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Safe Curb Parking Distance Near School-Gate Ensuring Child Pedestrians' Safety

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ABSTRACT: The presence of curb parking near school-gate is a serious threat to the safety of child pedestrians while crossing the road. Child pedestrians with limited discernibility often cannot sense an approaching vehicle obstructed by the parked vehicle(s). On the other hand, when child pedestrians are willing to cross the road between parked vehicles, it is also challenging for the driver of the approaching vehicle to spot them due to their short height. This often leads to a vehicle-child collision in front of the school-gate. This consequence of curb parking has been well identified and investigated in the literature. However, none of the past studies has forwarded any formula or methodology to determine 'up to what distance this curb parking should be prohibited from the school-gate?'. In this background, this paper introduces the Safe Curb Parking Distance (SCPD) and demonstrates a novel methodology to estimate it. The methodology is driven by the concept of stopping sight distance coupled with basic trigonometry. It is very generic and thus applies to any context with different traffic characteristics and driving cultures. After applying this methodology, the study revealed that for a design speed of 40 km/h and a parking width of 2.5 m, the curb parking should be prohibited up to a distance of 35 m from the school-gate. By doing so, when the child pedestrian intending to cross the road from the school-gate will be spotted for the first time, the driver of the approaching vehicle will have sufficient time and the distance ahead to stop the vehicle before the cross location. In addition, this paper includes four case studies where the proposed methodology was implemented to identify whether a site in front of a school-gate is safe for child pedestrians. As the SCPD estimated in each of these case studies was found to be higher than the available curb parking distance, all of these sites were identified as 'unsafe'.

KEYWORDS: Curb Parking; Pedestrian Safety; Heterogenous Traffic; Lateral Placement; Pedestrian Crossing

1. INTRODUCTION

1.1 Background

Curb parking is an efficient form of parking as it allows road users to park their vehicles nearer to their destinations and is also proven convenient in terms of land use (Marshall & Garrick, 2011). However, sometimes, the drawbacks of curb parking are observed to outweigh the benefits. Such drawbacks are the reduction in the mobility or the capacity of the road (Biswas et al., 2021, Pandey et al., 2023), the degradation of traffic safety for other road users (Biswas et al., 2017, Manville & Pinsky, 2021), etc. Therefore, it is essential for transport planners to know where and when curb parking should be permitted ensuring the benefits outweighing the drawbacks.

Curb parking near school-gates raises an important concern regarding the safety of child pedestrians (particularly, those aged below 15 years) due to their limited ability to discern an oncoming vehicle. As per a study report (Schwebel et al., 2018), less than one-third of children look at the oncoming traffic before crossing a street. Additionally, their small physical height makes it difficult for oncoming vehicles to spot them as well as for them to spot an oncoming vehicle. As a result, children are very likely to end up in fatalities caused by colliding with vehicles. Due to this, pedestrian crossing behavior in educational areas is significantly different and needs special attention (Ramesh et al., 2018).

Statistics also indicate that children account for a prominent proportion of pedestrian fatalities; while it only makes

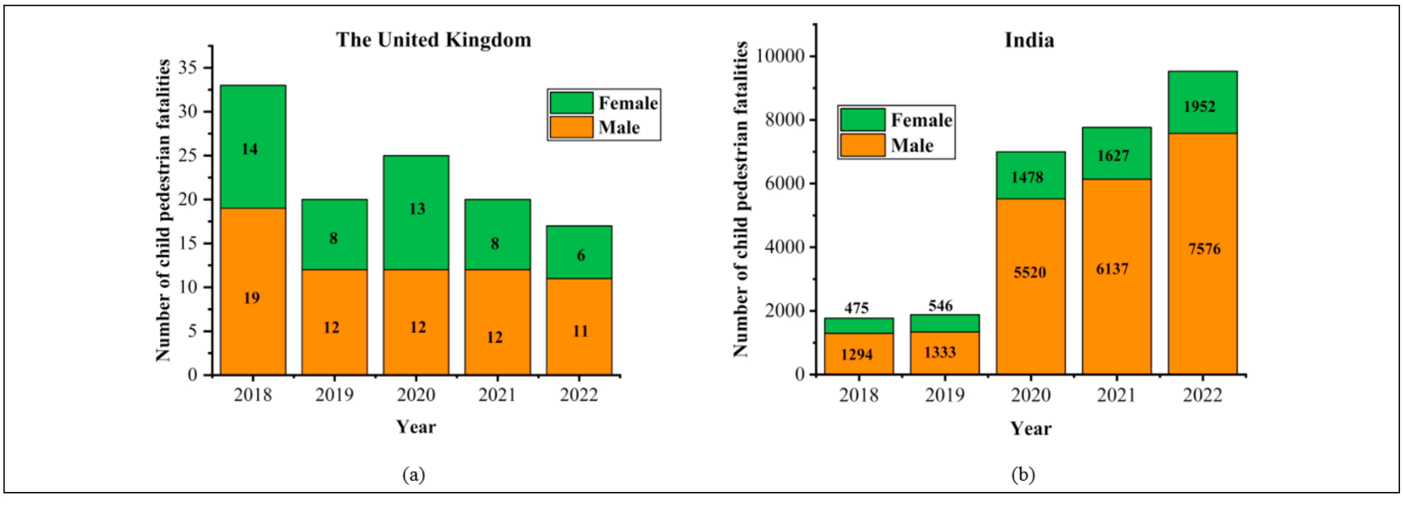

Figure 1. Statistics of gender-wise child pedestrian fatalities in recent years in a) The UK and b) India

up 2% in the USA (National Center for Statistics and Analysis, 2023), 4% in the UK (Department for Transport 2023), and 5% in Australia (BITRE, 2023), it exceeds 28% in a developing country like India (MoRTH 2018, 2019, 2020, 2021 & 2022). Moreover, a negative growth rate in the child pedestrian fatalities is observed in the majority of developed countries while India witnesses a notable increase over the years. For instance, the annual growth rates of child pedestrian fatality in the USA, the UK, the Czech Republic, Australia and India are -3%, -25%, -13%, -8% and 52% respectively (National Center for Statistics and Analysis, 2023; Department for Transport, 2023; International Transport Forum, 2024; BITRE, 2023; MoRTH 2018, 2019, 2020, 2021 & 2022). The number of child pedestrian fatalities in the UK and India in recent years, broken down by gender, is shown in Figure 1 which indicates respective declining and ascending trends.

However, these reports did not provide any segregated statistics on how many of these fatalities happened exclusively in school zones. In this context, the accident statistics, particularly for school-going children were reported in a case study (Tetali et al., 2015) based in Hyderabad, India. The data were collected from 45 schools located in the city. It was observed that the children who walk 2-3 km to school have the highest chances (25%) of road injuries as compared to commuting by school buses or private vehicles. However, the exact reason(s) behind those crashes such as the involvement of parked vehicles was not examined. In this regard, a volume of studies (Martin, 2006; Petch & Henson, 2000; DiMaggio & Durkin, 2002; Schwebel et al., 2011) highlighted that the intensity of curb parking has a direct and considerable association with child pedestrian injuries on urban roads. When parked cars block the vision of child pedestrians, they take longer time than usual to recognize a dangerous traffic situation (Meir et al., 2015). As per Mueller et al. (1990), a significant threat to child pedestrians is instigated by parked vehicles when they occupy more than 50% of the curb length. Following the interviews with children involved in recent traffic crashes, Carsten et al. (1989) concluded that roughly 73% of children were obscured by stationary vehicles and were unable to notice the approaching vehicle. This observation was supported by Great Britain's annual traffic casualty reports (Department for Transport, 2013) which revealed that the majority (50-65%) of the victims of parking-instigated crashes are the child pedestrians aged below 15 years.

Indian Roads Congress (IRC) guidelines IRC SP:12-2015 (Indian Roads Congress, 2015) recognize the issue of curb parking in front of school-gates on different Indian urban roads. The guidelines recommend the marking of parking spaces to restrict irregular curb parking and to minimize its effect on the traffic speed near school-gates. However, the guidelines did not give any emphasis on how the detrimental effect of curb parking on the safety of child pedestrians could be minimized.

1.2 Problem statement and objectives

An ample volume of studies emphasized the child pedestrians' safety and identified various factors contributing to it. However, a few among these past studies recognized the role of curb parking in obstructing the view of child pedestrians and assessed the subsequent impact on their safety. Despite these well-known detrimental effects, curb parking can be found commonly on road stretches in the vicinity of school-gates in India. This is largely due to the lack of awareness and enforcements made by the competent authorities. However, it is also impossible to overlook the absence of a technical guideline in the subject matter. For example, the previous studies consistently advocated the prohibition of curb parking near school-gate. However, none of them analyzed or forwarded any methodology to determine 'up to what distance the curb parking should be prohibited in front of a school to ensure the safety of child pedestrians'. Due to this absence of a guideline, relevant authorities are forced to adopt a longitudinal distance to restrict curb parking on an ad-hoc basis. In this background, the present study aims to conceptualize the Safe Curb Parking Distance and to formulate the methodology for its field estimation. To achieve this aim, the study conceives the following objectives:

1. to develop a methodology for the estimation of Safe Curb Parking Distance (SCPD) from the school gate; and
2. to implement the proposed methodology to identify a safe/unsafe school zone from the SCPD perspective.

2. METHODOLOGY

The Safe Curb Parking Distance (SCPD), in this study, is defined as the minimum longitudinal distance required between the nearest parked vehicle and the pedestrian cross location in front of a school-gate. The distance should be designed in such a way so that on seeing a curbside child pedestrian for the first time, the driver of an approaching vehicle will have adequate distance ahead to decelerate and stop before the pedestrian cross location avoiding collision with the child pedestrian. The methodology proposed in this paper to estimate SCPD is purely theoretical and based on the concept of *Stopping Sight Distance* coupled with basic trigonometry. Figure 2 illustrates a hypothetical situation when a child pedestrian positioned at O is willing to cross the road from the curbside near the school-gate. The curb parking and the school are present on the same side of the road. As shown in Figure 2, D is the longitudinal distance between the front of the nearest parked vehicle and the pedestrian cross location. Similarly, D′ is the longitudinal distance between the pedestrian cross-location and the front of an approaching vehicle when its driver can see the child pedestrian for the first time. The approaching vehicle positioned at more than D′ distance cannot see the child pedestrian due to the obstruction made by the parked vehicle. PW is the parking width which is considered as the lateral distance between the edge of the parked vehicle and the edge of the carriageway as shown in Figure 2. LP is the lateral placement of the approaching vehicle positioned at D′ distance from the pedestrian cross location. LP in this study is considered as the lateral distance between the right edge of the approaching vehicle and the edge of the carriageway as indicated in Figure 2.

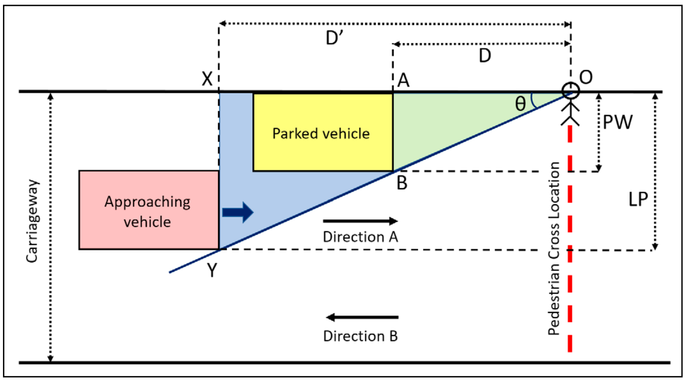

Figure 2. Geometric description of the situation for child pedestrian-vehicle conflict in the presence of curb parking.

The condition of avoiding a collision between the approaching vehicle and the child pedestrian is that D′ should be more than the Stopping Sight Distance (SSD). SSD can be obtained using the formula (Khanna et al., 2014) as given in Eqn. 1.

(1) $D' > SSD = vt + \frac{v^2}{2gf}$

Where SSD = Stopping sight Distance (m)
v = Speed of approaching vehicle (m/sec)
t = Reaction time of the driver (2.5 sec)
g = Gravitational acceleration (9.81 m/sec^2)
f = Coefficient of longitudinal friction (0.35)

The study considers two triangles ΔAOB and ΔXOY which create the same angle θ at O i.e., the position of the child pedestrian curbside when observed for the first time by the driver of the approaching vehicle. Due to the geometrical symmetry, Eqn. 2 is formulated.

(2) $\tan\theta = \frac{AB}{OA} = \frac{XY}{OX}$

As AB = PW, OA = D, XY = LP, and OX = D′, the Eqn. 2 is modified as

(3) $D = \left(\frac{PW}{LP}\right) \times D'$

Further, with reference to Eqn. 1, D′ should be greater than SSD to avoid a collision. Hence, the minimum required D can be determined using Eqn. 4.

(4) $D > \left(\frac{PW}{LP}\right) \times SSD$

Therefore, Eqn. 4 can be utilized to estimate the Safe Curb Parking Distance in front of a school-gate to warrant the safety of child pedestrians against colliding with the moving vehicle.

3. CURB PARKING RECOMMENDATIONS

The study made the following assumptions to arrive at the SCPD values to be recommended.

- As the standard dimension of a designated parallel curb parking space is 5 m × 2.5 m, PW was considered as 2.5 m (Indian Roads Congress, 2015).
- The passenger car was considered as the standard category of approaching vehicle since in the case of larger-sized vehicles like, Sports Utility Vehicles (SUV), buses, trucks, etc., the driver can see the child pedestrian much earlier due to the additional height and width of the vehicle, as compared to a passenger car. The standard width of a passenger car is 1.44 m as recommended in Indo-HCM (CSIR- Central Road Research Institute, 2017) .
- To be on the safer side, LP was considered as the minimum lateral placement possible for the right edge of the approaching vehicle with no lateral gap between the parked and the approaching vehicle. Additionally, there is an expected difference in lateral positions between the driver and the right edge of the same approaching vehicle. To consider this difference in the analysis, 0.5 m was further deducted from the minimum LP of the vehicle to arrive at the design LP ($\widehat{LP}$) i.e. 3.44 m as given in Eqn. 5.

(5) $\widehat{LP} = \underbrace{\overbrace{2.50}^{\text{parking width}} + \overbrace{1.44}^{\text{width of approaching vehicle}}}_{\text{minimum possible LP}} - \overbrace{0.5}^{\text{adjustment for driver position}} = 3.44\text{ m}$

- The design speed of the urban collector road is considered as 40 km/h as given in IRC: 86-2018 (Indian Roads Congress, 2018a).

Based on the given assumptions (v = 40 km/h, PW = 2.5 m, and $\widehat{LP}$ = 3.44 m), SCPD was estimated as 33.25 m using Eqn. 1 & 4. Hence, it is recommended to prohibit the curb parking up to 35 m from the school-gate to warrant the child pedestrians' safety. However, it is to be noted that the aforementioned assumptions were taken only to consider the most likely value of a parameter or the situation that leads to a conventional and safe SCPD. Therefore, these assumptions can be exempted or modified on a case-to-case basis depending upon the site circumstances as discussed in case studies later. Nevertheless, the proposed methodology will remain useful in the context of any other assumed vehicle categories, design speeds, and lateral gaps between parked and approaching vehicles. Even, the methodology is useful for the safety evaluation in a context where a portion of the parked vehicle's body is on the carriageway and the rest is on the shoulder or footpath which is commonly observed on Indian urban roads.

4. CASE STUDIES

4.1 Sites and data collection

The proposed methodology for the estimation of SCPD was implemented in four case studies that are further discussed in the following sections. Four sites were chosen for the case study within Silchar City, Assam, India. At each of these sites, a school is located roadside, and a substantial volume of child pedestrians is expected to cross the road. The following additional criteria were considered before selecting a site.

- The road should be a two-lane undivided type.
- The road should carry a significant traffic volume during peak hours.
- The surface condition of the road should be good and does not influence the lateral placement of moving vehicles.
- The site should have considerable curb parking.

Following the above-mentioned selection criteria, four sites were chosen in front of the following roadside schools viz. i) St. Capitanio Senior Secondary School, ii) Holy Cross H.S. School, iii) Borakhai High School, and iv) North Eastern H.S. School. Photograph of a site is shown in Figure 4a. Further details of each site are given in Table 1.

As per IRC guidelines (Indian Roads Congress, 2012 & 2018b), a dedicated crosswalk (zebra crossing) at every 30 m of the road length and 1.5-2.0 m of footpath beyond the bituminous width should be provided on the pedestrian-influenced streets. However, it has been commonly observed that these IRC guidelines are not consistently followed on such streets. The chosen sections (sites 1-4), despite having a roadside school where a good volume of child pedestrians are expected to cross the road, neither had any dedicated crosswalk nor a footpath for their safety. The data collected

Site	School Name	Road Name	Road Configuration	Carriageway Width (*m*)	Latitude and Longitude
Site 1	St. Capitanio Senior Secondary School	Hailakandi Road	Two-lane undivided	6.45	24.7731° N & 92.7912° E
Site 2	Holy Cross Higher Secondary School	Sonai Road	Two-lane undivided	7.80	24.8070° N & 92.7987° E
Site 3	Borakhai High School	Hailakandi Road	Two-lane undivided	6.50	24.7554° N & 92.7969° E
Site 4	North Eastern Higher Secondary School	Indira Sarani	Two-lane undivided	6.70	24.8089° N & 92.7847° E

Table 1. Details of sites selected for case studies.

in the field are classified into two categories; i) traffic data and ii) geometric data. Traffic data includes the speed and LP of approaching vehicles. On the other hand, the geometric data includes parking width, carriageway width, and available parking distance from school-gate. While the traffic data were collected by videography method, the geometric parameters were manually measured at the site. For videography, a video-camera mounted on a stand was kept roadside in such a way so that it could capture the moving traffic and the school-side parking activities together and uninterruptedly. The videography arrangement is shown in Figure 3.

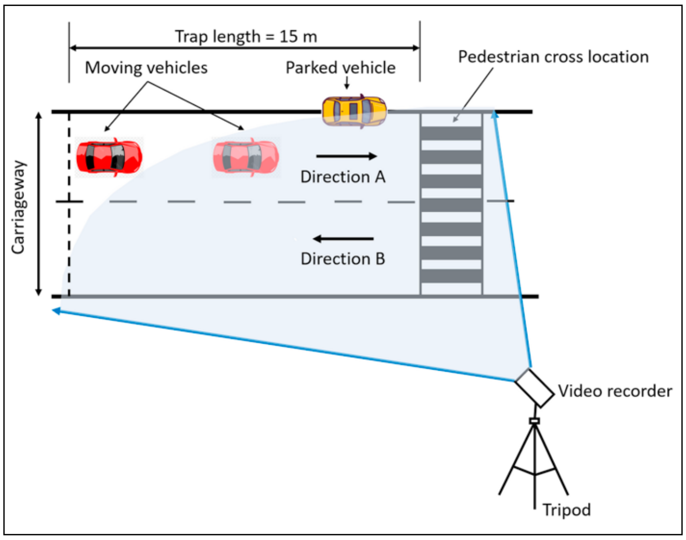

Figure 3. Videography arrangement.

At each site, a 15 m longitudinal trap length was made and the four corners of the rectangle (dimension of the rectangle: trap length × carriageway width) were marked. Then, the videography was performed for two hours at each site and the video files were taken to the laboratory to extract the required traffic data. Following the procedure given by Saini & Biswas (2020), a virtual set of gridlines (dimension 20 × 20) was painted on the above-said rectangle to locate the position of a wheel of the moving vehicle as shown in Figure 3b.

The width of each grid is calculated using Eqn. 6.

$$(6)\quad GW = \frac{CW}{20}$$

Where, GW = unit grid width (m)
CW = carriageway width (m)

For extracting the speed and the LP data of the moving vehicles, the video featuring the layout of the virtual gridlines was played on the computer screen. On the 15 m trap length, the entry and exit time of each vehicle which were recorded with an accuracy of 0.01 sec, were further used in Eqn. 7 to estimate its speed.

$$(7)\quad v = \frac{\text{trap length } (=15\text{ m})}{t_{exit} - t_{entry}}$$

Where v = speed of vehicle (m/sec)
t_{exit} = time of exit from the trap length (sec)
t_{entry} = time of entry into the trap length (sec)

As may be seen in Figure. 2, point Y i.e., the lateral position of the front right corner of the approaching vehicle plays a pivotal role in determining the SCPD. Hence, in the extraction of LP data, the position of the front right wheel in the case of four-wheelers (cars, buses, trucks, etc.) and only the front wheel in the case of motorized two-wheelers and three-wheelers were noted. The grid numbers (range: 1-20) accessed by the above-said wheels within the trap length, were recorded and further used in LP estimation. LP of these wheels was estimated from the edge line using Eqn. 8 (Bhavna & Biswas, 2022).

$$(8)\quad LP = \left(\frac{N_g - 0.5}{20}\right) \times CW$$

Where LP = lateral placement of subject wheel (m)
N_g = grid number

The speed and the LP data were collected for each vehicle particularly moving towards direction A (as indicated in Figure 3) within the observation period at each site. A wide variation in speed and LP of approaching vehicles was observed across sites. With reference to Figure 2, it was realized that an approaching vehicle with a higher speed and a lower LP from the edge of the carriageway is a greater threat to the child pedestrian crossing the road in the presence of curb parking. Hence, a 95th percentile of observed speeds and a 5th percentile of observed LPs were considered as the design values for the SCPD estimation.

4.2 Results and discussion

The parameters mentioned in *section 4.1* along with the observed parking width (PW, in m) and the available parking distance (D, in m) are given in Table 2. The curb parking was observed consistently in close proximity to the school-gate for all chosen sites and the available parking distance from the school-gate was found within [3.7 – 6.5 m]. On the other

Figure 4. a) Photograph of a site used in case study and b) layout of virtual gridlines within the trap length for the extraction of LP data.

hand, the body of the parked vehicles was found partially on the carriageway, and the rest occupied the shoulder. This was consistently observed at all sites and hence, the parking width was found to vary between 0.35 m and 1.10 m as given in Table 2.

The design speeds as given in Table 2 were taken as input in Eqn. 1 and the SSD was estimated separately for each of the sites. As reported in Table 2, the minimum and the maximum SSD were found to be 31.77 m and 51.04 m respectively for Sites 2 & 3. Subsequently, SSD, PW, and LP data were further used in Eqn. 4 to estimate the SCPD for each site. Table 2 provides the SCPD values estimated at different sites based on the proposed methodology. Since, the observed D i.e., the available parking distance from the school-gate was consistently found lower than the estimated SCPD, all sites considered in the case study were identified as 'unsafe' from the child pedestrians' perspective.

The study also forwards a comprehensive table, Table 3 for the easy adoption of suitable SCPD value under varying design speed and parking conditions.

The ability for a user to directly extract the suitable SCPD value from Table 3, without having to perform rigorous computations, will boost the field applicability of the proposed methodology's. It is also interesting to observe that when design speed and parking width at the site increase, so does the SCPD required for the school zone.

5. CONCLUDING REMARKS

5.1 Study contributions

The present study forwards a methodology to determine the safe curb parking distance from the school-gate. The methodology presented is theoretical and generic, and hence, can be implemented on any urban road passing by a roadside school. The methodology is based on fundamental geometry and involves the concept of stopping sight distance. Prohibiting curb parking up to a distance of SCPD can ensure the safety of a child pedestrian, visually obstructed by the parked vehicle, willing to cross the road.

Four case studies were performed to implement the proposed methodology. The required traffic and parking data were collected at four sites where a school is located roadside and an ample volume of child pedestrians cross the road during peak hours. The present study found each of these sites as 'unsafe' for child pedestrians as the available curb parking distance was lower than the SCPD estimated by the proposed methodology. Moreover, considering the design speed as 40 km/h, the standard parking width as 2.5 m, and no lateral gap between the parked and the approaching vehicle, a general SCPD of 35 m is recommended. The study also forwarded a comprehensive table providing SCPD values for the easy reference under any given design speed and parking width conditions.

5.2 Future research directions

Child pedestrians are the most vulnerable road users and their safety should be given foremost emphasis in order to reduce their crash risk in the future. The work presented in this paper is a rudimentary step toward diminishing the risk associated with a child pedestrian crossing the road in the presence of curb parking. Since the SCPD is conceptualized based on a theoretical premise, it has laid the base for future research on its practical validation to arrive at more realistic SCPD value.

A considerable uncertainty may be involved in two key governing factors for the estimation of SCPD, viz. i) speed of approaching vehicle and ii) lateral gap between approaching and parked vehicles. Therefore, developing a probabilistic SCPD model considering these uncertainties can be a meaningful venture in the future.

It is to be acknowledged that the methodology for SCPD estimation proposed in this study is only applicable to parallel curb parking. Hence, as a future scope, further research can be conducted to develop a similar methodology for other parking types also. Moreover, traits like age, gender, height, discernibly, etc., vary with every child pedestrian and may impact their crossing behaviour and overall safety awareness. Influence of these factors in SCPD estimation can be studied in future.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known conflict of interest or personal relationships that could have appeared to influence the work reported in this manuscript.

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Site	Design Speed (*km/h*)	Design LP (*m*)	PW (*m*)	D (*m*)	SSD (*m*)	SCPD (*m*)	Remarks
Site 1	43	0.75	0.35	4.5	49.89	23.28	Unsafe
Site 2	31	1.28	0.80	3.7	31.77	19.86	Unsafe
Site 3	43	1.44	0.70	5.7	51.04	24.81	Unsafe
Site 4	39	1.87	1.10	6.5	44.82	26.36	Unsafe

Table 2. Parameters involved in the estimation of SCPD at different sites.

Design Speed (*km/h*)	SCPD (m) corresponding to different Parking Widths (*m*)					
	0.5	1.0	1.5	2.0	2.5	3.0
30	10.74	15.95	19.03	21.05	22.49	23.56
40	15.88	23.58	28.13	31.13	33.26	34.84
50	21.81	32.37	38.61	42.73	45.65	47.82
60	28.51	42.32	50.48	55.86	59.68	62.53
70	36.00	53.44	63.73	70.52	75.34	78.94

Note: Approaching vehicle assumed as a standard passenger car; LP = PW + 1.44 - 0.5 (Refer Eqn. 5)

Table 3. Safe Curb Parking Distances (m) under different possible combinations of design speeds and parking widths

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