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ASSESSMENT OF PEDESTRIAN-VEHICLE INTERACTION ON URBAN ROADS: A CRITICAL REVIEW

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Abstract:

Walking is being promoted as either a main mode of transportation or as a part of multimodal mobility. However, a rapid growth and development in urban areas has resulted in a drastic increase in human population as well as vehicular population in most of the metropolitans across the globe. Due to this, there is an unavoidable increase in conflicts between vehicular traffic and pedestrians often sharing the same road space. At an undesignated crossing, pedestrians wait for suitable inter-vehicular gap to cross the road. However, in order to reduce the waiting delay, pedestrians often take risk by accepting smaller gaps while crossing the road. It increases the probability of their collision with approaching vehicles. Apart from the frequency of crashes, the crash severity is also vastly governed by traffic flow characteristics. In this regard, it is a common belief that the reduction in speed of approaching vehicles can significantly bring down the severity of pedestrian crashes. On the other hand, vehicular movements also get obstructed due to the pedestrian activities carried out on the carriageway. During pedestrian crossing maneuvers, pedestrians often force the approaching vehicle(s) either to slow down or to change the lane which leads to reduction in the average speed of traffic stream. However, in case of pedestrians walking along the road, vehicles tend to shy away towards the center of carriageway to ensure the safe movements of pedestrians. Hence, pedestrians irrespective of crossing or walking along the road, eventually results in the reduction in speed as well as capacity of the road and sometimes prove to be a promising threat to safety of the road users. Therefore, in order to delve into the phenomena of pedestrian-vehicle interaction, one should need to study the mutual influences of pedestrian and vehicular movements on each other. In this background, this paper puts forward a detailed literature review on the assessment of pedestrian-vehicle interaction on urban roads. Findings of the paper are specific and infer the behaviors of both pedestrians and vehicles while sharing the same road space.

Keywords: *pedestrian-vehicle interaction, pedestrian delay, pedestrian safety, pedestrian crossing.*

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1. Introduction

Walking is considered as one of the sustainable and environmentally beneficial modes of transportation which not only improves the health of a person but also reduces the traffic congestion on urban roads. Usually both traffic flow characteristics and pedestrian flow characteristics are studied separately (Asaithambi et al., 2018 and Rastogi, Ilango and Chandra, 2013). But in many countries, transportation mobility is constituted as combination of both traffic and pedestrian movements since they share common space and time on transportation facility. Hence, the interaction between these two modes of transportation has been given emphasis over a period of time. Keeping this pedestrian-vehicle interaction in mind, this review is divided into two phases: (1) Influence of vehicular traffic on pedestrian movements. (2) Influence of pedestrians on vehicular movements. Former phase includes how the movements of vehicular traffic impede the pedestrian movement. It causes not only delay to those pedestrians but also the safety is compromised for those who are accepting smaller gap to cross the road. Second phase is focused on how the through movement of vehicular traffic is affected due to the presence of pedestrians crossing and walking along the road. To ensure the safety to the pedestrians in the vicinity of vehicle, the driver tends to reduce its speed. This leads to reduce the average stream speed as well as the capacity of the road.

2. Influence of vehicular traffic on pedestrian movements

Pedestrians are one of the prime road users on urban roads and also vulnerable at un-protected mid-block locations under heterogeneous traffic. Vehicular traffic has an inverse effect on pedestrian movements. At un-signalized mid-block locations, some drivers do not yield to pedestrians which either increases pedestrians' delay or instigate pedestrians to take risk to cross the road by accepting smaller gaps which hampers the safety of the pedestrians. Ample volume of investigation was conducted to examine pedestrian flow characteristics in presence or in absence of vehicular traffic (Kwon, Morichi and Yai, 1998; Keegan and Mahony, 2003; Goh and Lam, 2004; Montufar *et al.*, 2007; Polus, Schofer and Ushpiz, 2008; Laxman, Rastogi and Chandra, 2010; Zhang and Seyfried, 2013; Gupta and Patel, 2014; Sarsam and Abdulameer, 2015; Gupta and Pundir, 2015; Vanumu, Ramachandra Rao and Tiwari, 2017; Banerjee, Kumar and Gregor, 2018). Also, pedestrian level of service (Mori and Tsukaguchi, 1987; Dixon, 1996; Henson, 2000; Baltes and Chu, 2002; Muraleetharan *et al.*, 2003; Lee *et al.*, 2005; Muraleetharan *et al.*, 2005; Petritsch *et al.*, 2007; Hubbard *et al.*, 2007; Hubbard, Bullock and Mannering, 2009; Archana and Reshma, 2013; Zhao *et al.*, 2014; Kadali and Vedagiri, 2016; Marisamynathan and Vedagiri, 2017) and behaviors of pedestrian at crossing (Hamed, 2001; Zhao and Wu, 2003; Lee and Lam, 2008; Harrell, 2010; Alhajyaseen, Nakamura and Asano, 2011; Galanis and Nikolaos, 2012; Serag, 2014; Jain, Gupta and Rastogi, 2014; Pasha *et al.*, 2015; Mako and Szakonyi, 2016; Ferenchak, 2016; Asaithambi, Kuttan and Chandra, 2016) were studied by many researchers.. However, very few studies led to further extent and assessed the influence of vehicular traffic on pedestrian movements.

2.1. Influence on gap acceptance behavior of pedestrian

With rapid urbanization, both human and vehicle population has been increased drastically on urban roads since last few decades. Hence, the frequency of conflict between vehicles and pedestrians has also been increased over the time. The term 'gap acceptance' has become a key factor to be considered in behavioral assessment of pedestrians while crossing a road at undesignated location.

Oxley et al. (2005) studied the influence of age difference on gap acceptance behavior of pedestrians and observed that older pedestrians took more time to make a crossing decision compared to other pedestrians which increases their waiting time. Even after that, it did not ensure their decisions as right and the safety is compromised. However, there was no behavioral difference in gap acceptance between old and young pedestrians while crossing a one-way road. Pedestrians take the 'distance' of approaching vehicle into consideration while making the crossing decision rather than the 'time to arrive' of approaching vehicle. The study also witnessed that vehicles far away, irrespective of their speeds, were judged less threatening than closer ones. However, for group movements of pedestrian, the gap between two consecutive vehicles had a little effect on crossing decisions. The study did not consider the gender of pedestrian as a potential factor influencing the gap acceptance behavior and the same can be treated as a limitation in the outcome. In this regard, Kadali and Vedagiri (2013) took the gender and the age of the pedestrian into the consideration but eventually arrived at an opinion that neither the gender nor the age is crucial in determining the gap acceptance behavior. This finding has conflict with many studies (Sun, Ukkusuri, and Benekohal 2003); (Das, Manski and Manuszak, 2005) as they reported that the gender and the age of pedestrians have a prominent impact on their gap acceptance behavior. In case of a divided road, pedestrians were more concerned about the vehicular gap available in the median lane irrespective of the side they start crossing (from curbside or median side). A higher proportion of heavy vehicles on the median lane was found as the prime reason behind this tendency. The study also observed that pedestrians cross the road in a staggered manner more frequently when starting from the median. Increase in traffic volume results in the increase in the waiting time of pedestrians intending to cross the road. A study conducted in Malaysia witnessed that when vehicles move in platoon, waiting time increases and may reaches to 23 seconds as drivers do not yield to pedestrians crossing the road (Ibrahim, Karim and Kidwai, 2005). Increase in waiting time may instigate risk-taking behavior of pedestrians as they started accepting shorter vehicular gaps (Sun, Ukkusuri, and Benekohal 2003; Das, Manski and Manuszak, 2005; Cherry et al., 2012). Behavior of pedestrian may change when waiting time is too long. This increase in waiting time either forces pedestrian to accept smaller gaps or pedestrians accumulate to form platoon which boosts their confidence to accept any vehicular gap available (Shi *et al.*, 2008). In contradiction, a number of studies showed that there is no significant contribution of waiting time towards the gap acceptance behavior of pedestrians (Wang et al., 2010; Yannis, Papadimitriou and Theofilatos, 2013).

Apart from traffic volume, speed of approaching vehicle also governs the pedestrian gap acceptance behavior. Pedestrian select minimum gap size based on vehicle speed rather than the type of vehicle. Probability of gap acceptance has a negative correlation with the speed of the approaching vehicles (Kadali and Vedagiri 2013; Pawar and Patil 2016). On the other hand, reduction in vehicle speed increases the probability of accepting a smaller gap (Rosén and Sander, 2009).

When traffic volume increases on a multi-lane road, pedestrians start choosing ‘rolling gap’ in response. A rolling gap is defined as the minimum gap accepted by the pedestrian by changing the crossing speed and the direction of movement while crossing the road (Figure 1).

Selection of rolling gap will increase the probability to choose the minimum gap size which leads to a substantial change in mean accepted gap. As a result, the probability of gap acceptance also increases (Kadali and Vedagiri 2013). However, it is obvious that waiting for adequate vehicular gap for all lanes is a safer crossing in all aspects as compared to rolling gap (Brewer et al. 2006). As per Cherry et al. (2012), the gap acceptance behavior is primarily dependent on waiting time of pedestrian, speed of approaching vehicle, size of the gap and whether the gap occurred on nearest pedestrian lane. However, gap acceptance process is not influenced by whether the pedestrian starts crossing the road from curb or median. Also, there was no significant relationship found between the gap acceptance behavior and the group size of pedestrian. In fact, pedestrians crossing the road in a group may respond differently under certain traffic circumstance (Rosenbloom, 2009 and Faria et al., 2010). Y. S. Chung (2019) witnessed that pedestrian gap acceptance behavior is dependent on the distance between pedestrian and approaching vehicle irrespective of the speed of that vehicle. The study also extended towards the development of a pavement marking-based thumb rule which is useful in decision making for pedestrians while crossing a two-lane road. It was recommended that pedestrians can make safe crossing decisions if the approaching vehicle is six white segments of broken center-line away from the pedestrian as shown in figure 2.

G. Yannis, Papadimitriou, & Theofilatos (2013) studied pedestrian gap acceptance behavior for mid-block street crossing and found that critical factors in making gap acceptance decisions are size and distance of approaching vehicle, gender and group size of pedestrians and presence of illegal parking. Lognormal regression and binary logit model gave satisfactory results for the analysis of accepted gaps and finding the crossing probability. When approaching vehicles were large in size and presence of illegally parked vehicles was there, pedestrians were found to be more alert while crossing. Also, the gap acceptance behavior is influenced by the gender

of pedestrian. On the other hand, Papadimitriou, Lassarre and Yannis, (2016) concluded that both the age and the gender of pedestrians were found to be insignificant in making a crossing decision.
The critical gap is the minimum headway between the two consecutive vehicles during which a pedestrian can safely cross the road. According to the Highway Capacity Manual (HCM), the critical gap is defined as "the time in seconds below which a pedestrian will not attempt to begin crossing the street". Chandra, Rastogi, & Das (2014) identified traffic volume is one of the effective factors (along with the number of lanes and direction of traffic movement) to be considered in determining the critical gap of pedestrian crossing as given in equation(1).

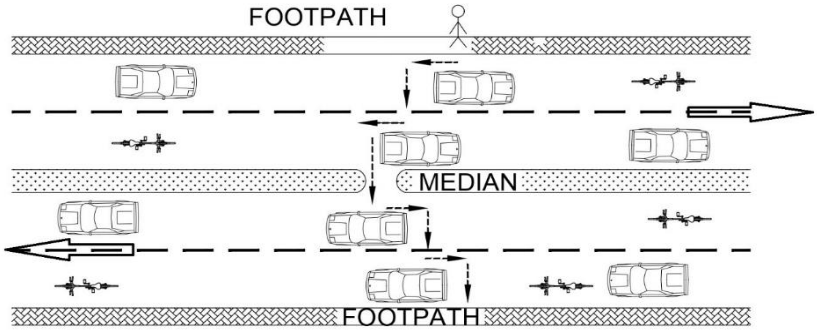

Fig. 1. Illustration of the rolling gap for typical four-lane divided urban road

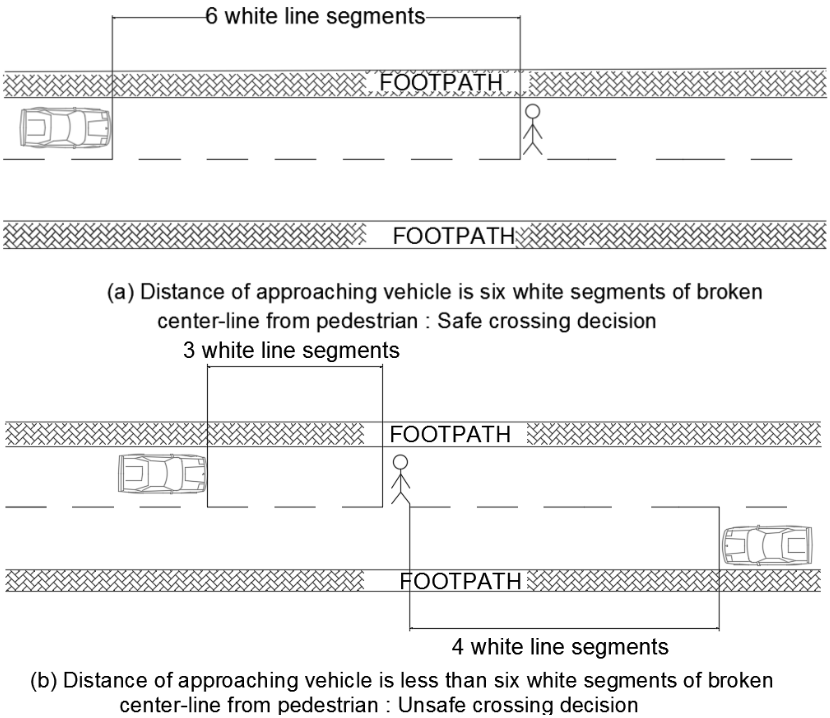

Fig. 2. Thumb rule based on road marking for crossing decision

$$C_{Gap} = 3.025 + \frac{11576.95}{Q} \qquad (1)$$

where, C_{Gap} - Critical Gap, second and Q - Traffic volume, PCU/h.

Effect of traffic volume on critical gap is shown in Figure 3. Kadali and Perumal (2016) used four methods namely, HCM method; Raff's method; MLE technique and Logit method, to estimate the critical gap and observed that the logit method outperforms other methods as the critical gap estimated through logit method were in a good agreement with the field observed values. It might be because the logit method incorporated pedestrian behavioral characteristics under mixed traffic, unlike others. Results also indicated that the age and the gender of pedestrians have considerable influence on the critical gap. However, Pawar and Patil (2016) observed that both logit method and maximum livelihood method give an accurate estimation of pedestrian critical gaps. Chandra *et al.*, (2014) found that gap acceptance behaviors for older pedestrians deviate more from the critical gap compared to behaviors of young and middle aged pedestrians. Authors also observed that single stage gap acceptance (crossing the road without stopping) has less deviation from critical gap compared to two-stage gap acceptance (crossing up to center and wait until suitable gaps) where deviation is as high as 84%.

This section concludes that age and gender of pedestrians are the critical factors associated with pedestrian gap-acceptance behavior. Distance of approaching vehicle from the crossing location is given more importance by the pedestrian as compared to the speed of approaching vehicle while making a crossing decision. Further, Logit method was thoroughly found the best method for accurate estimation of critical gap.

2.2. Influence on safety of pedestrians

Pedestrians were found as victims in 28.7% of all traffic crashes. Male pedestrians of all age groups are involved in 83.7% of pedestrian crashes because of their risk-taking behaviour by violating the pedestrian rules (Singh et al., 2007). Across the globe, about 21% of pedestrian fatalities alone constituted by children falling in the age group of 15 years or below (Peden et al., 2004). 20-30% of pedestrians in Australia (Holubowycz, 1995) and 61% of pedestrians in South Africa (Peden et al., 2004) were found under the influence of alcohol at the time of the collision with vehicles. A comparison of pedestrians' fatality rate in three different countries; India, USA and UK is shown in Figure 4. All these statistics are enough to indicate the safety scenario of pedestrians while sharing the space with vehicular traffic and thus stipulates to study the influence of vehicular traffic on the safety of pedestrians.

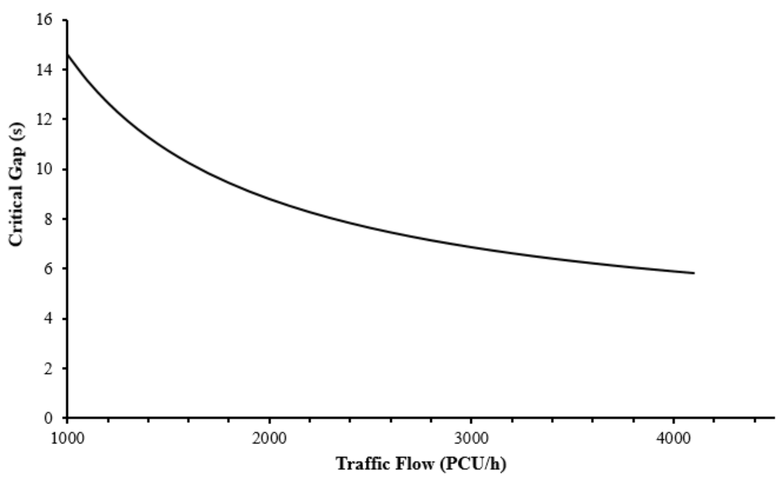

Fig. 3. Variation of the critical gap with traffic volume

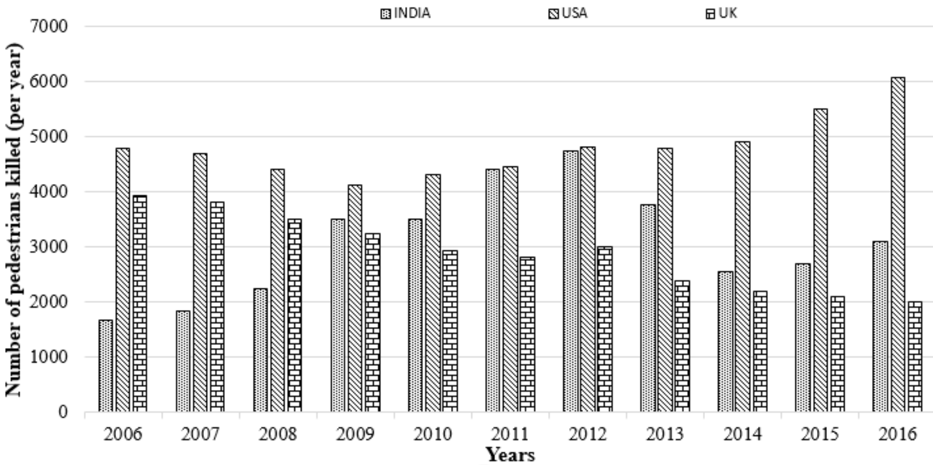

Fig. 4. Pedestrian fatalities in different countries over time

There are few empirical models which are commonly used to estimate the frequency of pedestrian crashes on the basis of traffic and pedestrian volume. According to Swedish Model,

$$N = 0.00000734\ Q^{0.50} \cdot P^{0.72} \tag{2}$$

where:
N - Number of pedestrian crashes per year,
Q - Traffic volume (veh/day),
P - Pedestrian cross-volume (ped/day).

English Model gives the following equation to estimate the pedestrian crashes.

$$N = 0.028\,(Q \cdot P)^{0.53} \tag{3}$$

where:
N - Number of pedestrian crashes per year ,
Q - Traffic volume (1000veh/day),
P - Pedestrian cross-volume (1000ped/day).

Researchers commonly are of opinion that the increase in traffic volume increases the pedestrian crash rate. The risk of injuries to children in the highest traffic volume has been increased by 13% compared to the least busy locations (Roberts et al., 1995). Similarly, Ma, Nie, Xu, Xu, & Zhang (2010) reported that arterials roads in China are having more traffic volume account for more severe pedestrian crashes as compared to low volume roads.

Apart from traffic volume, speed of approaching vehicles also has a considerable impact on the vehicle-pedestrian collisions. With the increase in operating speed of the vehicles, the probability of stopping before the collision decreases and hence, the force of impact during the crash also increases. Due to this, low-speed locations have a lower risk to pedestrian's safety compared to medium and high-speed locations (Gårder, 2004). In contrast, Roberts et al. (1995) witnessed that at medium speed locations, the risk associated with the pedestrian crash was highest compared to high-speed locations. It might be because pedestrian cross high-speed roads less frequently. Further, pedestrian-vehicle interaction at un-signalized locations are more frequent as compared to signalized locations (Gårder, 2004). Narrowing the street reduces the speed of approaching vehicles which eventually decreases the probability of crashes as drivers are more cautious while driving on narrow streets (Ewing and Dumbaugh, 2009).
A number of researchers realized that the speed of approaching vehicle also has a substantial influence on the crash-severity apart from the number of crashes. Anderson et al. (1997) defined the probability of pedestrian fatality by assigning Injury Severity Score (ISS) on the basis of 'impact speed during crash' and found that reducing the speed of vehicles by 5 km/h uniformly in speed limit zone of 60 km/h can reduce the pedestrian fatalities by 32% in Adelaide, Australia. On the other hand, Gaca and Pogodzińska (2017) observed a decrease in number

of pedestrian crashes with fatalities by 12% and 21% when average speed is reduced by 3 km/h and 5 km/h respectively on Polish roads. A case study done by Haleem, Alluri, & Gan (2015) in Florida, USA showed that if the speed limit is increased by 1.6 km/h on major roads at un-signalized pedestrian crossing, chance of severe injury increases by 30.32%. Probability of pedestrian's survival is 90% if the speed of approaching vehicle is less than 30 km/h and decreases to 50% when the speed of approaching vehicle exceeds 45 km/h (Peden et al., 2004). Davis (2001) developed a model that relates the severity of pedestrian crash with speed of approaching vehicle. The study observed that the probability of fatality is half when impact speed is between 70 and 75 km/h (Pasanen and Salmivaara, 1993) and Anderson et al. (1997) found that there were 50% chances of fatality when impact speed is 53 km/h and 45 km/h respectively. Davis (2001) also classified the severity level in three different categories; 'slight injury', 'serious injury' and 'fatality' (Figure 5).

It was observed that when impact speed is below 40 km/h, pedestrian injury is 'slight', above 40 km/h 'serious injury' is most frequent and 'fatalities' above 75 km/h. Severity levels obtained by Kurek, Jużyniec & Kielc (2018) were in good agreement with the classification recommended by Davis (2001).

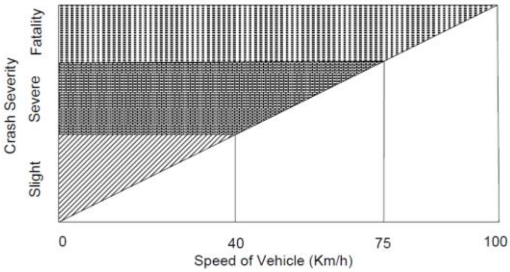

Fig.5. Categorization of Crash-severity with Speed of vehicle

Hence, literature commonly indicate that the frequency of pedestrian related crashes increases with the increase in traffic volume. However, the severity of pedestrian crash increases as the speed of approaching vehicle increases.

3. Influence of pedestrians on vehicular movements

A good volume of the research emphasizes on the influence of pedestrian movements on vehicular traffic flow. Movements of pedestrians which include walking along and crossing the road, have a negative impact on the performance of the traffic stream.

3.1. Influence of pedestrian movements on vehicular speed

In the absence and sometimes even in the presence of sidewalk, pedestrians use the carriageway while walking along the road. Absence of sidewalk (specifically on urban roads) forces the pedestrians to share the right-of-way with fast-moving vehicles and it causes a reduction of 7.23 km/h in average speed on urban roads (Bassani, Dalmazzo and Marinelli, 2013). Advani and Nisha (2013) and Adinarayana and Anil (2017) observed that lower speed on urban streets is associated with the high volume of pedestrians walking along the carriageway. Shukla et al. (2016) developed a speed prediction model as in Equation (4) for urban arterials having substantial pedestrian movements along the carriageway.

$$V = 51.14 - 0.35\,n_{ped} - 0.61\,n_c - 0.19\,n_{2w} - 0.16\,n_{3w} \quad (4)$$

where:

V - average speed (km/h)

n_{ped} - volume of pedestrians along the road (ped/min)

n_c, n_{2w}, n_{3w} - volume of car, two-wheeler and three-wheeler respectively (veh/min)

A 0.35 km/h reduction in speed was observed for every additional pedestrian walking along the road. On the other hand, Bang (1995) suggested weightage factors for pedestrian movement along with other side frictional elements on urban roads as given in Table 1.

Further, the range of side friction index which is the weighted sum of the side friction elements was classified into five levels; very low, low, medium, high and very high. It was found that free flow speed is reduced by 16 km/h at severe side friction and narrow shoulders for two-lane undivided interurban road, and by 18 km/h for two-lane undivided urban roads. The impact of side friction on free flow speed was found to be slightly lesser on four-lane roads.

Finally, the adjustment factor for each level was proposed to determine the free-flow speed and the capacity of the urban road.

Table 1. Weightage factors for elements of side friction (Bang, 1995)

Event type	**Weightage factor**
Pedestrian flow (Walking + crossing) (ped/h/200m)	0.5
Vehicle stops and parking manoeuvres (events/h/200m)	1.0
Vehicle entering and exiting roadside premises (veh/h/200m)	0.7
Slow-moving vehicles (veh/h)	0.4

Several other studies examined the influence of pedestrian crossing on the performance of an urban road segment. Zheng et al. (2015) showed that if the crossing manoeuvre takes place at undesignated location, the impact on stream speed is more severe. Várhelyi (1996) found that a vehicle slows down its speed by 2 km/h on an average when a pedestrian is present on one side of the road and about to cross it. However, in the case when pedestrians are present on both sides of the road and about to cross it, the average reduction in speed of a vehicle is 5 km/h. Kadali et al. (2015) carried out a videography survey on two mid-block locations of a four-lane divided urban road. One of the locations had a median opening which was allowing pedestrians to cross. The average speed of this location was observed 7.7 km/h lower compared to the other location. It is also observed that side frictions such as parked vehicles, pedestrians waiting for bus or auto can reduce the carriageway width which further decrease the speed of approaching vehicles. Due to the greater manoeuvrability of two-wheelers, pedestrians have less effect on the speed of two- wheelers compared to cars. Similarly, Thiessen et al. (2017) found a reduction of 2 km/h in operating speed due to pedestrian movements across the road. The common limitation of all these studies is the consideration of 'pedestrian cross movement' as a binary variable. Neither the reduction in speed was examined with a wide range of pedestrian volume crossing the road nor any adjustment factor or empirical model developed for this.

Some other investigations achieved better insight into the phenomenon how the influence on traffic flow changes with the change in the intensity of pedestrian cross movement. Hawas and Khan (2012) adopted the Fuzzy technique and showed graphically how operating speed decreases with the increase in the 'pedestrian volume' crossing the road. Jin et al. (2013) found that delay to vehicles increases exponentially with the increase in pedestrian cross volume. Some studies have suggested empirical models or adjustment factors to better explain the influence on traffic flow. For example, Aronsson and Bang (2006) proposed the following model (Equation (5)) to determine the average speed on urban roads.

$$V = 48.7 - 0.011\,x_1 - 0.015\,x_2 \tag{5}$$

where:
V - average speed (km/h)
x_1 - both-directional traffic flow (veh/h)
x_2 - volume of pedestrian cross movement (ped/h/km)

Chiguma (2007) developed a speed model and observed that pedestrian cross movement has the maximum influence on speed among all the side frictional elements. Similarly, Munawar (2011) developed a speed model (Equation (6)) where 'volume of pedestrian crossing' was considered as a design variable. Parking and stopping vehicles on the road were also found as critical factors influencing the speed of approaching vehicles.

$$V = 39.46 - 0.13\,x_2 - 0.13\,x_3 - 0.28\,x_4 - 0.13\,x_5 - 0.15\,x_6 \tag{6}$$

where:
V - average speed (km/h)
x_2 - volume of pedestrian cross movement (ped/h/200m)
x_3 - number of stopping bus (veh/h/200m)
x_4 - number of parking/stopping (veh/h/200m)
x_5 - number of entry vehicles into the street (veh/h/200m)
x_6 - number of heavy vehicles (veh/h)

Golakiya & Dhamaniya (2019) proposed a speed model for urban road having considerable pedestrian cross-volume. The model (Equation(7)) requires classified traffic volume, classified speed and volume of pedestrian cross movement as inputs to predict the average speed of particular vehicle category.

$$V_j = a_0 - \left[\sum \left(a'_i \frac{n_i}{V_i} \right) \right] - \left(a'_k \frac{n_{ped}}{V_j} \right) \quad (7)$$

where:
V_j - speed of particular vehicle under influence of other vehicles (m/s)
V_i - speed of various type of vehicles
a_o - regression coefficient for free flow speed of 'j^{th}' type vehicle
a'_i, a'_k - regression coefficient for impact of density of particular vehicle type and pedestrians on free flow speed of 'j^{th}' type vehicle respectively.
n_i - number of vehicles of particular type passing a section per second (vps)
n_{ped}/V_j - pedestrian-vehicle interaction factor which is the ratio of the number of pedestrian crossings per second to the speed of the vehicle type (in m/s).

The study revealed that speed of all vehicles types except heavy vehicles is reduced by the increase in pedestrian cross-volume if traffic volume is constant. However, the model requires iteration technique to determine the speed which is a tedious process can be considered as a limitation of this model from the aspect of practical utility.
After reviewing the literature, it was observed that many studies considered 'pedestrian movements' as a binary variable (either absent or present) while estimating the traffic speed on urban roads. Very few studies reached to further details and developed speed models to quantify the reduction in speed due to varying intensity of pedestrian movements.

3.2. Influence of pedestrian movements on capacity of roads

Kadali et al. (2015) and Kuttam et al. (2017) are among the few researchers who attempted to determine the impact of pedestrian cross movement on the capacity of urban roads. Kadali et al. (2015) observed a reduction of 30-37% in capacity due to the presence of pedestrian cross movements while Kuttam et al. (2017) found it as 32%. Two other studies, Bak and Kiec (2012) and Dhamaniya and Chandra (2014), further explored and developed empirical models (given in Equation (8) and (9) respectively) correlating the capacity and the volume of pedestrian cross movement.

$$C = 1550\, e^{\frac{-(1.75\, x_7 \,+\, 4.24)\, x_2}{3600}} \quad (8)$$

$$PRC = 11.09 + 0.025\, x_2 - 8 \times 10^{-6}\, x_2^{\,2} \quad (9)$$

Where:
C - capacity (veh/h)
PRC - percent reduction in capacity
x_2 - volume of pedestrian cross movement (ped/h)
x_7 - percentage of drivers willing to give way to pedestrians

According to Bak and Kiec (2012), this influence is completely governed by the tendency of drivers in giving way to pedestrians which varies largely across the countries as per driving culture. However, both of these studies (Bak and Kiec, 2012; Dhamaniya and Chandra, 2015) arrived at the same conclusion that the reduction in capacity is negligible up to a cross flow of 200 ped/h**.**
Limited research has been conducted to estimate the influence of pedestrian cross movements on capacity of road. However, the influence of pedestrians walking along the road on capacity was not investigated.

4. Concluding remarks

The present study has revisited the former studies which concentrated towards the influence of vehicular movements on pedestrians or vice-a-versa in urban context. However, it was realised that the intensity of influence may vary depending upon the country and their prevailing priority regulations. For example, in majority of European countries like Germany, France etc., pedestrians are given priority over vehicles on pedestrian crosswalks resulting in minimal influence of vehicular movements on pedestrians but a greater impact of pedestrian movements on vehicular traffic. In contrary, drivers in majority of countries in Asian and African continents are reluctant in giving priority to pedestrians approaching for crossing. On such occasion, impact of vehicular traffic on pedestrian movements intensifies in terms of delay and crash potential however, vehicular movements face little influence. In this regard, the example of Poland can be instanced. Polish traffic regulations provide priority to pedestrians exclusively when they are already on crosswalks otherwise, the vehicles should be prioritised when a pedestrian(s) is approaching towards the crosswalk.

However, in reality majority of the pedestrians presumed their priority on crosswalks at any point of time and do not consider the presence of approaching vehicles while making crossing decision. This eventually augments the potential of crash occurrence. Major findings of the review and the scope for future work are reported below.

- The present study observed that the distance of approaching vehicle from crossing location is given priority in making a crossing decision by pedestrians over the speed of the approaching vehicle.
- Increase in traffic volume results in the increase in delay of pedestrians waiting roadside for crossing the road. As delay increases, pedestrians often become impatient and accept smaller gaps. Hence, increase in traffic volume eventually impairs the safety of pedestrians.
- Literature indicate that the speed of approaching vehicle increases the severity of pedestrian crashes. However, the relation between the speed and the crash frequency is doubtful.
- Many authors utilized 'absence' or 'presence' of pedestrian movements as binary variable in estimation of traffic speed on urban roads. Limited studies were extended to propose speed models which considered 'pedestrian cross-volume' in quantification of decrease in speed.
- While a number of empirical models were available to determine the speed under the influence of pedestrian movements, very few attempts were made to develop similar models for capacity. In fact, no study was performed to find the influence of pedestrians walking along the road on capacity as per the best knowledge of the authors.
- Most of the results reported in these studies were contextual to divided urban roads. Even though the pedestrian movements are generally less restricted and predominantly found on undivided urban streets, insufficient research was done on this category of road. Hence, there is a further scope to develop empirical models estimating the speed and the capacity of undivided urban road under the influence of pedestrian 'along' as well as 'across' movements.

Notations

C_{Gap} = Critical Gap
C = Capacity
P = Pedestrian cross-volume
PRC = Percent Reduction in Capacity
Q = Traffic volume
V = Average speed
N = Number of pedestrian crashes per year
n_{ped} = volume of pedestrians along the road
n_c = volume of car
n_{2w} = volume of two-wheeler
n_{3w} = volume of three-wheeler
x_1 = both-directional traffic flow
x_2 = volume of pedestrian cross movement
x_3 = number of stopping bus
x_4 = number of parking/stopping
x_5 = number of entry vehicles into the street
x_6 = number of heavy vehicles
x_7 = percentage of drivers willing to give way to pedestrians
V_j = speed of particular vehicle under influence of other vehicles
V_i = speed of various type of vehicles
a_0 = regression coefficient for free flow speed of 'j^{th}' type vehicle
a'_i = regression coefficient for impact of density of particular vehicle type on free flow speed of 'j^{th}' type vehicle
a'_k = regression coefficient for impact of pedestrians on free flow speed of 'j^{th}' type vehicle
n_i = number of vehicles of particular type passing a section per second

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