Pedestrian crossing warrants – a review of global practices

Udit Jain* and Rajat Rastogi

Department of Civil Engineering, Indian Institute of Technology, Roorkee 247 667, India

Pedestrians are the largest number of road accident victims. Majority of these accidents have been reported at mid-block locations where pedestrian crossing facilities were missing. Pedestrian crossing warrants (PCWs) help in identifying the type of facility to be provided at a location. This article examines the literature on PCWs around the world. Various factors used in the existing PCWs have been identified and summarized. The discussion highlights the limitations associated with existing guidelines and the need to improve upon the existing PCWs.

Keywords: Facilities, global practices, pedestrian crossing warrants, road accidents.

According to the World Health Organization (WHO), 'More than 5000 pedestrians are killed on the world's roads each week because their needs have been neglected for decades, often in favour of motorized transport'[1].

Vehicle and pedestrian flows in urban areas have increased drastically over the years due to increase in population density and economic growth. As a result, the pedestrian–vehicle interactions on the roads have also increased. Traffic engineers mostly emphasize on achieving frictionless vehicle movement, which often leads to negligence in making provisions for pedestrian facilities, thus making them vulnerable and prone to road crashes.

More than 270,000 pedestrians lost their lives on the world's roads in 2013, accounting for 22% of the total 1.24 million road traffic deaths[2]. In 2013, a pedestrian was killed every 2 h and injured every 8 min in traffic crashes on an average in USA. Pedestrian deaths accounted for 14% of all traffic fatalities in road accidents[3]. This share was 23% in 2014 in the UK[4]. In India, 8.8% of total road accident fatalities in 2014 has been reported to be pedestrians[5]. Although the percentage share is lower compared to other countries, the actual number of pedestrian fatalities was 12,291. This is equivalent to losing a fully loaded Boeing 777 aircraft every week. In India, upon classifying the road accident fatalities according the place of occurrence, it was found that 10.3% of all the road accident fatalities took place at pedestrian crossing locations[6]. In USA, 69% of the pedestrian fatalities occurred at non-intersection locations, 20% at intersections and 10% at other locations like sidewalks and bicycle lanes[3]. The absence of pedestrian crossing facilities also lead to a large number of pedestrian road accidents at mid-block locations. In the UK, 75% of pedestrian accidents occurred where pedestrian crossing facilities were not present at the crossing location[7]. According to the data provided by Department of Transport, UK, pedestrians have the second highest fatality rate (deaths per billion passenger miles) after motorcyclists among all other road users[4]. To prevent such crashes and ensure safe pedestrian crossing movements, appropriate facilities should be provided at crossing locations.

Pedestrian crossing warrants (PCWs) are the guidelines that recommend the type of pedestrian crossing facility to be provided under the given traffic and site conditions. PCWs are usually based on a set of macroscopic traffic flow parameters like pedestrian volume and vehicle volume, and microscopic traffic flow parameters like pedestrian delay and crossing opportunities. Different countries have their own formal guidelines which use a combination of these factors to recommend PCWs. A few of these guidelines have formally defined the road users who will be considered as 'Pedestrians'. According to the Highway Capacity Manual[8], USA, a pedestrian is any person making a journey on foot. According to the formal guideline of Canada and India, any person on foot, or wheelchair, or pushing the wheelchair/bicycle on foot is considered as a pedestrian. The definition of a pedestrian remains more or less similar around the world, other than a few additional considerations. For example, the Australian and Canadian guidelines also consider mobility aids (like motorized wheelchairs) with speed less than 10 kmph as pedestrians. In-line skaters and skateboarders are also considered as pedestrians by the formal guidelines of USA (Manual on Uniform Traffic Control Devices; MUTCD).

Similarly, the types of crossing facilities recommended in the PCW guidelines may slightly differ across countries, but they follow a hierarchical structure based on the level of control. Figure 1 shows the different types of crossing facilities observed in various countries. Most of the PCW guidelines identify and recommend a type of crossing facility to be installed at a particular location.

This article reviews the various guidelines and research conducted on PCWs across the globe. Factors used in these guidelines and by other researchers have also been

*For correspondence. (e-mail: udit17788@gmail.com)

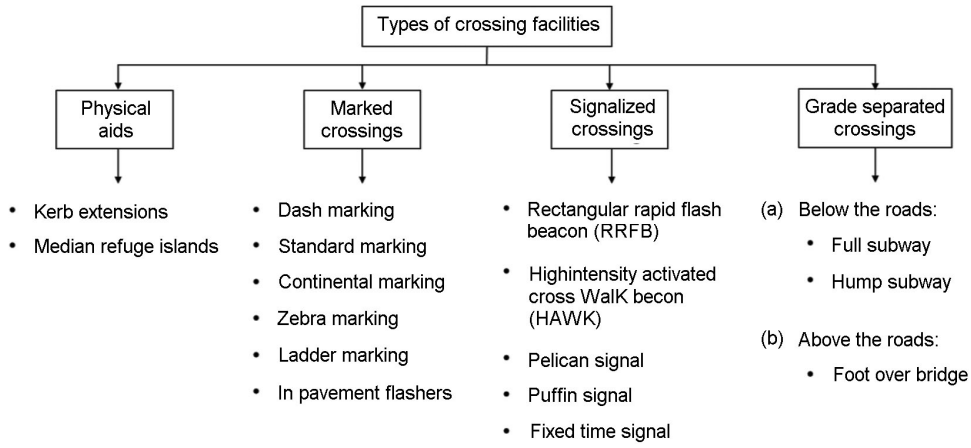

Figure 1. Types of pedestrian crossing facilities.

discussed and summarized. Similarities between some of the most widely followed PCWs in different countries have also been highlighted. The discussion justifies the need to re-examine the existing warrants and develop multi-criteria-based PCWs.

Pedestrian crossing warrants in USA

PCWs in USA have evolved since 1935. The formal national guidelines on the subject are listed in the MUTCD. Initially, factors considered in PCWs were pedestrian volume, vehicle volume and vehicle speed. These were revised based on exhaustive critiques by several researchers[9–12]. In 1998, the threshold values for pedestrian volume and vehicular volume were decreased from 300 pedestrians per hour and 750 vehicles per hour to 150 pedestrians per hour and 600 vehicles per hour respectively[13]. Lower threshold values imply that the warrant criteria would be satisfied for smaller volumes of pedestrians and vehicles. This would ensure better safety standards for pedestrians. The number of available vehicular gaps replaced the vehicle volume warrant criteria in the 1998 MUTCD warrants[13]. The 2001 MUTCD warrants were more or less similar to their predecessor[14], though Carlson and Turner[15] provided several recommendations to ensure safer movements of pedestrians and cyclists.

All PCWs reported in USA were based on single threshold values of certain factors and did not consider the effect of increase in the number of lanes. Zegeer *et al.*[16] reported a new form of tabulated warrants based on the number of lanes, vehicle volume and vehicle speed. These became the basis for the current MUTCD warrants (2009). These and other trends in USA are discussed in the following sub-sections.

Current MUTCD warrants

The crossing warrants were based on the same three factors as in the previous editions – pedestrian volume, vehicular volume and vehicular speed, but used a wide range of pedestrian and vehicular flows, rather than a single threshold value and presented them in the form of a graph[17] (Figure 2). Four curves were reported based on 4 h or peak hour pedestrian volume and vehicle speed. It was recommended that a traffic signal should be installed if the point representing pedestrian volume and vehicle volume lies above the respective curve. These warrants just indicated whether a particular location qualified to be a signalized crosswalk or not. Other types of crossing facilities are not recommended which are essential to ensure efficient flow for both pedestrians and vehicles. Microscopic factors like delay and crossing opportunities (gaps) were also not considered as a criterion.

Other trends

City of River Falls[18] reported point-based multiple-criteria PCWs, as a combination of macroscopic and microscopic factors. Points are assigned on a scale of 10 to 8 h pedestrian volume (macroscopic), peak hour pedestrian volume (macroscopic) and average number of accepted gaps in a 5 min period (microscopic). Table 1 presents the point criteria. The type of crossing facility is recommended based on the points scored by a potential location and its proximity to the nearest marked crosswalk. Table 2 presents these PCWs. The point-based approach appears to be logical as it takes into account both macroscopic and microscopic traffic flow parameters. Other parameters like vehicle speed and waiting time can also be examined in this approach.

In some studies conducted on PCWs[16,19,20], the pedestrian volume criterion has been omitted in the crossing warrants. These recent warrants are in a tabulated form, based on the number of lanes, average daily traffic and vehicle speed, and are more or less similar to one another. The PCW table reported by Lu and Noyce[19] is presented in Figure 3, while Table 3 presents the corresponding type of crossing facility to be installed on the site.

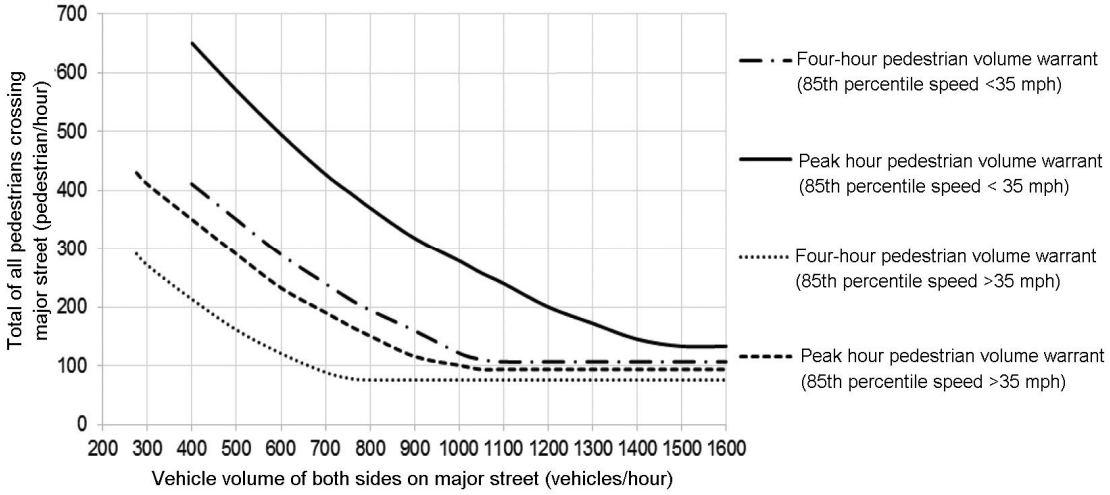

Figure 2. Pedestrian crossing warrants – MUTCD, 2009 (ref. 17).

Table 1. Point criteria[18]

Eight-hour pedestrian volume (ped/h)	Points	Peak-hour pedestrian volume (ped/h)	Points	Average number of gaps per 5 min period	Points
0–40	0	0–10	0	<1.00	10
41–120	2	11–30	2	1–1.99	8
121–180	4	31–60	4	2–2.99	6
181–240	6	61–90	6	3–3.99	4
241–300	8	91–120	8	4–4.99	2
>300	10	>120	10	>5.00	0

Table 2. Pedestrian crossing warrant criteria[18]

Distance (ft) to the nearest crosswalk based on type				
Type II	Type III	Type IV	Type V	Points required
<200	<400	<400	<400	Marked crosswalk not allowed
200–600	400–800	400–800	400–800	16
>600	>800	>800	>800	12

Type I, Pavement markings
Type II, Signs and pavement markings
Type III, Signs and pavement markings with ground-level warning flashers
Type IV, Signs and pavement markings with overhead warning flashers
Type V, Signal controlled crosswalks

Warrants presented in this format are easier to comprehend. For example, if the vehicle volume and vehicle speed at a particular location are greater than 15,000 vehicles per day (vpd) and 40 mph on a two-lane road, then it corresponds to the last cell of two-lane row in Figure 3. This coloured cell indicates the need of a level-5 device at this location, which is given in Table 3. However, these studies do not consider any microscopic traffic flow parameters like pedestrian delay and crossing opportunities.

Pedestrian crossing warrants in Canada

The Pedestrian Crossing Control Manual for British Columbia[21] (PCCMBC) is the guideline document followed for PCWs in Canada. It provides recommendations for the type of crosswalk to be installed for a given number of crossing opportunities and the equivalent adult unit (EAU) of pedestrians per hour. The number of crossing opportunities is equal to the number of accepted vehicular gaps. EAU is a relative weighing of pedestrians on the basis of

Roadway Configuration	Roadway ADT and Vehicle Speed											
	< 9,000 vpd			9,000 - 12,000 vpd			12,000 - 15,000 vpd			> 15,000 vpd		
	≤ 30 mph	35 mph	≥ 40 mph	≤ 30 mph	35 mph	≥ 40 mph	≤ 30 mph	35 mph	≥ 40 mph	≤ 30 mph	35 mph	≥ 40 mph
2 Lanes	A	A	B	A	A	B	A		C	A	B	C
3 Lanes					B	C	B			B	C	
4 or more Lanes (Raised median)										C		
4 or more Lanes (No median)		B	C	B		C						

A - Level 1 or Level 2 devices, **B -** Level 3 or Level 4 devices, **C** – Level 5 devices if feasible

Figure 3. Pedestrian crossing warrants – Lu and Noyce, 2009 (ref. 19).

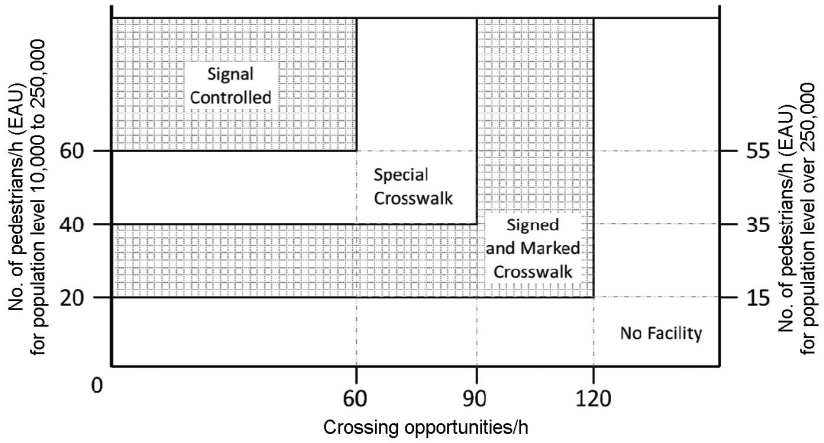

Figure 4. Pedestrian crossing control warrant chart – British Columbia, 1994 (ref. 21).

age groups. It is similar to the Passenger Car Unit (PCU) factor used for vehicles. It is multiplied by the number of pedestrians to get the corresponding EAUs of pedestrians. The EAU factors considered in this guideline for different category of users are as follows: (a) Children (<12 years) – 2.0; (b) Seniors (>65 years) – 1.5; (c) Physically challenged – 2.0; (d) Adults – 1.0.

A warrant chart (Figure 4) has been presented for different EAUs and number of crossing opportunities. According to this document, if, for example, at a particular location, there are 30 crossing opportunities and 70 pedestrians in an hour, then the graph recommends a pedestrian signal at that location. The pedestrian behaviour is taken into account by considering the number of crossing opportunities as a warrant criterion. For the grade-separated facilities, the document suggests that there should be no norms and it should be considered on a case by case basis.

Pedestrian crossing warrants in New Zealand and Australia

PCW in New Zealand

In 2007, New Zealand Transport Agency came up with a guideline document focusing on safe pedestrian movements[22]. The guideline follows a systematic process using tables and flowcharts based on pedestrian crossing level of service (LOS) criteria (Table 4). LOS is identified based on average pedestrian delay. Figure 5 shows a flowchart which first checks whether a particular location qualifies for the provision of crossing facilities or not. The pedestrian delay is estimated using pedestrian crossing time, vehicle volume and the number of lanes to be crossed. The guideline recommends the values of pedestrian delay (for both interrupted and uninterrupted flow) based on delay tables developed using the modified Tanner's delay function. Modifications made to the original Tanner's delay function[23] have been explained by Abley *et al.*[24]. Further, to recommend the type of crossing facility, physical aids like kerb extension and median refuge are first considered. If the provision of these aids does not achieve the desired LOS, then zebra crossing or traffic signal is recommended based on pedestrian volume and comparison of pedestrian and vehicular delay. In this manner the procedure initially uses macroscopic traffic flow parameters for preliminary analysis and then recommends a facility based on microscopic parameters like crossing time and delay.

PCW in Australia

In Australia, several studies have been conducted on pedestrian facilities. The guidelines for assessing the level

Table 3. Levels of pedestrian facilities[19]

Level	Device	Level	Device
Level 1	Standard, marked crosswalks Raised crosswalks Rumble strips	Level 3	Refuge Islands Split pedestrian crossover Bulb-outs
Level 2	Textured pavement crosswalks Zebra and continental crosswalks	Level 4	Overhead signs and flashing beacons In-Roadway warning lights
	Triple-four crosswalks	Level 5	Pedestrian-actuated signals Grade-separated crossings

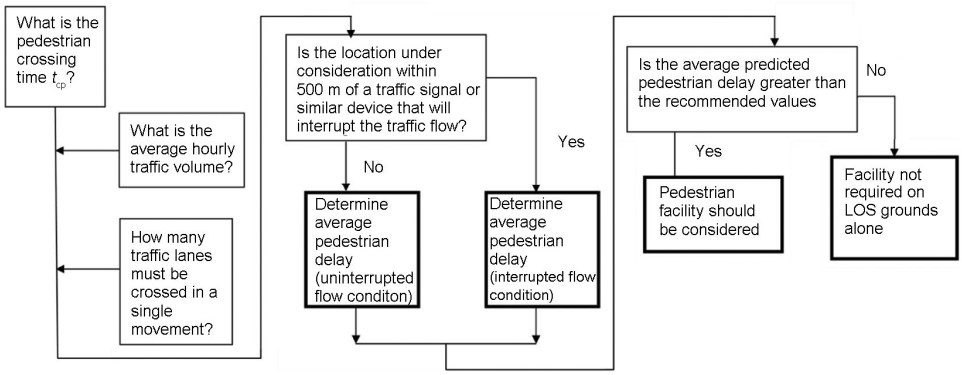

Figure 5. Flowchart based on level of service – NZ Transport Agency, 2007 (ref. 28).

of service by Main Roads Western Australia (MRWA)[25] recommend the level of service criteria based on qualitative parameters. This report does not consider factors like pedestrian delay and traffic volume. The types of crossing facilities to be provided have also not been discussed. The Australian MUTCD[26] (Queensland Government) provides a detailed account of geometric features and installation of crossing facilities. However, selection of a crossing facility has been primarily based on sight distance and vehicle speed.

The Traffic Road Use Management Manual (TRUM)[27] published by the Queensland Department of Transport and Main Roads (QTMR) is considerably more detailed than the other guidelines. The QTMR guidelines[27] are primarily based on factors like pedestrian volume, vehicle volume, speed limit, sight distance, crash history and distance to the nearest designated crosswalk. This report considers all the different types of crossing facilities, except the grade-separated facilities. The report lacks discussions and recommendations on economic evaluation of crossing facilities, which are available in the NZ Transport Agency guidelines[22] in detail.

Recent trend

Australian researchers identified that a common pedestrian crossing facility selection tool would be appropriate for both Australian and New Zealand[24]. Although there is no specific evidence of behavioural homogeneity among Australia and New Zealand pedestrians, both countries share the same set of guidelines in several areas like traffic engineering, road safety and road design[24]. The NZ Transport Agency[22] and QTMR[27] guidelines were taken as the starting point for the development of this common pedestrian crossing facility selection tool[24,27,28]. The tool has been developed by Autroads and Abley Transportation Consultants in Sydney, Australia and it is an open-access java-based tool which runs in any modern web browser[29]. It takes walkability of crossings as the primary factor to assess the different types of crossing facilities for mid-blocks and uncontrolled intersections. The level of service criteria proposed is based on pedestrian delay, pedestrian safety and overall walkability. This tool not only recommends the crossing facility which is appropriate for the traffic environment, but also provides a feasibility assessment based on pedestrian delay, vehicle delay, LOS and economic evaluation. This web-based tool for the selection of pedestrian crossing facility is user-friendly and can also be comprehended with the help of an on-line webinar video posted by Austroads[30].

Pedestrian crossing warrants in the UK

PV^2 criteria-based warrants

PCWs were first introduced in the UK by the Institution of Highways and the Department of Transport (DoT) in

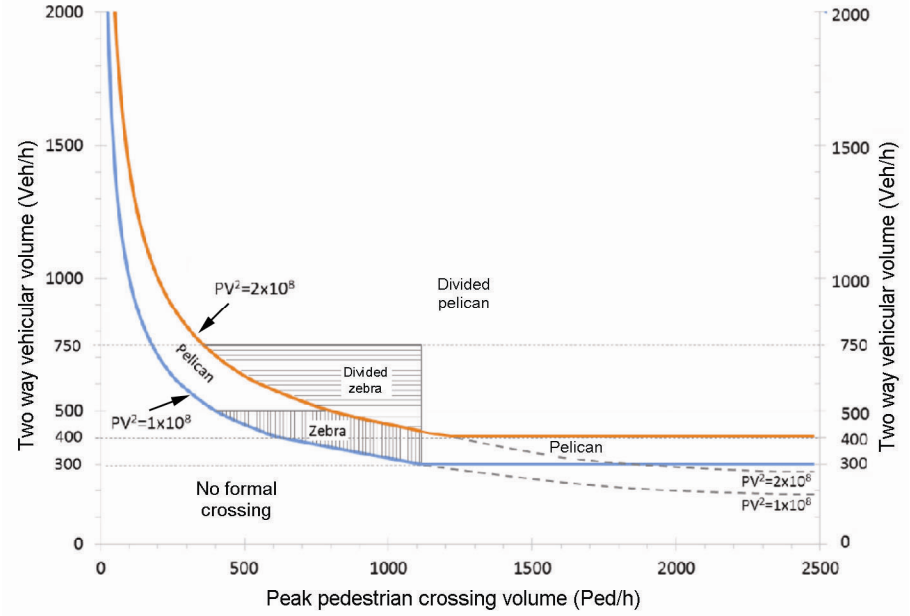

Figure 6. PV^2-based pedestrian crossing warrant graph – UK, 1987 (ref. 31).

Table 4. Level of service (LOS) table based on pedestrian delay – NZ transport agency, 2007

Average pedestrian delay (sec)	LOS	Definition
<5	A	Excellent
5–10	B	Very good
10–15	C	Satisfactory
15–20	D	Some concern
20–40	E	Major concern
>40	F	Unsatisfactory

1987 (ref. 31). These warrants were primarily based on the PV^2 criteria where P is pedestrian volume and V vehicular volume. The types of at-grade crossing facilities that should be provided were demarcated using the threshold values of PV^2 on a V versus P graph (Figure 6). The threshold values of PV^2 reported by DoT, UK[31] are 1×10^8 and 2×10^8. To demonstrate how the type of facility can be identified using Figure 6, let consider that the two-way vehicle volume is 500 vehicles/h and pedestrian volume is 1000 pedestrians per hour. This point lies above the $PV^2 = 2 \times 10^8$ curve, in the shaded region which recommends a divided zebra crossing for these volumes. The limitations associated with these warrants are the same as those with the 2009 MUTCD warrants[17] of USA. These warrants do not consider the effect of number of lanes and microscopic factors like gap size and delay. The PV^2 criteria based warrants have been widely adopted and modified by several counties of the UK and developing countries of the world. The modified PV^2 criteria-based warrants have been discussed in the next sub-section.

Modified PV^2 criteria-based warrants

Microscopic traffic flow factors like the number of acceptable vehicular gaps and pedestrian delay have been included as part of the warrant criteria in USA[12–14]. It was evident that these factors played a vital role in the pedestrian crossing decision-making process and warrant criteria based on PV^2 alone were inadequate.

In 1995, the DoT, UK, along with several other agencies came up with the Local Transport Note (LTN) 1/95 for the assessment of pedestrian crossings[32]. This report suggested that the decision to provide a crossing and its type, should be a balanced judgement based on consideration given to all the information included in the site assessment framework provided in the report. The framework was based on site characteristics, pedestrian crossing details, vehicular flow details and accident history. The type of crossing facility to be provided was assessed using factors like difficulty in crossing which was based on waiting time and gap size, vehicle delay, reduction in capacity and cost of the facility.

Since the publication of LTN-1/95, several city councils in the UK have started developing their own pedestrian crossing policy using a combination of PV^2 criteria and detailed site assessment framework reported by DoT[31] and LTN-1/95 (ref. 32) respectively. Most of the city councils use 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 by the PV^2 value

Table 5. PCW for 4- and 6-lane divided roads

Four-lane divided roads		Six-lane divided roads	
Lane crossing time (sec)	Facility to be provided	Lane crossing time (sec)	Facility to be provided
≤13	No facility required	≤15	No facility required
>13 and ≤19	Zebra crossing	>15 and ≤19	Zebra crossing
>19 and ≤34	Signals with zebra crossing	>19 and ≤24	Zebra crossing with overhead flashing signal
>34	Grade separation	>24 and ≤31	Signals with zebra markings
		>31	Grade separation

Table 6. LOS criteria and crossing warrants

LOS	Delay (sec)	Crossing facility
A	<5	Zebra crossing
B	>5 and <10	Signalized crossing
C	>10 and <30	
D	>30 and <55	
E	>55 and <75	Grade separator
F	>75	

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[33–39].

Pedestrian crossing warrants in Iran

Iran also follows PV^2 criteria-based PCWs. In 2005, Amini and Ghahramani[40] suggested that the threshold values of the PV^2 criteria reported in the UK in 1987 (ref. 31) need to be modified to suit the traffic conditions in Iran. Data were collected at 30 locations with different pedestrian crossing facilities. The pedestrian and vehicular volume at these locations were plotted on a graph; 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. Figure 7 shows the PCW based on these relocated curves. The new PV^2 threshold values for traffic flow conditions in Iran were found to be 5×10^9 and 2×10^9.

Pedestrian crossing warrants in India

PV^2 criteria-based warrants

In India, planning and design of pedestrian facilities is based on the guidelines provided by the Indian Road Congress document IRC: 103 (ref. 41) titled 'IRC: 103 was first published[42] in 1988 and the warrants reported were more or less similar to those reported by DoT, UK[31]. This document suggests that mid-block crossings may be warranted if PV^2 is greater than 1×10^8 for undivided carriageways, or 2×10^8 for divided carriageways. Other factors like vehicle speed and waiting time for pedestrians and vehicles have been mentioned in the warrant criteria, but more or less in a subjective manner. There are no threshold values or range of values to quantify these factors. IRC: 103 was revised in 2012, but the threshold values of PV^2 criteria and other warrant criteria recommendations remain the same as first published in 1988. The threshold values of PV^2 were based on peak flows in 1980s in the UK. Due to the tremendous increase in peak flows over the years and mixed traffic conditions in India, these threshold values are likely to be much higher. Quantification of microscopic factors like waiting time is also required. Most importantly, the PCWs in India do not identify the different types of crossing facilities to be installed.

Recent trend

Recent studies on PCWs were conducted by Teja[43] and Prabhu[44] at Indian Institute of Technology Roorkee and School of Planning and Architecture, New Delhi respectively. Teja[43] proposed PCW-based on lane crossing time for 4- and 6-lane divided roads (Table 5). Lane crossing time is the time taken by a pedestrian to cross from kerbside to the median (half of the total crossing distance). It is calculated as the sum of optimum crossing time (crossing time without any delay) and average pedestrian delay (sum of waiting time and operational delay). The optimum crossing time is constant and reported as 8.4 and 14.5 sec on 4- and 6-lane divided roads respectively. As optimum lane crossing time is constant, these warrants are indirectly based on pedestrian delay.

Prabhu[44] used pedestrian delay to develop the LOS criteria and PCWs (Table 6). The data used were for a 4-lane one-way road and a 4-lane divided two-way road in Delhi. The pedestrian crossing behaviour varies significantly due to the different road configurations. This variation has been overlooked, and unified LOS and PCWs have been recommended for all roadway configurations.

In India, there is a need to re-examine the existing PV^2-based warrants and also consider other factors like pedestrian delay, vehicular gaps and the number of lanes

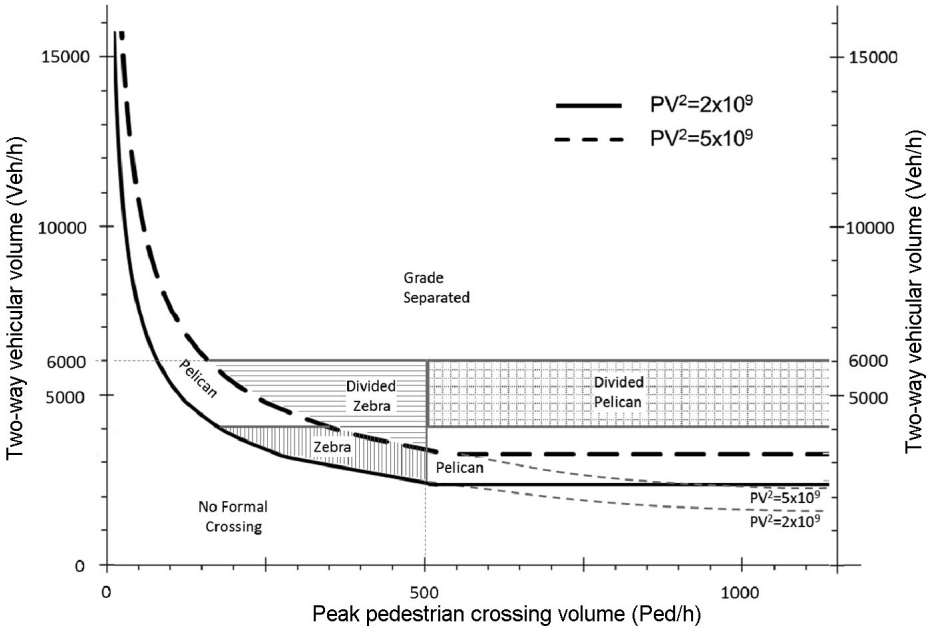

Figure 7. Pedestrian crossing warrants – Iran, 2005 (ref. 40).

to be crossed as part of the warrant criteria. The next section discusses the various factors considered in the existing PCW guidelines around the world.

Factors considered in existing PCW guidelines

Factors used by researchers and various formal PCW guidelines around the world have been categorized as follows: (1) macroscopic factors; (2) microscopic factors; (3) geometric factors and (4) other factors.

While most of the factors have been quantified in the PCW guidelines, some like land use, delay and lighting have been used subjectively in a qualitative form. To identify whether a factor has been used quantitatively or qualitatively, they have been given the signs '√' and 'O' respectively. Table 7 provides a summary of these factors.

It is evident from the existing literature that till date, macroscopic factors like pedestrian volume, vehicular volume and vehicle speed are the most widely used in PCWs ever since they were first introduced in 1935.

Microscopic factors like number of crossing opportunities (vehicular gaps) and pedestrian delay are used in the formal guidelines of very few countries like Canada[21], New Zealand[22] and UK[32]. Microscopic traffic flow parameters play a crucial role in pedestrian crossing behaviour, but are often neglected in PCWs. Pedestrian crossing decision is usually based upon a safe gap which is perceived differently by each individual[45]. When the available vehicular gap is perceived as insufficient by a pedestrian, the waiting time at the kerbside increases. As the waiting time increases, one of the following two scenarios may take place: impatience comes into play and pedestrians tend to accept smaller vehicular gaps for crossing, or there is a platoon formation at the kerbside. In both cases, pedestrian risk-taking tendency increases which makes them vulnerable to road accidents[45,46]. Thus, it is essential to consider both macroscopic and microscopic traffic flow parameters as a part of PCW. Though researchers have advocated the use of microscopic factors in PCW[11,14], the use of such factors is yet to be seen in the formal guidelines of countries like USA, India and Iran.

Geometric factors like number of lanes and proximity to the nearest designated crosswalk have also been widely used in several guidelines. These factors have an impact on both vehicular traffic and pedestrian behaviour. Vehicular volume and vehicular speed are directly proportional whereas ease of pedestrian crossing is inversely proportional to the number of lanes. Effect of number of lanes has been taken into consideration by most researchers. However, it has not been considered in the formal guidelines of USA, UK, Canada or India. Other factors like lighting, land use and accident history have been used in some guidelines. Though significant, these factors are used sparingly due to the difficulty in quantifying them. The similarities between some of the existing PCWs are discussed in the next section.

Similarities between existing pedestrian crossing warrants

In light of the existing literature, the most widely accepted PCWs are the PV^2-based warrants and MUTCD warrants developed in the UK and USA respectively. These have

Table 7. Factors used in various PCWs

		Macroscopic factors			Microscopic factors				Geometric factors			Other factors		
Author/guidelines	Country	Pedestrian volume	Vehicle volume	Vehicle speed	Crossing opportunities	Pedestrian delay	Elderly/ disabled pedestrians	Vehicle delay	Number of lanes	Proximity to nearest crosswalk	Sight distance	Lighting	Accident history	Land use
Box and Alroth[9]	USA	√				√								
Lieberman *et al.*[10]	USA	√	√		√				√					
King[11]	USA	√	√			√			√					
Zegeer *et al.*[12]	USA	√			√		√							
Axler[47]	USA	√	√						√	√		O		
DoT[31]	UK	√	√											
Smith and Knoblauch[48]	USA	√	√							√	O	O		
PCCMBC[21]	CAN	√			√		√							
LTN-1/95 (ref. 32)	UK	√	√		√	√	√						O	
City of River Falls[18]	USA	√		√	√		√			√	√	O		
Carlson and Turner[15]	USA	√		√	√					√				O
Cornwall County Council[49]	UK	√	√	O							√			
Zegeer *et al.*[16]	USA		√	√					√					
Amini and Ghahramani[40]	IRAN	√	√		√	√								
NZ Transport Agency[22]	NZ	√	√	√				√	√					
Lu and Noyce[19]	USA		√	√	O	O			√					
MUTCD[17]	USA	√	√	√						√				
TRUM[27]	AUS	√	√							√	O		O	
City of Boulder[20]	UK	√	√	√					√					
City of Mankato[50]	USA	√		√							O	O	O	O
IRC: 103 (ref. 41)	IND	√	√	O		O		O					O	
Teja[43]	IND					√			√					
Prabhu[44]	IND					√								
Total √	√	19	15	8	7	6	4	1	8	6	2	0	0	0
Total O	O	0	0	2	1	2	0	1	0	0	3	4	4	2

√, Used quantitatively O, Used qualitatively.

Table 8. KS test results

Datasets compared	Parameter	Value	Statistical check	Statistical inference
KS test results for MUTCD (speed < 35 mph) and DoT ($PV^2 = 2 \times 10^8$)	Maximum deviation (d)	0.25	$t > d$	The two datasets are statistically similar at 95% confidence level
	KS test statistic (t)	0.79		
	Alpha value	0.05	$p > \alpha$	
	P-value	0.56		
KS test results for MUTCD (speed > 35 mph) and DoT ($PV^2 = 1 \times 10^8$)	Maximum deviation (d)	0.37	$t > d$	The two datasets are statistically similar at 95% confidence level
	KS test statistic (t)	1.12		
	Alpha value	0.05	$p > \alpha$	
	P-value	0.16		

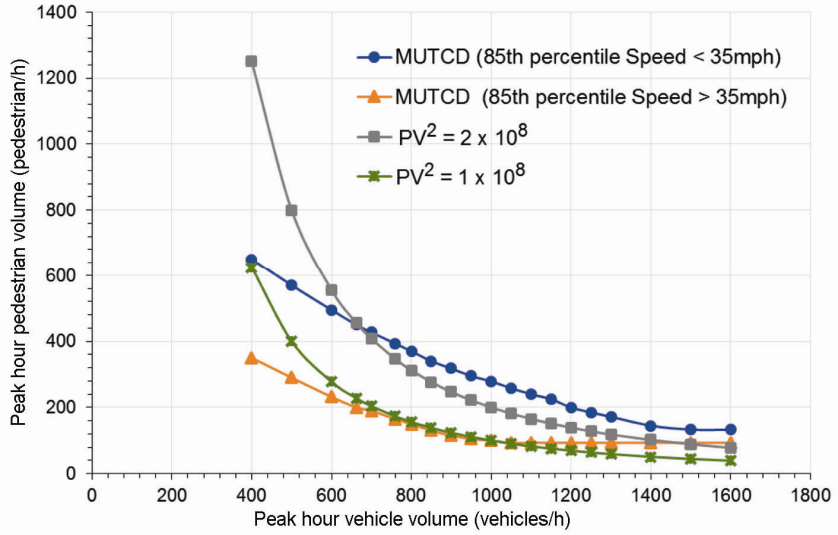

Figure 8. PV^2 and MUTCD warrant chart.

been modified by several researchers and adopted in various parts of their respective countries and the rest of the world. Both these warrants are in the form of a graph between peak pedestrian volume and vehicular volume. The curves reported by DoT, UK[31] and MUTCD, USA[17] have been plotted together on the same scale and presented in Figure 8 for visual similarity. The graph indicates that the MUTCD[17] curve for 85th percentile speed less than 35 mph is similar to the DoT[31] curve of $PV^2 = 2 \times 10^8$. Similarly, the MUTCD[16] curve for 85th percentile speed greater than 35 mph is similar to the DoT[31] curve of $PV^2 = 1 \times 10^8$. To check the statistical similarity between these two sets of curves, two-sample Kolmogorov–Smirnov (KS) test was conducted on the data at 95% confidence level. Table 8 summarizes the KS test results. It can be inferred from the KS test results that the PV^2-based DoT[31] warrants and vehicle speed-based MUTCD[17] warrants are statistically similar.

The MUTCD warrants differentiate the two curves on the basis of speed limit, but the DoT warrants do not use any known traffic parameters to differentiate the two curves. Instead, the latter uses threshold values of PV^2 to arrive at the two curves. These two curves representing a single threshold value (PV^2) based on P and V alone make the task easier for the implementing agencies. To check if the location qualifies for the provision of a crossing facility, the MUTCD warrant chart must be referred by implementing agencies to see if the point depicting the pedestrian volume (P) and vehicle volume (V) at a particular site lies above or below the curve provided in the graph. Whereas the DoT warrants simply provide a threshold value. If the product of P and V^2 is greater than the threshold value, then the location qualifies for provision of a crossing facility. It is not necessary to refer to the UK warrant graph each time to assess if the location qualifies for the provision of a facility. These warrants have been developed separately using different methodologies in the UK and USA, but the warrant criteria of both these guidelines are satisfied for the same set of pedestrian and vehicular volume.

Factors to be considered for Indian warrants

The recent studies on PCWs in India have used pedestrian delay as the warrant criterion. But some of the most widely used macroscopic and microscopic factors have been overlooked by the researchers. These factors may influence the pedestrian's decision to cross the road and

therefore, should be considered. In the light of the existing literature, the role of the following parameters should be examined while developing the PCW criteria in India: (a) Pedestrian volume, (b) vehicle volume, (c) vehicle speed, (d) vehicle gaps, (e) pedestrian delay, (f) number of traffic lanes, (g) proximity to alternate crosswalk and (h) crash history.

Conclusion

It is evident that extensive research has been carried out on PCWs in the UK, USA, New Zealand and Australia. These countries have formal national guidelines for PCWs. However, some implementing agencies at the state level felt the need to improvise upon the formal guidelines and develop their own guidelines for PCWs. As already discussed, warrants in the UK and USA have been developed using different methodologies and presented in different forms, but they are more or less similar to one another in terms of satisfaction of the warrant criteria for a set of pedestrian and vehicular volume. Both these warrants are based solely on macroscopic traffic flow parameters, which could be one of the reasons why city councils have developed their own crossing warrants using a combination of both macroscopic and microscopic traffic flow parameters. The PCWs in Canada and New Zealand are also based on a combination of macroscopic and microscopic traffic flow parameters. More importantly, the warrants of Canada and New Zealand and the modified warrants of USA recommend the type of crossing facility to be provided at a location, which the formal crossing warrants of USA (MUTCD) do not. Very limited research has been conducted on PCWs in developing countries like India and Iran. The crossing warrants followed in India and Iran are almost similar to those developed in the UK in 1987. The formal PCWs in India are also primarily based on macroscopic factors and do not recommend the type of crossing facility. Keeping in mind the pedestrian vulnerability to road crashes, extensive research is required in the field of PCWs. These should take pedestrian behaviour into consideration by including both macroscopic and microscopic factors as a part of the warrant criteria. Also, these warrants should clearly identify the most appropriate crossing facility to be installed at a particular location based on the site conditions.

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