ASSESSING THE STREAM SPEED OF REGULAR TRAFFIC UNDER IMPACTS OF ON-STREET PARKING

Naynish Pandey[1,*], Raman Parti[1], Subhadip Biswas[2]

[1]Department of Civil Engineering, National Institute of Technology Hamirpur, Hamirpur, Himachal Pradesh, India
[2]Department of Civil Engineering, National Institute of Technology Silchar, Silchar, Assam, India

*E-mail of corresponding author: pandeynaynish@nith.ac.in

Naynish Pandey 0000-0002-2004-2131, Raman Parti 0000-0001-9147-1972, Subhadip Biswas 0000-0002-5102-0795

Resume

Stream speed pattern of traffic plays a crucial role in urban transportation. The presence of on-street parking significantly reduces this speed by narrowing the carriageway width available for traffic movement, impeding the traffic flow. Therefore, understanding the traffic flow behavior in the context of on-street parking could be challenging. In this context, the present study explores the influence of on-street parking on the stream speed of regular traffic. To achieve this, data were collected at various ideal and parking sections. The stream speed ranges from 39.28 km/h to 51.47 km/h for ideal sections with significant percentage reduction observed at parking sections, ranging from 39.09% to 81.30%. This speed reduction was then modelled considering the most significant parking parameters conceptualized in this study. The findings of the study offer valuable insights that can be implemented for developing the on-street parking norms.

Available online: https://doi.org/10.26552/com.C.2024.046

Article info

Received 2 May 2024
Accepted 10 July 2024
Online 22 July 2024

Keywords:

on-street parking
stream speed
urban roads
traffic congestion
speed model
road transport

ISSN 1335-4205 (print version)
ISSN 2585-7878 (online version)

1 Introduction

Developing countries like India witnessed rapid advancement and urbanization in the last few decades. These countries have gone through the fast transformations leading to a good lifestyle, especially in urban areas due to the innovation in technologies. People often use personal vehicles rather than taxis or public transport to move from one place to another within the city. As a result, Indian urban roads have become overly crowded, which affects the speed of moving traffic. According to Shangliao Sun's report, the number of vehicles witnessed significant growth over 10 years. For example, in 2009, there were 115 million vehicles in India, and by 2019, this number had risen to 295.8 million, reflecting an approximate increase of 157% in 10 years, as stated earlier. So, every year vehicular ownership increases, but to accommodate the increased number of vehicles, road infrastructure is limited, which results in congestion on urban roads [1]. To accommodate the increased number of vehicles, parking lots are provided in most of the major cities that primarily reduce congestion, however, parking lots fail to accommodate all the vehicles in peak hours due to limited space and capacity. As a result, the on-street parking seems to be an alternative to parking lots for drivers, as it helps the drivers park their vehicles near their destinations [2]. Apart from this, vehicles in search of parking spaces, meandering here and there along the urban road also create havoc, congestion, more fuel intake, and gas emissions causing air pollution. The on-street parking also affects the performance of the road in terms of stream speed. It causes a reduction in stream speed as it borders the width of the carriageway forcing the traffic to move into the reduced carriageway. Moreover, the frequent parking and unparking maneuvers along the road also interrupt the movement of regular traffic causing a reduction in stream speed. The interaction between the on-street parking and the movement of regular traffic is governed by various other factors as identified in former research. The degree of this interaction is subject to variation in both parking intensity and traffic volume levels. Parking fee is one of the crucial factors that may attract or discourage drivers to park their vehicles on streets resulting in variation in parking intensity [3].

Further, the day of week or the time of day also plays a significant role in determining the parking intensity, which is generally higher on weekdays [4]. However, the effect of time of day on parking intensity may change depending on the land use pattern. Similarly, the prevailing traffic volume on a street also varies with the day of the week and the time of day [5]. Hence, as the intensity of both parking intensity and prevailing traffic volume increase on the street, it instigates more severe interaction resulting in substantial impact on street mobility. On the other hand, in the case of wider streets with multiple lanes, vehicles of regular traffic often change their lateral position away from the parked vehicles to maintain mobility or minimize the reduction in speed. Therefore, the number of lanes on a street characterizes the impact of on-street parking on stream speed [6]. Numerous research conducted so far has assessed on-street parking and its impacts on the stream speed. However, the limitation associated with the majority of these studies is their treatment of on-street parking as a binary variable considering only its presence or absence. Consequently, the findings of these studies neither proposed any mathematical model nor proposed or suggested any guidelines regarding permissible limits of the on-street parking. Apart from these, some of the previous studies quantified the impacts of the on-street parking considering only limited parking parameters, which may cause inappropriate results and show inconsistencies in the findings of these studies. Therefore, in the absence of appropriate parking data, transportation planners ask for consultation and norms related to on-street parking while designing the urban roads. In this background, the present study tries to examine the intricacies of on-street parking and its impacts on the stream speed. The proposed study tries to consider all the possible parking parameters to develop a speed reduction model.

The research paper starts with the "introduction" that discusses on-street parking, its limitation and effects on the stream speed. This is followed by "literature review" that summarizes the work done in the previous studies and their limitations. The next section is "research methodology" that details site selection, data extraction and procedure for developing the speed models. This is followed by a section on "field data collection" containing the methods used for collecting data. The "results" section presents the developed speed model followed by "validation" section that covers the accuracy of the model. Finally, the "conclusion" section summarizes the key contributions of the study and includes future research directions.

2 Literature review

Ample volume of research was conducted in the past to understand the impacts of on-street parking on the stream speed of moving traffic. In this regard [7-8] considered parking density (number of parked vehicles) and parking pattern, whether it was the parallel or angled type, to examine the impact of on-street parking. The study shows the 8.05 km/h to 13 km/h reduction in the stream speed. On the same background, authors of [9] conducted their research and found that there was a 12% to 15% reduction in the stream speed for different categories of vehicles. This speed reduction reflects that there could be other parking parameters that may reduce the stream speed more. Then, in [10-11] the influence of on-street parking on the stream speed was examined by considering on-street parking as a binary variable i.e., 0 when the on-street parking was absent, and 1 when it was present. In [10] is suggested that the presence of on-street parking led to a decrease in the stream speed of traffic by 5.1 km/h. The study neither suggested any model, nor quantified the impact of on-street parking with varying intensity. Later, authors of [12] came up with a speed model and quantified the impact of on-street parking on both two-lane and four-lane roads. The study also proposed a parking parameter named the number of parked vehicles. The number of parked vehicles cannot capture the heterogeneity, which means that the parked vehicles may be of any type (2w, 3w, car or lcv, etc.). Here, lcv denotes the low commercial vehicles. Therefore, in [13] the stream speed was defined as a function of several factors, such as traffic volume (FLOW), carriageway width (CW), shoulder width (SW), and side friction (FRIC). Moreover, the FRIC was modelled as pedestrian volume (PED), bicycle volume (BIC), stopping and parking vehicles (PSV), and non-motorized vehicles (NMV) as described in:

$$FRIC = 1 \times PED + 0.45 \times BIC + 0.08 \times \\ \times NMV + 0.37 \cdot PSV. \tag{1}$$

This comprehensive model, aimed to capture the various elements affecting the stream speed and provided the framework for assessing the impact of these factors on traffic flow and road performance. The model suggests that parked vehicles, as a side friction parameter have less significant influence than pedestrians and bicycles. This is in contrast to the existing literature that identified the on-street parking as the most significant side friction factor. In the same way, in [14] was considered the number of parked cars and proposed a quadratic model showing the free flow speed as a function of parked cars. The findings of that study revealed that initially free flow speed increases with an increase in parking density (say, 29 parked cars), while it decreases later (beyond 29 parked cars), showing the discrepancy in the findings of previous research. Therefore, the model becomes unfit and needs justification as to why the free-flow speed increases initially.

Apart from this, in [11] is considered another aspect (safety) of the on-street parking and authors

***Table 1** Various Speed Models Suggested by Researchers*

Author Name	Speed Models Used	Parameters Considered
[13]	$V = 79.6 - 0.008 \times FLOW - 0.028 \times FRIC - 6.085 \times CW + 11.8 \times SW$	Parking and Stopping Vehicles
[14]	$Y = -0.0837x^2 + 4.856x + 0.2772, R^2 = 1$	Number of parked cars
[15]	$Y = 39.458 - .132x_2 - .126x_3 - 0.280x_4 - .126x_5 - .153x_8$	Parking and Stopping Vehicles
[19]	$V_{park} = 50.57 - 0.67n_{man} - 0.09t_i - 0.20n_{vp} - 0.11n_c - 0.06n_{2w} - 0.28n_{3w}$	Number of parking maneuvers/100m
[20]	$Y = 47.788 - 0.166x, R^2 = .7088$	Number of parked vehicles (parking density)

where: V, Y, V_{park} = Stream speed, Free-flow speed, Stream speed for on-street parking,
$FLOW$ = Traffic volume,
$FRIC$ = Side friction,
CW = Carriageway width,
SW = Shoulder width,
x = Number of parked cars, density of vehicles,
x_2 = Number of stopping city buses,
x_3 = Pedestrian movement,
x_4 = Number of parking/stopping passenger cars,
x_5 = Number of entry vehicle into the street,
x_8 = Number of heavy vehicles per hour,
n_{man} = Number of parking maneavers per 100m,
t_i = influence time of parking and unparking vehicles,
n_{vp} = Number of vehicles parked per 100m on sides of carriageway,
n_c, n_{2w}, n_{3w} = Number of cars, two wheelers, three wheelers respectively.

have limited their research to the safety of the passengers. The study discovered that urban roads with the existence of on-street parking have a higher frequency of crashes at stream speed exceeding 35 km/h. However, that study considered the on-street parking as a categorical variable. In later years, some research has been conducted to understand the influence of on-street parking on the stream speed in an improved way. Munawar [15] developed a speed model and considered several parking parameters. It was later found that parking/stopping vehicles (coefficient value is 0.280) was one of the most crucial parking parameters that significantly lowered the stream speed. Rather than this, parking maneuvers were also proved to be one of the prominent parameters in the later studies. In the context of this, a study conducted by [16] focused on on-street parking and found that when the parking maneuvers, such as vehicles entering or exiting the parking spaces, were carried out on the road, there was a significant reduction in the stream speed. This speed reduction was likely to occur due to the need for vehicles to slow down or stop to accommodate these parking maneuvers, which can disrupt the flow of traffic on urban roads. Research conducted in [17] measured the impact of on-street parking on the stream speed. Authors considered a wide range of parking intensity from 0% to 100% for different Volume/Capacity ratios. However, the findings of the study revealed that the stream speed continuously decreased up to 45% parking intensity which was later followed by a sudden increase in speed from 45% to 75% parking intensity, and then again decreased. The authors could not explain this behavior and it remains unsolved, which needs further investigation to support the research findings.

Similarly, in [18] is assessed the impact of on-street parking on the stream speed and performed sensitivity analysis. The study's findings show that the speed was reduced to 44% with a wide range of 0% to 70% of parking intensity. Later, it was also found that this reduction was 37% for the one-lane and 28% for the two-lane urban roads, which means speed reduction can be less on broader roads. In a separate study conducted by [19], the researchers examined the parking maneuvers and developed multiple speed models to assess the influence of on-street parking on the stream speed. The study's conclusions revealed that a significant reduction in the stream speed varies within a range of 27.5% to 37.2%. This reduction was observed over different traffic volumes ranging from 1000 PCU/h to 3000 PCU/h. Furthermore, this reduction also increases with an increase in parking maneuvers for the same range of traffic volume. Hence, these results underscored the substantial influence of on-street parking on the stream speed. To shed more light on how the on-street parking affects stream speed, authors of [20] researched the impact of on-street parking on the stream speed and considered the number of parked vehicles and encroachment of the carriageway as major parking parameters. That study was further concluded that there was a substantial reduction in speed, which varied in a wide range of 45% to 67%. This reduction was observed concerning the number of parked vehicles, which varies from 157-1580 veh/km. A recently conducted research [21] scaled the various side frictions named "SF" and developed the speed model that showed a 51% reduction in stream speed. However, the model did not examine the individual impact of side frictions, i.e., on-street parking, pedestrians, or wrong movement of vehicles at stream speed. In recent years, in [22] was assessed the on-street parking and used the product limit method. The study found a 50% reduction in stream speed in sections with on-street parking. However, the authors of the study limited their research to evaluate the impact in the presence or absence of on-street parking.

In brief, significant research has been considered in the past decades to assess on-street parking and its impacts on stream speed. Few of them considered parking as a binary variable, while others quantified it and presented the speed models. The various speed models, developed in the past research, are tabulated and found in *Table 1.*

Summarily, it is worth noting that a good volume of research has been carried out in the past and various speed models have been developed to assess the impact of on-street parking. Outcomes of some studies underscore the substantial impact of parked vehicles on the stream speed, with an extensive decrease when number of parked vehicles increased along a road while some research was engrossed in assessing how the stream speed is affected by the presence or absence of the on-street parking remiss of considering other specific parameters or local conditions. Though the past research findings provided an esteemed perception of on-street parking and its effects on stream speed, it may be thoughtful for future work to dig deeper into on-street parking problems and gain substantial knowledge of the imprint of the on-street parking on traffic parameters.

3 Research methodology

The presented work was divided into three phases namely: (i) site selection and videography, (ii) data extraction, and (iii) speed models. Each of these phases is discussed one by one in the manuscript.

3.1 Site selection and videography

To carry out the research work, both base and parking segments were selected in various major cities across India. Base segments were those where the on-street parking was absent, and it was present at segments with considerable space called parking segments. Apart from this, all the selected segments should have the following conditions.

- All the segments should be in straight alignment without any vertical curve or gradient.
- All the segments should be quite far away from the nearby intersections so that there cannot be any distractions other than the on-street parking.
- There should not be any bus stops, pedestrian movements, or access points in the vicinity of the selected segments.
- All the selected segments should be in urban areas and within the city limits.

Based on the above-mentioned criteria, several base and parking segments were chosen in different major cities across India as shown in *Figure 1 (a) and (b).*

After the selection of segments, the videography was performed to carry out the data collection on weekdays (Monday to Friday) using a video camera mounted on a 1.5m tall tripod. While performing the data collection smoothly, a tripod stand was kept in such a way that it could capture the entire segment without any interruptions. Later, the video files were taken to the laboratory to extract the required data. Details of various segments chosen in the study are given in *Table 2*.

3.2 Data extraction

All the recorded video files were taken to the laboratory to extract the required data. Three types of data were extracted from the video files, i.e., (i) Traffic data, (ii) Geometric data, and (iii) Parking data. A 30m

(a) (b)

Figure 1 (a) *Base Segment and* ***(b)*** *Parking Segment*

Table 2 *Details of various base and parking sections*

Section Name	Type of section	Name of road	Carriageway Width (m)	City
I1	Base Section	Lohia Park Road	6.4	Lucknow
I2		Akbar Road	7.2	New Delhi
I3		Vikas Khand Road	7.9	Lucknow
I4		Virbal Sahni Road	8.3	Lucknow
I5		Butler Road	8.5	Lucknow
I6		Vigyan Path	9.0	Chandigarh
P1	Parking Section	Sector G Main Road	6.9	Lucknow
P2		Hospital Road	7.0	Dehradun
P3		Kanwali Road	7.5	Dehradun
P4		Janpath Road	7.6	Lucknow
P5		DAV College Road	8.9	Chandigarh

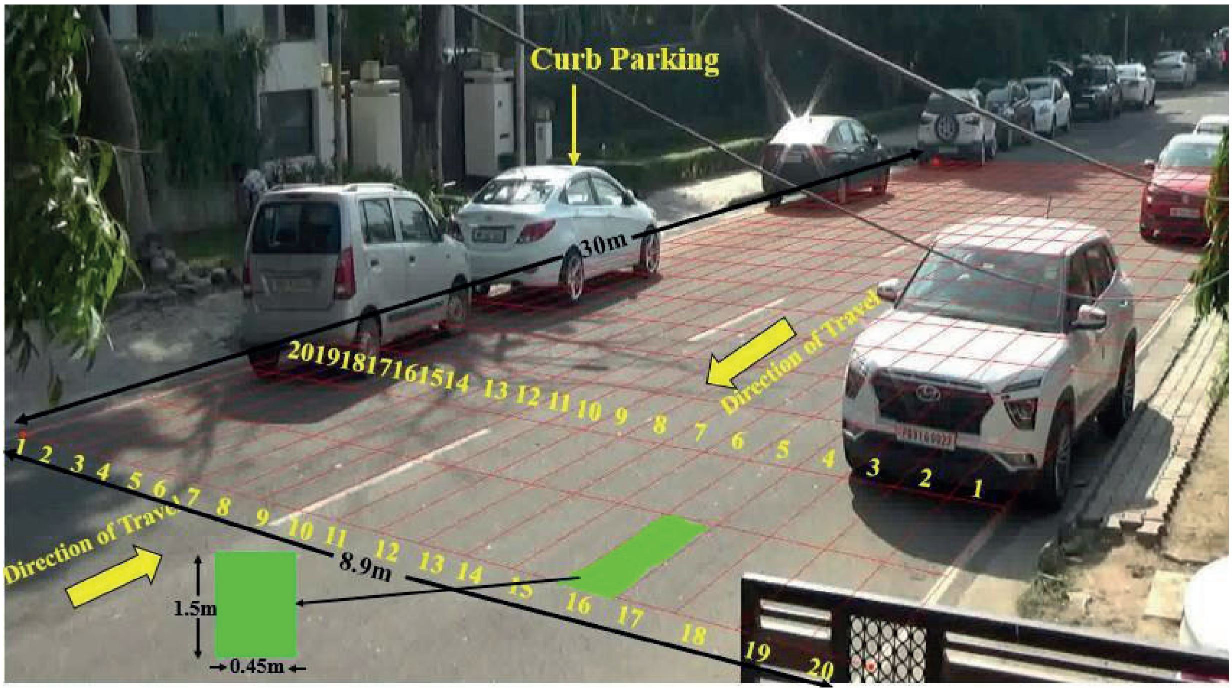

Figure 2 *Grid analysis of carriageway width*

trap length was temporarily marked by bordering two reference lines on selected road segments. The vehicles observed manually in the segments were classified into different categories. Hence, classified traffic volume was extracted by counting the number of vehicles of diverse categories crossing the segments in each 5-minute interval. The classified speed of each vehicle was measured by noting down the time taken by each vehicle from one reference line to another within the particular interval. Before extracting the data, all the video files were edited using the video annotation software Kinovea [23]. In geometric data, the width of the carriageway was measured manually. To extract the required parking data, some parking parameters, such as parking density, parking maneavers, etc were extracted simply by observing the videos. To extract the parking width, it is required to pinpoint the exact position of the parked vehicles on the carriageway. To do this, the entire carriageway width was divided into 20 small grids using the video editing software Kinovea [23], as shown in *Figure 2*.

The accuracy of parking width measured in the study is highly governed by the number of segments that the carriageway width is being divided into. More is the However, splitting the carriageway into more than twenty equal segments makes the video clumsy and the wheel positions of vehicles on these segments become indistinguishable. Therefore, it was decided to divide the carriageway width into twenty virtual segments yielding an acceptable 5% error in the extracted data [24].

Finally, the parking width was estimated for each parking segment by counting the segment numbers occupied by the parked vehicles from the edge of the carriageway.

While estimating the parking width, two attributes were considered i.e., the traffic composition and the dynamic nature of parked vehicles as explained in the following:

a) The parked vehicles were of diverse categories and occupied different lateral distances from the edge of the carriageway. So, it was difficult to estimate the parking width based on their actual widths. In addition, the area covered by the parked vehicles remained unutilized for the moving traffic. Hence, the actual parking width was estimated as the maximum of individual actual widths of the parked vehicles as given in:

$$PW^m = maximum\ (PW_1, PW_2, \ldots PW_i \ldots \ldots \ldots PW_n), \quad (2)$$

where: PW^m = maximum parking width (m) for the trap length within a given time interval t,
PW_i = individual parking width (m) of vehicle I,
n = total number of parked vehicles observed within time t.

b) The actual width of the parked vehicles was not expected to be the same within a given time interval. It varies when a new vehicle is being parked, or a parked vehicle is taken out. To account for this, the parking width was estimated using:

$$PW^A = \frac{\sum_1^n PW_i^m t_i}{\sum_{i=1}^n t_i}, \quad (3)$$

where: PW^A = Actual parking width (m) for the entire trap length,
t_i = time duration (minutes) corresponding to ith interval,
n = number of time intervals.

3.3 Speed models

3.3.1 Speed prediction models

The classified speeds of the vehicles, estimated at each base segment, were combined and used to develop the speed prediction models for the base segments. In the Indian traffic scenario, speed was dependent on several parameters, i.e., traffic composition (*NMV, 2-wheeler, 3-wheeler, standard car, LCV, HCV*, etc.) and width of carriageway. The percentage composition of all these parameters for base sections is presented in *Figure 3*.

Later, a multiple regression technique was used to predict the speed model for the base section, based on different parameters. The best-fitted parameter with good significance was then considered for the model prediction. In this connection, carriageway width, standard car, two-wheeler, and *HCV* were proved to be the most significant parameters and hence selected for the model development. The model was formulated using [25] Statistical Package for Social Sciences (SPSS 26.0). The developed model is shown in:

$$V = 7.399 \text{x} CW + 0.035 \text{x} SC – 0.013 \text{x} 2W – 0.234 \text{x} HCV \quad (4)$$
$$(23.597) \quad (3.601) \quad (2.228) \quad (3.354)$$

where: 2W = 2-wheeler,
CW = Carriageway Width.

The values inside the parenthesis in *Equation (4)* represent the t-stat values of each constant. During the model development, the constant was forcibly kept to zero as predicting stream speed at the road section was not feasible in the absence of traffic proportion. Several significant observations were noted during the data

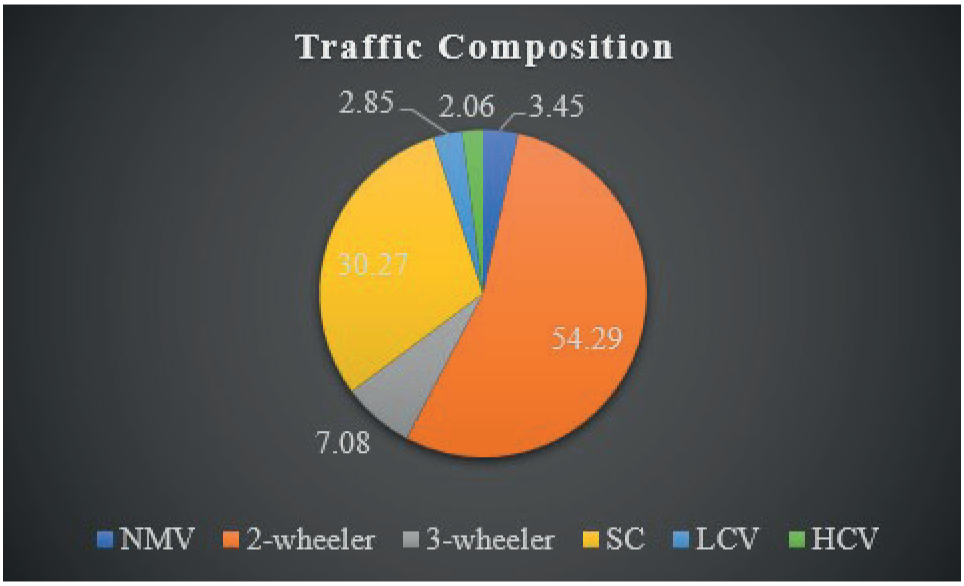

Figure 3 *Traffic proportion at various base sections, where NMV = Non-motorized vehicle, LCV = Low commercial vehicles, HCV = High commercial vehicles, SC = Standard car*

***Table 3** Stream Speed at various sections*

Section Name	Section Type	Carriageway Width (m)	Stream Speed (km/h)
I1	Base Section	6.4	51.47
I2		7.2	49.38
I3		7.9	50.52
I4		8.3	46.21
I5		8.5	39.28
P1	Parking Section	6.9	12.00
P2		7.0	24.57
P3		7.5	26.52
P4		7.6	19.43
P5		8.9	22.15

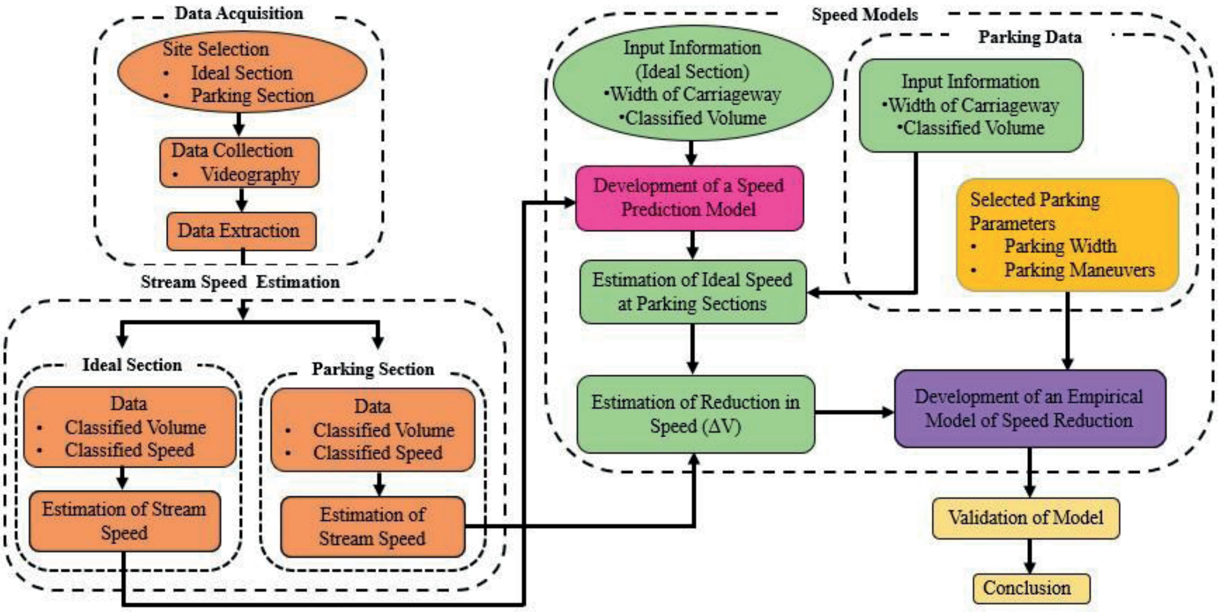

***Figure 4** Flow chart of the research methodology*

collection for development of a speed model for the base section.

The study employs several independent parameters such as standard car, *HCV, 2W*, and width of carriageway. As depicted in *Figure 3*, the 2-wheeler and standard cars collectively represent a substantial proportion accounting for 54.29% and 30.27%, respectively, among all the vehicle categories moving on the road. However, the two-wheelers establish a negative correlation with the stream speed, likely due to frequent variation in speed, as well as extensive manoeuvring causing hindrance to the other vehicles along the road. Consequently, a high proportion of the two-wheelers along the road slightly diminishes the stream speed. Additionally, an increase in the carriageway width is associated with the higher stream speed as it provides more room for the movement of the vehicles.

In the developed model, the speed also demonstrates the inverse relationship with the proportion of *HCV* (high commercial vehicles). This is because the HCV generally moves at a slower speed along the road. For undivided urban roads, an increase in the proportion of these vehicles in the traffic stream can force the other vehicles to move at a slower speed as overtaking these slow-moving vehicles can be a challenging task. Ultimately, the overall stream speed at the road section was affected. Furthermore, the stream speed exhibits a positive correlation with standard cars as they tend to move at higher speeds and maintain a constant gap between each other indicating the free flow condition to some extent. As a result, the stream speed at a particular road section attains a maximum value (base speed) where the proportion of standard cars is higher.

The presented model for a base section, as given in *Equation (4)*, was further used to predict the stream speed of a regular traffic under the influence of on-street parking. Here, "regular traffic" implies that the usual flow or movement of vehicles on the road under normal conditions excluding the parking and unparking maneavers. The procedure for estimation of the stream speed at parking sections is later discussed.

3.3.2 Speed reduction model

Classified speeds at each base and parking section were used to estimate the stream speed of the through traffic at a 5-min temporal aggregation level, and tabulated as given in *Table 3*.

It is confirmed that the stream speed at base sections varies from 39.28 km/h to 51.47 km/h, while it varies within a range of 12.00 km/h to 26.52 km/h for parking sections. In addition, it was expected and can be seen in the table that stream speed at parking sections was comparatively lower than at base sections. Hence, the speed reduction (ΔV) was calculated at all the selected parking sections and a mathematical model was developed by considering the most crucial parking parameters. Before finalizing the model, it is a prerequisite to check the dependency of all the selected parking parameters and their influence on the stream speed using Pearson's correlation coefficients. Finally, the speed reduction model (ΔV) was developed based on the most influencing parking parameters. The procedure adopted in the study is given in *Figure 4*.

4 Field data collection

To conduct the research, field data was collected at five base and six parking sections in different major cities across the country. All the selected sections were the two-lane undivided devoid of any distress or pavement unevenness. In addition, all the sections were straight with no gradient and curvature. Data collection utilized videography techniques at designated locations. All the data were collected for three hours preferably in the morning peak and off-peak hours in a weekday under normal weather conditions. Each road had a 30m stretch marked on the road using white tape or chalk. A high-resolution video camera mounted on a 1.5m tall tripod was kept roadside at a suitable height in such a way that it can capture the marked section continuously. Subsequently, all the recorded video files were taken to the laboratory and played on the computer screen to extract the required data.

5 Results

The traffic composition and carriageway width play significant roles in estimating the stream speed, especially in the Indian context. The proportion of different categories of vehicles on urban streets and the width of the carriageway significantly affect the stream speed. Hence, the linear base speed equation was derived by considering the traffic compositions and carriageway width as independent variables as given in *Equation (4)*.

From the video files, the stream speed at each parking section was estimated and compared to the speed of the base sections. The speed at various parking sections was much lower than the base speed, as given in *Table 4*.

The study revealed that the stream speed significantly reduces within a wide range of 39.09% to 81.30% due to the presence of on-street parking parameters. The results of speed reduction were compiled with parking parameters and multiple regression techniques were used to develop a speed reduction model (ΔV). In this connection, the required parking data from selected parking sections were extracted and analysed for dependency check. The most crucial parameters, influencing the stream speed, were later selected for the model development as given in *Table 5*.

Finally, the speed reduction model was developed based on the most effective on-street parking parameters as given in:

$$\Delta V = 16.968 \times PW + 0.021 \times PM, \quad (5)$$

where: ΔV= Reduction in speed (%),
PM= Parking maneuvers (veh/km/h),

Table 4 *The reduction in speed due to the presence of on-street parking*

Section	Base Speed using Eqn.4 (km/h)	Speed (km/h)	Speed Reduction ΔV (km/h)	Speed Reduction (%)
P1	64.18	12.00	52.18	81.30
P2	41.51	24.57	16.94	40.81
P3	43.54	26.52	17.02	39.09
P4	67.16	19.43	47.73	71.07
P5	80.44	22.15	58.29	72.46

Table 5 *Details of the most efficient parking parameters*

Parking Parameter	The range for various parking sections	Unit
PM	728-2900	veh/km/h
PW	0.88-3	m

***Table 6** Details of the model*

Parking Parameter	Coefficients	t-stat	p-value	VIF (Variance Inflation Factor)	R^2
PM	0.021	6.904	0.006	2.046	0.983
PW	16.968	5.916	0.010	2.046	

PW= Parking width (m).

The details of the model are given in *Table 6.*

6 Validation

To check or validate the accuracy of the model, another set of data was collected and extracted. Details of the section are given below.

- Location- Subhash Marg, Lucknow
- Carriageway width = 7.2m, Parking width = 0.897m, and Parking maneuvers = 1333.33 veh/km/h.
- Stream Speed (data extraction) = 28.72 km/h.

Initially, the base speed of the section was estimated 54.83 km/h using *Equation (4).* Afterwards, the stream speed of the vehicles on the selected section was measured manually by simply playing the video files on a computer screen throughout a 30m trap length bordered by the two reference lines using Kinovea [23]. The speed was estimated as 28.72 km/h. Finally, the values of selected parking parameters were given as input in *Equation (5)* to obtain the speed reduction (ΔV) following the estimation of speed based on the proposed model as 31.13 km/h. The comparison between the results shows the error as -8.422%, showing the effectiveness of the model. A negative error shows the speed estimated using the model was slightly greater than that extracted.

7 Conclusions

A methodology to estimate the stream speed of the parking section is proposed in the present study. The study conceptualizes the most efficient parking parameters influencing the stream speed of the vehicles. These parameters were compatible with the Indian traffic context. Below are the major findings of the study.

- The speed at parking sections was significantly reduced in the presence of on-street parking that highlights the importance of considering the parking maneuvers and parking width in data analysis. This decline varies within a wide range of 39.09% to 81.30%.
- A speed reduction model was created by considering the two major parking parameters, which predict the impact of on-street parking on the stream speed. Further, the developed model can be a valuable tool for urban planning and designing.
- A favorable agreement (-8.422% error) was established between the speed derived from the data extraction and the speed reduction model, which suggests that the proposed model can accurately estimate the stream speed at the parking sections with varying intensity of on-street parking.
- The findings provide valuable insights for developing norms regarding the on-street parking facilities whether on-street parking can be prohibited or allowed and if it is allowed then up to what extent? The model also reveals how the stream speed of vehicles at parking sections enhances or declines in the presence or absence of on-street parking.
- The proposed model can be helpful for urban transportation planners for easy estimation of the stream speed at parking sections saving valuable time in the data extraction process.
- The methodology adopted in this research can be further implemented in the future to extend the work and explore the impacts of different parking patterns such as angled or perpendicular on the stream speed. Additionally, this research also provides suggestions to examine the driver's behavior when vehicles are parked in designated bays or on the roadside.

In summary, the present study can be effective for urban transportation planners, while providing parking regulations. The proposed model offers a straightforward approach for estimating the stream speed under varying intensities of on-street parking, providing valuable insights for the traffic management and urban transportation planning efforts. This research can contribute to better understanding of on-street parking and stream speed, which offers practical solutions to overcome traffic congestion in urban areas.

7.1 Future scope of the study

This study opens several avenues for further research to deal with the impacts of on-street parking on the stream speed.

- The type of on-street parking, whether unregulated or with designated parking bays, may instigate a considerable difference in the impact of on-street parking on the regular traffic flow. The impact is expected to be reduced in the case of a designated parking bay, as compared to an undesignated parking bay. However, the designated parking bay on a collector type of road is not common in India. Hence, comparing the impacts of unregulated parking with the designated parking bays is beyond the scope of the present study. Nevertheless, this comparison will be interesting to see and can be investigated in future studies.

- The type of on-street parking (parallel, angled or perpendicular) may play a significant role in determining its impact on the stream speed. However, considering the fact that the parallel parking is the most commonly found parking type on Indian urban roads, the same has been adopted in the present study. Nevertheless, comparing the impacts of different parking types can be a meaningful venture and will be taken up in future studies

Acknowledgements

The authors received no financial support for the research, authorship and/or publication of this article.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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