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Pragmatic Modeling of Pedestrian Jay walking Behaviour at Signalised Intersections in Urban Area

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In developing countries, people often jaywalk and indulge in irregular/illicit crossing at signalised crossings which leads to an exponential increase in odds of fatal accidents. This in turn reduces the service quality of signalised crosswalks. Hence, an observational and field study have been undertaken to analyse and model the pedestrian jaywalking behaviour at prominent signalised intersections in an urban Indian city. The authors have collected pedestrian, flow, geometric and crosswalk characteristics using the video-graphic technique followed by the statistical techniques (Multi-Correlation and Exploratory Factor Analysis). The results specify 7 principal factors (socio-demographics, crossing pattern, arrival attributes, road features, dimensions, physical attributes and flow physiognomies) of the pedestrian jaywalking index. Further, binary logit model has identified 7 significant variables namely gender, crossing pattern, type of signal at arrival, number of lanes, width of crosswalk, presence of guard rails and average pedestrian delay in determining the probability of pedestrian jaywalking with 90.39% success rate. Moreover, the area under Receiver Operating Characteristic (ROC) curve (0.891) directs an excellent level of discrimination. The authors suggest to use the developed model by the transport professionals in the evaluation of pedestrian jaywalking behaviour and dealing with safety issues at signalised crosswalks; thus, improving the LOS.

Keywords: Signalised crossings, Jaywalking behaviour, Crosswalk characteristics, Socio-demographics, Binary logit model, ROC curve

1 Introduction

Pedestrian safety has become a serious traffic safety problem nowadays due to rapid urbanization, high population and vehicular density, lack of obedience to traffic regulations by road users i.e., drivers non-yielding and pedestrians jaywalking behaviour. According to latest report on Road Accidents in India (released by MORTH in 2019)[1], arise of 31% in numbers of road crashes and 25.6% in fatal road crashes have been observed in the past ten years. Road accidents have increased by around 0.46% during 2018, and fatalities resulting from these accidents have risen by about 2.4%.Cyclists, pedestrians and two-wheeler riders have 54% share of fatalities in road accidents. Statistics also shows that traffic junctions are points of conflict and hence, are prone to road accidents. In 2018, about 37% of the total accidents took place on junctions itself. According to PRS (Policy Research Studies) Legislative Research[2], India; the pedestrian fatalities mainly occur at crosswalks/junctions due to lack of pedestrian facilities and pedestrian's negligent behaviour in abiding the traffic rules while crossing (i.e., crossing during pedestrian red). Also, Mohan *et al.*[3], indicates that, about 60% of accidents occurred in urban areas with 85% of those accidents, occurred at crosswalks. This indicates high pedestrian–vehicle conflicts at the crosswalk locations[4].

At signalised intersections, lack of adherence to traffic rules/regulations by drivers (i.e., crossing during red light) and encroachment of zebra crossing by vehicles mainly encourage pedestrians either to engage in erratic crossing in order to gain priority/right of way over the approaching vehicles or cross at undesignated/un-marked locations. This gives rise to jaywalking by the pedestrians at signalised crosswalks and are the major cause of pedestrian-vehicle conflicts[5,6]. Therefore, pedestrian road crossing behaviour has emerged out to be the matter of great concern for traffic flow related problems in urban areas. This arises the need to study the behaviour of pedestrians and analyse the pedestrians' decision to jaywalk on road crossing location in developing countries like India.

In broad terms, jaywalking means either crossing the road illicitly without any regard for approaching traffic or non-compliance with the pedestrian signals (at signalised junctions). In laymen terms,

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jaywalking occurs usually when a pedestrian crosses a street that has traffic, other than at a suitable crossing point, or otherwise in contempt of traffic rules. Pedestrians who cross within width of zebra marking (varying between 2-4m as per IRC) are said to be complying with the crossing location and pedestrians with their crossing paths partially in the crosswalk area are known as partial jaywalkers[7].This indicates that jaywalking is directly related to the crossing pattern of the pedestrians.

The literature also reveals that in India, pedestrian usually follows four type of crossing movements at intersections- one-stage perpendicular or oblique (crossing in one go without stopping at median)and two-stage perpendicular or oblique (crossing in two stages by stopping at the median)[8-9]. Another simplified classification of crossing stages is- single-stage, two-stage and rolling-stage. Pedestrians usually prefer two-stage crossing with one-way traffic movement (divided carriageway), whereas single or rolling stage crossing on two-way roads (un-divided carriageways); which undoubtedly saves crossing time but jeopardizes the safety of the pedestrians[10]. A study conducted by Paul and Rajbonshi[11]reckons that most of the jaywalking behaviour associates with the rolling behaviour and oblique crossing pattern of the pedestrians[11].

Numerous studies have endeavoured to identify the factors influencing the crossing/jaywalking behaviour of pedestrians such as socio-demographics (age, gender, group size, marital status), gap size and waiting time, baggage effect (Rosenbloom[12], Kadali *et al.*[13], Bansal *et al.*[14]); approaching vehicle type and vehicular speed (Shaaban[15]), speed of pedestrians (Bansal *et al.*[16]); geometric features, site conditions and environmental characteristics (number of traffic lanes, presence of pedestrian crossing signals and central traffic islands) (Brosseau *et al.*[17], Shaaban *et al.*[18]); pedestrians' crossing location decisions (Ma *et al.*[19]); vehicular gap acceptance (Pratelli *et al.*[20]);effect of traffic engineering and control measures (traffic rules and regulation compliance) (Schattler*et al.*[21], Hubbard *et al.*[22]). Zhou *et al.*[23] and Guo *et al.*[24] indicate that male pedestrians have more tendencies to disrupt traffic rules and cross in risky situations (jaywalk) than their female counter parts. The literature also depicts that elderly people have less tendency to jaywalk than the other age-group people (children, young and middle-aged) because of higher obligation for traffic signals at controlled pedestrian crossings and signalized junctions (Lobjois and Cavallo[25], Zhuang and Wu[26]).Studies conducted by Holland and Hill[27] and Ren et al.[28]portray that pedestrian with driving experience left smaller safety margins than non-drivers, indicating selection of gap and judgement of traffic being the potential determinants of jaywalking behaviour of the pedestrian. Koh and Wong[29] have employed binary log it model and reveal that type of gap and the location of crossing (i.e., designated zebra crossing or un-designated crossing point) majorly influence pedestrians' crossing decisions. Ma et al.[30]in their research also reveal that illegal crossings occur with a higher probability for "crossing outside of a crosswalk" as compared to "crossing at a red light". The literature also indicates that log it models yield better results as compared to the conventional regression methods in characterizing the effects of explanatory variables used for predicting the probability of jaywalking[12,17].

From the above literature, it is evident that the effects of influencing variables vary with the site location. The mixed traffic conditions and different operability characteristics of signals at intersections prevailing in developing country like India affects the pedestrians' perceptions towards crossing. This formulates the basis for analysing the crossing behaviour and determining the factors responsible for pedestrian jaywalking decision in Chandigarh, one of the well-planned cities of India with the heterogeneous traffic conditions.

2 Materials and Methods

2.1 Identification of Study Location

The location for studying the pedestrian jaywalking behaviour and modeling the pedestrian crossing choices is based on the amalgamation of land uses, road width and the type of intersection. Data was collected from 36 signalised crosswalks of 9 signalised intersections, Chandigarh city, India. A typical representation (aerial view) of the study area is illustrated in Fig. 1. During 2014-2018, out of total 615 lives claimed during road accidents, 196 were pedestrians accounting for 31.87% of the total deaths[31]. Most of the accidents took place at crosswalks which arises the need to study the pedestrian jaywalking behaviour at the time of crossing.

2.2 Identification of Influencing/Explanatory Variables

At each crosswalk, the video recording was carried out for the peak hour in the morning in order to capture pedestrian and vehicular movements. For the

Fig. 1 — Aerial view of study area

present study, Total 2508 pedestrian data were collected from 36 signalised crosswalks (equipped with both traffic and pedestrian signals).

At crosswalks with pedestrian phase signals, proportion of male pedestrians (58.57%) was observed to be higher than the female counterparts (41.43%). 33.57% of pedestrians were of age group between 18-30 years, followed by 26.40% in 30-45 years age group, 22.17% pedestrians are of 18 years and below, 13.60% pedestrians in 45-60 years age group and 4.26% pedestrians are above 60 years. The proportion of pedestrians crossing alone (58.57%) exceeded persons crossing in pairs (34.13%) or in group (7.30%). Of all the pedestrians, 28.87% were carrying the baggage and 2.15% people were using the mobile phones. Further, it was found that 64.51% of pedestrians followed the one-stage crossing, and 35.49% followed the two-stage crossing. The most adopted crossing pattern was one-stage perpendicular (22.89%) followed by one-stage mixed (22.17%), one-stage oblique (19.46%), two-stage mixed (13.28%), two-stage oblique (11.12%) and two-stage perpendicular (11.08%). Majority of the pedestrians (35.29%) partly used the crosswalk and 33.69% pedestrians did not use the crosswalk. Rest of pedestrians (31.02%) crossed at the designated crosswalk locations.

The geometric characteristics of the study area indicate that the width of crosswalks varied from 2.86 to 3.25 m whereas, the length of crosswalks varied over the wide range from 12.40 to 35.10 m. The width of pedestrian island also varied for different crosswalks between 4.5-25.0 m. Of the total 36 crosswalks, 35 crosswalks were divided carriageways (four-lane, six-lane or eight-lane) whereas one of the crosswalks was three-lane undivided carriageway. 38.89% of the total crosswalks (14 crosswalks) were observed to have highly visible markings, 50.0% (18 crosswalks) had moderately visible markings whereas 2.78% (1 crosswalk) had slightly visible markings. Rest 8.33% (3 crosswalks) did not have any markings at all. Of total 36 crosswalks, 22.22% (8 crosswalks) were observed to have very good surface condition and 50.0% (18 crosswalks) were observed to have good surface condition. 19.45% (7 crosswalks) surface condition was observed as fair (average) whereas 8.33% (3 crosswalks) had poor surface condition. Of the total 36 crosswalks, only 4 crosswalks (11.11%) had raised table-top crossing. All 36 crosswalks had refuge islands/central islands except one crosswalk that was undivided. It is also observed that 33.33% crosswalks (12 crosswalks) had fully operational separate cyclist crossing, whereas 22.22% of crosswalks (8 crosswalks) cycle paths were in semi-operational condition (under-construction). Rest 44.45% (16 crosswalks) did not have separate cyclist crossings. 22.22% (8 crosswalks) were furnished with the curb ramps and 52.78% (19 crosswalks) were equipped with the guard rails. Although, the nature of land-use of crosswalk sites was majorly mixed type (61.11%) but certain sites also had commercial land-use type (38.89%).

The pedestrian signal timings were observed to be different from the traffic signal timings. The pedestrian red time ranged between 43-159 s and green time was found to vary between 17-75 s. The flashing green time was observed as either 2 or 3 s. The minimum pedestrian arrival rate was observed to be 20 ped/hour (0.3 ped/min) and the maximum was observed as 191 ped/hour (3.18 ped/min). The field delay was observed at each crosswalk by averaging the individual delays for the pedestrian arrival rate both for pedestrian compliance and non-compliance behaviour. Individual delay was calculated by subtracting the ideal crossing time (time taken by a randomly selected pedestrian who has not encountered any conflicts) from the field crossing time (time from the arrival of a pedestrian at one end of the curb to reach the other end of the curb). The field delay includes waiting time, crossing time and pedestrian-vehicle interaction time delay. The average pedestrian delay varied between 5.4-22.19 s.

The average pedestrian speed ranged between 1.29-1.55 m/s. The conflicting traffic flow observed during the survey ranged between 2099-4071 PCU/h with the mean traffic speed between 40.6-52.5 km/h. Out of total 2508 pedestrians observed, 1252 (49.92%)

pedestrians arrived during red or flashing green signals and rest 1256 (50.08%) pedestrians entered the crosswalk when the signal was green. The rate of compliance with the traffic signal was observed to be 50.96% indicating almost equal proportion of pedestrians complying with signals and not complying with signals (49.04%). Of the total 2508 pedestrians (either arriving during red or green) observed, 1846 (73.60%) pedestrians were found jaywalking i.e., crossing a roadway with traffic at a site other than a suitable crossing point, or otherwise in disregard of traffic rules (non-compliance). Also. Of the total pedestrians, 1180 (47.05%) pedestrians experienced delay due to pedestrian-vehicle interaction caused at crosswalk during pedestrian green or non-green phase. It was also observed that the time lag between pedestrian entering crosswalk and vehicle arriving crosswalk varied between 2.89-26.48 s.

Out of total 2508 pedestrians observed, 1846 pedestrians (73.60%) were found jaywalking. In order to identify the variables prompting the pedestrian jaywalking decision, the modeling was carried out using Logit Regression technique. Table 1 represents the data set used for modeling jaywalking behaviour which includes pedestrian demographics, crossing characteristics, geometric features, flow and operability features of the signalised crosswalks. Although, the nature of land-use of crosswalk sites was majorly of mixed type but certain sites also had commercial land-use type. The signal cycle was found to vary between 100-223 seconds. The minimum pedestrian arrival rate was observed to be 0.3 pedestrian/min and the maximum was 3.18 pedestrian/min.Before modeling, the association of pedestrian demographic and crossing characteristics with the pedestrian jaywalking was checked using statistical tests.Further, Exploratory Factor Analysis (EFA) was employed to extract the influencing variables affecting the pedestrian's decision to jaywalk and formulate the pedestrian jaywalking index.

2.3 Pedestrian Jaywalking Index

Pedestrian Jaywalking Index is defined as the set of primary factors consisting of the influencing variables (responsible for jaywalking of pedestrians) obtained after conversion of all variables into different groups on the basis of dispersion in their variances. Based on Exploratory factor analysis, the main factors were extracted from pedestrian characteristics, geometric features, and flow and operability characteristics. Further, modeling of jaywalking index was carried out using Binary Logit/Logistics model (BL Model) with the help of SPSS software (Statistical Product and Service Solutions)to define the prediction power of the identified factors. For modeling, 80% of data (2008 pedestrian's data) was used and rest 20% data (500 pedestrian's data) was used for validation purpose. The calibration of model, accuracy check of the parameters and goodness-of-fit tests of the model were performed using the same statistical program.

3 Results and Discussions

3.1 Statistical Investigation of Influencing Variables

The results of statistical analysis of the various influencing/explanatory variables and their association with the pedestrian jaywalking behaviour are presented in the subsequent sections.

3.1.1 Effect of Pedestrian Socio-Demographic Features (Gender, Age-Group, Group Size) on Jaywalking Behaviour

The socio-demographic characteristics like gender, age, group size and crossing pattern of pedestrians were observed using video graphic technique. More than 70% of the pedestrians of different demographics indulged in jaywalking either by entering the crosswalk before the pedestrian signal finally turns green (non-complying with the signals) or not conforming with the crossing location. Among the total jaywalked pedestrians, 57.26% of pedestrians were males and 42.74% pedestrians were females. Most of the pedestrians (33.80%) jaywalking was in the age group of 18-30 years (estimated approximately on the basis of deduction capability of authors). Also, most pedestrians (54.06%) jaywalked while crossing alone. Further, the association of pedestrian demographics and jaywalking is checked using Chi-square statistics along with the OR statistics and the results are presented in Table 2**.** It was observed that of the total males, 71.95% of male pedestrians and of the total females, 75.946% of females jaywalked. The results of Chi-Square test indicate that a significant association exists between gender and jaywalking behaviour $\{\chi^2 (1) = 4.974, p = 0.026\}$. Further, the odds-ratio statistical value (0.813 with 95% CI between 0.678-0.975) depicts that the males have less tendency to jaywalk than females. This may be due to casual approach towards crossing by females. This may be either due to non-conformity to the traffic signals by females, following the

Table 1 — Collection of data for different variables at signalised crosswalks

Variable	Type of Variable	Attributes		Count	%age
Pedestrian Socio-Demographic Characteristics					
Gender	Nominal	Male		1469	58.57%
		Female		1039	41.43%
Age (Estimated approximately on the basis of deduction capability of authors)	Nominal/ Ordinal	≤18		556	22.17%
		18-30		842	33.57%
		30-45		662	26.40%
		45-60		341	13.60%
		>60		107	4.26%
Group Size	Nominal	1		1469	58.57%
		2		856	34.13%
		≥3		183	7.30%
Baggage	Continuous	--		724	28.87%
Mobile	Continuous	--		54	2.15%
Pedestrian Crossing Characteristics					
Crossing Pattern	Nominal	One-Stage	Perpendicular	574	22.89%
			Oblique	488	19.46%
			Mixed	556	22.17%
		Two-Stage	Perpendicular	278	11.08%
			Oblique	279	11.12%
			Mixed	333	13.28%
Crosswalk Usability	Nominal	Completely Used		778	31.02%
		Partly Used		885	35.29%
		Not Used		845	33.69%
Flow and Operability Characteristics at Crosswalks					
Pedestrian Signal Timings (s)	Continuous	Red		Min 43 Max 159	
		Green		Min 17 Max 75	
Pedestrian Flow (ped/h)	Continuous	-- --		Min 20 Max 191	
Average Pedestrian Speed (m/s)	Continuous	-- --		Min 1.29 Max 1.55	
Average Pedestrian Delay (s)	Continuous	-- --		Min 5.4 Max 17.69	
Conflicting Traffic Flow (PCU/h)	Continuous	-- --		Min 2099 Max 4071	
Average Vehicular Speed (km/h)	Continuous	--		Min 40.6 Max 52.5	
Pedestrian Arrival Rate (ped/min)	Continuous	--		Min 0.30 Max 3.18	
Type of Signal at Arrival	Nominal	Green		1256	50.08%
		Red/Flashing Green		1252	49.92%
Signal Compliance	Continuous	Compliant (Crossing on Green) *	Arriving on Green	767	60.02%
			Arriving on Red	511	39.98%
			Total	1278	50.96%
		Non-Compliant (Crossing on Red) **	Arriving on Green	489	39.76%
			Arriving on Red	741	60.24%
			Total	1230	49.04%
Jaywalking Behaviour	Nominal	No		662	26.40%
		Yes		1846	73.60%
Geometric Characteristics					
Width of Crosswalk (m)	Continuous	-- --		Min 2.86 Max 3.25	

(*Contd.*)

Table 1 — Collection of data for different variables at signalised crosswalks (*Contd.*)

Variable	Type of Variable	Attributes	Count	
Length of Crosswalk (m)	Continuous	--	Min 12.40	
		--	Max 35.10	
Width of Pedestrian Island (m)	Continuous	--	Min 4.50	
			Max 25.0	
Classification of Road	Nominal	Three-Lane Undivided	1	2.78%
		Four-Lane Divided	16	44.44%
		Six-Lane Divided	18	50.00%
		Eight-Lane Divided	1	2.78%
Number of Lanes	Continuous	--	Min 3 lanes	
			Max 8 lanes	
Visibility of Crosswalk Markings	Ordinal	Not Visible	3	8.33%
		Slightly Visible	1	2.78%
		Moderately Visible	18	50.00%
		Highly Visible	14	38.89%
Crosswalk Surface Condition	Ordinal	Very Poor	0	0.00%
		Poor	3	8.33%
		Fair	7	19.45%
		Good	18	50.00%
		Very Good	8	22.22%
Level of Crosswalk	Nominal	Level	32	88.89%
		Raised	4	11.11%
Presence of Refuge Islands/Central Islands	Nominal	No	1	2.78%
		Yes	35	97.22%
Separate Bicycle Path for Crossing of Cyclists	Ordinal	Not Available	16	44.45%
		Semi-Operational	8	22.22%
		Fully-Operational	12	33.33%
Presence of Curb Ramps	Nominal	No	28	77.78%
		Yes	8	22.22%
Presence of Guard Rails	Nominal	No	17	44.22%
		Yes	19	52.78%
		Nature of Land-Use		
Nature of Land-Use	Nominal	Educational	0	0.00%
		Commercial	14	38.89%
		Residential	0	0.00%
		Shopping	0	0.00%
		Recreational	0	0.00%
		Mixed	22	61.11%

Note: *Pedestrian arriving on red is said to be compliant if the pedestrian crosses at the start of green signal or the pedestrian starts crossing at red but the signal changes to green during crossing.

**Pedestrians arriving on green is said to be non-compliant if the pedestrian crosses at the start of red signal or the pedestrian starts crossing at green but the signal changes to red during crossing.

footsteps of their male counterparts, or the casual approach towards crossing.

The age-wise distribution reflects that of all the pedestrians of age above 60 years, (79.44%) were found jaywalking with the casual approach towards crossing. For the age-group 30-45 years, 71.90% of pedestrians jaywalked. The Chi-Square test indicates that no significant association exists between age group and jaywalking $\{\chi^2 (4) = 3.047, p = 0.550\}$. The OR values indicate that for the pedestrians either ≤18 years, 18-30 years or >45 years are more inclined to jaywalk in comparison to the pedestrians lying in the age-group of 30-45 years. This suggests that people above 45 years age group tend to commit more violations and non-comply with the suitable crossing location in order to save time and energy. These results are in contradiction to the previous literature as people above 45 years of age are observed to cross near to their destination centres irrespective of the crosswalk location. Also, pedestrians in the age group of ≤30 years are poised about their instincts to evade danger due to their more speed and flexibility; thus, overlook the traffic and non-comply with the signals.

Table 2 — OR Statistics for Gender, Age, and Group Size on Jaywalking Behaviour

Statistics	Gender		Age (X) (Years)					Group Size		
	Male	Female	≤18	18<X≤30	30<X≤45.	45<X≤60	>60	1	2	≥3
N	1469	1039	556	842	662	341	107	1469	856	183
Jaywalking										
N	1057	789	408	624	476	253	85	998	698	150
%	71.95	75.94	73.38	74.11	71.90	74.19	79.44	67.94	81.54	81.97
No Jaywalking										
N	412	250	148	218	186	88	22	471	158	33
%	28.05	24.06	26.62	25.89	28.10	25.81	20.56	32.06	18.46	18.03
OR	0.813	1	1.077	1.118	1	1.123	1.51	1	2.085	2.145
95% CI of OR	0.678 - 0.975	--	0.836 - 1.388	0.889 - 1.407	--	0.836 - 1.510	0.917 - 2.485	--	1.699 - 2.558	1.449 - 3.176
*p value**	0.026				0.550				0.000	
Df	1				4				2	
χ^2	4.974				3.047				58.631	

Note: N = Total Pedestrians, n = Pedestrians in respective categories, OR= Odd's Ratio, CI- Confidence Interval, df = Degree of Freedom. *Significance level (p) <0.05 means significant association exists between two groups for that parameter.

For the different group size, 81.97% proportion of pedestrians crossing in group of more than two were found jaywalking whereas pedestrians crossing alone had 67.94% jaywalking rate. The Chi-Square tells that there is significant association between pedestrians crossing either alone, in a pair or in a group of more than two, and jaywalking behaviour {χ^2 (2) = 58.631, p = 0.000}. Table 2 also depicts that either pedestrians crossing in a group of more than two (OR=2.145) or crossing in a pair (OR=2.085) tend to jaywalk more as compared to the pedestrians crossing alone. This may be due to the mindset of pedestrians which get influenced by the behaviour of others in a group. Pedestrians crossing in a group more likely follow their peer's behaviour and results in jaywalking.

3.1.2 Effect of Pedestrian Crossing Pattern on Jaywalking Behaviour

Among the total jaywalking pedestrians, 65.44 % pedestrians followed one-stage crossing and rest 34.56% followed two-stage crossing. Of jaywalked pedestrians, 24.86% adopted one-stage mixed pattern (partially perpendicular and partially oblique) crossing followed by 21.61% of the pedestrians crossing in one-stage oblique fashion, 18.96% walking perpendicularly in one-stage over the crosswalk area, 14.69% following two-stage mixed pattern crossing, 11.97% crossing in two-stages in oblique manner and 7.91% adopting two-stage perpendicular pattern for crossing. Majority of the pedestrians following either oblique or mixed crossing pattern were indulged in jaywalking (72.5%). The probable reason behind jaywalking is either pedestrians' unawareness about the true significance of the cycle length or eagerness to cross at the location which is relatively closer to their final destination irrespective of the designated crosswalk location. Further, the association of crossing pattern and jaywalking is checked using Chi-square statistics whose results along with the OR statistics has been presented in Table 3**.** The Chi-Square value {χ^2 (5) = 165.262, p = 0.000} confirms a strong association between the crossing pattern and jaywalking behaviour of pedestrians. Further, the odds ratio statistics reflect that pedestrians jaywalking (OR = 1.164) are inclined to adopt one-stage crossing as compared to the two-stage crossing. This indicates the tendency of pedestrians to adopt the shortest crossing distance without any halt.

3.1.3 Effect of Operability Characteristics on Jaywalking Behaviour

The flow and operability characteristics are also considered to assess the vehicle-pedestrian accident risk that will facilitate in accurate prediction of pedestrian crossing/jaywalking decision. It was observed that among the jaywalking pedestrians, 48.16% pedestrians arrived at the time of green signal and rest 51.84% pedestrians arrived during red signal. The Chi-square value indicates that variable type of signal at arrival of pedestrian is significantly associated with the jaywalking behaviour of the pedestrian {$\chi^2(1) = 10329$, $p = 0.000$}. The OR statistics (OR=0.747) indicates that pedestrians arriving at red signal have more tendency to jaywalk as compared to pedestrians arriving at green signal. The other variables such as pedestrian signal timings, average pedestrian crossing speed, average pedestrian delay, conflicting traffic flow, average vehicular speed and pedestrian arrival rate effect on pedestrian jaywalking behaviour was further checked using correlation analysis (Eta correlation). The correlation results revealed that pedestrian signal timings (R = 0.671, p = 0.000), average pedestrian delay (R = 0.577, p = 0.000) and pedestrian arrival rate (R = 0.707, p = 0.000) were significantly correlated with the pedestrian jaywalking, hence act as predictors for predicting jaywalking behaviour.

Table 3 — OR statistics for gender, age, and group size on Jaywalking behaviour

Statistics	Jaywalking Behaviour	
	Jaywalk	No Jaywalk
N	1846	662
One-Stage Perpendicular (OP)		
n	350	224
%	18.96	33.84
One-Stage Oblique (OO)		
n	399	89
%	21.61	13.44
One-Stage Mixed (OM)		
n	459	97
%	24.86	14.65
Two-Stage Perpendicular (TP)		
n	146	132
%	7.91	19.94
Two-Stage Oblique (TO)		
n	221	58
%	11.97	8.76
Two-Stage Mixed (TM)		
n	271	62
%	14.69	9.37
OR (One: Two Stage)	1.164	1
95% CI of OR	0.968-1.399	--
p value*	0.000	
Df	5	
χ^2	165.262	

Note: N = Total Pedestrians, n = Pedestrians in respective categories, OR= Odd's Ratio, CI- Confidence Interval, df = Degree of Freedom. *Significance level (p) <0.05 means significant association exists between two groups for that parameter.

3.1.4 Effect of Geometric Features on Pedestrian Jaywalking Behaviour

Along with the socio-demographic factors, the jaywalking behaviour also depends on the geometric features of the crosswalk such as width of crosswalk, length of crosswalk, width of pedestrian islands, visibility of cross-markings, presence of guard rails, classification of road and signal cycle length. Table 4 represents the co-relation analysis (Eta-correlation analysis for continuous factors and Phi-coefficient/Cramer's V analysis for nominal variables and Rank Biserial analysis for ordinal variables) and the significant co-relation was observed for width of crosswalk, length of crosswalk, number of lanes, and presence of guard rails**.** The width of crosswalk was found negatively correlated as decrease in width of crosswalk increases the jaywalking of the pedestrians. Increase in length of crosswalk and number of lanes prompt the pedestrians to cross from the point of shortest distance. Also, the presence of guard rails was positively correlated as it restricts the pedestrian movement and prevent jaywalking behaviour. After correlation analysis, the multi collinearity was also checked using VIF values. As the VIF values for both the length of crosswalk and number of lanes exceeded

Table 4 — Correlation of Jaywalking with respect to different geometric factors

Type	Attributes/Factors	Nature of Variable	Co-Relation		Analysis Tool
			R	P-Value	
Geometric Features	Width of Crosswalk	Continuous	-0.715	0.000**	Eta-Correlation (Interval by Nominal***)
	Length of Crosswalk	Continuous	0.524	0.000**	
	Width of Pedestrian Island	Continuous	-0.107	0.445	
	Number of Lanes	Continuous	0.428	0.001**	
	Nature of Land Use	Nominal	0.010	0.931	Phi Coefficient/Cramer's V (Nominal by Nominal)
	Presence of Curb Ramps	Nominal	0.201	0.103	
	Presence of Guard Rails	Nominal	-0.446	0.000**	
	Visibility of Cross Markings	Ordinal	0.135	0.245	Rank Biserial (Ordinal by Nominal)
	Crosswalk Surface Condition	Ordinal	0.056	0.540	
	Separate Bicycle Path for Crossing of Cyclists	Ordinal	0.114	0.314	

Note: *- Significant, if p<0.05, **- Significant, if p<0.01. ***Pedestrian Jaywalking is nominal variable

10, therefore, length of crosswalk was removed/dropped out for further analysis. Finally, nine explanatory variables were obtained - gender, group size, crossing pattern, type of signal at arrival, pedestrian arrival rate, number of lanes, width of crosswalk, presence of guard rails and average pedestrian delay.

3.2 Identification of Factors of Jaywalking Index obtained from EFA

From EFA results, KMO Test (value = 0.876) and Bartlett Test of Sphericity (χ^2 = 1796.80, p = 0.001) indicate that the variables (obtained after co-relation analysis) were pertinent to engage in factor analysis. Further, the variables were categorized into latent variables using rotated component matrix (obtained during factor analysis) and the pedestrian jaywalking index system was formulated as illustrated in Fig. 2. Pedestrian jaywalking index system consists of 3 groups being characterized into 7 sub-groups with 9 explanatory variables. After factor analysis, total 7 principal factors with the same number of explanatory variables (two variables were dropped out due to lower factor loadings than 0.4)were obtained designated as P1, P2, P3, R1, R2, R3 and F1as depicted in Table 5**.** The emerged principal factors (P1, P2, P3, R1, R2, R3 and F1) correspond to the different variables namely gender (Y1), crossing pattern (Y3), type of signal at arrival (Y4), number of lanes (Y6), width of crosswalk (Y7), presence of guard rails (Y8), and average pedestrian delay (Y9), respectively. These were further used for predicting the pedestrian decision-making process to jaywalk or not.

3.3 Pedestrian Jaywalking Decision-Making Modeling Results

The pedestrian jaywalking decision-making condition was described by Binary Logit/Logistics model (BL Model) with 7 principal factors (P1, P2, P3, R1, R2, R3 and F1) namely gender (females or males), crossing pattern (perpendicular, oblique or mixed), type of signal at arrival (green or red), number of lanes, width of crosswalk, presence of guard rails (no or yes) and average pedestrian delay as the predictors. The findings show that chi square (χ^2) = 70.876, with a significance value of 0.013 is less than required level of significance, $p < 0.05$. Hence, it is concluded that the predictors have a significant effect on the dependent variable. Furthermore, the Hosmer and Leme show goodness of fit tests was employed to check the accuracy of model fitting. The

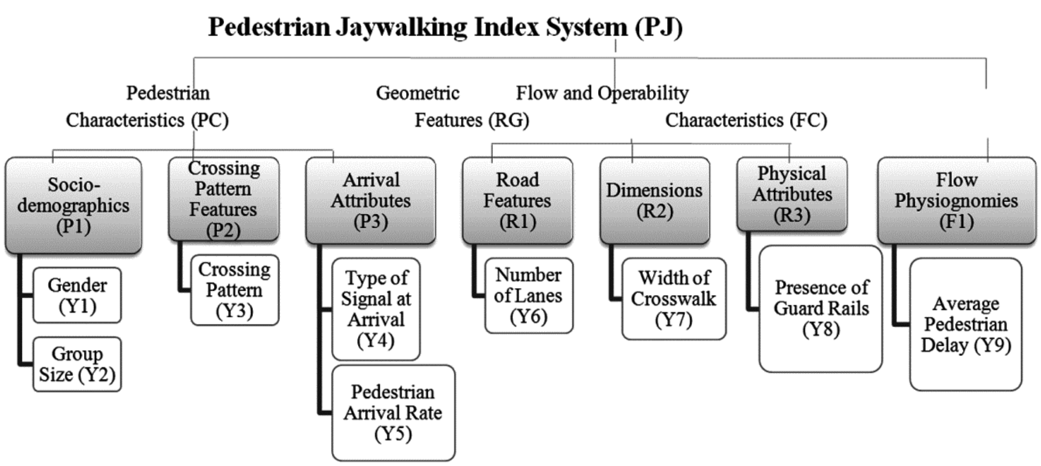

Fig. 2 — Pedestrian Jaywalking index system.

Table 5 — Pedestrian Jaywalking index characteristics

Type of Variables	Number of original Variables	Number of Principal Factors	Principal Factors
PC	5 (Y1, Y2, Y3, Y4, Y5)	3	P1=*0.783Y1+0.318Y2* P2 = *0.919Y3* P3=*0.821Y4+0.206Y5*
RG	3 (Y6, Y7, Y8)	3	R1=*0.929Y6* R2=*0.956Y7* R3=*0.967Y8*
FC	1 (Y9)	1	F1=*0.982Y9*

Note: Y2 and Y5 have very factor loadings less than 0.4, therefore are dropped out for further analysis[33].

probability of the model chi-square (χ^2 = 18.930, p = 0.178), is higher than the required level of significance i.e., 0.05. Therefore, no difference is found between observed and model-predicted values (using binary logit model), inferring that the model's estimates fit the data at an adequate level. After assessing the model fit, the strength of relationship was checked between the predictor (independent) variables and the dependent variable using *Nagelkerke's R square value.* Nagelkerke's R-square value was observed to be 0.797, thus, depicts a strong relationship of 79.7% between the predictors and the dependent variable. This also indicates that high level of %age variance can be explicated by the independent variables. Hence, the model estimating the likelihood of jaywalking behaviour was obtained with their results presented in Table 6. All seven variables/factors emerged out as the influencing variables (gender, crossing pattern, type of signal at arrival, number of lanes, width of crosswalk, presence of guard rails and average pedestrian delay). According to the model estimation results, model for jaywalking decision-making is formulated as given in Eq. 1, and probability of adopting jaywalking behaviour P(i) is given by Eq. 2.

$$Ui = -5.116 - 0.207\,P1 + 1.079\,P2(1) + 1.450\,P2(2) + 0.383\,P3 + 0.819R1 - 0.313R2 - 2.064\,R3 + 1.125\,F1 \quad ...(1)$$

$$P(i) = \frac{1}{1+e^{(-5.116 - 0.207\,P1 + 1.079\,P2(1) + 1.450\,P2(2) + 0.383\,P3 + 0.819\,R1 - 0.313\,R2 - 2.064\,R3 + 1.125\,F1)}} \quad ...(2)$$

where, Ui = the utility of choosing an alternative i; i= the alternative (pedestrian jaywalks/pedestrian does not jaywalk); n= number of independent variables; α = constant; β = coefficients.

From binary logit model, it was found out that Gender (1) *(Males)*, Crossing Pattern (1) *(Oblique),* Crossing Pattern (2) *(Mixed)*, Type of Signal at Arrival *(Red/Flashing Green)*, Number of Lanes, Width of Crosswalk, Presence of Guard Rails and Average Pedestrian Delay act as significant predictors affecting the jaywalking model. Among the various significant variable's; presence of guard rails, crossing pattern and average pedestrian delay were the best predictors with the maximum likelihood of predicting the pedestrian jaywalking behaviour. The co-efficient of Gender1 was negative (B=-0.207) with its exponential coefficient (Exp B = 0.813). This signifies that Gender (1) (Males) have lower probability to indulge in jaywalking as compared to Females. The probability of females to jaywalk is 1.23 (inverse of exp B) times that of females. This is contradictory to the results of the preceding studies which suggests otherwise i.e., males jaywalking tendency is more than females [5,18].

With regard to crossing pattern, pedestrians following oblique crossing (Crossing Pattern 1) and mixed crossing (Crossing Pattern 2) were found to have positive relationship with the predicted probability of jaywalking. The odds-ratio values (Exp B) for the different crossing patterns indicate that persons adopting either oblique (2.942) or mixed (4.263) crossing pattern have more likelihood to jaywalk than the pedestrians adopting perpendicular crossing. Pedestrians usually comply with the signals and tend to use the crosswalk while crossing perpendicularly over the crosswalk.

With respect to the type of signal at arrival, pedestrians arriving at the time of red signal were found to be indulged more in jaywalking. The odds-ratio value of pedestrians to jaywalk for red/flashing green type of signal at arrival versus green type of signal is 1.467, a statistically significant effect, $\chi^2(1)$ = 3.898, p = 0.007. This is due to impatience of the pedestrians to wait for signal to turn green.

In case of number of lanes, the positive relationship designates that pedestrian tend to jaywalk more as the

Table 6 — Parameter estimation of pedestrian Jaywalking model

Symbols	Variables	B	S.E.	Wald	df	p	Exp(B)
P1	Gender (1) *(Males)*	-0.207	0.100	4.285	1	0.020*	.813
P2	Crossing Pattern	--	--	3.991	2	0.010*	--
P2(1)	Crossing Pattern (1) *(Oblique)*	1.079	0.424	6.476	1	0.012*	2.942
P2(2)	Crossing Pattern (2) *(Mixed)*	1.450	0.513	7.989	1	0.015*	4.263
P3	Type of Signal at Arrival (1) *(Red)*	0.383	0.194	3.898	1	0.007**	1.467
R1	Number of Lanes	0.819	0.362	5.123	1	0.038*	2.269
R2	Width of Crosswalk	-0.313	0.437	0.513	1	0.035*	0.731
R3	Presence of Guard Rails (1) *(Yes)*	-2.064	1.191	3.003	1	0.021*	0.127
F1	Average Pedestrian Delay	1.125	0.477	5.562	1	0.017*	3.080
	Constant	-5.116	2.083	6.031	1	0.026*	0.006

Note: *Significant, p<0.05, **p<0.01

number of lanes at crosswalk increases. Increase in crossing distance forces the pedestrian to neglect the traffic signals and indulge in risky crossing at their own determination. Whereas, the width of crosswalk had negative impact on the probability of jaywalking as an increase in width increases the crosswalk area and motivate the pedestrians to use the designated crossing location; thus, decreasing the probability of jaywalking. Moreover, increase in width may give a sense of safety and comfort to the pedestrians and will encourage them to comply with the traffic rules and regulations.

Considering the variable average pedestrian delay, an increase in delay (expressed in seconds) was associated with an increase in the odds of jaywalking, with an odds ratio of 3.080, Wald $\chi2(1) = 5.562$, $p = .017$. Higher delay prompts the pedestrians not to comply with the signals and cross at their own will. With regard to presence of guard rails, the odds ratio of pedestrians to jaywalk for guard rails to be present versus absence of guard rails was 0.127, a statistically significant effect, $\chi2(1) = 3.003$, $p = .021$. Presence of guard rails prevent the pedestrians to cross at other than the designated location and likely to encourage pedestrians to use crosswalks.

3.2.1 Category Prediction and Confusion Matrix

Binary Logit Model estimated the probability of pedestrian jaywalking decision on the basis of a cut-off point (i.e., 0.5). The estimated probabilities ≥ 0.5 are classified as occurrence of the event (i.e., pedestrian decides to jaywalk) and < 0.5is classified as the non-occurrence of the event (i.e., pedestrian does not decide to jaywalk)[32]. In the absence of independent variables, 79.48% cases (1596 out of 2008) could only be correctly classified by assuming all the cases as 'pedestrian decides to jaywalk'. However, with addition of explanatory variables, percentage accuracy in classification (PAC) rises to 90.39% due to improved prediction of cases into their observed categories as depicted in Table 7.

3.2.2 Receiver operating characteristic (ROC) curve

This is a measure of goodness-of-fit tests for the evaluation of the Binary Logit model which is based on the simultaneous measure of sensitivity (True positives: 90.66%) and specificity (True negatives: 89.32%) for all probable cut-off points. ROC curve was then plotted using SPSS statistical software with sensitivity on the ordinate and (1-specificity) on the abscissa as shown in Fig. 3. Higher area under the ROC curve (0.5-1.0) indicates better fit of the results[33]. The area under the curve is 0.891 (95% CI, .796 to .986)puts the discrimination (correctly classify cases) of this model as excellent discrimination. Also, the area under the curve has 0.000 significance value which reflects the significant classification of groups using binary logit model.

3.2.3 Validation of Model

The pedestrian jaywalking model formulated was fitted to the validation dataset (500 pedestrian points) and predicted result was compared with the observed category. The model accurately predicted data in case of 444 pedestrians. Therefore, the model accuracy for validated data came out to be 88.8%. This reflects that the socio-demographics (gender), crossing features (crossing pattern), arrival attributes (type of signal at arrival), road features (number of lanes), dimensions (width of crosswalk), physical attributes (presence of guard rails) and flow physiognomies (average pedestrian delay) are the significant contributing factors of the pedestrian jaywalking decision model.

Table 7 — Confusion matrix

Observed		Predicted: Pedestrian decides to Jaywalk No	Predicted: Pedestrian decides to Jaywalk Yes	% age Correct (%)
Pedestrian decides to Jaywalk	No	368	44	89.32
	Yes	149	1447	90.66
Overall %age				90.39

Note: The cut-off value for classification is 0.5.

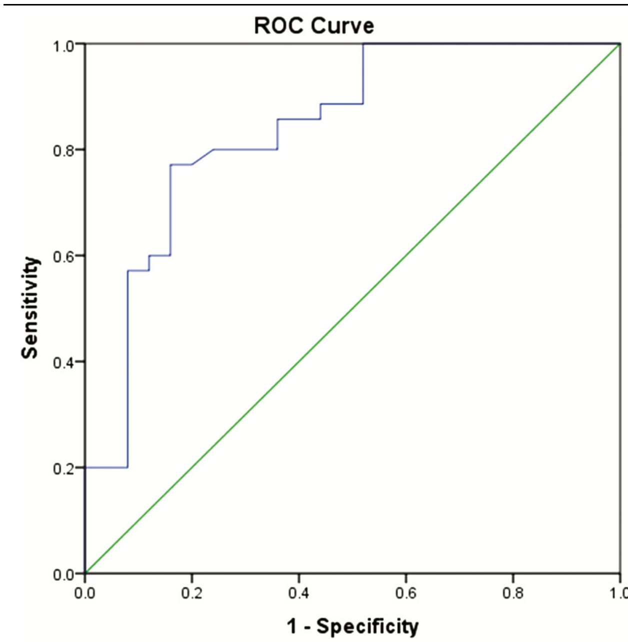

Fig. 3 — ROC curve for estimated probability by logit model

4 Conclusion

The study has explored the causal factors of pedestrians' jaywalking behaviour and proposed a binary logit model to predict the jaywalking at 36 signalized crosswalks of Chandigarh, India. The pedestrian individual characteristics (gender, age), pedestrian arrival characteristics (type of signal at arrival and crossing time), road geometric features (number of lanes) and crosswalk characteristics (width of crosswalk) have emerged as the significant contributing factors of the pedestrian jaywalking decision model. The results reveal that females are more likely to jaywalk than males which reflects the eagerness of females towards crossing. Pedestrians following oblique and mixed crossing pattern usually jaywalk because of leisure attitude towards crossing or to find the suitable gap while crossing, if non-complying with the signals. Also, the study highlights the ambiguity among the pedestrians in comprehending the true significance of the signals. It seems that most pedestrians being aware of the fact that crossing during red/flashing green signal is prohibited but they still engage in crossing manoeuvres. This reflects the incompetence of the traffic police to a certain extent to successfully impose the rules and regulations on pedestrians. The delay incurred by pedestrians directly depends on the waiting time and crossing time of the pedestrian. Increase in delay may lead pedestrians to take the risk of jaywalking (crossing during red or flashing green signal) rather than wait for another cycle length; thereby, endangering their own safety. Increase in number of lanes inflict the pedestrians to adopt jaywalking behaviour because of increase in crossing distance and the eagerness of the pedestrians to reach their desired destination results in jaywalking. On the other hand, increase in width of crosswalk reduces the chances of pedestrians to jaywalk as it leads to increase in crosswalk area which pedestrian can efficiently use. Presence of guard rails reduces the chances of jaywalking and ensure the safety of pedestrians.

Based on the study, it is recommended to provide pedestrian actuated signals with countdown timers to assist pedestrians crossing in more efficient manner and prompt them to cross during green signal only. Another suggestion is proper provisioning of guard rails along the footpaths/sidewalks as per IRC:103 (2012) that will enforce the pedestrians to cross at appropriate designated locations and reduce their jaywalking tendency[34]. It should be noted that in India, the jaywalking has not yet explicitly considered as an offendable law rather classified as 'obstruction of traffic' under metropolitan laws.Therefore, the authors suggest that from time to time, drives against jaywalking should be conducted by traffic police and offenders should be fined depending upon the jurisdiction and subjected to Motor Vehicle Act, 2019 (Examples include section 28B of the Delhi Police Act, 33B of the Bombay Police Act and 92G of the Karnataka Police Act relating to non-conformity of traffic rules). Overall, it is observed that pedestrian's decision to jaywalk reflects the shortcomings in the geometric attributes of the crosswalk. Moreover, the measures taken up for averting jaywalking (such as controlling variable parameters like vehicular speed and conflicting traffic flow; discouraging abrupt crossing behaviour of pedestrians; improving crosswalk geometric features- length of crosswalk, width of crosswalk, width of pedestrian islands, crosswalk surface condition etc., and providing good operability conditions; proper provisioning of guard rails along the footpaths/sidewalks enforcing the pedestrians to cross at appropriate designated locations) will also improve the LOS of the crosswalks. Therefore, jaywalking act as a significant contributor in determining the LOS of crosswalks.

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