and fitting suitable distribution of crossing speed at signalized intersections; (c) identify the most significant factors affecting pedestrian compliance behaviour and find out the reasons for pedestrian noncompliance; and (d) determine the factors influencing pedestrian-vehicular interactions and finding probability of pedestrian interact with vehicle in crosswalk at signalized intersections under mixed traffic conditions by using logit model.

4. Data collection and methodology

4.1 Study Location

Mumbai is fifth most populous city in the world, with an estimated population of 12.5 million. Ten crosswalks from eight signalized intersections were selected in Mumbai suburban, India. The study sites selected were of typical four arm type signalized intersections with fixed traffic signal cycle lengths. From selected intersections, major road pedestrian crosswalks were considered for videography survey. Two video cameras were set up in the direction of pedestrian upstream to downstream movement and downstream to upstream movement at selected crosswalk in each intersection and one hour video surveys were conducted at these sites during peak hours. Signal times were measured from field by using a stop watch and length of crosswalk measured from field by using measuring wheel. A detailed description about selected study sites and collected samples are shown in Table 1.

Table 1 Information of the selected study sites

Location Name	*C/W Identity*	*Time of Survey*	*C/W length (m)*	*Green (s)*	*Flashing Green (s)*	*Red (s)*	*Cycle Time (s)*	*Ped flow per hr**
Link Road Junction	A	5.00-6.00pm	27	23	4	152	179	175
Malad Junction	B	5.30-6.30pm	22.4	26	3	149	178	395
Mahim Junction	C1	8.00-9.00am	13.5	19	3	121	143	272
	C2	8.00-9.00am	20	35	2	106	143	402
Mahatmagandhi Road Junction	D	9.00-10.00am	27.6	36	3	114	153	89
Holkar Junction	E1	5.00-6.00pm	31.5	22	3	121	146	337
	E2	5.00-6.00pm	25	25	3	55	83	84
Samaj Junction	F	8.30-9.30am	19	12	3	118	133	148
Chembur Naka Junction	G	8.15-9.15am	27	20	3	132	155	303
Andheri-Link Road Junction	H	5.00-6.00pm	27	19	3	138	160	271

Note: C/W indicates crosswalk and * represents bidirectional flow

4.2 Selected Variables for Pedestrian Behaviour Models

The required data were extracted from all of the above mentioned location videos by using ALLCapture® software. ALL Capture® is screen recording software and provides features such as video editing, insert captions, notes and special effects. The data were extracted with 0.05s accuracy level. The recorded video provided information about pedestrian characteristics, behaviour, traffic and geometric characteristics. The selected various variables used in this studyare shown in Table 2 with encode parameters based on literature review and field conditions. Totally 2476 pedestrians were clearly observed from recorded video and detailed information on pedestrian crossing behaviourwas obtained.

Table 2 List of variables and their definitions

Levels	*Variable*	*Description*
General Characteristics	Gender	0 for female pedestrian and 1 for male pedestrian
	Age	0 for child pedestrian (<18years), 1 for adult (18-60 years) and 2 for elder pedestrian (>60years)
Behavioural Characteristics	Platoon	0 for multi pedestrians and 1 for single pedestrian
	Direction	0 for pedestrian upstream to downstream movement (U2D) and 1 for pedestrian downstream to upstream movement (D2U)
	Crossing speed	Pedestrian crossing speed (m/s)
	Gap size	Time difference between pedestrian departing time and near by approaching vehicle to reach the pedestrian crosswalk
	Crossing type	0 for pedestrian travelling the crosswalk by running and 1 for pedestrian travelling by walking
	Waiting time	Pedestrian waiting to enter the crosswalk from non-green phase to green phase.
	Median delay	0 for pedestrian receiving delay at median and 1 for pedestrian not receiving delay at median while crossing the crosswalk.
	Interaction	0 for pedestrian not interact with vehicle in crosswalk and 1 for pedestrian interacting with vehicle in crosswalk.
	Compliance with signal	0 for pedestrian comply with traffic signal and 1 for pedestrian noncomplying with traffic signal.
Traffic and Roadway Characteristics	Crosswalk marking	0 for pedestrian walking in crosswalk marked area and 1 for pedestrian crossing in unmarked area
	Pedestrian arrival signal phase	0 for pedestrian arriving the crosswalk during pedestrian green phase, 1 for pedestrian arriving the crosswalk during pedestrian red phases and 2 for pedestrian arriving the crosswalk during pedestrian flashing red phases.
	Approaching vehicle direction	Pedestrian finding gap size from approaching vehicle and start crossing during pedestrian non-green phases. 0 for through movement vehicles, 1for right turning vehicle and 2 for left turning vehicles.
	Approaching vehicle type	Pedestrian accepting vehicle to cross the crosswalk during pedestrian non-green phases. 0 for Car (C), 1 for Two wheeler (TW), 2 for LCV, 3 for HCV and 4 for Auto (A).
	Approaching vehicle lane	The lane at which the first vehicle reaches the crosswalk during pedestrian noncompliance with traffic signal. From curb to median considered as 1,2,3

Pedestrian flows were considered for bi-directional movement during peak hour. The required data were extracted from all the selected location videos by using ALL Capture® software. The software provided a resolution of 20 images per 1sec interval and a total of 144000images were extracted from 1h video with two cameras. The required data were extracted from these imagesof all eight signalized intersections.

To identify significant parameters which influence on the pedestrian crossing behaviours and to describe the effect between two groups, a one way analysis of variance (ANOVA), Pearson correlation coefficient test and odd ratio (OR) test are applied and binary logit model is developed to identify the probability of pedestrian interact with vehicle by using SPSS and NLOGIT. NLOGIT is a complete econometrics and statistical package used to get full information about maximum likelihood estimator for a variety of multimodal choice models. Pedestrian crossing speed distribution and pedestrian arrival pattern distribution are tested and best fit identified by using Minitab 16.

5. Pedestrian crossing behaviour analysis

At present, there is no pedestrian crossing behaviour studies that has been examined completely based on all possible pedestrian crossing behaviour at signalized intersections under mixed traffic conditions. An attempt has been made in this paper to analyse pedestrian crossing behaviour like pedestrian arrival pattern, crossing speed, possible noncompliance behaviour of pedestrians, and pedestrian-vehicle interaction on crosswalk based on field observed data.

5.1 Pedestrian Arrival Pattern

Existing studies (Highway Capacity Manual 2010; Virkler 1998; Li et al. 2005)assumed that pedestrian arrival pattern followa uniform distribution at signalized intersections. The assumption of uniform arrival pattern fails to estimate accurate pedestrian waiting time delay. To estimate the time delay and to reflect the exact condition of pedestrians at signalized intersection, there is a need to identify the appropriate distribution for pedestrian arrival pattern. From the collected data, pedestrian arrival pattern has been analysed for both direction of pedestrian crossing movement and totally 14 directional pedestrian movements were examined at signalized intersections. Signal time was divided into equal intervals of 10 sec and at each interval pedestrian arrival was calculated from field video data at all the selected locations. Suitable fitting distributions were tested for observed pedestrian arrivals by using software Minitab® 16. Data of 15 min with 10 sec equal interval were considered for distribution fitting. All possible distributions like uniform, normal, lognormal, exponential, Weibull, gamma, logistic, log-logistic, Poisson, negative binomial and negative exponential distribution were tested with all location data.

Chi square test was conducted for goodness of fit for selected distributions. Chi square critical values were taken from chi square distribution table for 0.05 confidence levels and compared with chi square estimated values. If the difference between chi square estimated and critical is positive and the significant P value is greater than 0.05, the observed data follows particular distribution. Among 11 distributions including uniform, Poisson and negative binomial distribution were fitted with 14 locations. The best fit has been chosen by comparing the chi square differences from both the distributions at that particular intersections and the less positive difference in chi square represents the best fit of observed pedestrian arrivals.

Statistical performance evaluation such as mean absolute percentage error (MAPE) and root mean square error (RMSE) has been carried out to analyse the performance level of developed arrival models. MAPE (-0.0009) and RMSE (2.0702) values of Poisson model estimates are very less compared to MAPE (0.0364) and RMSE (2.1547) values of negative binomial model estimates. The negative value in MAPE shows that Poisson model overestimates but it has negligible error. Poisson distribution is found to be the best fit estimating the observed pedestrian arrival at 7 signalized intersections data and negative binomial distribution matches well with observed pedestrian arrivals at remaining 7 locations.

The main reasons for non-uniform distribution at these locations are due to the crossing of pedestrians as a group rather than as individuals, bunching of arrivals and noncompliance behaviour. Pedestrian arrival distribution models were compared using pedestrian hourly volume at crosswalk and pedestrian volumes were categorised in interval of 20ped for finding threshold level of best distribution fit. It is observed from the chi square values that the Poisson distribution model predicted arrivals exactly when the pedestrian flow rates are greater than 180 ped/hr whereas the negative binomial distribution model predicted accurately for flow rates areless than180 ped/hr.

5.2 Pedestrian Crossing Speed

Crossing time is the time that the pedestrian uses to travel in the crosswalk without including waiting time. Crossing speed is defined as the crossing distance divided by the crossing time. The crossing speeds of all identified pedestrians from video data were calculated at all the selected locations and the 15^{th} and 85^{th} percentile crossing speed are 1.035m/s and 1.429m/s respectively.

The average pedestrian crossing speed was found to be 1.29m/s and nearly equal to field value of 1.33m/s measured in China (Li et al. 2005) and also compared with other international average crossing speed values of 1.21m/s for US (Gates et al. 2006), 1.15m/s for Malaysia (Rahmanet al., 2012), 1.45m/s for HongKong (Lamet al., 2002) and 1.8m/s for London.

5.2.1 Factors affecting Pedestrian Crossing Speed

ANOVA test was performed to investigate the main factors that affect the pedestrian crossing speed at signalized intersections by using SPSS 16.0 software. Gender, age group, group size, crossing direction and signal phase during pedestrian departure are the parameters considered for ANOVA test which are also the parameters considered in most of the literatures.

From analysis, pedestrian gender, age, group size, crossing direction and departure signal had significant effect on pedestrian crossing speed at 95% confidence intervalwhere as expected, pedestrian gender (F=9.68, p=0.002 which is <0.005) had more significant effect on pedestrian crossing speed. Male pedestrian crossing speed (1.285) was always more than female pedestrians (1.212). Male pedestrians easily non-comply with traffic signal by increasing crossing speed. It is to be noted that pedestrian age (F=18.879, p=0.000 which is <0.005) also had significant effect on pedestrian crossing speed. Adult pedestrians make the largest portion in the classification and were found to have the fastest crossing speed compared to child and elderly pedestrians. Pedestrian group size (F=25.262, p=0.000 which is <0.005) had the most significant effect on crossing speed and pedestrian crossing speed of a group (1.203) was less than the crossing speed of a single pedestrian (1.304). In a group, each pedestrian depend on other pedestrians or leader pedestrian and thus tend to reduce or increase crossing speed. It is found from analysis that pedestrian crossing speed during non-green phase was more than pedestrian crossing speed during green phase (F=7.963, p=0.000 which is <0.005). The major reason for this was that pedestrians were always in a hurry to cross and do not comply with signal during non-green phase. Pedestrian crossing direction also had significant effect on crossing speed and U2D directional pedestrian crossing speed was higher than D2U directional pedestrian (F=10.525, p=0.001 which is <0.005).

5.2.2 Pedestrian Crossing Speed Distribution

The crossing speed of pedestrian is computed at all selected locations and suitable distribution function is fitted to the crossing speed. All the proposed distribution models were tried to fit with pedestrian crossing speed and found that the normal, lognormal, logistic, and loglogistic model yield suitable fitting results. The best fit distribution is identified by Kolmogorov-Smirnov test (KS test) and Anderson-Darling test (AD test). The data follows specified distribution if the values of KS sig and AD-P are greater than the chosen α-level and null hypothesis is accepted. Both the tests were conducted at 0.05 confidence level and the results are shown in Table 3 with estimated parameters of passing KS test models.

Table 3 Comparisons of goodness-of-fit of distribution models and estimated parameters for passing KS test distribution models

Location	*Volume (ped/hr)*	*Distribution*	*mu*	*sigma*	*KS Value*	*AD Value*	*P Value*
A	75	**lognormal**	0.1231	0.1415	**0.0605**	**0.452**	**0.267**
		Logistic	1.1366	0.0947	0.0616	0.691	0.042
		loglogistic	0.1227	0.0832	0.0665	0.627	0.066
		Normal	1.1423	0.1624	0.0622	0.605	0.113
B	223	lognormal	0.1187	0.1350	0.0179	0.632	0.099
		Logistic	1.1329	0.0893	0.0161	0.947	0.008
		loglogistic	0.1201	0.0790	0.0263	0.833	0.018
		Normal	1.1362	0.1524	**0.0150**	**0.757**	**0.050**
C	211	lognormal	0.1800	0.1479	0.0362	0.506	0.199
		Logistic	1.2077	0.1022	0.0373	0.584	0.089
		loglogistic	0.1834	0.0854	0.0435	0.724	0.035
		Normal	1.2102	0.1774	**0.0299**	**0.361**	**0.442**
D	141	**lognormal**	0.1788	0.1433	**0.0406**	**0.276**	**0.649**
		Logistic	1.2030	0.1005	0.0542	0.395	>0.250
		loglogistic	0.1796	0.0837	0.0420	0.350	>0.250
		Normal	1.2080	0.1727	0.0648	0.348	0.468
E	262	**Normal**	1.3217	0.1559	**0.0371**	**0.311**	**0.452**
F	95	**lognormal**	0.2374	0.1355	**0.0124**	**0.206**	**0.869**
		Logistic	1.2721	0.0984	0.0299	0.365	>0.250
		loglogistic	0.2366	0.0770	0.0238	0.226	>0.250
		Normal	1.2796	0.1755	0.0296	0.550	0.154
G	149	**lognormal**	0.1416	0.1497	**0.0141**	**0.787**	**0.040**
		Logistic	1.1644	0.0993	0.0366	0.661	0.050
		loglogistic	0.1468	0.0865	0.0246	0.870	0.014
		Normal	1.1648	0.1715	0.0273	0.490	0.218

From table 3, best fit was provided by lognormal distribution for pedestrian crossing speed at crosswalk when the pedestrian flow rate is less than 150ped/hr while normal distribution matches well when the flow rate is greater than 150 ped/hr. The combination of pedestrian crossing speed data from all locations does not follow any specified distributions. Johnson transformation was applied on the combined data and tested for normal distribution. It is seen that the P value for best fit is 0.159 (which is >0.05) and of bounded (Bounded System - SB) variable type with 0.64 value of Z fit. It is concluded that the overall pedestrian crossing speed data follows normal distribution with Johnson transformation.

Traffic signal timing for pedestrians is typically based on 15th percentile crossing speed. The 15th percentile speed of pedestrian is assumed as constant in IRC models (1.2m/s). The field analysis shows that the pedestrian crossing speed is varying related to the pedestrian age group. Thus a new design crossing speed for pedestrians has been defined using the field data at all the selected locations. Pedestrian crossing speed for design purposes has been obtained and was found to vary between 0.89 m/s to 1.05m/s.

5.3 Pedestrian Compliance Behaviour

The pedestrian compliance behaviour has been determined by direct observation from the field video data. Pedestrians using the crosswalk during pedestrian green phases are considered as compliance pedestrians while those who use them during non-green phases are considered as noncompliance pedestrians. Vehicle drivers have to stop or reduce vehicle speed to avoid interaction with noncompliance pedestrians.A case of pedestrian noncompliance with traffic signal is shown in Figure 1.

Figure 1. Pedestrian noncompliance behaviour with traffic signal at signalized intersections (a) crosswalk A1 (b) crosswalk G

The amount of pedestrians complying with traffic signal is 53%, indicating higher noncompliance being prevalent at highly populous regions. From results, average pedestrian noncompliance (47%) in Mumbai has also been compared with results from studies performed by Virkler(Virkler 1998) (69% for Columbia) and Li et al. (Li et al. 2005) (67% for China). It is inferred that in developing countries, the average pedestrian noncompliance rate is more or less the same, which requires special attention in designing pedestrian facilities, providing safe and adequate crosswalks at signalized intersections.

Reason for pedestrian noncompliance with signal was to reduce more waiting time or save time. Less or no traffic flow on roads results in noncompliance with traffic signal. In addition, more pedestrian red time, absence of crosswalk marking or crossing facilities and traffic assistants were reasons for pedestrian noncomplying with signal at signalized intersections.

5.4 Factors Influencing Pedestrian Noncompliance Behaviour

Based on 2476 pedestrian data, pedestrian noncompliance behaviour has been analysed, based on pedestrian characteristics (Gender, and age), behaviour (No. of pedestrian, crossing type, crossing speed, crosswalk utilization, and pedestrian direction) and traffic conditions (Approaching vehicle direction). Pearson's correlation coefficient test and ANOVA test were used to investigate the main factors that affect the pedestrian compliance with traffic signals at signalized intersections. Both the tests were performed in SPSS 16.0 software and the statistical results are shown in Table 4.

Table 4. Statistical results of factors affecting pedestrian compliance behaviour

Factor	*Pearson correlation*		*ANOVA Test*		*Significant*
	Correlation	*Sig*	*F Value*	*p value*	
Gender	0.066	0.001	10.916	0.001	Significant
Age	0.029	0.049	8.982	0.000	Significant
Group Size	-0.055	0.006	7.619	0.006	Significant
Run/Walk	0.154	0.000	26.780	0.000	Significant
Road Marking Usage	0.159	0.000	25.680	0.000	Significant
Approaching Vehicle Direction	0.146	0.000	20.485	0.000	Significant
Crossing Speed	0.017	0.481	2.485	0.000	Not Significant
Direction	0.01	0.647	0.210	0.647	Not Significant

From Table 4, it is clear that pedestrian gender, age, group size, crossing mode, road marking utilization and approaching vehicle direction had significant effect on pedestrian compliance behaviour at 95% confidence interval. Crossing speed and pedestrian direction make insignificant effect on pedestrian compliance behaviour. Pedestrian crossing choice between two groups was identified by odd ratio (OR) value.

5.4.1 Gender

The Sig value of Pearson correlation test (0.001) and p value (0.001) of ANOVA test are less than 0.05 implying that the correlation considered is significant. The sign of correlation coefficient (0.066) is positive; denoting that an increase in flow of male pedestrians would increase the rate of pedestrian noncompliance. The F value (10.916) of ANOVA test is greater than F critical value (3.9201) and it suggests that the gender parameter significantly affects the pedestrian compliance behaviour. From OR value, it can be seen that male pedestrians are more likely to non-comply with traffic signal at signalized intersections. It is hypothesized that the male pedestrians who have higher average crossing speed are finding gap size to cross the crosswalk, noncomplying with traffic signal than female pedestrians.

5.4.2 Age

ANOVA p value (0.000) is less than 0.05 and F value (8.982) is greater than F table (3.0718) value. It is seen that pedestrian age parameter significantly influences the pedestrian compliance behaviour. The sign of correlation coefficient is positive (0.029) indicates that an increase in the flow of adult pedestrians results in high rate of pedestrian noncompliance. The OR value of adult (0.472) pedestrian is less than the child (1.0) and elder (0.542) pedestrians. It clearly shows that noncompliance behaviour as well as average crossing speed of adult pedestrians is higher than that of other age groups of pedestrians, allowing them to non-comply frequently.

5.4.3 Platoon

The value of Pearson Sig (0.006) and ANOVA p (0.006) is less than 0.05 and the ANOVA F value (7.619) is greater than F table value (3.9201). It is indicated that group size of pedestrians have significant effect on pedestrian compliance behaviour with traffic signal. The sign of correlation coefficient is negative (-0.055) i.e., as the number of pedestrians in a group increases, the rate of pedestrian noncompliance increases. The OR value of single pedestrian (1.254) is more than one and it is clearly shown that single pedestrian tend to comply with signal. A group of pedestrians comprising of adult or elderly or child pedestrians tend to non-comply with traffic signal because pedestrian does not care about signal, increasing crossing speed and following other pedestrian in group, thus reducing the compliance rate.In pedestrian platoon movement, noncompliance of the leader results in an avalanche effect causing the followers to also be in noncompliance with the traffic signal and thus increase the rate of noncompliance.

5.4.4 Crossing Type

The result of Pearson Sig (0.000) and ANOVA p value (0.000) is less than 0.05 and the value of ANOVA F obtained (26.78) is greater than that of F table (3.9201). It is shown that pedestrian crossing type had most significant influence effect on pedestrian compliance behaviour. The sign of Pearson correlation coefficient is positive (0.154) i.e., as the flow of running pedestrian increases, the rate of pedestrian noncompliance also increases. The running pedestrian OR value (0.405) is less than walking pedestrian OR value. It is observed that the speed of the running noncomplying pedestrians were different in the crosswalk which depend on the gap size and the approaching vehicles. The rate of running pedestrians is higher in the non-green phase than during green phase of traffic signal.

5.4.5 Approaching Vehicle Direction

The Pearson Sig (0.000) and ANOVA p values (0.000) are less than 0.05 and ANOVA F obtained value (20.485) is greater than F table value (3.0718). The sign of Pearson correlation coefficient (0.146) is positive i.e., most of the noncompliance by the pedestrians are when the traffic movement is of accepting turning vehicle direction. The results indicated that pedestrians did not find difficulty when acceptable approaching vehicle is in left turning direction while noncomplying with traffic signal. Turning vehicle drivers were also reducing the vehicle speed while turning and the volume of such vehicles are also low compared to through movement vehicles, which favours pedestrian to find acceptable gap to use the crosswalk during pedestrian non-green phase.

5.4.6 Crosswalk Marking Usage

The value of Pearson Sig (0.000) and ANOVA p value (0.000) is less than 0.05 and the F obtained value (25.68) is greater than F critical value (3.9201). The pedestrian crosswalk marking utilization had significant effect on pedestrian compliance behaviour. Pearson correlation coefficient value is positive (0.159) i.e., the presence of crosswalk marking, reduce the rate of pedestrian noncompliance with traffic. It is observed that if crosswalk marking is present, most of the arriving pedestrian comply with traffic signal and wait for pedestrian green phase. Pedestrians non-comply with traffic signal at unmarked area or if crosswalk marking is absent.

5.5 Pedestrian-Vehicular Interactions

From the observed data, 47% of pedestrians' noncompliance with traffic signal and among them 23% of pedestrians has interacted with vehicle. During pedestrian green phase or vehicle flashing green phase, vehicle interactions occur with pedestrians due to driver's noncompliance behaviour. During pedestrian non-green phase or pedestrian flashing green phase, pedestrian interactions occur with vehicle due to pedestrian noncompliance behaviour. Due to interaction with vehicle, pedestrians face safety related problems and also delay in crosswalk at signalized intersections.A case of pedestrian-vehicular interaction is shown in Figure 2.

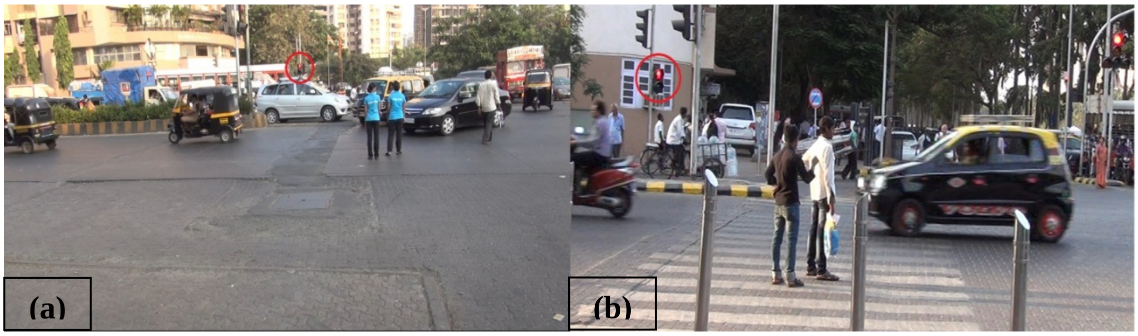

Figure 2. Pedestrian-Vehicular interaction at signalized intersections during pedestrian non-green phases (a) crosswalk A (b) crosswalk E 1

5.6 Factors Influencing Pedestrian-Vehicular Interaction

Pearson's correlation coefficient test and ANOVA test were used to examine the significant factors that influencing the pedestrian-vehicular interaction in crosswalk. Tests were performed in SPSS 16.0 software. The main factors analysed in statistical test were pedestrian gender, age, group size, crossing direction, gap size, crossing speed, approaching vehicle direction, approaching vehicle lane, approaching vehicle type, median delay and road marking usage and the statistical results are shown in Table 5.

From Table 5, pedestrian crossing direction, gap size, approaching vehicle direction and approaching vehicle lane had significant effect on pedestrian-vehicular interaction in crosswalk during pedestrian non-green phases.

The value of Pearson Sig and ANOVA p value is less than 0.05 and F value (3.912) is greater than F table (3.842) for pedestrian crossing direction. Pearson correlation coefficient (-0.095) was negative i.e., the interaction between pedestrian-vehicle in U2D direction is lower than D2U direction interaction.

Table 5. Statistical results of factors influencing pedestrian-vehicular interaction

Factor	*Coefficient*	*Sig*	*F Value*	*F Table*	*Sig*	*Significant*
Gender	-0.067	0.169	1.900	3.8415	0.169	Not Significant
Age	0.088	0.069	1.955	2.9957	0.143	Not Significant
Group	0.101	0.139	4.356	3.8415	0.037	Not Significant
Direction	-0.095	0.049	3.912	3.8415	0.049	Significant
Gap size	0.22	0.000	2.951	1.2826	0.000	Significant
Approaching Vehicle Direction	0.265	0.000	26.248	2.9957	0.000	Significant
Approaching vehicle	0.061	0.206	3.663	2.3719	0.006	Not Significant
Approaching Vehicle Lane	-0.337	0.000	15.223	2.0986	0.000	Significant
Crossing Speed	-0.056	0.246	1.77	1.0000	0.000	Not Significant
Median Delay	-0.027	0.582	0.303	3.8415	0.582	Not Significant
Road Marking Usage	-0.078	0.109	1.325	2.9957	0.267	Not Significant

5.6.1 Gap size

The results of Pearson sig (0.000) and ANOVA p value (0.000) is less than 0.05 and the value of ANOVA F obtained (2.951) is greater than F table (1.2826). It is shown that pedestrian accepting gap size had significant influence effect on pedestrian-vehicular interaction. The sign of Pearson correlation is positive i.e., as the pedestrian accepting gap size increases, the frequency of interaction between vehicles and pedestrians also decreases. Generally, pedestrian are accepting gap size from approaching vehicle and non-comply with vehicles. The acceptance of small gap size tends to interaction with vehicles in crosswalk.

5.6.2 Approaching Vehicle Lane

The value of Pearson Sig (0.000) and ANOVA p value (0.000) are less than 0.05 and the F value (15.223) is greater than F table value (2.0986) with high differences (13.1244). So it represents that approaching vehicle lane parameter had significant effect on pedestrian-vehicular interaction. The sign of Pearson correlation coefficient (-0.337) is negative, which is, the lane of approaching vehicle closer to the pedestrian then the possibilities of interaction between pedestrian and vehicle are less. Usually, pedestrians identify the gap size from the first lane of the crosswalk to the approaching vehicle and non-comply with traffic signal based on that. However, for lanes farther from the pedestrian, they are unable to identify gap size and receive interaction from vehicles which may result in accidents or delay to pedestrians.

5.7 Model Development

Logit model is used to predict binary response from binary predictor, used to predict categorical dependent variable based on predictor variables. Therefore, a binary logit model was defined as follows.

$$P(y_n) = \frac{e^X}{1+e^X} \quad (1)$$

$$X = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots\ldots + \beta_p x_p \quad (2)$$

where, $P(y_n)$= probability that pedestrian n interact with vehicle, x = characteristics that determine the probability of discrete outcome for n, β_p = estimating parameters, p = number of independent variables.

From Table 5, significant test were conducted from eleven selected parameters and four parameters had significant effects on pedestrian-vehicular intersections. A Binary Logit (BL) model is developed using four significant parameters. The model is used to predict the probability of pedestrian interaction with vehicle in crosswalk based on utility function. A BL model was developed in NLOGIT 4 software by using 80% of pedestrian samples. The model is described in Table 6.

Table 6 Binary Logit (BL) model test results

Variable	*Coefficient (β)*	*Standard error*	*t-value*	*p-value*
Approaching vehicle direction (x_1) (through, right, and left turn)	-0.469	0.148	10.084	0.001
Approaching vehicle lane (x_2) (curb to median)	0.489	0.108	20.651	0.000
Gap size (x_3)	-0.350	0.041	72.593	0.000
Pedestrian crossing direction (x_4) (U2D and D2U)	0.908	0.232	15.253	0.000
Binary logit model	$X = g(x) = -0.161 - 0.469x_1 + 0.489x_2 - 0.350x_3 + 0.908x_4$			
R-Squared Value	0.472			
Overall correct prediction	80.12%			

Note: t and p – values significant at 99% confidence level.

From the model, it is found that most of the pedestrian-vehicular interactions occur when pedestrians accept through movement vehicles and are very less with left turning vehicles. The frequency of pedestrian vehicular interaction increases when the vehicular gap size decreases.

The probability of pedestrians interacting with vehicles at crosswalk is calculated from Equation 1. The success prediction table, R-Square and Hosmer-Lemeshow (HL) test, which are widely used to test the logistic model's goodness of fit, is selected to judge the overall model prediction. The results show that the percentage of correct predictions of model is 80.12%. The value of R-square indicates a strong relationship of 47.2% between the predictors and the prediction. HL statistic has a significance of 0.050 which means that a good fit is provided by the model.

Of the collected data, 80% were used for development of model and remaining 20% of data were used for validation of the developed models. Two sets of 50 samples data were used for model validation. The percentage of success predictions of the model are 75.42% and 76.19% respectively. The values prove that the developed BL model has better prediction capabilities for pedestrian-vehicular interaction at crosswalk.

6. Conclusions

In this study, pedestrian crossing behaviours were examined by using 2476 pedestrian samples from eight different signalized intersections in Mumbai, India. Pedestrian crossing behaviour were analysed in terms of pedestrian arrival pattern, crossing speed, noncompliance behaviour and pedestrian-vehicular interaction. The following important inferences were drawn from the study,

1. Poisson distribution gives a close fit to pedestrian arrival pattern, where the pedestrian flow rates are greater than 180ped/hr whereas the negative binomial distribution predicts accurately for flow rate of less than 180ped/hr under mixed traffic conditions.
2. The lognormal distribution was adopted as the best fit for pedestrian crossing speed at crosswalks when the pedestrian flow rate is less than 150ped/hr and normal distribution predicted well for flow rate greater than150ped/hr.
3. Crossing speed and noncompliance rate of male pedestrians are more than female pedestrians when crossing the crosswalk.
4. Noncompliance of adult pedestrians is more than children and elder pedestrians. Their crossing speed also higher than other age groups, allowing them to non-comply with traffic signal.
5. A group of pedestrians tend to mostly non-comply with traffic signal than single pedestrians.
6. Pedestrians couldn't find any difficulty when an acceptable approaching vehicle is turning left while the pedestrian attempts to non-comply with traffic signal.
7. While noncomplying with traffic signal, the acceptance of small gap size with vehicles leads to frequent interactions.

The pedestrian arrival pattern followed Poisson and NB distribution with respect to pedestrian volume. The arrival pattern is useful to simulate pedestrian arrival at signalized intersections that represents the actual behaviour and also to compute accurate pedestrian waiting time delay with respect to non-uniform arrival pattern. With respect to pedestrian safety, critical parameter is the 15th percentile crossing speed rather than the mean crossing speed. Statistical evidences show that this is varying between 0.89m/s and 1.05m/s. This parameter can be used for developing design codes for pedestrian facilities at signalized intersections under mixed traffic conditions.

Long crosswalks make it difficult for the pedestrian to cross in the stipulated time with normal crossing speed. In addition to this, absence of refuge islands allows the pedestrians to run and non-comply with the signal during the red time. Presence of crosswalk markings would reduce pedestrian noncompliance behaviour. Non-compliance was found to be large among the pedestrians when the red phase is longer due to impatience caused by various factors. Providing an optimal green time for crossing pedestrians based on volume could decrease the rate of noncompliance at signalized intersection. Redesign traffic control devices and management measures to enhance pedestrian safety at signalized intersections.

Increased compliance among pedestrians would reduce pedestrian-vehicular interactions. Pedestrians estimate turning vehicles, non-comply with traffic signal and suffer interaction when there is insufficient gap. Establishment of separate lanes for turning vehicles could reduce pedestrian noncompliance and interaction with vehicles at signalized intersections. Research on pedestrian compliance behaviour and vehicular interaction are helpful to traffic planners and policy makers for better understanding of the pedestrian crossing behaviours for local conditions and also provide pedestrian facilities based on safety aspects, where pedestrian noncompliance are predominant at signalized intersections.

References

Braun & Roddin, 1978. NCHRP Report 189: Quantifying the Benefits of Separating Pedestrians and Vehicles. *Transportation Research Board, National Research Council*.

Canbin Huang & Ma, W., 2010. A Statistical Analysis of Pedestrian Speed on Signalized Intersection Crosswalk. *International Conference of Chinese Transportation Professionals, ASCE*, China, pp.1401–1407.

Chen, J. et al., 2011. Pedestrian Behaviour and Traffic Violations at Signalized Intersections. *International Conference of Chinese Transportation Professionals, ASCE*, China, pp.1103–1110.

Daamen, W. & Hoogendoorn, S., 2003. Experimental Research of Pedestrian Walking Behavior. *Transportation Research Record*, 1828(1), pp.20–30.

Gates, T.J. et al., 2006. Recommended Walking Speeds for Pedestrian Clearance Timing Based on Pedestrian Characteristics. *Transportation Research Record: Annual Meeting (CD-Rom)*, Washington.

Highway Capacity Manual, 2010. *Transportation Research Board (TRB): National Research Council*, Washington, D.C.: Transportation Research Board (TRB): National Research Council.

Hubbard, S., 2009. Right turns on green and pedestrian level of service: Statistical assessment. *Journal of Transportation Engineering*, pp.153–159.

Indian Road Congress (IRC), 1985. *Guidelines on Design and Installation of Road Traffic Signals*, New Delhi, India.

Kuan-min, C. et al., 2010. Towards the pedestrian delay estimation at intersections under vehicular platoon caused conflicts. *Scientific Research and Essays*, 5(9), pp.941–947.

Lam, W.H.K., Lee, J.Y.S. & Cheung, C.Y., 2002. A study of the bi-directional pedestrian flow characteristics at Hong Kong signalized crosswalk facilities. *Transportation*, 29(2), pp.169–192.

Laxman, K.K., Rastogi, R. & Chandra, S., 2010. Pedestrian Flow Characteristics in Mixed Traffic Conditions. *Journal of Urban Planning and Development*, 136(1), pp.23–33.

Li, Q. et al., 2005. Pedestrian delay estimation at signalized intersections in developing cities. *Transportation Research Part A: Policy and Practice*, 39(1), pp.61–73.

Ling, Z., Ni, Y. & Keping, L., 2012. Modeling Interactions between Pedestrians and Right turn Vehicles at Signalized Intersections. *COTA International Conference of Transportation Professionals*, pp.2072–2084.

Lipovac, K. et al., 2013. Pedestrian Behavior at Signalized Pedestrian Crossings. *Journal of Transportation Engineering*, 139(2), pp.165–172.

Marisamynathan & Vedagiri, 2013. Modeling Pedestrian Delay at Signalized Intersection Crosswalks under Mixed Traffic Condition ELSEVIER, ed. *Procedia - Social and Behavioral Sciences*, 104, pp.708–717.

Ministry of Road Transport and Highway, 2012. Government of india ministry of road transport & highways transport research wing, New Delhi, India.

Nagraj, R. & Vedagiri, P., 2013. Modeling pedestrian delay and level of service at signalized intersections crosswalks under mixed traffic condition. *Transportation Research Record: Journal of the Transportation Research Board*, 2394, pp.70–76.

Qi, Y. & Yuan, P., 2012. Pedestrian Safety at Intersections Under Control of Permissive Left-Turn Signal. *Transportation Research Record: Journal of the Transportation Research Board*, pp.91–99.

Rahman, K., Ghani, N.A. & Kamil, Anton Abdulbasah Mustafa, A., 2012. Analysis of Pedestrian Free Flow Walking Speed in a Least Developing Country : A Factorial Design Study. *Research Journal of Applied Sciences, Engineering and Technology*, 4(21), pp.4299–4304.

Ren, G. et al., 2011. Crossing Behaviors of Pedestrians at Signalized Intersections. *Transportation Research Record: Journal of the Transportation Research Board*, 2264, pp.65–73.

Virkler, M.R., 1998. Pedestrian Compliance Effects on Signal Delay. *Transportation Research Record: Journal of the Transportation Research Board*, 1636(1), pp.88–91.

Wang, X. & Abdel-Aty, M., 2008. Modeling left-turn crash occurrence at signalized intersections by conflicting patterns. *Accident; analysis and prevention*, 40(1), pp.76–88.

Xie, D., Gao, Z. & Zhao, Xiao-mei and Wang, D.Z.W., 2012. Cellular Automaton Modeling of the Interaction between Vehicles and Pedestrians at Signalized Crosswalk. *Journal of Transportation Engineering*, 138(12), pp.1442–1452.

Ying-feng, L., Zhongke, S. & Zhirna, Z., 2009. Estimation of Probability of Swarming Pedestrians Violation at Signalized Intersections in Developing Cities. *Journal of Southwest Jiaotong University*, 17(1), pp.80–85.

Yordphol, B., Siang, S. & Division, T., 1986. Pedestrian Characteristics Study in Singapore. *Journal of Transportation Engineering*, 112(3), pp.229–235.

Zhou, Z. ping, Ren, G. & Wang, W., 2011. Modeling Violations of Pedestrian Road-crossing Behavior at Signalized Intersections. *International Conference of Chinese Transportation Professionals , ASCE*, pp.2490–2499.