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Identification of Factors Affecting Pedestrian Crossing Behavior at Signalized Intersection

Yogesh Verma[1], Girish Hingwey[2], Pawan Dawar[3]

[1,2,3]*Assistant Engineer, Madhya Pradesh Public Works Department, Bhopal - 462003*

Abstract - In developing nations like India a significant number of pedestrian fatalities takes place every year because of the uncontrolled growth in the number of vehicles and lack of facilities for pedestrians on street/crossings. In order to provide pedestrian crossing facilities and to improve the level of safety while crossing the road a comprehensive understanding of pedestrian crossing behavior should be known. This paper attempts to identify the critical factors affecting crossing behavior of pedestrians from a study conducted at Bhopal city (Madhya Pradesh state in India). Pedestrian data was recorded manually during evening peak hours in a predesigned performa. The impact of pedestrian characteristics (gender, age, pedestrian group size, utilization of crosswalk, compliance with signal, way of crossing, carrying baggage/luggage and use of mobile phone) over pedestrian crossing speed was studied. A multiple linear regression model was developed to determine the relationship between pedestrian crossing speed and pedestrian characteristics. Pedestrian data was recorded manually during evening peak hours in a predesigned performa.

Key Words: **Crosswalk, Signalized Intersection, Pedestrian Crossing Speed, Crossing Behavior**

1. INTRODUCTION

Walking is the basic mode of travel. It is healthy and sustainable to human society. The term 'Pedestrian' includes person who walk, sit, stand in public areas or use mobility aids like walking stick, crutches or wheelchair, be they children, teenagers, adults, elderly persons with disabilities, workers, residents, shoppers or people watchers (IRC, 2012). In majority of the developing nations like India, involvement of pedestrian in traffic accidents is a noteworthy security issue. As per MoRT&H, 2016 of the total road accidents about 37% of the accidents occurred on the intersections and within junctions 27.1% of accidents occurred at controlled intersections. By reviewing the data it can be conclude that two wheelers (34.8% i.e. 52,500) and pedestrians (10.5% i.e. 15,746) represent the most vulnerable group of road users killed in road accidents. In order to provide a sound and safe infrastructure for the pedestrians it is essential to have comprehensive understanding of the pedestrian crossing behavior. Pedestrian possesses dynamic behavior which is influenced by a number of pedestrian characteristics and behavioral parameters.

As per the report "Road Accidents in India, 2016" by MoRT&H, about 49 percent of total accidents took place on the junctions itself during the calendar year 2016. Further, 13,276 accidents occurred at roundabouts which killed 3,725 persons and left 11,577 injured. The report also revealed that 20,320 accidents occurred at pedestrian crossing 5.934 fatalities and 17,534 injuries. If the total accidents which occurred in 2016 are classified on the basis of responsibilities of drivers, 10,360 accidents occurred because the drivers did not give right of way to pedestrians. Of the total number of persons killed in road accidents in 2016, 9.5 percent constituted of pedestrians. In all, 13,894 pedestrians were killed in road accidents on Indian roads in the year 2016. Chart 1 gives the percentage share of the road accident deaths in the year 2016.

Further, Table 1 shows the percentage share for the factors responsible for road accidents across the Sates/UTs

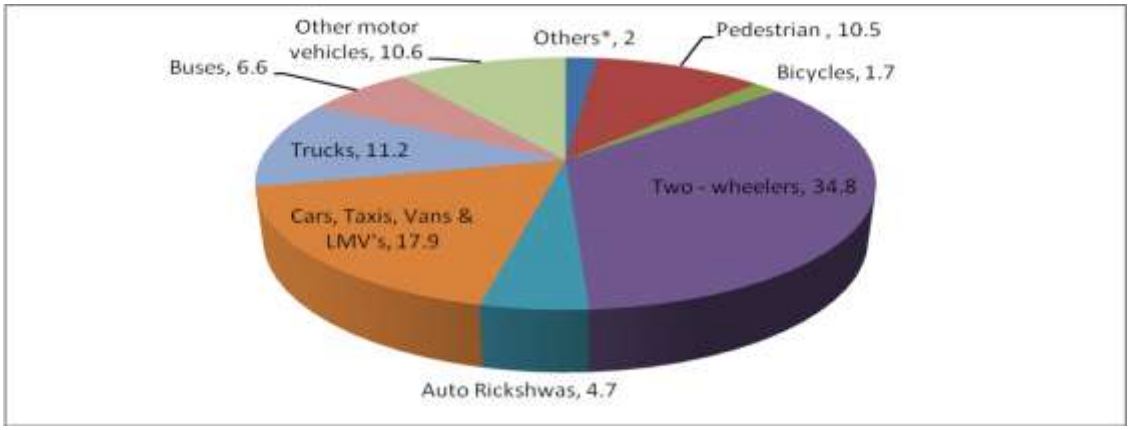

Chart -1: **Share of the total number of persons killed in road accidents in terms of road user categories: 2016**

*Includes: Animal drawn vehicles, cycle rickshaws, hand carts, e – rickshaws and other persons

(Source: Road Accidents in India, MORT&H, 2016)

Table -1: Factors responsible for road accidents as reported by States/U.Ts: 2016

Cause	Accidents	Killed	Injured
Fault of Driver of motor vehicle	4,03,598 (84.0)	1,21,126 (80.3)	4,14,785 (83.9)
Fault of Driver of non-motorized vehicle	6,546 (1.4)	2,250 (1.5)	7,620 (1.5)
Fault of Pedestrian	8,298 (1.7)	3,091 (2.0)	7,465 (1.5)
Fault of Pedestrians	5200 (1.1)	2,181 (1.4)	4,535 (0.9)
Mechanical Defect in motor vehicle	6,688 (1.4)	2,823 (1.9)	6,956 (1.4)
Engineering/ Designing fault of Roads	1,289 (0.3)	589 (0.4)	1,217 (0.2)
Defect in road condition (surface of roads/surface condition of roads)	7,158 (1.5)	2,983 (2.0)	6,579 (1.3)
Stray Animal	1,604 (0.3)	629 (0.5)	1,307 (0.3)
Poor light condition	3,833 (0.8)	1,631 (1.1)	4,477 (1.0)
Other causes	20,858 (4.3)	7,312 (4.8)	23,380 (4.7)
Causes not known	15,580 (3.2)	6,170 (4.1)	16,303 (3.3)
Total	**4,80,652**	**1,50,785**	**4,94,624**

Figures in bracket are the percentage share

(Source: Road Accidents in India, MORT&H, 2016)

2. Literature Review

Pedestrian moving on crosswalk possesses dynamic nature. Most of the studies have investigated only the pedestrian characteristics and pedestrian flow characteristics in sidewalks and walkways (Laxman et al. 2010; Yordphol et al. 1986). The current design of roads does not provide services upto a satisfactory level to pedestrians and thus, there exists consistent clashes between the vehicles and the pedestrians sharing the constrained space on the road (Marisamynathan et al. 2013). Impact of carrying luggage/baggage on pedestrian crossing speed was very uncommon parameter (Rastogi et al. 2014). Chandra et al. 2013 studied the impact of trajectory of pedestrian over pedestrian crossing speed. Very few studies have analyzed the impact of land use pattern over pedestrian crossing speed (Sukhadia et al. 2014). Few psychological researchers have the studied impact of mobile phone over behavior and attentiveness of pedestrians (Stavrinos et al. 2011 and Haga et al. 2016). List of factors considered by different authors for the study are shown in Table 2.

Table -2: Factors Affecting Pedestrian Crossing Speed Considered by Different Authors

Sr.No.	Authors	Year	Factors
1	Shaaban et al.	2018	Gender, Age, Type of clothing, Group size, Carrying baggage, Use of mobile phone, Waiting time, Number of attempts, Way of crossing, Path of pedestrian
2	Hao et al.	2008	Pedestrian crossing facilities, Age, Traffic conditions, Waiting time, Crossing status (unaccompanied or accompanied).
3	Rastogi et al.	2014	Age, Gender, Carrying luggage or baggage, Crossing pattern, Waiting time, Gap acceptance
4	Marisamynathan et al.	2014	Age, Gender, Group size, Crossing behavior, Crossing locations, Compliance with signal, Gap acceptance.
5	Papadimitriou et al.	2016	Age, Gender, Income, Walking frequency, Crossing behavior (risk perception).
6	Tarawneh	2001	Age, Gender, Group size.

7	Chandra et al.	2013	Gender, Age, Utilization of crosswalk facilities.
8	Goh et al.	2012	Age, Gender, Group size, Carrying luggage or baggage, Holding hands or assisting other pedestrians.
9	Ferenchak	2016	Age, Gender, Utilization of crosswalk, Waiting time.
10	Haga et al.	2015	Age, Gender, Use of mobile phone.
11	Koh et al.	2014	Age, Gender, Group size, Carrying baggage or luggage, Use of mobile phone, Way of crossing.
12	Yingying et al.	2013	Land use pattern, Travel purpose, Condition of road infrastructure, Pedestrian volume, Presence of pedestrian signals.

From the above mentioned existing studies majority of the factors that have been neglected about pedestrian crossing behavior have been identified. Further- more, there has not been a study that has examined pedestrian crossing speed variation and pedestrian compliance with signal in crosswalks of signalized intersections with factors such as pedestrian characteristics and behavior. This paper examines all possible parameters that influence pedestrian crossing behaviors.

3. Objectives

The main objectives behind the study are: (1) Identification of factors influencing the crossing speed of pedestrian and assessment of predominant factors. (2) Development of regression model to determine the impact of characteristics/behavior of pedestrian on crossing speed.

4. Data Collection and Details about the Study Area

For the present study, four signalized intersections lying in the newly developed area of the city of Bhopal, India having considerable vehicular and pedestrian traffic were selected. The four selected intersections include Rangamahal Intersection, Roshanpura Intersection, Board Office Intersection and Jytoti Talkies Intersection. The study sites were mainly the CBD's of the city. All the selected signalized intersection sites chosen were four legged with fixed traffic signal cycle lengths.

Pedestrian intercept survey was carried out at sixteen crosswalks of four signalized intersections scattered in different parts of the city during evening peak hours. At each of the 16 crosswalks, 25 pedestrians were surveyed i.e. in all 400 pedestrians were surveyed. Geometric details of crosswalks are shown in Table 3. Representation of crosswalks at selected intersection sites is done in Figure 1 Paper-pencil based manual count technique was used for pedestrian traffic volume survey. Detailed information about the pedestrian crossing speed and pedestrian volume at study sites are shown in Table 4.

Table 3: Geometric Details of Crosswalks

Sr.No.	Name of Intersection	Crosswalk No.	Length of Crosswalk (m)	Width of Crosswalk (m)
1.	Rangmahal Square	1	24.5	2.0
		2	24.0	2.0
		3	24.5	2.0
		4	24.0	2.0
2.	Roshanpura Square	1	27.9	2.5
		2	32.8	2.5
		3	25.5	2.5
		4	36.6	2.5
3.	Board Office Square	1	30.4	2.5
		2	26.0	2.5
		3	27.5	2.5
		4	26.0	2.5
4.	Jytoti Talkies Square (M.P Nagar)	1	25.5	Crosswalk markings were absent
		2	20.2	
		3	32.7	
		4	28.9	

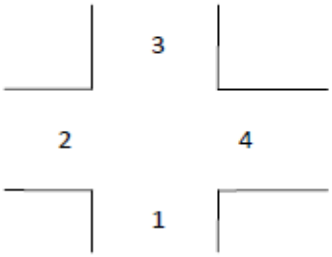

Fig -1: Representation of Crosswalks at Intersection

Table 4: Information of Pedestrian Crossing Speeds and Pedestrian Volume at Study Sites

Location	1	2	3	4
Intersection	Rangmahal Intersection	Roshanpura Intersection	Board Office Intersection	Jyoti Talkies Intersection
Number of samples	100	100	100	100
Mean speed (m/s)	1.285	1.318	1.338	1.252
Standard deviation	0.27069	0.27343	0.28922	0.20450
Pedestrian Volume (ped/hr)	1872	982	1580	1008

The pedestrian intercept survey offered information about pedestrian crossing speed, characteristics/behavior of pedestrians like age, gender, way of crossing, way of crossing, use of mobile phone, compliance with signal, utilization of crosswalk and carrying luggage/baggage. The various variables used in this study are shown in Table 5 along with their respective definitions and parameters.

Table 5: List of Variables and Their Definitions and Parameters

S.No	Parameter	Classification	Code
1	Gender	Male	0
		Female	1
2	Age	0 – 15	0
		15 – 35	1
		35 – 50	2
		> 50	3
3	Group size	Single	0
		Upto 3	1
		> 3	2
4	Utilization of crosswalk	Yes	0
		No	1
5	Compliance with signal	Yes	0
		No	1
6	Way of crossing	Walking	0
		Running	1
7	Carrying baggage/luggage	Yes	0
		No	1
8	Use of Cell Phone	Yes	0
		No	1

5. Pedestrian Crossing Behavior

400 pedestrians were intercepted to gather detailed information about the crossing behavior of pedestrians. Compliance with signal is the term used to mark the pedestrians moving on crosswalk during green phase of the signal. Pedestrian characteristics and behavior information are mentioned below:

a) During peak hours the percentage share of male pedestrians (59.25%) is greater than female pedestrians (40.75%).

b) Proportion of pedestrians of age group 15-35 years is the largest, whereas proportion of pedestrians of age group 0-15 years is least during peak hours. Proportion of pedestrians of age group > 50 comes on the third position.

c) Female pedestrians (68.01%) showed higher signal compliance rate as compared to male pedestrians (52.32%).

d) Pedestrians of age group > 50 years show the highest rate of compliance with signal (83.33%), whereas the pedestrians of age group 15-35 years show the lowest rate of compliance with signal (50.00%).

e) About 81.60% of female pedestrians make use of crosswalk while moving on crosswalk; on the other hand 75.94% of male pedestrians make use of crosswalk while moving on crosswalk.

f) Maximum utilization of crosswalk has been shown be pedestrian of age group > 50 years (85.72%), whereas minimum utilization of crosswalk has been shown by the pedestrian of age group 35-50 years (73.22%).

g) 88.89% of the pedestrians of group size greater than three, 55.84% of single pedestrians and 66.26% of pedestrians of group size upto three showed compliance with the signal.

h) Signal compliance rate of pedestrians not using the mobile phone (60.53%) while crossing the road is much higher than signal compliance rate of pedestrians using the mobile phone (32%) while crossing the road.

6. Pedestrian Crossing Speed

Crossing distance is basically the length of the crosswalk which was measured by meter tape. Crossing time is defined as the time taken by the pedestrian to travel the crosswalk and is exclusive of waiting time. Crossing speed is the ratio of crossing distance and the crossing time. This analysis is mainly concerned with the variation of crossing speed of pedestrians and various parameters influencing the same at signalized intersections. A sample of 400 pedestrians was taken for the analysis of pedestrian crossing speed. For determining the parameters influencing the crossing speed of pedestrians at signalized intersections ANOVA test was performed at 95% confidence interval. The analysis was carried out by using SPSS 20.0 software.

The results of ANOVA analysis showed that gender, age, group size, compliance with signal, way of crossing and use of cell phone are the significant parameters influencing the crossing speed of pedestrians. There was no significant impact of carrying luggage/baggage on pedestrian crossing speed. The results of ANOVA tests are shown in Table 6. The average crossing speed of pedestrians comes out to be 1.29 m/s, this value is comparable with value of 1.31 m/s determined in highly populated region of china (Li et al. 2005).

Average crossing speed of male pedestrians (1.34 m/s) is higher than that of female pedestrians (1.24m/s). Pedestrians moving in a group on crosswalk were found to move at lower crossing speed than single pedestrians. With the increase in age, crossing speed of the pedestrians gets reduced. Pedestrians of age group 0-15 years, 15-35 years, 35-50 years and > 50 years had average crossing speed of 1.63 m/s, 1.30m/s, 1.29 m/s and 1.12 m/s respectively.

Table 6: Results of ANOVA test for Identification of Factors Influencing Crossing Speed

Sr.No	Source	Sum of Squares	df	Mean Square	F	Sig.	Remarks
1	Gen	0.127	1	0.127	8.113	.005	Significant
2	Age	1.362	3	0.454	28.926	.000	Significant
3	GS	0.117	2	0.058	3.721	.025	Significant
4	CWS	0.521	1	0.521	33.218	0.000	Significant
5	WC	4.837	1	4.837	308.145	0.000	Significant
6	CI	0.017	1	0.017	1.110	.293	Insignificant
7	CELL	.146	1	0.146	9.275	.003	Significant

7. Pedestrian Compliance with the Signal

During the pedestrian intercept survey it was found that owing to the multiple reasons pedestrians are not in compliance with the traffic signal. Pedestrian noncompliance rates are 38%, 43%, 40% and 44% at Rangmahal Intersection, Roshanpura Intersection, Board Office Intersection and Jyoti Talkies Intersection respectively. Compliance behavior of pedestrians is analyzed using ANOVA test, Student *t* test and Pearson's correlation coefficient at 95% confidence interval to determine the significant factors influencing the pedestrian compliance with traffic signal. Age, Gender, pedestrian group size, use of mobile phone and pedestrian crossing speed are the parameters which are considered for the statistical tests. Outcomes of the analysis are shown in Table 7.

Table 7: Statistical Results of Factors Influencing Compliance with Signal

Sr.No.	Factors	Pearson Correlation		ANOVA		Student-t Test	
		Coefficient	P Value	F Value	Sig.	t	P Value
1	Gender	-.157	.002	0.433	0.512	.133	.894
2	Age	-.185	.000	6.461	.000	-21.625	.000
3	Group Size	-.123	.014	3.960	.021	4.372	.000
4	Use of Mobile Phone	-.140	.005	3.594	.060	-18.135	.000
5	Crossing Speed	-.184	.000	2.570	.000	-29.509	.000

Outcomes of the statistical analysis suggest that age, pedestrian group size and crossing speed of pedestrians are the parameters which significantly influence the pedestrian's compliance with the traffic signal.

8. Development of Model for Pedestrian Crossing Speed

A multiple linear regression analysis was performed for the development of pedestrian crossing speed model. Behavioral and characteristics parameters of the pedestrians were used as independent variables for the analysis. The pedestrian crossing speed obtained through pedestrian field survey was taken as dependent variable.

The pedestrian crossing speed model developed after performing multiple linear regression analysis on the collected data takes the following form:

$$V_{ped} = 1.455 - 0.089\,Gen - 0.100\,Age - 0.073\,GS - 0.059\,CU - 0.157\,CWS + 0.728\,WC + 0.072Cell$$

Where,

V_{ped} = Pedestrian Crossing Speed (m/s)

Gen. = Gender (0 = male, 1 = female)

Age = Age group (0 = 0-15 years, 1 = 15-35 years, 2 = 35-50 years, 3 = greater than 50 years)

CU = Crosswalk Utilization (0 = using crosswalk, 1= not using crosswalk)

CWS = Compliance with Signal (0 = complying with signal, 1 = not complying with signal)

WC = Way of Crossing (0 = walking, 1 = running)

Cell = Use of Mobile Phone (0 = using mobile phone, 1 = not using mobile phone)

The crossing speed model has a R^2 (coefficient of determination) value of 0.677, also adjusted R^2 value of 0.670.

9. Conclusion

Characteristic parameters such as gender, age and group size of pedestrians and behavioral parameters such as compliance with signal, way of crossing and use of mobile phone significantly influence the crossing speed of pedestrians. As the age of pedestrian increase his behavior becomes more conservative. The maximum crossing speed of 2.6 m/s was shown by pedestrian of age group 0-15 years, on the other hand minimum crossing speed of 0.8 m/s was shown by pedestrian of age group >50 years. The measured average pedestrian crossing speed at study locations was 1.29 m/s. Factors like age, group size and crossing speed of pedestrians influence the pedestrian's compliance with the signal. It can be concluded that young male pedestrians and pedestrians using the mobile phone while moving on crosswalk are more likely to violate the traffic rules and regulations. Analyzing the pedestrian crossing behavior including gap acceptance, path (trajectory) of pedestrians, waiting time, numbers of attempts made by the pedestrian to enter the crosswalk with influencing parameters would increase the robustness of this work in future. This work can further be extended to varied land use patterns like intersections near state railway junction and bus terminus or airports.

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