Influence of Crossing Pedestrians at Undesignated Locations on Capacity of 4-lane Urban Midblock Sections

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***Abstract*—Pedestrian crossings at grade in India are very common and pedestrian cross the carriageway at undesignated locations where they found the path to access the residential and commercial areas. Present paper aims to determine capacity loss on 4-lane urban arterials due to such crossings. Base capacity which is defined as the capacity without any influencing factor is determined on 4-lane roads by collecting speed-flow data in the field. It is observed that base capacity is varying from 1636 pcu/hr/lane to 2043 pcu/hr/lane which is attributed to the different operating conditions at different sections. The variation in base capacity is related with the operating speed on the road sections. Free flow speed of standard car is measured in the field and 85th percentile of this speed is reported as operating speed. Capacity of the 4-lane road sections with different pedestrian cross-flow is also determined and compared with the capacity of base section. The difference in capacity values is reported as capacity loss due to the average number of pedestrian crossings in one hour. It has been observed that capacity of 4-lane road section reduces from 18 to 30 percent with pedestrian cross-flow of 800 to 1550 peds/hr. A model is proposed between capacity loss and pedestrian cross-flow from the observed data.**

***Index Terms*—capacity, pedestrian, urban arterial, free flow speed, operating speed**

I. Introduction

In recent times, many cities have seen a large increase in road traffic and transport demand, which has consequently led to deterioration in capacity and inefficient performance of traffic systems. The main characteristic of traffic on Indian urban roads is its heterogeneous nature and loose structure of regulatory system. It requires an elaborate analysis procedure to arrive at number of lanes at desired level of service by considering all factors affecting roadway capacity. Activities at the road side and on the carriageway are always expected to affect the operation of the traffic stream and may cause delay, thus affect the capacity of any road and the speed at which it operates. Crossing of pedestrian at undesignated locations on urban roads in India is very common and likely to obstruct the continuous traffic movements. It consequently affects the capacity of the midblock sections also. Figure 1 shows such crossings at midblock section of 4-lane divided arterial road.

The crossing by the pedestrians on a road at undesignated locations has two fold effects. One, the pedestrians put themselves on risk and second the speed and capacity also adversely affected.

Figure 1. Undesignated pedestrians cross-flow on typical 4-lane urban road.

A study carried out at Indian Institute of Technology (IIT) Delhi reported that urban road traffic accidents have been increasing at about 8 percent annually and 60 percent of the victims are pedestrians, and out of that 85 percent of these fatalities occur at midblock sections [1]. It is reported that 935 pedestrians were killed in New Delhi alone in the year 2011 which is almost 45 percent among all fatalities on urban roads in the city [2]. A study conducted by the Ministry of Urban Development (MOUD) also found 19 percent pedestrian share in road accidents in Hyderabad, India [3]. Kumar and Parida [4] reported that 54 percent accidents are related to the road crossing activity. All these studies are related to the serious issue of pedestrian safety without any mention of adverse effect of pedestrian cross-flow on road capacity.

Several other studies are reported in the literature but majority of them are related to pedestrian flow characteristics rather than their effect on speed-flow relation on urban midblock sections. Duncan *et al*. [5], Bang *et al*. [6] Aronsson and Bang [7], Munawar [8], Bak. and Kiec [9] have attempted to derive the influence of pedestrian flow on capacity of urban road links as given

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above, but all these studies are also not able to isolate the effect of pedestrians on capacity. The problem of influence of pedestrian cross-flow on capacity and performance of urban mid block sections is not addressed in the HCM [10] and IRC [11] also. In HCM method, it is possible to determine the reduction in roadway capacity at intersections only, whereas influence of pedestrian cross-flow on capacity of urban midblock section has been omitted. There is no other study reported in literature which explicitly defines the influence of pedestrian cross-flow on capacity. The study presented in this paper is an attempt to derive a relationship between pedestrian cross-flow and capacity reduction at urban midblock sections.

II. Field Data Collection

Data for the present study were collected at seven different sections of urban arterial roads in New Delhi. Three sections were without the influence of pedestrian crossings, bus stops, parked vehicles, curvature, gradient, intersection and any other side friction. Also, the sections have wide variations in proportions of different categories of vehicles. Remaining four sections were selected at the locations of pedestrian cross-flow. Traffic studies were carried out to determine the traffic volume, composition of traffic stream, and the speed of different types of vehicles at the selected road sections. A section of about 500 m was selected having uniform traffic operating conditions with no access point and a longitudinal trap of 60 m was made in the middle of this section for measurement of flow and speed. Since it was not possible to cover the entire stretch of 500 m in the camera view, speed measured in the trap length of 60 m was taken as the average speed on 500 m section. The data were collected through video camera at each section on a typical weekday during 6:00 AM to 6:00 PM. The recorded film was replayed in the laboratory to extract the desired information. All vehicles in the traffic stream were divided into five categories as small car (CS) or standard car, big car (CB), heavy vehicles (HV), motorized three-wheelers (3W) and motorized two-wheelers (2W). The physical dimensions and other details of these vehicle categories are given in Table I. Even in the same category of car, there are several models plying on Indian roads. Therefore, cars are also divided into two categories as small car (standard car) and big car.

TABLE I. Vehicle Categories and Their Sizes

Vehicle Type	Vehicles included	Length (m)	Width (m)	Rectangular Plan Area (m^2)
Small Car	Car	3.72	1.44	5.36
Big Car	Big utility vehicle	4.58	1.77	8.11
Heavy Vehicle	Standard bus	10.10	2.43	24.54
3-wheeler	Auto-rickshaw	3.20	1.40	4.48
2-wheeler	Scooters, Motorcycles	1.87	0.64	1.20

Small car in Table I represents all cars having their engine power of around 1400 cc and average length and width of 3.72 m and 1.44 m respectively. This is also taken as the standard car in the present study and passenger car unit (PCU) factors were derived for all vehicles with respect to this car. The big car is the one having length of 4.58 m, width 1.77 m and engine power of around 2500 cc. The size of a vehicle was measured in field by taking its maximum length and maximum width. In case, where more than one type of vehicle is included in a category (for example motorized two wheeler) the average dimensions were considered.

III. Data Analysis

The data on classified volume count and average speed of each vehicle category on a midblock section were extracted from the video film in the manner as explained in the previous section. The data were analyzed to obtain the composition of traffic stream, hourly traffic volume (vph) and speed (km/hr) of each type of vehicle on different sections. The average time taken by each vehicle to travel through the trap marked on carriageway was measured with an accuracy of 0.01 s using software developed for this purpose. This time was used to calculate the speed of a vehicle passing through the trap. Table II provides the details of traffic composition at different sections.

A. Estimation of PCU Values

Traffic on Indian roads is of heterogeneous nature with wide variation in the static and dynamic characteristics of different types of vehicles. One class of vehicles cannot be considered equal to any other vehicle class as there is considerable difference in their physical and flow characteristics. One way of accounting this non-uniformity in the static and dynamic characteristics of vehicles is to convert all vehicles in to a common unit and the most accepted unit for this purpose is the Passenger Car Unit (PCU). The PCU is a complex parameter and depends upon all factors of geometry and traffic operation. Many researchers have developed methods to estimate PCU for a vehicle type and there exists a large variation in PCU values being adopted in different parts of the world [12], [13].

In the present study, the PCUs were calculated using Equation 1 which is based on the concept that PCU is directly proportional to the ratio of speed, and inversely proportional to the space occupancy ratio with respect to the standard design vehicle which in the present study is small car [14].

$$PCU_i = \frac{V_c / V_i}{A_c / A_i} \tag{1}$$

where:

V_c and V_i are the space mean speed of standard car and vehicle type i and A_c and A_i are their projected rectangular area respectively.

The PCU factors were calculated for each type of vehicle in each 5-min count on a section to convert mixed traffic flow into homogenous flow in PCU/hr.

TABLE II. OBSERVED TRAFFIC COMPOSITION AT DIFFERENT SECTIONS

Sec. No.	Type of Section	Average Composition (%)				
		Small Car (CS)	Big Car (CB)	Heavy Vehicle (HV)	3-wheeler (3W)	2-wheeler (2W)
I	Without Pedestrian	49.00	8.80	2.50	18.90	20.80
II	Without Pedestrian	58.08	11.04	2.03	7.71	21.14
III	Without Pedestrian	45.76	5.76	4.13	18.41	25.94
IV	With Pedestrian	32.08	9.19	6.18	19.21	33.34
V	With Pedestrian	31.80	11.69	4.66	21.56	30.29
VI	With Pedestrian	30.12	8.18	3.68	22.54	35.48
VII	With Pedestrian	33.43	5.17	2.86	22.15	36.39

B. Speed-Volume Relationships

Three basic parameters of traffic flow; speed, volume and density are used for estimation of traffic carrying capacity of a road. Since field measurement of traffic density is difficult, attempts have always been made to concentrate on speed-volume relationship [15], [16]. For determination of speed-volume relationship in heterogeneous traffic condition, the volume calculated by total vehicles recorded for each counting period were converted into equivalent number of passenger cars using PCU values obtained from Equation 1.

In a mixed traffic situation, large variation exists in speeds of slow moving and fast moving vehicles. Therefore, spot speed or space mean speed of cars cannot be considered for mixed traffic. It needs to be modified to suit the heterogeneous traffic conditions. For this purpose many researchers suggested use of mean stream speed or weighted average space mean speed as given by Equation 2 and the same is used in the present study also [14], [17].

$$V_m = \frac{\sum_{i=1}^{N} n_i v_i}{\sum_{i=1}^{N} n_i} \quad (2)$$

where,

V_m = mean stream speed (km/hr),

n_i = number of vehicles of category i, in a count period

V_i = Speed of vehicles of category i (km/hr), included in the count period

N = Total number of categories of vehicles in the traffic stream.

The average stream speed calculated from Equation 2 is plotted against traffic volume to obtain the speed-flow curve.

C. Capacity under Base Conditions

Traffic flow data collected at first three sections are under no influence of side friction including pedestrian cross flow as mentioned earlier. Therefore capacity estimated at these sections is taken as the base capacity of a midblock section of four-lane divided urban arterial road.

The speed-volume data on a section were used to obtain the speed-density data using the fundamental relation between the flow, density and speed. Various forms of relations were tried, but the straight line relation as suggested by Greenshields was found to be the best based on R^2 value of the model [18]. This model was then used to plot the speed-flow curve over the entire range of traffic volume to determine the capacity using Greenshields speed-flow model. The capacity of this section is obtained as 3142 pcu/hr for one direction of traffic flow. Capacity of other two sections was also determined in the similar manner as discussed above and found to be 4086 and 3272 pcu/hr in one direction.

It may be observed that all the three sections (base sections) of 4-lane roads located in the same city have substantially different capacity values. As mentioned earlier, all sections were identical in terms of geometry and there was no side friction which can influence the capacity. Therefore, variation in capacity is due to some other factors like surface condition of the road or driving habits of the drivers. Both of these characteristics are reflected in free flow speed (FFS) of a vehicle. Therefore, FFS of standard cars was measured at each site when traffic volume was less than 1000 veh/hr [10]. Free speed data were used to determine 85th percentile speeds of standard cars on the road. This speed is termed as the operating speed of the road section. A relationship between capacity and operating speed suggested by Dhamaniya and Chandra [19] given in Equation 3.

$$\textbf{Lane Capacity} = 2694 - 49.53V_{os} + 0.496V_{os}^2 \quad (3)$$

$$(R^2 = 0.98)$$

where, V_{os} is the operating speed of the section.

The FFS data of standard car at these sections are observed in the field and operating speed of the sections was determined by taking 85th percentile of observed free speeds. The capacity of these sections termed as base capacity was determined using the Equation 3.

TABLE III. OPERATING SPEED AND BASE CAPACITY OF MIDBLOCK SECTIONS WITH PEDESTRIAN CROSSING

Section No.	Sample size	Operating speed of the section (V_{os}) (kmph)	Lane capacity (Equation 3) (PCU/hr)	Base capacity of section (PCU/hr)
IV	100	78.00	1848	3696
V	100	81.00	1936	3872
VI	100	80.20	1912	3824
VII	100	82.60	1987	3974

The base capacity as defined earlier is the capacity of the section without the influence of side friction factor including crossing pedestrians. Operating speed and base capacity of these sections are given in Table III.

IV. Effect of Pedestrian Cross-flow

The capacity of the sections with pedestrian cross-flow was determined by plotting speed-density and speed-flow curves. Typical curves at section VI is given in Fig. 2. Similar curve were drawn, at other sections also in order to determine capacity of these sections and compared with the corresponding base section capacity values as given in Table III. The reduction in capacity due to pedestrian cross-flow is given in Table IV.

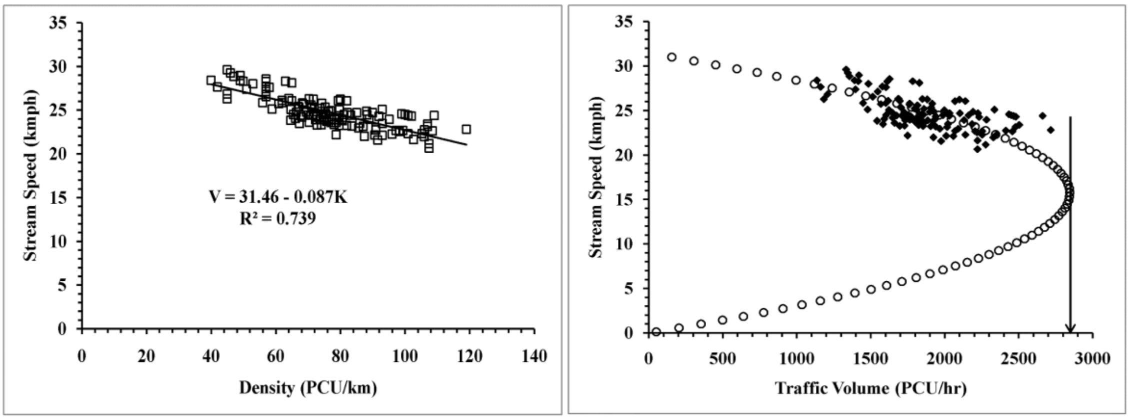

Figure 2. Speed – density and speed – flow relationship at section –VI.

It may be observed from the Table IV that capacity of a section reduces with the presence of pedestrian cross-flow when compared with the capacity of the base section. The effect of pedestrians crossing the traffic stream is to reduce the stream speed and capacity of the section. Similar trend is observed in the present study also. Last column in Table IV indicates percent reduction in capacity due to pedestrian cross-flow with respect to capacity of base section.

TABLE IV. Capacity and Pedestrian Cross-Flow at Different Sections

Section	Direction capacity (PCU/hr)	Lane capacity (PCU/hr/lane)	Lane capacity of base Section (PCU/hr)	Pedestrian cross-flow (peds/hr)	Reduction in capacity (%)
IV	2504	1252	1848	1550	32.25
V	2808	1404	1936	1204	27.48
VI	2844	1422	1912	832	25.63
VII	2906	1453	1987	1080	26.87

A relation is developed between pedestrian cross-flow and reduction in capacity as shown in Fig. 3. It may be observed that a second degree polynomial relation given in Equation 4, describe better the given dataset.

$$\textbf{Percent Reduction in Capacity } (Q_p) = 2.30 + 0.031 * Q_{peds} - 9\times10^{-6} * Q^2_{peds} \qquad (R^2 = 0.96) \qquad (4)$$

where, Q_p is the percent reduction in capacity and Q_{peds} is the pedestrian cross-flow (peds/hr).

Crossing of a road by a pedestrian is essentially a gap acceptance process where the pedestrian would evaluate the gap available in all the lanes to be crossed before entering the road. Availability of the gap would depend on traffic volume in the lane and acceptance (or rejection) of the gap would depend upon the perception of the pedestrians about the gap. This pedestrian vehicle interaction is a complex phenomenon and has deep safety implications apart from creating loss in capacity of the road. Indian standards suggest that pedestrian crossing facility must be provided whenever PV^2 (where P is the pedestrian volume per hour and V is the traffic volume per our) is more than $2x10^8$ for divided roads [20]. The value of PV^2 at all sections selected for the present study is more than $2x10^8$ as the volume range at all the sections are more than 1000 vph which indicates the need of a pedestrian facility and at majority of these sections, pedestrian foot over bridges have been provided. However, pedestrian choose to cross the road at-grade to save their time. Safety of pedestrians or motor vehicles due to such behaviour of pedestrian has not been considered in this study.

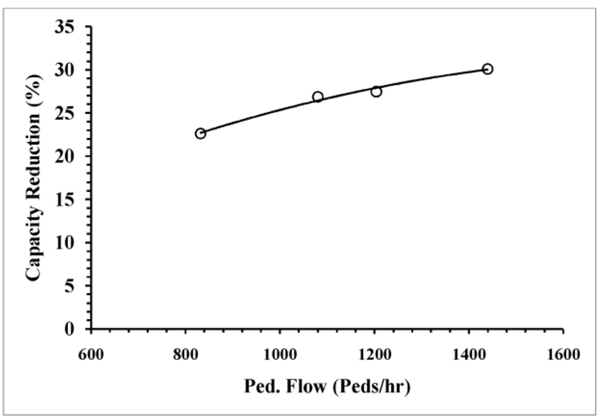

Figure 3. Reduction in capacity at sections with pedestrain cross-flow.

V. CONCLUSIONS

The present paper evaluates the influence of pedestrian cross-flow on midblock capacity of four-lane urban arterial roads. Since Indian standards on capacity have not been revised for last more than 20 years, capacity under base conditions was also determined by taking speed-volume data on sections having no influence of side friction. The base capacity of an urban midblock section was estimated and finds to be significantly different at different sections although the geometric standards are same across the sections. This variation in capacity is attributed to some other factors like surface condition of the road or driving habits of the drivers. A capacity model is used to determine the base capacity of the sections with pedestrian cross-flow. Further the speed-flow plots were drawn to determine the capacity of the sections with pedestrian cross-flow and compared with the capacity of the base section. It is found that capacity of the section reduces by 25 to 32 percent when pedestrians cross-flow in the range from 832 to 1550 peds/hr. A second degree polynomial relation is also developed to determine the capacity reduction.

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