



REVISION OF PV^2 CRITERIA BASED PEDESTRIAN CROSSING WARRANTS

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Abstract. Several guideline documents on pedestrian crossing warrants are followed around the world. Peak hour pedestrian volume “ P ” and vehicular volume “ V ” are two most commonly used factors in these guidelines. PV^2 is a criteria, which is used in guideline documents of India, Iran and UK to identify the need of warranting a particular mid-block location. In India, these guidelines were adapted from UK in 1988 and have not been revised in the last three decades. These guidelines report a benchmark value, in the excess of which a location should be warranted. The benchmark values are based on peak flows of 1980s, which have increased drastically over the years. In addition, the guidelines do not identify the type of crossing facility, which should be provided at a particular location. Therefore, these guidelines need to be revised. In this paper, PV^2 matrices have been developed for a variety of road configurations using the maximum field hourly flows as the upper bounds. Further, probability distributions have been fitted to the PV^2 values. Threshold values have been proposed based on the curvilinear characteristics of the probability distributions. The revised PV^2 values vary from $0.6 \cdot 10^8$ to $2.1 \cdot 10^{11}$ for different roadway configurations. The ranges formed using these values have been used to classify the type of crossing facility to be installed using a systematic hierarchical approach. The warrant charts and PV^2 value ranges can be used to identify the need, as well as the most appropriate crossing facility for the site based on the peak hour pedestrian volume and vehicular volume. The proposed PV^2 values and warrants are based on Indian traffic flow conditions. These threshold values may require modifications for application in any other country.

Keywords: pedestrian, crossing warrants, crossing facilities, PV^2 , distribution fitting, pedestrian safety.

Introduction

Vehicle and pedestrian flows in urban areas have increased drastically over the years due to the increase in the population density and economic growth. As a result, the pedestrian-vehicle interactions on the roads have also increased. Traffic engineers’ emphasis on congestion free vehicle movement often leads to negligence of pedestrian provisions making the pedestrians vulnerable and prone to road accidents. In India, the total number of road accidents reported by Ministry of Road Transport and Highways (MoRTH 2015) of the Government of India were 0.48 million. The highest number of fatalities in road accidents have been reported to be pedestrians (MoRTH 2015; Tiwari *et al.* 2000). Pedestrians and cyclists were never the striking vehicle, but constituted the highest number of fatalities in road accidents in metropolitan cities (MoRTH 2015). Due to heavy vehicular flows, high speed and unavailability of safe gaps, majority of the pedestrian accidents have been observed at mid-block sections. Mohan

et al. (2009) reported that 84% of the total fatal accidents in Kota (India) and 97% in Mumbai, occurred at mid-block locations. To prevent such accidents, appropriate pedestrian crossing facilities should be provided to minimize the pedestrian-vehicle interaction.

Absence of pedestrian crossing facilities can lead to a large number of pedestrian road accidents (DfT 2006). STATS19 is the police data of road accidents in Great Britain. It reported that 75% of the pedestrian road crashes occurred where pedestrian crossing facilities were missing. The remaining 25% of the road crashes happened even when crossing facilities were provided. This indicates that considering the hazardous and unstable conditions, it is necessary not just to provide a crossing facility, but to provide the appropriate type of crossing facility to enable safe and easy pedestrian crossing movements.

Pedestrian crossing warrants are guidelines that suggest the type of pedestrian crossing facility, which should

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be provided under the given traffic and site conditions. These warrants help in identifying the most appropriate type of crossing facility to be provided at a particular location based on certain factors. There are several guidelines being followed in different countries that report pedestrian crossing warrants. The PV^2 criteria based pedestrian crossing warrants are widely used in India, Iran and UK. Over the years, peak flows in cities have increased drastically and the roads have become wider. Iran and several counties in UK have modified the original warrant criteria to address these issues. In India, the formal guideline document for pedestrian facilities (IRC:103-2012) was revised in 2012, but there were no modifications made to the pedestrian crossing warrants since it was first published in 1988 (IRC:103-1988; IRC:103-2012). Therefore, there is a need to re-examine the pedestrian crossing warrants for Indian traffic flow conditions. This study recommends revised PV^2 threshold values and warrants based on Indian traffic flow conditions. These threshold values may require modifications for application in any other country.

This paper is structured as follows: Section 1 provides an insight to the pedestrian crossing warrants and guidelines that are being used in different countries. Section 2 describes the study design and data collection. Data analysis has been presented in Section 3. Section 4 presents the proposed threshold values of PV^2 and the revised pedestrian crossing warrants. The conclusions are presented towards the end.

1. Pedestrian crossing warrants and guidelines

Pedestrian crossing warrants are usually based on threshold values of a combination of certain traffic parameters like vehicular volume, number of lanes, pedestrian volume etc. Such warrants are used both formally and informally around the world to ensure safe and efficient pedestrian crossings at mid-block sections and intersections. In this section, pedestrian crossing warrants and guideline documents implemented in different countries, have been reviewed and discussed.

Pedestrian crossing warrants based on the PV^2 criteria were first reported by the Department for Transport in UK (DfT 1987). These warrants are presented in the form of a “V” versus “P” graph (Figure 1), demarcating the types of at-grade crossing facilities that should be provided. The recommended threshold values for PV^2 were $1 \cdot 10^8$ and $2 \cdot 10^8$.

In 1995, the Department for Transport (UK), along with several other agencies came up with the *Local Transport Note 1/95* for the assessment of pedestrian crossings (DfT 1995). This report suggests that the decision to provide a crossing, and its type, should be a balanced judgment based on consideration of all the information included in the site Assessment framework provided in the report. The framework includes site characteristics, pedestrian crossing details, vehicular flow details and accident history. The type of crossing facility to be provided can be

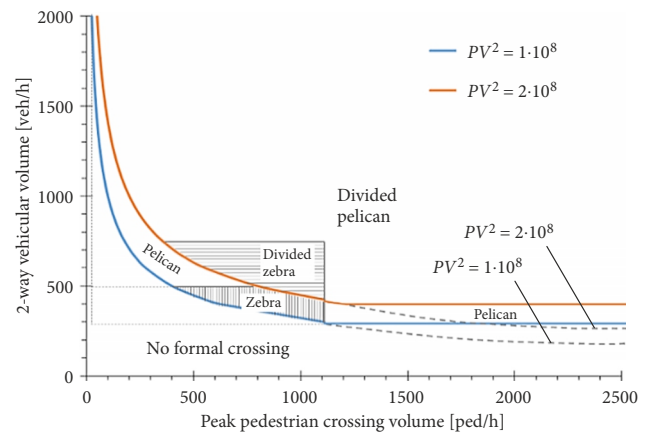


Figure 1. PV^2 based pedestrian crossing warrant graph for Department for Transport (UK)

assessed using factors like difficulty in crossing which is based on waiting time, gap size, vehicle delay, reduction in capacity and cost of the facility.

Since the publication of *Local Transport Note 1/95* (DfT 1995), several city councils in UK have started developing their own pedestrian crossing policy using a combination of PV^2 criteria and detailed site assessment framework reported by DfT (1987, 1995). These city councils first used a pre-qualification criteria based on the observed PV^2 value. Then the detailed site assessment framework is carried out to collect information on factors like proportion of elderly, children, bicycles, wheelchairs, vehicle categories, road width, crossing time, waiting time, vehicle speed, accident history etc. These factors are given certain weights and multiplied to the PV^2 value to get the adjusted PV^2 value. The type of crossing facility to be provided is then identified based on this adjusted PV^2 value (BHCC 2011; CEC 2011; RMBC 2011; DC 2014; WCC 2014; TCEC 2012; WSCC 2005).

The threshold values of $1 \cdot 10^8$ and $2 \cdot 10^8$ reported by DfT (1987) were formulated using empirical data based on peak flows of 1980s. These threshold values are likely to be much higher today due to the tremendous increase in peak flows. As discussed earlier, it has been observed that several counties in UK have reported different threshold values of the PV^2 criteria that best suit to the present traffic conditions. In addition, the warrants reported by DfT (1987) do not comment on the provision of grade separated facilities like foot over bridges underpasses, which are now being widely used as pedestrian crossing facilities.

In US, the *Manual on Uniform Traffic Control Devices for Streets and Highways* (FHWA 2009) recommend pedestrian crossing warrants that are primarily based on peak pedestrian and vehicular flows. These warrants indicate whether a particular location qualifies to be a marked crosswalk or not. It does not identify the type of crossing facility to be provided which is essential to ensure efficient flow for both pedestrians and vehicles (FHWA 2009). The warrants reported by City of Riverfalls (CRF 2001), Zegeer *et al.* (2005) and Lu, Noyce (2009) identified the

type of facility to be provided and have introduced vehicle speed and number of lanes as a part of the warrant criteria. However, pedestrian volume has not been used in these warrants.

New Zealand (NZTA 2009) and Australia (DTMR 2010) considered both macroscopic and microscopic traffic flow parameters in the warrant criteria. These warrants take care of both road user behaviour and traffic flow. A common pedestrian facility selection tool was developed by Austroads (2020) and Abley *et al.* (2015) based on pedestrian delay, pedestrian safety and overall walkability of the crossing. It is a web based tool, which not only recommends the crossing facility, which is appropriate for the traffic environment, but also provides a feasibility assessment based on the pedestrian delay, vehicle delay, level of service and economic evaluation. Although this approach seems to be the most logical one, the data collection and data extraction of microscopic traffic flow parameters is an exhaustive and time consuming task. This makes the applicability and implementation of these crossing warrants a challenge for the field engineers (Carlson, Hawkins 1998).

In India, planning and design of pedestrian facilities is based on the guidelines provided by the Indian Road Congress *Guidelines for Pedestrian Facilities* (IRC:103-2012). This document suggests that mid-block crossings may be warranted when one or more of the following conditions exist:

- peak hour volumes of pedestrians “ P ” and vehicles “ V ” are such that $PV^2 > 1 \cdot 10^8$ for undivided carriageways and $PV^2 > 2 \cdot 10^8$ for divided carriageways;
- approach speeds of vehicles exceed 65 km/h;
- waiting time for pedestrian/vehicle becomes too long;
- accident records indicate 5 or more injuries to pedestrian in a year due to collision with vehicles.

Recent studies on pedestrian crossing warrants were conducted by Teja (2013) and Prabhu (2014). These studies were conducted on four-lane road and a six-lane road in Jaipur and Delhi (India). Critical gap, crossing speed and crossing time was calculated using the extracted data. The pedestrian crossing warrants recommended in these studies were developed using K -means cluster analysis on pedestrian delay.

Iran also follows the PV^2 criteria based pedestrian crossing warrants. Amini and Ghahramani (2004) suggested that the threshold values of the PV^2 criteria reported in UK in 1987 (DfT 1987) need to be modified to suit the traffic conditions in Iran. Data was collected at 30 locations with different pedestrian crossing facilities. The pedestrian and vehicular volume at these locations were plotted on a graph and it was observed that the existing PV^2 curves were far below the observed data. These curves were relocated to relate to the type of crossing facility at the location where the data were collected. The new PV^2 threshold values were found to be $5 \cdot 10^9$ and $2 \cdot 10^9$.

The pedestrian crossing warrants followed in India and Iran are more or less an adaptation of the warrants reported by DfT (1987). In Iran, Amini and Ghahramani

(2004) have reported the modified threshold values of PV^2 criteria. In India, these threshold values are same as they were originally reported in 1987 (DfT 1987; IRC:103-1988; IRC:103-2012). Other factors like vehicle speed, waiting time and accident history have been used, but more or less in a subjective form and need to be quantified properly. These warrant criteria is same for all the road configurations. The effect of increase in the number of lanes is not considered. Moreover, these warrants do not identify the type of crossing facility to be installed. Researchers like Teja (2013) and Prabhu (2014) have developed warrants using only pedestrian delay. Other factors also need to be considered while formulating crossing warrants like pedestrian and vehicle flows and the number of lanes to be crossed by the pedestrian. The pedestrian crossing warrants should identify the type of crossing facility to be provided and should also be easy to implement in the field. The next section describes the study design and data collection process of the present study.

2. Study design and data collection

For this study, the maximum hourly vehicular flow, maximum hourly pedestrian flow, critical gap and follow up time for pedestrians is required to develop the PV^2 matrices for mid-block sections of different categories of urban roads. The maximum hourly flows are used as the upper bounds of the PV^2 matrices. The field data is collected at urban roads in two mega cities in India: Delhi and Chandigarh. Delhi is the National Capital of India and has the largest road network in the country, whereas Chandigarh is a Union Territory and Capital of Punjab and Haryana states. Both these cities have heterogeneous traffic conditions and high vehicular traffic flows on the roads. The mid-block sections were selected where sufficient pedestrian crossing and conflicting vehicular movements were observed in the city. Other criteria for the selection of these mid-block sections were that the section should be away from the influence of any upstream/downstream signal controlled intersections. There should be no parking or bus stops in the vicinity of the section. In addition, the section should not have any horizontal curves or gradients. The details of data collection locations are presented in Table 1.

Field data collection program was designed to have information on traffic flow, traffic composition, speed, free-flow speed, geometric elements of the road like road width and number of lanes etc. Video recording technique was used as the primary method to capture the vehicle and pedestrian traffic flow characteristics. Trap lines were marked on the road with a trap width of 10 metres each using traffic cones and white paint (Figure 2). The videos were recorded for two hours at each location with a clear view of the conflict area and the traffic stream. Geometric details like road width and crosswalk width were collected manually using measuring wheel and measuring tape.

The raw videos were processed for decoding the information. Virtual red colour lines were superimposed on the trap lines and embedded in the video. Data extraction was done by playing the recorded video in the laboratory on a large screen monitor. Figure 3 shows the camera view of the sites used for data extraction after embedding the virtual trap lines in the videos.

Frame by frame data extraction technique was used to record the arrival time, crossing start time, mid-way halt duration (in case of multiple stage crossing), crossing end time for every pedestrian. The video was played frame by frame several times to record the time stamps when the vehicle’s head and the vehicle’s tail crossed the trap lines. These time stamps were recorded for all the conflicting

Table 1. Data collection locations

Site code	City	Location	Roadway configuration
Site A	Chandigarh	Sector-17 Bus Terminal	2-lane 2-way-undivided
Site B	Chandigarh	Neelam Cinema Hall	4-lane 2-way-divided
Site C	Delhi	Dwarka Sector-6 Market	6-lane 2-way-divided
Site D	Delhi	Ramprastha Crossing	8-lane 2-way-divided

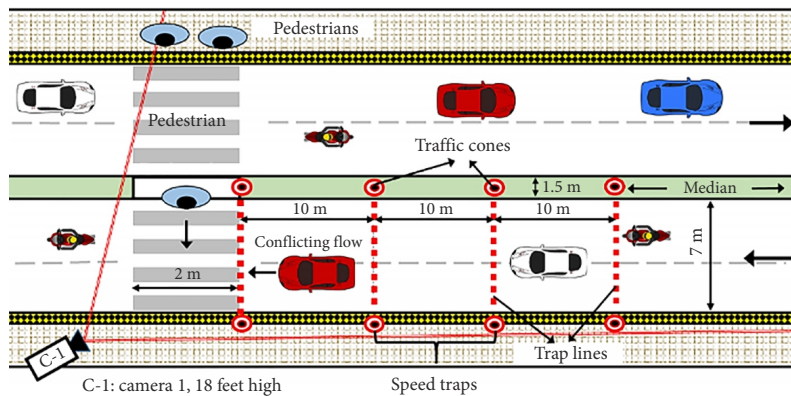


Figure 2. Schematic diagram depicting data collection technique

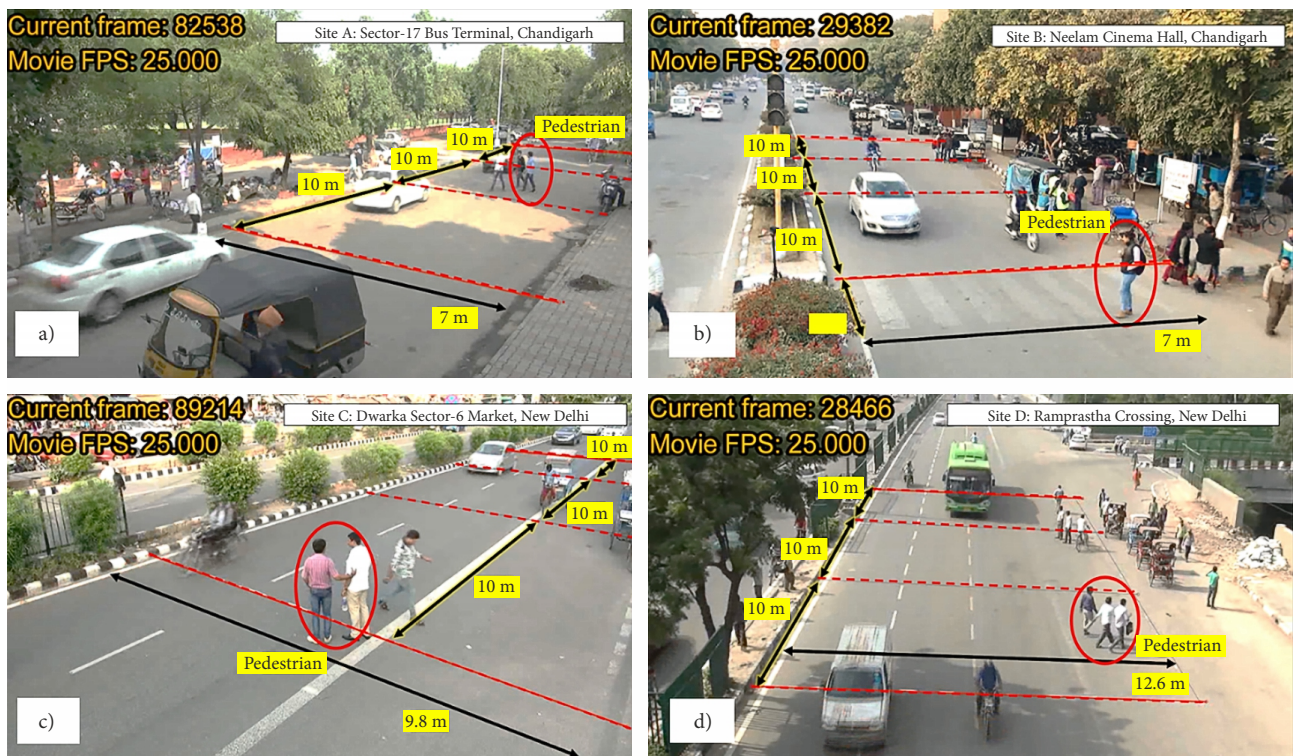


Figure 3. Data extraction camera view of: a – Site A; b – Site B; c – Site C; d – Site D

vehicles faced by a pedestrian. Both the pedestrian and conflicting vehicle data were used to prepare the extracted data set comprising of pedestrian gender, volume, crossing time, follow up time, crossing speed, lag/gap size, acceptance/rejection of gap, vehicular volume, approach speed and the type of vehicle.

3. Data analysis

3.1. Maximum hourly vehicular flow analysis

Preliminary data analysis revealed that the majority of the traffic comprises of cars and two-wheelers with a significant amount of slow moving vehicles sharing the same road space as the other motorized vehicles. The vehicle speed

distribution follows a normal distribution with an average speed of 29.7 km/h and standard deviation of 7.9 km/h. The traffic flow composition and the vehicle speed distribution are presented in Figure 4a and 4b respectively.

For the estimation of maximum hourly vehicular flow, different models like Greenshield model, Greenberg model, Underwood model, Pipes model etc. were used to fit the speed–density data of vehicles. The Greenshield model was found to best fit the data and describe speed–density curve. The speed–density equations, speed–flow curves and speed–flow equations of the Greenshield model used for the estimation of maximum hourly vehicle flows have been presented in Figure 5. The estimated values of maximum hourly vehicle flow are summarized in Table 2.

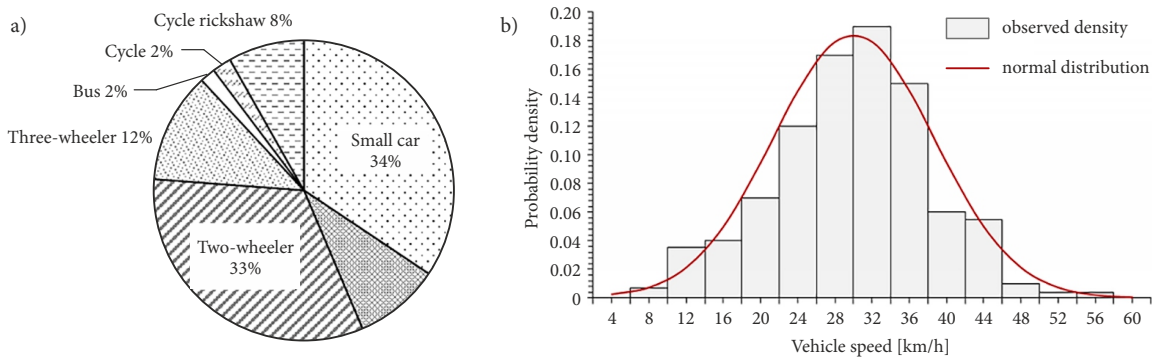


Figure 4. Average traffic composition (a) and vehicle speed distribution (b) for sites

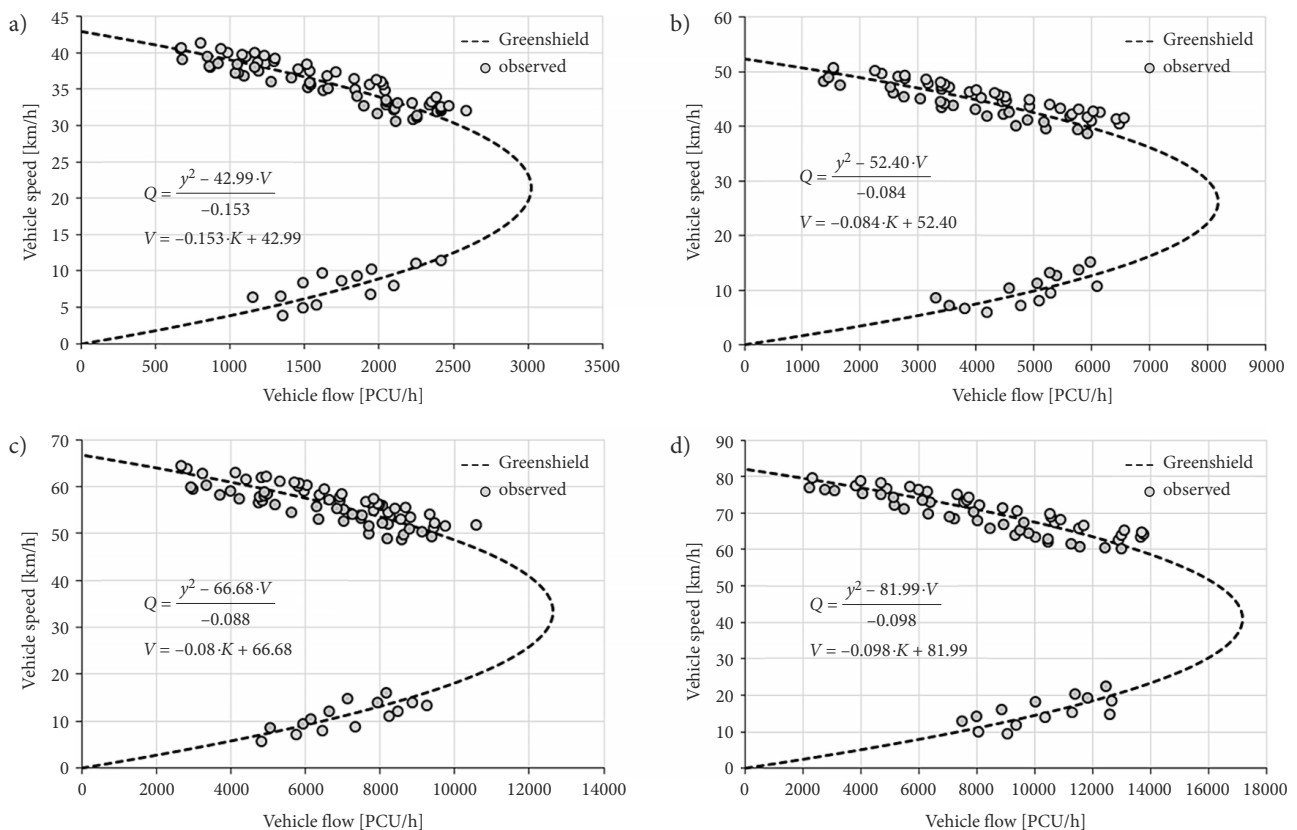


Figure 5. Speed–flow curves fits of Greenshield model for different road configurations (where: Q – flow; V – speed; K – density): a – 2-lane 2-way-undivided road; b – 4-lane 2-way-divided road; c – 6-lane 2-way-divided road; d – 8-lane 2-way-divided road

Table 2. Maximum hourly vehicle flow

Site code	Roadway configuration	Maximum hourly vehicle flow [PCU/h]
Site A	2-lane 2-way-undivided	3018
Site B	4-lane 2-way-divided	8172
Site C	6-lane 2-way-divided	12630
Site D	8-lane 2-way-divided	17149

3.2. Maximum hourly pedestrian flow analysis

The lag and gap data is used to estimate the critical gap and the follow up time of pedestrians. 3461 lag/gap data points were recoded from the field data. The lag/gap observations were tested for different probability distributions. They follow log-normal distribution with the mean and standard deviation of 0.045 and 1.078 s respectively. The Kolmogorov–Smirnov test statistic and the critical values at 95% confidence level are 0.019 and 0.023 respectively, indicating a statistically significant fit for log-normal distribution. The various distribution fits attempted are presented in Figure 6. The critical gap is estimated using maximum likelihood method (Brilon *et al.* 1999; Troutbeck 1992, 2014) and found to be 2.76 s. The average follow up time for pedestrians observed from the data is 0.80 s.

The maximum hourly pedestrian flow is estimated using the *Highway Capacity Manual* (TRB 2010) method, which is based on gap acceptance. The potential capacity of minor stream is calculated using Equation (1). The conflicting flow in the major stream is 3624 veh/h, the critical gap is 2.76 s and the follow up time is 0.80 s. The solution of this equation is maximized using linear programming technique to get the maximum hourly pedestrian flow. Conflicting major stream vehicle flow rate v_{cx} is the decision variable in this linear programming problem subject to the constraints that vehicle flow rate, critical gap and follow-up time are always positive. The maximum hourly flow calculated using Equation (2) is found to be 4500 ped/h.

$$c_{px} = v_{cx} \cdot \frac{e^{-\frac{v_{cx} \cdot t_{cx}}{3600}}}{1 - e^{-\frac{v_{cx} \cdot t_{fx}}{3600}}}; \tag{1}$$

$$\max \left(c_{px} = v_{cx} \cdot \frac{e^{-\frac{v_{cx} \cdot t_{cx}}{3600}}}{1 - e^{-\frac{v_{cx} \cdot t_{fx}}{3600}}} \right)$$

subject to: $v_{cx}, t_{cx}, t_{fx} > 0,$ (2)

where: c_{px} – the potential capacity of pedestrians; v_{cx} – the conflicting major stream vehicle flow rate; t_{cx} – the critical gap for pedestrians; t_{fx} – the follow-up time for pedestrians.

The estimated maximum hourly flow is then verified based on the guidelines provided in the Indian manual for pedestrian facilities (IRC:103-2012). The flow rate of pedestrians reported in IRC:103-2012 is 45 ped/min/m.

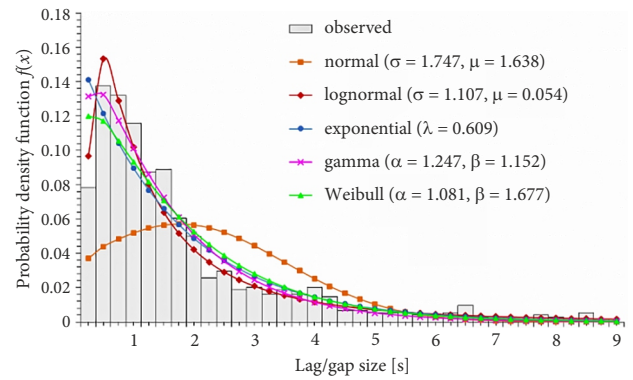


Figure 6. Distributions fitted to lag/gap data

For a crosswalk width of 2 m, the maximum hourly flow comes out to be the same as that calculated by the *Highway Capacity Manual* (TRB 2010) method. These maximum hourly flow rates have been used as the upper bounds for developing the PV^2 matrices. The PV^2 analysis has been discussed in the following sub section.

3.3. PV^2 analysis

The maximum hourly pedestrian flow and vehicle flow are used as upper bounds for developing the PV^2 matrices. The values of “P” and “V” are increased from zero to the upper bounds with increments of 100. The probable values of PV^2 thus obtained from the matrices represent the range of all possible combinations of pedestrian and vehicle flows which may occur in the Indian traffic flow conditions. The data set of PV^2 values was divided into several class intervals and a frequency distribution table was prepared. Then, using Kolmogorov–Smirnov test, the data was examined for possible fit of probability distributions like normal, exponential, Erlang etc. It was observed that the data did not follow any of these distributions at 95% level of confidence. Then, logarithmic transformation of the data set was carried out. The transformed data set of $\log_e(PV^2)$ was found to be normally distributed. The Kolmogorov–Smirnov test statistics for the data sets are presented in Table 3. The normal Quantile–Quantile (Q–Q) plots indicating that the data set is heavily tailed and negatively skewed are presented in Figure 7.

The Cumulative Distribution Function (CDF) of normal distributions fitted to the $\log_e(PV^2)$ values are presented in Figure 8a. Several researchers have identified the thresholds of parameters in traffic studies based on CDF of the normal distribution. The commonly used thresholds of CDF are 15th, 50th and 85th percentile of the normal distribution (Harkey *et al.* 1998; Kadali, Vedagiri 2018; Vedagiri, Kadali 2016). These threshold values are identified based on the change in the curvature of the CDF of a symmetric normal distribution. The present dataset of $\log_e(PV^2)$ follows a heavily tailed and negatively skewed normal distribution. Therefore, the threshold values where the curvature of the CDF changes in a skewed normal distribution differs from the threshold values of a sym-

metric normal distribution. Based on the observed CDF of $\log_e(PV^2)$, the threshold values where the curvature changes have been identified at the 2nd, 5th and the 75th percentile. These thresholds are marked on the CDF of $\log_e(PV^2)$ data and presented in Figure 8b. The $\log_e(PV^2)$

and PV^2 values corresponding to these percentiles are calculated from the CDFs and are presented in Table 4. These threshold values have been used in the next section for developing the ranges of PV^2 values and pedestrian crossing warrants.

Table 3. Kolmogorov–Smirnov test results

Roadway configuration	Value				Reject H_0 ?
	Alpha	Statistic	Critical	P	
2-lane 2-way-undivided	0.05	0.10761	0.17231	0.4590	No*
4-lane 2-way-divided	0.05	0.11048	0.17231	0.4259	No*
6-lane 2-way-divided	0.05	0.11544	0.17231	0.34681	No*
8-lane 2-way-divided	0.05	0.11795	0.17231	0.37223	No*

Notes: *null hypothesis (H_0): data follows normal distribution. “No” indicates that there is not sufficient evidence to reject the null hypothesis at 95% level of confidence; thus, data follows normal distribution.

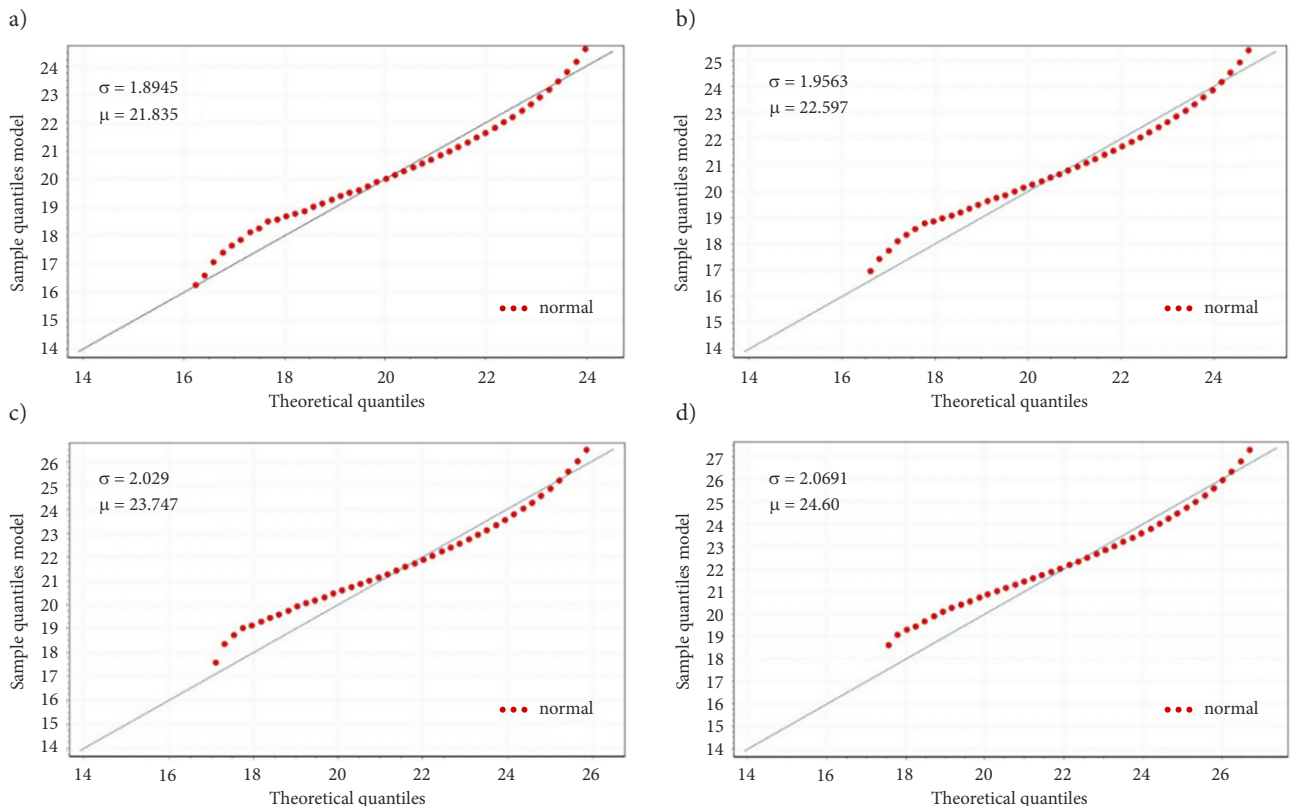


Figure 7. Q–Q plots: a – 2-lane 2-way-undivided road; b – 4-lane 2-way-divided road; c – 6-lane 2-way-divided road; d – 8-lane 2-way-divided road

Table 4. Percentile values of the fitted distributions

kth percentile	Values							
	$\log_e(PV^2)$				PV^2			
	2-lane 2-way-undivided	4-lane 2-way-divided	6-lane 2-way-divided	8-lane 2-way-divided	2-lane 2-way-undivided	4-lane 2-way-divided	6-lane 2-way-divided	8-lane 2-way-divided
2nd	18.00	18.90	19.80	20.50	$0.66 \cdot 10^8$	$1.61 \cdot 10^8$	$3.97 \cdot 10^8$	$8.00 \cdot 10^8$
25th	20.60	21.35	22.45	23.40	$8.84 \cdot 10^8$	$1.87 \cdot 10^9$	$5.62 \cdot 10^9$	$1.45 \cdot 10^{10}$
75th	23.20	24.00	25.20	26.10	$1.19 \cdot 10^{10}$	$2.65 \cdot 10^{10}$	$8.79 \cdot 10^{10}$	$2.16 \cdot 10^{11}$

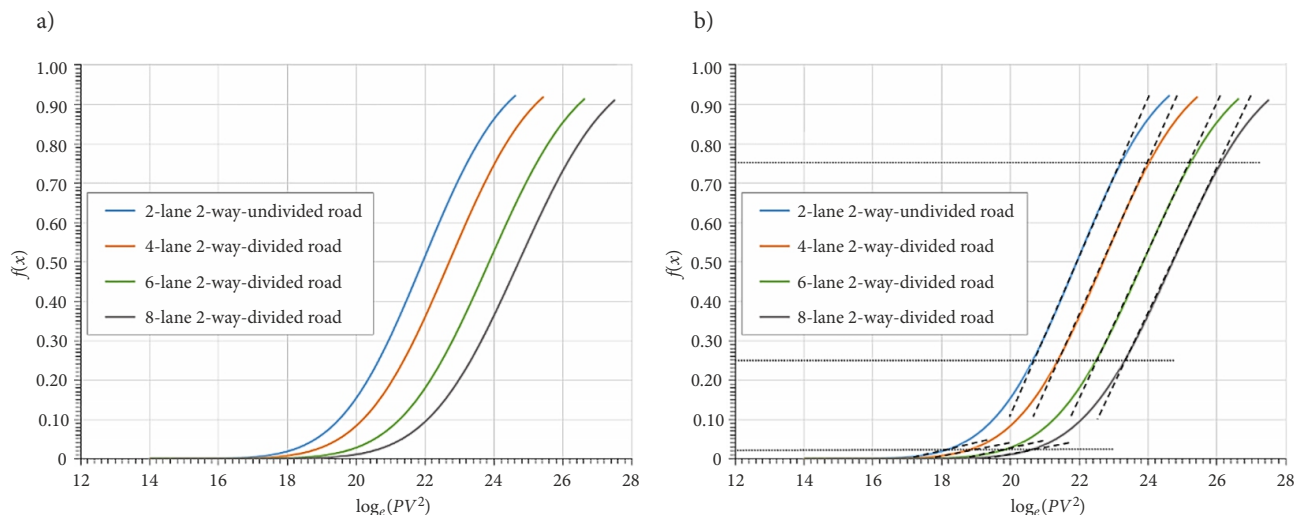


Figure 8. CDFs: a – for different carriageway types; b – marked with thresholds

4. Pedestrian crossing warrants

Pedestrian crossing warrants have been developed using the percentile values of PV^2 calculated from the CDFs of the fitted normal distributions. Four ranges have been created for the development of the warrants – less than 2nd percentile, from 2nd to 25th percentile, from 25th to 75th percentile and greater than 75th percentile. Higher the percentile, higher will be the PV^2 value and higher will be the difficulty faced by the pedestrians in crossing the road. Pedestrian crossing facilities have been assigned to these ranges in a hierarchical order to ensure pedestrian safety. The pedestrian crossing warrants are presented in Table 5. The warrants are also presented in Figure 9 in the form of a “V” versus “P” graph for the ease of comprehension and applicability.

The zebra crossing should be provided with a proper opening in the median, which is at the same level as the carriageway on both sides of the median. In addition, there should be a flashing amber signal provided along with the zebra crossing to seek the driver’s attention and ensure pedestrian safety. The next level of crossing facility, i.e., the pedestrian traffic signal may be a push button activated or fixed cycle time pelican signal. Sensor based puffin signal may also be used instead of the pelican signal. Considering the high cost of the puffin signals, it should be assessed depending upon the severity and need at the location. The grade separated facilities may be a foot-over-bridge, a full-subway or a hump-subway depending upon the availability of space and financial factors. It should be ensured that when a grade separated facility is provided, the median along the carriageway is closed with guard rails and the grade separated facilities are easily accessible and well-lit at all times to ensure effective utilization of the infrastructure.

For a particular road configuration, as the value of PV^2 increases, a better pedestrian crossing facility in terms of pedestrian safety has been recommended in the warrants. The increase in the PV^2 value indicates higher level of pe-

destrian-vehicle interaction on the roads. To comprehend the physical significance of this statement, one must first understand the impact of the increase in “P” and “V” on the PV^2 value, separately. If the PV^2 value increases due to an increase in the number of pedestrians “P”, it implies that pedestrian volume is very high and there is a need to provide a crossing facility. It also indicates that the vehicles might be facing delay due to the high pedestrian volumes thereby causing congestion and higher pedestrian-vehicle interactions. On the other hand, if the PV^2 value increases due to the increase in the number of vehicles “V”, it implies that there are higher number of vehicles on the road and pedestrians have to wait more to get safe gaps between vehicles, thus subjecting them to delay. This is more critical of the two situations because pedestrians tend to take risks and accept smaller vehicular gaps if they face higher delay. The point to be noted here is that for a unit increase in “P”, there will be a unit increase in PV^2 , but for a unit increase in “V”, there will be a quadratic increase in the PV^2 value. The square of “V” in the PV^2 criteria ensures priority to the number of pedestrians in the PV^2 criteria. For a small increment in the number of vehicles “V”, there will be a drastic increase in the PV^2 value, which will indicate difficulty in crossing the road and the need to provide or upgrade the crossing facility. This phenomenon can be observed graphically too. The slope of the PV^2 curves in the warrant charts is flatter at lower values of “V” and with the increments of “V”, the steepness of the slope increases drastically. To demonstrate the application of the proposed warrants, the observed PV^2 values at the four locations have been checked against the proposed PV^2 ranges. The application of the proposed warrants is demonstrated in Table 6.

The recommended crossing facility has been identified by checking the observed PV^2 value against the proposed PV^2 ranges presented in Table 5 and the warrant charts presented in Figure 9. Site A was a 2-lane 2-way-undivided unprotected crossing. Based on the peak flows observed at this site, the PV^2 value is found to be $6.55 \cdot 10^9$.

Table 5. Warrant table based on PV^2 value ranges

Crossing facility	PV^2 value ranges*			
	2-lane 2-way-undivided	4-lane 2-way-divided	6-lane 2-way-divided	8-lane 2-way-divided
No facility	$< 0.66 \cdot 10^8$	$< 1.61 \cdot 10^8$	$< 3.97 \cdot 10^8$	$< 8.00 \cdot 10^8$
Zebra crossing	$0.66 \cdot 10^8 \dots 8.84 \cdot 10^8$	$1.61 \cdot 10^8 \dots 1.87 \cdot 10^9$	$3.97 \cdot 10^8 \dots 5.62 \cdot 10^9$	$8.00 \cdot 10^8 \dots 1.45 \cdot 10^{10}$
Pedestrian signal	$8.84 \cdot 10^8 \dots 1.9 \cdot 10^{10}$	$1.87 \cdot 10^9 \dots 2.65 \cdot 10^{10}$	$5.62 \cdot 10^9 \dots 8.79 \cdot 10^{10}$	$1.45 \cdot 10^{10} \dots 2.16 \cdot 10^{11}$
Grade separated	$> 1.19 \cdot 10^{10}$	$> 2.65 \cdot 10^{10}$	$> 8.79 \cdot 10^{10}$	$> 2.16 \cdot 10^{11}$

Notes: * where “P” is the peak hour pedestrian flow and “V” is the peak hour vehicle flow of both directions.

Table 6. Application of proposed warrants

Site code	City	Location	Configu- ration	Peak hour pedestrian flow [ped/h]	Peak hour vehicle flow [PCU/h]	PV^2	Existing crossing facility	Recommended crossing facility
Site A	Chandigarh	Sector-17 Bus Terminal	2-lane	4080	1267	$6.55 \cdot 10^9$	unprotected	zebra / speed table
Site B	Chandigarh	Neelam Cinema Hall	4-lane	3237	2544	$2.09 \cdot 10^{10}$	zebra crossing	signal controlled
Site C	Delhi	Dwarka Sector-6 Market	6-lane	3360	4604	$7.12 \cdot 10^{10}$	unprotected	signal controlled
Site D	Delhi	Rampratha Crossing	8-lane	4688	6827	$2.17 \cdot 10^{11}$	unprotected	grade separated

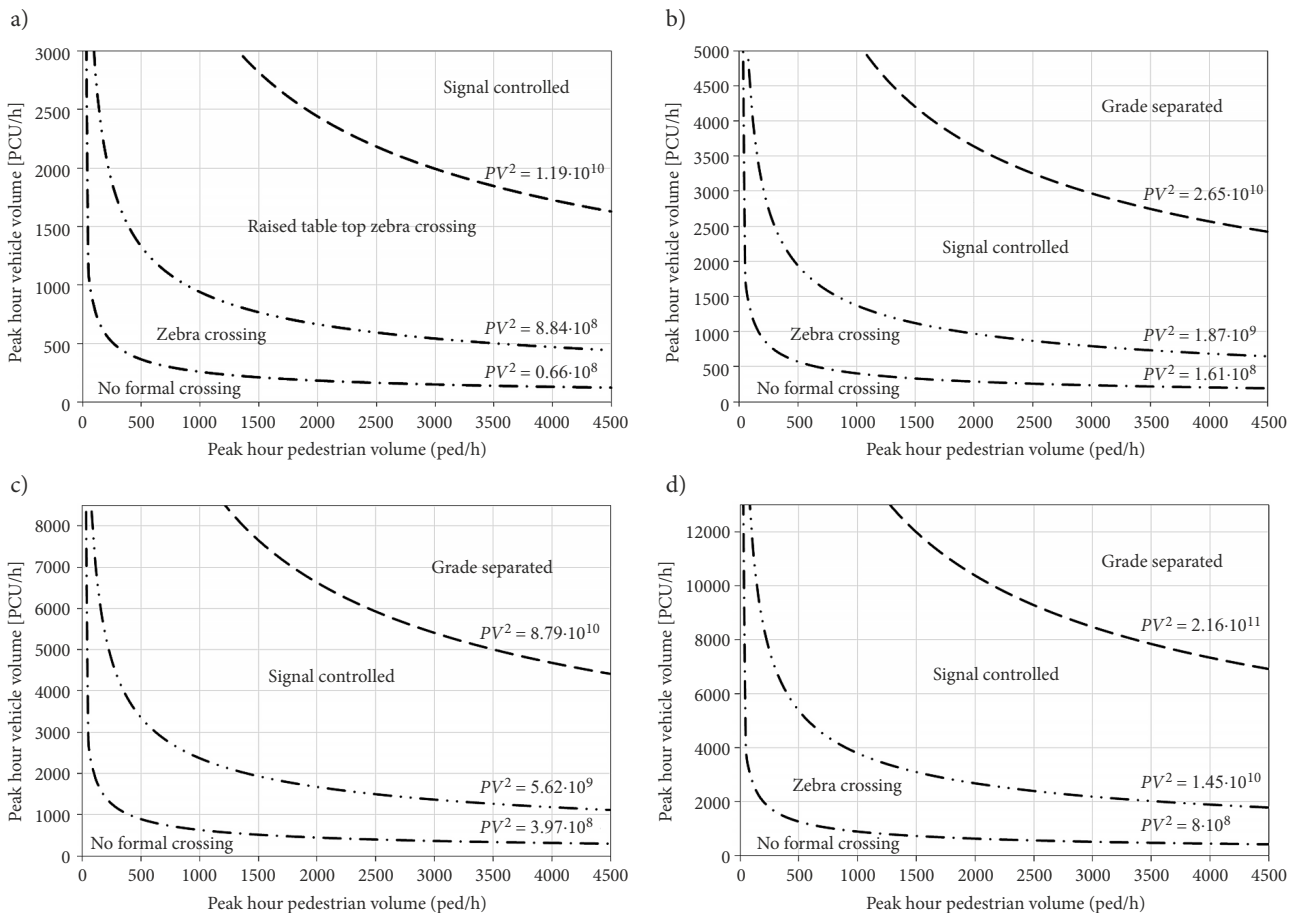


Figure 9. Warrant charts for different carriageway types: a – 2-lane 2-way-undivided road; b – 4-lane 2-way-divided road; c – 6-lane 2-way-divided road; d – 8-lane 2-way-divided road

As per the proposed warrants, this value qualifies Site A for a zebra crossing with a speed table (raised table top crossing). Similarly, Site B and Site C are recommended to be upgraded with a signal controlled crossing and Site D with a grade separate crossing.

Conclusions

In this paper, PV^2 threshold values have been identified for different roadway configurations for the selection of pedestrian crossing facilities. The revised PV^2 threshold values and pedestrian crossing warrant charts are based on the present traffic flow conditions in India. The revised values vary from $0.66 \cdot 10^8$ for 2-lane 2-way roads to $2.16 \cdot 10^{11}$ for eight lane divided roads. These values are higher than those originally recommended in 1987 in UK and those currently practiced in India. These values are comparable to the values proposed by Amini and Ghahramani in Iran and adjusted PV^2 values recommended in UK. The higher values of PV^2 are expected because of the tremendous increase in peak pedestrian and vehicle flows in cities over the years.

The existing pedestrian crossing warrants in India do not identify the type of crossing facility to be provided. In addition, there is an ambiguity in the number of lanes for which vehicle volume needs to be ascertained. These issues have been addressed in the pedestrian crossing warrants recommended in this study. The pedestrian crossing warrants have been proposed separately for each type of road configuration to avoid any ambiguity. To identify the type of crossing facility to be provided, the peak hour pedestrian flow and peak hour vehicle flow observed at a location can be plotted on the respective warrant chart. Different crossing facilities have been recommended on the warrant charts based on the threshold values of PV^2 . The range in which the plotted point would lie on the warrant chart would identify the crossing facility to be installed at that location. These ranges have been created based on PV^2 values for different road categories. The facility can also be identified by comparing the observed PV^2 value with the proposed threshold PV^2 values for that location.

In Indian cities, it has been observed that sometimes an automated fixed time signalized pedestrian crossing is provided at mid-block sections, but the pedestrian flow is extremely low. At a few locations, it has also been observed that the signalized pedestrian crossing is unable to cater to the high pedestrian crossing demand. The former is a case of underutilization of facility and causing unnecessary delay to vehicles whereas the latter is a case of saturated conditions at a facility causing excessive delay to the pedestrians. Installation of appropriate crossing facilities at a mid-block crossings would prevent such underutilization or saturated use of crossing facilities. This study was limited to the revision of PV^2 based pedestrian crossing warrants. During the analysis, it was observed that microscopic traffic parameters like delay faced by pedestrians and critical gap play a vital role in the pe-

destrian's decision to cross the road. Even though these factors are a function of pedestrian flow and vehicular flow, further research should be conducted to observe the impact of these microscopic traffic parameters on pedestrian crossing decisions and pedestrian safety. Inclusion of these factor would further refine the proposed pedestrian crossing warrants. Another limitation in this study is that the proposed warrants have been developed based on the traffic flows observed in Indian cities. The values of maximum hourly flow rates may vary from country to country depending upon the traffic composition and driving behaviour. The methodology used in this research may be adopted for arriving at modified PV^2 values using the peak flow rates observed in any other country.

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