International Journal for Traffic and Transport Engineering, 2014, 4(1): 103 - 116

DOI: http://dx.doi.org/10.7708/ijtte.2014.4(1).08 *UDC: 625.712.34*

PEDESTRIAN CROSSING BEHAVIOUR ANALYSIS AT INTERSECTIONS

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Received 17 February 2013; accepted 22 January 2014

Abstract: Pedestrian crossing behavior is analyzed for the provision of proper pedestrian facilities at desired locations, as well as to improve their safety while crossing the road. This paper presents the analysis of pedestrian crossing behavior from a study conducted at Roorkee city (Uttarakhand state in India). The effect of pedestrian characteristics like age, gender and that of carrying baggage and luggage as well as their crossing patterns were examined on pedestrian flow characteristics like crossing speed and waiting time. Pedestrian safety was also analyzed with respect to safety margins and gaps accepted by pedestrian in traffic stream. Crossing patterns were observed for different age group and gender.

Keywords: pedestrian crossing behavior, crossing pattern, waiting time, gaps accepted, safety margins.

1. Introduction

Traffic accidents involving pedestrians have become a major safety problem all over the world, particularly in developing countries, due to high population density, rapid urbanization, and lack of adherence to traffic regulations by both drivers and pedestrians. Lack of adherence to traffic regulations at pedestrian crossings particularly by drivers create a paradigm in which pedestrians may become bold and force approaching vehicles in the traffic stream to brake in order to gain priority at the pedestrian crossing. On the other hand, pedestrian crossings with heavy pedestrian flow are likely to cause unacceptable vehicular delay. Pedestrians are observed to be a major component of the total urban traffic accidents. In India, pedestrians account for 65% of the accident deaths and out of these, 35% are pedestrian children. Hence, there is a special need to analyze the crossing behavior of pedestrians to ensure their safety on roads.

1.1. Literature Review

Earlier studies provide significant facts about pedestrian demographic characteristics (such as age, gender) and how these characteristics influence road crossing behavior. Such studies have focused on detailed experiments to find out the effect of age on road crossing decisions with effect of vehicle distance or speed of vehicle (Oxley et al., 1997; Lobjois and Cavallo, 2007). Most of these studies have been carried out in a virtual environment. Road crossing behavior with respect to gender and baggage held has also been observed in various studies. Males have a tendency to show more hazardous road crossing behavior than females due

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to less waiting time (Khan et al., 1999; Tiwari et al., 2007). Few studies have also explored the importance of the pedestrian speed at different locations (Knoblauch et al., 1996; Rastogi et al., 2011), such as the zebra crossing location (Varhelyi, 1998) and signalized intersections (Tarawneh, 2001). Outline of these studies suggest that males walk significantly faster than females while crossing the roads. A recent study was focused on legal versus illegal pedestrian road crossing behavior at mid-block location in China (Cherry et al., 2012). Few studies have identified pedestrian behavior in mixed traffic streets and developed a micro-simulation model in order to find out the fundamental characteristics as well as the conflicts of the pedestrian movement (Shahin, 2006). A study in Beijing, investigated pedestrian behavior and traffic characteristics at un-signalized midblock crosswalk. Authors have explained the pedestrian speed change condition with pedestrian behavior (Shi et al., 2007). Some studies have also addressed pedestrian road crossing behavior by considering the effectiveness of educational training programs (Dommes et al., 2012). Studies had identified the importance of the environmental characteristics, such as type of crossing facility, traffic volume and roadway geometry on road crossing behavior (Kadali and Vedagiri, 2013). Some studies have also explored the pedestrian road crossing behavior before and after re-construction of traffic facility (Gupta et al., 2010).

1.2. Types of Pedestrian Crossings

Pedestrian crossing can be broadly classified (IRC: 103-1988) as:

1. At-grade crossings,
2. Grade separated crossings.

At grade crossings the pedestrians cross the carriageway at the same level as that of vehicular movement. It is very common in cities and towns. It may be controlled and uncontrolled. Uncontrolled crossings are those where the pedestrian cross walk is marked by studs or paint line but not controlled by any system of signals or a zebra form of crossing. With respect to locational aspects, such crossings can be classified as:

1. Pedestrian crossings at intersections,
2. Mid-block crossings.

These are the crossings where the pedestrians are required to cross the carriageway at a level different from that of vehicular movement. It may be in the form of a pedestrian subway or a foot over bridge across the road.

1.3. Crossing Behavior of Pedestrians

Previous researches have made theoretical and methodological contribution to a practical understanding of pedestrian's behavior and the interaction between the driver and the pedestrian at pedestrian crossings (Sun et al., 2011). Pedestrians arriving at the pedestrian crossing look for acceptable gaps between vehicles in the traffic stream. They either accept or reject such gaps. Rejection of prevailing gaps leads to longer waiting time at the curb side. Pedestrian crossing behavior is divided here into four categories namely "one stage", "two-stage", "perpendicular direction" and "oblique direction". Each of these serves to minimize crossing time while still providing a degree of safety.

1.3.1. Factors Affecting

Pedestrian crossing behavior is usually get influenced by various factors related to pedestrian characteristics, pedestrian movements, traffic conditions, road conditions and environmental surroundings. Rosenbloom et al. (2008) observed unsafe crossing behavior of children, like not stopping at the curb, not looking before crossing, attempting to cross when a vehicle is nearing and running across the road. Female pedestrians are observed accepting more gaps and less risk compared to male pedestrians. Oxley et al. (2005) have done experimental studies on the effect of age of a pedestrian in gap selection. They reported that, for all age groups, gap selection is primarily based on vehicle distance and speed.

Hamed (2001) reported that approaching traffic volume and vehicle speeds are instrumental in determining the pedestrian's waiting time (delay) and the number of crossing attempts. Pedestrians, who accept higher risk, have to cease their waiting time, whereas pedestrians, who are likely to lower the risk, have to extend their waiting time at pedestrian crossings. Yagil (2000) reported that pedestrian's belief, motives and situational factors can affect their crossing behavior at signal controlled crossings. Situational factors like presence of other pedestrians and their behavior towards 'Walk' and 'Don't Walk' signs affect the behavior of female pedestrians and traffic volume affect the behavior of male pedestrians at signalized crossings.

1.4. Objectives of the Study

The main objectives of this study are:

- To study the crossing behavior pedestrians at uncontrolled intersections.
- To analyze and study the effect of various factors related to pedestrian characteristics, pedestrian movements, traffic conditions, road conditions, walking environmental surroundings and intersection conditions.

2. Data Collection

2.1. Identification of Study Locations

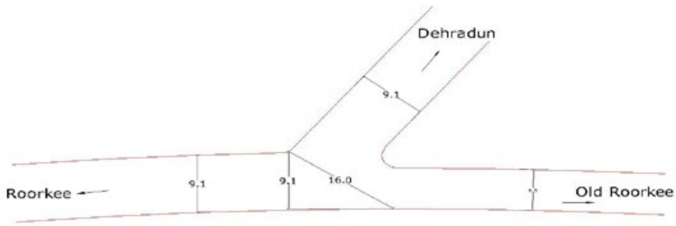
The locations for carrying out the pedestrian study are decided based on the combination of land uses, width of the road and the type of intersection. Data were collected from the following locations in Roorkee city:

1. BSM intersection,
2. Chungi Naka intersection,
3. Civil Lines IIT Roorkee intersection.

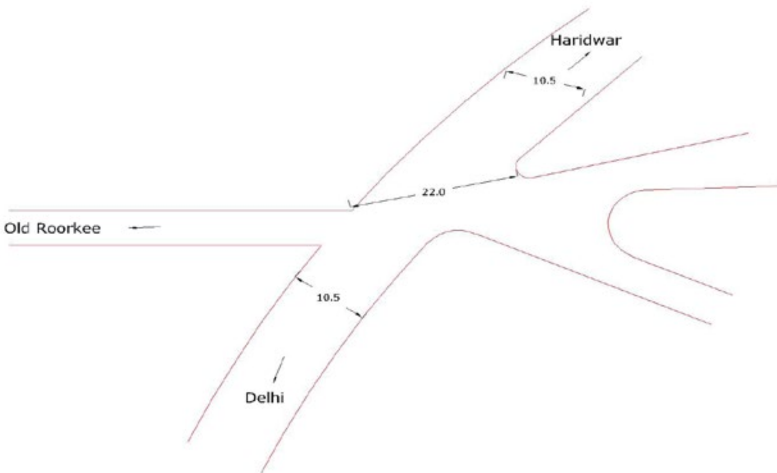
The study locations chosen for the present study, satisfies the following criteria:

- The pedestrian traffic is enough.
- The traffic flow is continuous.
- The effective width of the road is uniform throughout the length considered.
- For video recording of pedestrian flow, the road width considered should be easily accessed from vantage point.

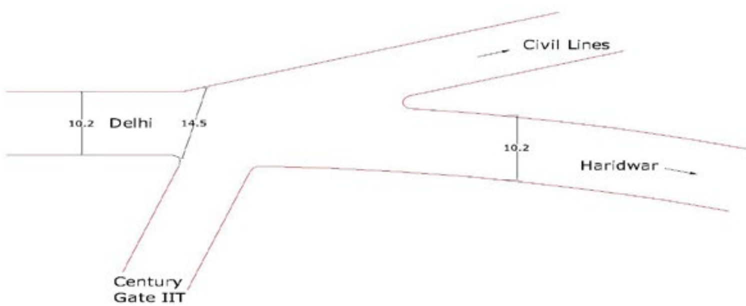
The schematic diagrams of the above intersections are given in Fig. 1 (all dimensions are in meter). The photograph showing actual pedestrian crossing scenario are given in Fig. 2.



BSM Intersection, Roorkee



Chungi Naka Intersection, Roorkee



Civil Lines - IIT Roorkee Intersection, Roorkee

Fig. 1.
Schematic Plans of Study Locations

BSM Intersection, Roorkee | Chungi Naka Intersection, Roorkee | Civil lines - IIT Roorkee Intersection, Roorkee

Fig. 2.
Pedestrian Crossing Scenario at Different Study Locations

2.2. Data Collection Technique

There are different methods for data collection. These are given below:

1. Direct observation methods,
2. Video observation methods,
3. Time Lapse Photography,
4. Pedestrian opinion surveys.

Out of the above, video graphic method is used in the present study. The camera was fixed in an elevated position so as to obtain an overall view of the selected test locations. Recording was done for about 60 minutes at a time, during morning (10.00 am to 12.00 noon) and evening peak periods (4.00 pm to 6.00 pm) on a normal working day. The width of the road sections (i.e. perpendicular and oblique) are measured using an instrument called measuring wheel as shown in Fig. 3.

Fig. 3.
Measurement of Width of Road

3. Methodology for Data Analysis

Recorded video is used to extract data. The values of pedestrian waiting time and crossing time are observed from the videos and recorded in MS-Excel work sheets for further processing of the data. Based on the above recorded information and using the value of road width sections, pedestrian speeds are estimated. Behavioral aspects like gap acceptance, safety margins etc. are also calculated and examined using the data. Variation in speed with respect to pedestrian personal characteristics like age and gender and effect of carrying baggage while moving on the speeds of the individuals are also studied.

3.1. Data Analysis

This section presents the relationships plotted between pedestrian crossing time, waiting time, total travel time and cumulative percentage of pedestrians. Based on these relationships, the values of pedestrian characteristics like crossing speed are computed for mixed traffic flow conditions. Variation in pedestrian speeds according to age and gender, and for conditions like moving with and without baggage; and other conditions like geometry of intersections, traffic density etc. are also analyzed. Along with that the accepted and rejected gaps curves are developed and safety margins are studied.

3.2. Pedestrian Crossing Behavior

3.2.1. Crossing Patterns

During the analysis of recorded data from different study locations, two major crossing patterns are observed which can be classified as (a) one step/two step; (b) perpendicular/oblique crossings. The proportion of pedestrians estimated within these different crossing patterns are shown in Table 1 for all study locations.

Table 1
Pedestrians Crossing Patterns

Crossing Patterns	Percentage of Pedestrians (%)	
	One Step Crossing	**Two Step Crossing**
Perpendicular Crossing	53.98	7.36
Oblique Crossing	31.90	6.74
Overall	85.89	14.11

3.2.2. Crossing Time and Waiting Time

After collecting the data from study location using video graphic technique, the analysis of pedestrian crossing speeds with respect to certain pedestrian characteristics is usually desired. For that purpose, firstly the pedestrian crossing time and waiting time is observed from the video of study locations. The crossing and waiting time is observed for perpendicular and oblique crossing condition separately. The analysis of crossing time and waiting time is done for one step crossing and two step crossing separately. The analysis presented here uses data of all study locations. The combined cumulative frequency curves of pedestrian crossing time and waiting time for the crossing patterns are given in Figs. 4-7.

The general range of crossing time and waiting time as well as 50th percentile volume are given in Table 2.

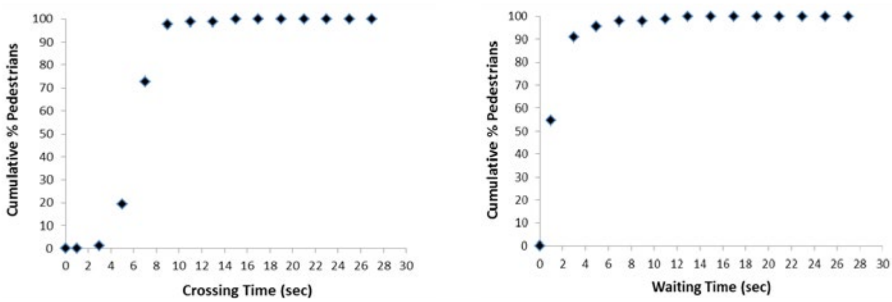


Fig. 4.
Cumulative Frequency Curves for Perpendicular Movements in One Step Pedestrian Crossing

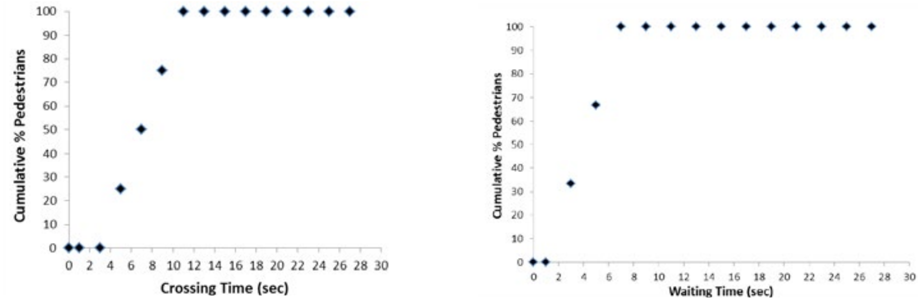


Fig. 5.
Cumulative Frequency Curves for Perpendicular Movements in Two Step Pedestrian Crossing

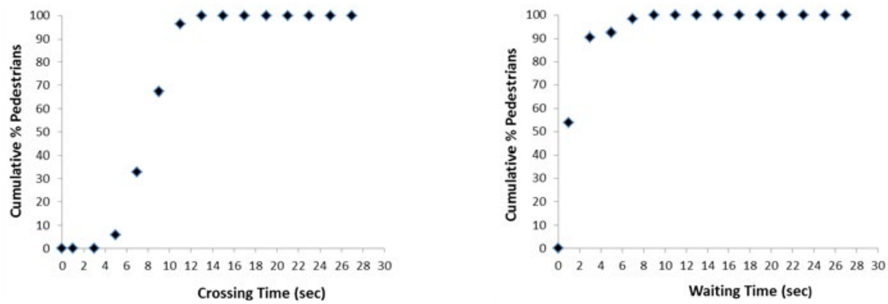


Fig. 6.
Cumulative Frequency Curves for Oblique Movements in One Step Crossing

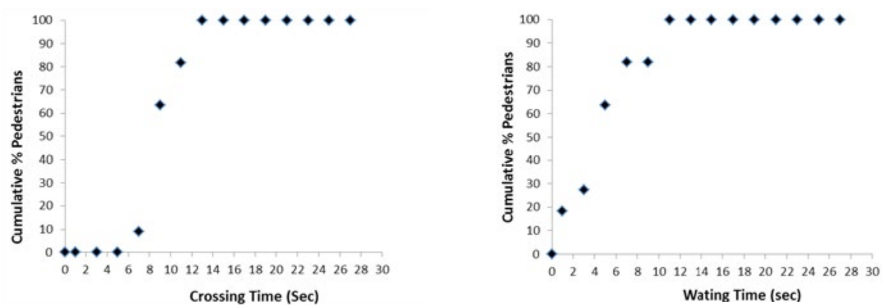


Fig. 7.
Cumulative Frequency Curves for Oblique Movements in Two Step Crossing

Table 2

Observed 50th Percentile Waiting and Crossing Time and 80th Percentile Range

Location	Crossing Patterns	Perpendicular Crossing		Oblique Crossing	
		Waiting Time in sec	Crossing Time in sec	Waiting Time in sec	Crossing Time in sec
Overall	One step	1.5 (0-3.5)	6.0 (5.0-9.0)	1.0 (0-3.0)	8.0 (5.0-11.0)
	Two step	4.5 (2.0-7.0)	7.0 (3.0-12.0)	4.5 (0-10.0)	9.0 (5.5-13.0)

3.2.3. Variations in Pedestrian Waiting and Crossing Time

Variation in average pedestrian crossing and waiting time is generally affected by various factors like (a) Way of pedestrian crossing (one step or two step crossing); (b) Age of Pedestrian (c) Pedestrian gender (d) Handling baggage.

The variation in estimated crossing and waiting time are given in Tables 3-6.

Table 3

Variation with Respect to Pedestrian Crossing Patterns

Location	Crossing Patterns	Perpendicular crossing		Oblique crossing	
		Avg. Waiting Time in sec	Avg. Crossing Time in sec	Avg. Waiting Time in sec	Avg. Crossing Time in sec
BSM inter-section	One step	1.77	6.47	1.25	7.6
	Two step	4.75	8.00	5.43	8.71
Chungi Naka inter-section	One step	2.34	7.2	1.90	9.63
	Two step	5.25	9.5	6.5	9.0
Civil Line IITR inter-section	One step	0.63	6.2	2.2	9.52
	Two step	3.25	7	5.5	8.5
Overall	One step	1.58	5.62	1.78	8.91
	Two step	4.41	9.17	5.81	8.87

Table 4

Variation of Time with Respect to Age of Pedestrian

Location	Adults		Older People		Children	
	Avg. Waiting Time (sec)	Avg. Crossing Time (sec)	Avg. Waiting Time (sec)	Avg. Crossing Time (sec)	Avg. Waiting Time (sec)	Avg. Crossing Time (sec)
BSM intersection	2.03	7.11	3.6	7.9	0.0	4.0
Chungi Naka intersection	2.44	8.36	3.25	9.25	3.67	6.83
Civil line- IITR intersection	1.64	7.58	1.5	8.25	1.67	7.67

Table 5
Variation with Respect to Pedestrian Gender

Location	Male		Female	
	Avg. Waiting Time (sec)	Avg. Crossing Time (sec)	Avg. Waiting Time (sec)	Avg. Crossing Time (sec)
BSM intersection	2.27	6.92	2.13	8.27
Chungi Naka intersection	2.32	7.93	3.4	8.33
Civil lines IITR intersection	1.27	7.27	2.12	7.93

Table 6
Variation with Handling or without Handling Baggage

Location	With Baggage		Without Baggage	
	Avg. Waiting Time (sec)	Avg. Crossing Time (sec)	Avg. Waiting Time (sec)	Avg. Crossing Time (sec)
BSM intersection	1.0	6.5	2.13	6.07
Chungi Naka intersection	2.33	8.33	2.79	7.97
Civil Lines IITR intersection	1.92	7.57	1.37	7.43

3.3. Pedestrian Crossing Speeds

3.3.1. Average Crossing Speeds at Study Locations

Average crossing speeds estimated based on the crossing times are given in Table 7 for different study locations. Overall average, 15th percentile, 50th percentile and 85th percentile crossing speeds are given in Table 8.

Table 7
Pedestrian Average Crossing Speeds at Study Locations

Location	Crossing Patterns	Average Pedestrian Crossing Speeds (m/sec)	
		Perpendicular Crossing	Oblique Crossing
BSM intersection	One step	1.41	2.11
	Two step	1.13	1.83
Chungi Naka intersection	One step	1.45	2.28
	Two step	1.1	2.44
Civil Line IITR intersection	One step	1.64	1.52
	Two step	1.46	1.71

Table 8
Pedestrian Overall Average Crossing Speeds

Crossing Patterns	Perpendicular Crossing Speed (m/sec)				Oblique Crossing Speed (m/sec)			
	Avg. Speed	15th Percentile Speed	50th Percentile Speed	85th Percentile Speed	Avg. Speed	15th Percentile Speed	50th Percentile Speed	85th Percentile Speed
One step	1.50	1.16	1.40	1.78	1.97	1.54	1.83	2.36
Two step	1.23	0.97	1.16	1.43	1.99	1.58	1.86	2.39

3.3.2. Analysis of Variation in Speeds

Variation in speed with respect to pedestrian personal characteristics like age category and gender; and crossing patterns like one step or two step crossing is analyzed. The effect of carrying baggage on the speeds of the individuals is also studied. While calculating speed of the pedestrian with baggage, the pedestrian carrying heavy baggage is considered. The variations in crossing speeds are given by the bar chart in Fig. 8.

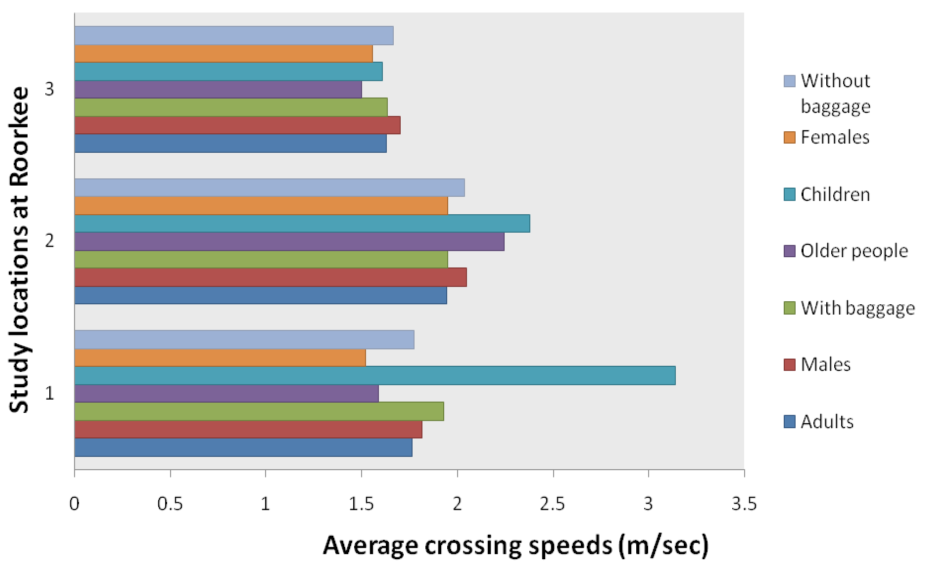


Fig. 8.
Variations of Pedestrian Crossing Speeds at Study Locations
Note: Location 1: BSM Intersection; Location 2: Chungi Naka Intersection; Location 3: Civil Line IITR Intersection

3.4. Gaps Accepted and Safety Margins

Safety margin of a pedestrian is defined as the time taken by the approaching vehicle to reach the point at the other end of the road where the pedestrian ends crossing the road without conflicting it. Time gap is defined as the time taken by the pedestrian so that it starts crossing the road without conflicting the approaching vehicle just coming to start point. The pedestrians having high safety margins and high time gap are more precautious in crossing and they take very less risk. The cumulative curves for time gaps accepted by the pedestrians and for the safety margins of pedestrians are given in Fig. 9 and Fig. 10.

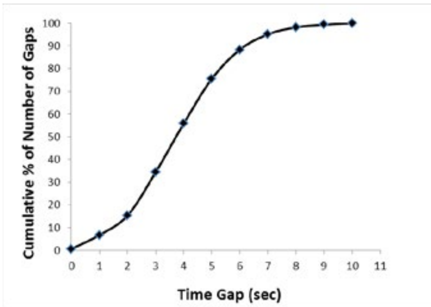


Fig. 9.
Cumulative Curve for Gaps Accepted

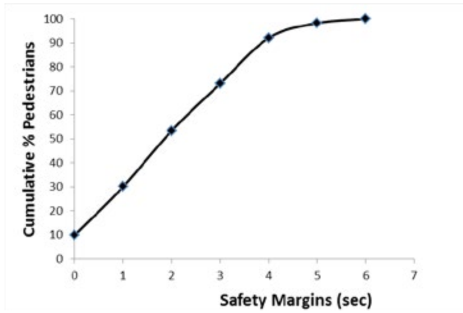


Fig. 10.
Cumulative Curve for Pedestrian Safety Margins

The estimated average value of the time gaps and safety margins or 50th percentile volume of corresponding cumulative curves similar to Fig. 5 and Fig. 6, for various categories of pedestrians according to their gender and age are given in Table 9.

Table 9
Average Values of Gap Accepted and Safety Margins

Category	Average Safety Margins (sec)	Average Time Gap (sec)
Males	1.75	3.7
Females	2.25	4.0
Adults	1.85	3.95
Olders	2.4	3.0
Children	2.0	4.35

4. Findings

The major findings of this study are given below:

- Two types of pedestrian crossings movements namely perpendicular movements and oblique movements are observed at the selected study locations in Roorkee. Apart from that approximately one out of seven pedestrian crosses the road in two stages.
- It is found that for majority of pedestrians, the crossing time varies between 4 sec to 10 sec and waiting time

varies from 1 sec to 6 sec.

- The calculated average crossing and waiting time values are found to be comparable to the observed average crossing and waiting time values (50^{th} percentile value) from the cumulative frequency curves.
- It is further observed that waiting time is more in case of oblique and two step crossing; and for females and older people. Children are found to cross with very less waiting time. This may be attributed to their negligence to traffic rules.
- The average pedestrian crossing speed is estimated to be 1.36 m/sec for perpendicular movement conditions and as 1.98 m/sec for oblique movement conditions. As the pedestrian has to look both the sides during perpendicular movement which make their movement slow as compared to oblique movement.
- The 15^{th} percentile, 50^{th} percentile and 85^{th} percentile pedestrian crossing speed is estimated to be 1.07 m/sec, 1.28 m/sec and 1.61 m/sec respectively for perpendicular crossing. Similarly for oblique crossing the 15^{th} percentile, 50^{th} percentile and 85^{th} percentile pedestrian crossing speed is 1.56 m/sec, 1.85 m/sec and 2.38 m/sec respectively, which is higher than the perpendicular movement.
- The crossing speed for males is found to be 1.85 m/sec and that of females was 1.67 m/sec.
- Among various categories of pedestrians children are found to cross at higher speeds than others. There is not much difference between the average crossing speeds for adults and older people. No significant variation is observed in pedestrians crossing speeds due to handling of baggage.
- In the gap acceptance and safety margin analysis it is found that majority of pedestrians have the safety margins between 1 sec to 4 sec and gap accepted between 2 sec to 6 sec.
- Apart from that 10% pedestrians having safety margin 0 sec. They take very high risks while crossing.
- Among various categories of pedestrians females and older people have higher accepted time gaps and safety margins. Hence they are inclined to take very less risks than others.

5. Conclusions

Among the crossing patterns more pedestrians crosses the roads in perpendicular direction and very few of them crosses the roads in two stages. The average crossing speeds at different study locations are varied with respect to various pedestrians' characteristics like gender, age category, baggage handling condition, volume and composition of traffic moving on road. Among them males and children have the higher crossing speeds. There is no significant variation in pedestrian's speeds due to handling of baggage. The majority of pedestrian are not inclined to take risks since the safety margins and time gaps were not very high but some pedestrians are there who take very high risks while crossing the roads. Approximately one out of five pedestrians has the safety margins of 0 sec.

The pedestrian crossing behavior analysis is the important factor for deciding the assurance of pedestrian safety on roads and the pedestrians waiting time can be used to decide the need of pedestrian facility in the area.

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