Effect of On-street parking on Effective Carriageway Width and Capacity of Urban Arterial Roads in India

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Abstract

In developing countries like India, road side friction factors play an important role to decrease the speed of the vehicles and capacity of the road. These friction factors are on-street parking, pedestrians, bus stops and non motorized vehicles. It is a challenging task for traffic engineers to quantify the influence of these friction factors on the capacity of the road. This paper quantitatively analyzes the impact of on-street parking on six lane divided urban road capacity and effective carriageway width. The base capacity for six lane divided urban arterial roads is taken as 6000 PCU/hr from literature. Field data are collected through three midblock sections of six lane divided urban arterial roads in India. Study locations are selected with various degree of parking manoeuvres. All modes of transport presented in the traffic stream are classified into five different categories. The data from all the friction sections are pooled and the correlation is established between speed of a vehicle type and densities of all categories of vehicles with density of parking manoeuvres in their individual terms. These equations are solved for certain assumed values of traffic flow and parking manoeuvres. By plotting speed flow curves, the capacities at different number of parking manoeuvres are determined. Finally the impact of on-street parking on road capacity and effective width of carriageway is found out. This study shows that when the parking manoeuvres increases, capacity reduction increases and effective carriageway width decreases.

*Keywords:*On-street parking, Effective Width, Roadway Capacity, Parking Manoeuvres

1. Introduction

For any developing city in India, traffic management is an important concern to accommodate the increased number of vehicles per day. The main problem existing is that the traffic is not homogeneous but mix mode type with anenormous range of vehicles plying on it (i.e. bus, truck, car, auto, cycle, rickshaw etc.) without separation. Every year the vehicular ownership increases but to accommodate that number of vehicle, road infrastructure is limiting. As a result of which congestion is created.On-

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street parking is one of the serious problems that the developing countries like India are facing due to the increasing vehicular traffic. The increased number of vehicle ownership has also brought into the picture of requirement of parking. Parking takes considerable street space leading to the lowering of the road capacity and stream speed. Thus traffic flow characteristics (like speed, flow and density) are greatly affected by on-street parking.

The US Highway Capacity Manual (HCM-2000) defines the capacity as “the maximum sustained 15 minutes flow rate, expressed in passenger cars per hour per lane that can be accommodated by a uniform freeway segment under prevailing traffic and roadway conditions in one direction of flow". Capacity of an urban road is influenced by a number of factors like roadway conditions, traffic conditions, control conditions and weather conditions. Roadway factors that influence capacity of a urban road include lane width, gradient, lateral clearance, width and type of shoulder. Important traffic conditions that affect capacity of an urban road are composition of traffic stream, directional split and presence of slow moving vehicles in the stream. Environmental conditions such as wet pavement or snow and ice conditions, rain, darkness, fog, parking regulation affect the driver performance and hence capacity. Beside these factors Capacity of urban roads is also a function of the Side Friction Factors. They include but not limited to pedestrians, bus stops, non-motorized vehicles, parked and stopping vehicles etc. These factors are normally very frequent in densely populated areas in developing countries like India, while they are random and sparse in developed countries making it of less interest for research and consequently there is comparatively little literature about them. Most of these factors are not explicitly addressed by methodologies evolved in developed countries for planning, design and analysis of roadways.

Roads in developing countries are much affected by a side friction factor called on-street parking. This on-street parking leads to reduction in the width of carriage way due to which the available road space for the movement of traffic gets affected. Because of parking manoeuvres, way of adjoining vehicle deviates which diminishes speed of surrounding vehicles as well as capacity of the road.In this study, an attempt is made to understand how the parking manoeuvres affect the movement of traffic flow. Figure 1 shows the effect of parking manoeuvres on the traffic flow.

Figure 1: Effect of Parking Manoeuvres on Traffic Flow

Due to parking manoeuvres (Figure 1), path of the vehicle in adjacent lanes deviates. That reduces the effective width of carriageway available for traffic movement. Parking manoeuvres also reduces the speed as well as capacity of the road. In this study, the selection of locations is based on the availability of on-street parking along the roads (friction condition). While selecting the sites, it is also considered that the traffic should be heterogeneous and all roads should be under the category of six lane divided urban arterials. This study aims to determine the relation between number of parking manoeuvres and capacity reduction of the roadway. This study gives the quantitative measure of the effect of on-street parking on the roadway capacity and effective width of carriageway.

2. Literature Reviews

The traffic flow characteristics like speed and flow are very much affected by side friction factors. Many researchers had tried to find out the impact of side frictions on speed-flow characteristics but major work done for homogeneous traffic conditions. Chandra and Kumar (2003) gathered information from different regions of the India. They chose ten distinct sections of two lane roads. The information gathered is additionally arranged into nine distinct vehicles class. They developed second degree polynomial relationship between capacity and total width of carriageway and derived adjustment factors for capacity corresponding to lane width. Aronsson and Bang (2005) in Sweden conducted a study, which showed possible relevance to the definition and measurement of side friction. They analyzed the factors that influence speed on urban streets and they finally develop speed prediction models. Mei et al. (2009) developed model for continuous flow that is for non-manoeuvre lane occupied parking lot. Ge et al. (2009) collected data for two lane roads with curb parking and analyzed the effect of parking on the traffic flow. Munawar (2011) carried out surveys at congested urban roads (with high side friction) in the city of Yogyakarta during peak hours, to analyze the effects of the characteristics of urban roads, specially the side friction, in reducing the capacity and speed. It is than compared the results to the capacity and speed predicted by Indonesian HCM. It is also compared the actual speed-flow relationship and that predicted by Indonesian HCM. It is found that the capacity and speed predicted by Indonesian HCM are too high. The effects of side frictions, e.g.: on-street parking, city bus stopping anywhere on the roadway (there is no specific bus stop for city bus), exit/entry vehicles and U-turn vehicles are higher than those predicted by Indonesian HCM.Yaqin and Jie (2011) analyze the disturbances in dynamic traffic by vehicles pulling in and out of parking spaces. They provide the model for road capacity for curb side parking. Cao and Sano (2012) proposed the precise methodology to calculate motorcycle equivalent units (MEUs) in heterogeneous traffic condition by considering the characteristics of moving vehicles, such as velocity and effective space. In addition to, the effective space required for each type of vehicle was estimated considering the influence of velocity, physical dimension of the subject vehicle, and the surrounding motorcycles. The study proposed that the capacity of urban roads with four, three and two lanes per direction is 24335, 21725 and 13358 MEU/hr respectively. They gave the quantitative measures for it. Patel and Joshi (2014) carried out their study on six lane divided urban arterial road in Patna and Pune city of India. Both the road having distinct differences in terms of the vehicle composition and the road side parking. Arterial road in Patna city has 33% of non-motorized mode, whereas Pune arterial road dominated by 65% of Two wheeler. Also road side parking is observed in Patna city. The field studies using video graphic techniques are carried out for traffic data collection. Data are extracted for one-minute duration for vehicle composition, speed variation and flow rate on selected arterial road of the two cities. Speed-flow relationship is developed and capacity values are achieved. Equivalency factor in terms of dynamic car unit is determine to represent the vehicle is single unit. The variation in the capacity due to side friction, presence of non-motorized traffic and effective utilization of lane width is compared at concluding remarks. Silvano and Bang (2015) made observations on posted speed limit (PSL) changes on the free flow speeds on urban arterials. The analysis was conducted on the mean free flow speed difference and speed variability. Ashalatha et al. (2016) worked on impact of roadside friction in traffic characteristics of urban roads of India. Their study was conducted at major cities of India like Mumbai, Bengaluru and Thiruvananthapuram. They concluded that roadside friction was limited to bus-stops, pedestrian crossing andon-street parking of vehicles. Multiple liner regression carried out by them and analysis was done for the all stretch to study of effect of roadside friction. Rao et al. (2016)review the literature on the impact of different types of frictional activities on urban roadway capacity and speed. It has been observed that presence of a friction points eventually reduces the roadway capacity and an attempt has been made to quantify the amount of speed reduction due to friction points. Video-graphic technique is used to collect traffic data. Number plate survey is conducted for every 15-min during morning and evening peak hours to find intensity of the on-street parking. Global Positioning System (GPS) is used to collect the segmental speeds over the selected sections using floating car technique. Dhamaniya and Chandra (2017)analyses the effect of operating speed on capacity of a midblock sections of urban road using field data collected at 12 midblock sections in India. Choudhury et al. (2018)analysed the effects of interventions like street-works, on-street parking, road closures, changes in speed limits, etc. on network capacity. Authors presented an outline to analyse the capacity impacts of such troublesome interferences using a microscopic traffic simulation based approach and apply it to determine capacities of two networks in Central London, UK. Gulivindala and Mehar (2018) analyse the influence of the side friction activities on the speed by conducting series of traffic field surveys. Pedestrian movements, parked vehicles and entry-exit of vehicles from surroundings, and wrong way movements are observed from videos and analyzed to estimate weighing factors. To examine the combined effects of all the activities the weighing factors are used to determine total value of side friction on the road. They suggest model to estimate average speed of vehicular stream with the effect of side friction and volume on the roads section. It was found that the vehicular speed decreases as side friction increases at all the levels of traffic volume. However, no change in the speed was observed at lower level side friction. Capacity value obtained for combined data based on Greenshields (1935) that showed 9% reduction in the value considering with and without side friction.

The review of literature presented above reveals that many researchers tried to develop speed models and to quantify the effect of side friction on traffic characteristics but most of studies have been carried out for homogeneous traffic. Only a few studies have been reported for mixed traffic condition with non-following lane discipline. Study related to speed model with side friction (on-street parking) is yet not attempted for mixed traffic conditions and the present study attempted to develop speed models for friction section (with on-street parking) and to develop a correlation between effective width and capacity reduction.

3. Research Objectives

On-street parking is an especial condition which is observed in the developing countries like India. This is due to either inadequate availability of parking space or absence of such facilities around the roads. On-street parking affects the capacity of the road as well as speed of the vehicles moving on that road. The broad objective of this study is to identify the road side friction factor and to identify how these are affecting and what kind of changes they are producing on the capacity. Determination of speed and capacity in mixed traffic condition is complex and time consuming process. In this study, capacity reduction due on-street parking has been found out by developing speed prediction models. The proposed models only require volume data measured from field to estimate speed of a vehicle and consequently stream speed.As per literature reviews, there are few literatures available which study the effect of parking manoeuvres on the capacity reduction of the road. This study quantifies the effect of parking manoeuvres on road capacity by developing speed models. The key objective of this study is to determine quantitatively the impact of number of parking manoeuvres on roadway capacity and effective width of carriageway.

4. Research Methodology

For six lane divided urban arterial roads, the base capacity is taken as 6000 PCU/hr from Dhamaniya and Chandra (2017). Capacity obtained for base sections is known as base capacity. Base sections are the road sections free from the effect of any side frictions (like pedestrian movement, bus stop, stopped or parked vehicles, non-motorized vehicles etc.) and also well away from intersections to avoid its effect. These sections do not have any curvature or gradient.In this study, reduction in capacity due to on-street parking (friction condition) is found by developing speed models.Here friction condition means those road sections in which vehicles are parked and stopped along the side of carriage way. These sections are having uniform geometrical features without any side frictions other than on-street parking. The data are collected from three midblock friction sections of six lane divided urban arterial roads from different parts of the India. Data extraction is carried out for speed and volume for each vehicle categories and data sets of five-minutes interval are made. The data sets of speed and flow for all the friction sections are pooled together and speed prediction models are developed for friction condition for various categories of vehicles including number of parking manoeuvres taken as an independent variable in the models with other variables. By using speed flow curves developed from models, the capacities for various numbers of parking manoeuvres are determined for the friction condition. All these capacities obtained for different parking manoeuvres are compared with base capacity and the capacity reduction for different parking manoeuvres are calculated. Afterwards, parking manoeuvres are correlated with available effective width and finally a relationship is established between capacity reduction and available effective width.

5. Data Collection and Extraction

The study has come up with the objective of analysing the effect of number of parking manoeuvres on roadway capacity and width quantitatively. To achieve the objective, three midblock friction sections of six-lane divided urban roads are selected with different levels of parking manoeuvres.The data are collected from two different cities of India those are Jabalpur and Surat. Video-graphic method is used for data collection.

The data are collected for different timings of the day. All the data are collected on the weekdays only. For all the sites, a 50 m stretch is marked and data are collected for 7-8 hours. The camera is mounted on a stand at sufficient height so that it can capture the total 50m stretch with some margin on both sides. From the inventory survey, the geometric details of the sections are obtained and the types of vehicles flowing in the stream at those sections are observed.There are several models of the same category of the car running on the roads of India. Therefore, cars are divided into two separate categories as small or standard car (SC) and the big car (BC). The classification of the car is carried out according to its size and engine power. The small car is identified with engine power around 1400 cc and the big car is categorized with engine power more than 1400 cc. The average dimension of the vehicle is taken if more than one type of vehicle is included in the same category. It is found that 2 Wheeler (2W), 3 Wheeler (3W), Small Car (SC), Big Car (BC) and Heavy commercial vehicle (HCV)/Bus are found in all sections. The speed and flow data are extracted through the recorded video-graphic film. The recorded film is played on large screen computer. For speed measurement, entry and exit time of the different vehicle categories is found for 50m trap length. The entry and exit time of vehicle in the trap is noted down using the software Avidemux 2.6 which converts the one-second video into 25 frames. The time is measured with the accuracy of 40 (millisecond) ms. For counting flow, the video is played and each category of vehicle is counted per minute. This procedure is further repeated for all the midblock sections considered in this study. The data extracted through the video-graphic survey is converted to data sets of five minutes classified traffic volume count. Also, the number of parking manoeuvres counted from video for each five-minute interval. Table 1 shows the percentage vehicular composition of the various sections considered in this study.

Table 1: Percentage Vehicular Composition of Various Sections

Section No.	*Section Name*	*Type of Section*	*Vehicular Composition in Percentage*				
			2W	*3W*	*SC*	*BC*	*HCV/ BUS*
I	Surat Session Court, Surat	Six lane divided friction section	59.56%	18.26%	15.62%	4.31%	2.25%
II	MR-4 Road , Jabalpur	Six lane divided friction section	73.16%	12.73%	7.47%	4.51%	2.13%
III	B K Castel Area, Jabalpur	Six lane divided friction section	59.24%	9.58%	22.61%	6.23%	2.34%

6. Data Analysis

The data collected are further utilized to calculate the capacity of the friction sections. The data obtained from all three friction sections are pooled together. All the extracted values of entry and exit time for each category of vehicle in all the stretches are used to convert data sets of five-minute interval. The traffic volume is converted from heterogeneous traffic stream to homogeneous traffic stream by using an adjustment factor called Passenger car unit (PCU). The analysis of a non-uniform stream of vehicles is simplified if the relative effect of each vehicle type can be expressed in terms of some common unit. The Highway Capacity Manual (HCM) (Highway Research Board 1965) discussed the issue of passenger carunit (PCU) or passenger car equivalent (PCE) for this purpose.PCU is a measure of relative interaction caused by a vehicle to a traffic stream compared to a passenger car under a specified set of roadway, traffic, and other conditions. This interaction will depend on traffic, roadway, and environmental conditions. For a given facility, roadway and environmental conditions remain almost unchanged during field observation time, and therefore traffic characteristics like traffic composition, traffic volume, speed of each category of the vehicle and physical size of the vehicle must be able to explain all variations in PCU values for a vehicle type. The composition accounts for any change in the traffic and changing degree of damaging effect at different volume levels. The vehicular interaction and all other geometric influences culminate in the speed of the vehicle and the physical size of a vehicle is supposed to indicate maneuverability, acceleration or deceleration capability, and space occupancy on the road, which are crucial in the measurement of density.Chandra and Kumar (2003)presented the concept using speed as a primary variable to determine the PCU of vehicles on urban midblock. They mentioned that speed of any vehicle type is a true representation of overall interaction of that vehicle type with other vehicle types. According to their concept, PCU is directly proportional to speed ratio and inversely proportional to projected area ratio with respect to the standard vehicle as shown in Eq. (1) and same is used in present study also.

$$PCU_i = \frac{(V_c/V_i)}{(A_c/A_i)} \qquad (1)$$

Where PCU_i= PCU of i^{th} category of vehicle
V_c/V_i= Ratio of velocity of car to velocity of i^{th} category of vehicle
A_c/A_i= Ratio of projected area of car to projected area of i^{th} category of vehicle

Table 2 shows the geometric details of various categories of vehicles mentioned in this study.

Table 2: Geometric Details of Various Vehicle Categories

S. No.	*Vehicle Category*	*Length (m)*	*Width (m)*	*Projected Rectangular Area (m^2)*
1	2 Wheeler	1.87	0.64	1.2
2	3 Wheeler	3.2	1.4	4.48
3	Small Car	3.72	1.44	5.36
4	Big Car	4.58	1.77	8.11
5	HCV/Bus	10.1	2.43	24.54

The PCU values are determined for each category of vehicles mentioned in the study in each five-minute interval to convert heterogeneous traffic flow into homogeneous traffic flow in PCU/hr. Using Eq.(1), PCU is determined and the values shown in Table 3 is the average PCU for all count period with standard deviations.

Table 3:Average PCU Values and Standard Deviations at Various Midblock Sections

Section No.	*Average PCU Values*				*Standard Deviations*			
	2W	*3W*	*BC*	*HCV/Bus*	*2W*	*3W*	*BC*	*HCV/Bus*
I	0.27	1.21	1.58	6.31	0.02	0.06	0.22	1.46
II	0.24	1.08	1.64	5.23	0.02	0.29	0.15	1.62
III	0.29	1.34	1.60	5.09	0.02	0.16	0.12	1.12

It may be seen from Table 3 that there is a large variation in estimated PCU values for a vehicle type at various midblock sections. Even for the same midblock section, PCU values varied from one interval to another as shown by the standard deviation values given in Table 3.

7. Development of Speed Prediction Models for On-street Parking

In friction condition, the speed of the vehicle is influenced by on-street parking. The number of parking manoeuvres per second is worked out along with other traffic characteristics. To analyze the effect of on-street parking on the speed of different categories of vehicles, Greenshields equation (1935) was used to develop speed models. This model gives the relationship between speed, flow and density of traffic stream. Greenshield assume the linear relationship between speed and density. The generalized form of the model is v=a-b*k where v is the space mean speed, a is free flow speed, b is the ratio of free flow speed to jam density and k is the density. In many studies(Cao and Sano 2012, Chandra and Kumar 2003, Dhamaniya and Chandra 2017)carried out for developing countries, the capacity of urban arterial in mixed traffic conditions has been estimated by using Greenshields model. Moreover, in recently developed Indo-HCM (2017), capacity of urban arterials has been worked out from collected field data using Greenshields model. A factor$\left(\frac{n_{park}}{V_i}\right)$ is introduced in Greenshields equation (1935) to develop speed models for friction condition. Thus, the impact of parking manoeuvres on the speed of different vehicle category is quantified. The mathematical model proposed for friction condition by considering the effect of parking manoeuvres on the speed of the vehicle is given below in Eq. (2).

$$V_i = a_0 - a_1\left(\frac{n_{2W}}{V_{2W}}\right) - a_2\left(\frac{n_{3W}}{V_{3W}}\right) - a_3\left(\frac{n_{SC}}{V_{SC}}\right) - a_4\left(\frac{n_{BC}}{V_{BC}}\right) - a_5\left(\frac{n_{HCV}}{V_{HCV}}\right) - a_6\left(\frac{n_{park}}{V_i}\right) \quad (2)$$

Where,

a_0 = 98th percentile Speed of vehicle category i in m/sec which would be same as in base condition.

i= Category of vehicles.

a_1, a_2, a_3, a_4, a_5 and a_6= Regression Coefficient.

$\left(\frac{n_{park}}{V_i}\right)$= the ratio of number of parking manoeuvres per second to the speed of vehicle type i in m/sec.

In this study, the sections considered for the formulation of the models are Surat session court, Surat, MR 4 Road, Jabalpur and B K Castel Area, Jabalpur. Total 227 data sets are considered for the models formulation. The observed traffic composition for friction condition is 45%, 12%, 30%, 8% and 5% for 2W, 3W, SC, BC and HCV/Bus respectively.

The models prepared for different categories of vehicles for six lane divided friction sections are given by Eq. (3) to (7) with their t-stat values. The t-stat values for all the co-efficient are obtained at 95% level of significant. The observed flow values in field data is in the range of 500 vehicles/hr to 6000 vehicles/hr.

$$V_{2W} = 20.34 - 47.6\left(\frac{n_{2W}}{V_{2W}}\right) - 109.12\left(\frac{n_{3W}}{V_{3W}}\right) - 31.04\left(\frac{n_{SC}}{V_{SC}}\right) - 59.84\left(\frac{n_{BC}}{V_{BC}}\right) - 111.2\left(\frac{n_{HCV}}{V_{HCV}}\right) - 191.23\left(\frac{n_{park}}{V_{2W}}\right) \quad (3)$$

(6.75) (2.5) (2.54) (3.06) (14.89) (3.09) R^2 =0.986

$$V_{3W} = 17.93 - 26.16\left(\frac{n_{2W}}{V_{2W}}\right) - 72.16\left(\frac{n_{3W}}{V_{3W}}\right) - 88.16\left(\frac{n_{SC}}{V_{SC}}\right) - 96.12\left(\frac{n_{BC}}{V_{BC}}\right) - 122.48\left(\frac{n_{HCV}}{V_{HCV}}\right) - 480.00\left(\frac{n_{park}}{V_{3W}}\right) \quad (4)$$

(6.28) (2.09) (4.14) (3.34) (14.42) (3.33) R^2 =0.963

$$V_{SC} = 21.19 - 27.76\left(\frac{n_{2W}}{V_{2W}}\right) - 147.12\left(\frac{n_{3W}}{V_{3W}}\right) - 68.88\left(\frac{n_{SC}}{V_{SC}}\right) - 51.36\left(\frac{n_{BC}}{V_{BC}}\right) - 134.08\left(\frac{n_{HCV}}{V_{HCV}}\right) - 242.69\left(\frac{n_{park}}{V_{SC}}\right) \quad (5)$$

(5.51) (3.82) (3.99) (3.63) (15.11) (5.01) R^2 =0.97

$$V_{BC} = 21.85 - 37.20\left(\frac{n_{2W}}{V_{2W}}\right) - 143.36\left(\frac{n_{3W}}{V_{3W}}\right) - 46.72\left(\frac{n_{SC}}{V_{SC}}\right) - 116.32\left(\frac{n_{BC}}{V_{BC}}\right) - 157.20\left(\frac{n_{HCV}}{V_{HCV}}\right) - 288.77\left(\frac{n_{park}}{V_{BC}}\right) \quad (6)$$

(5.89) (2.52) (3.82) (3.76) (13.79) (4.25) R^2 =0.972

$$V_{HCV} = 18.72 - 19.36\left(\frac{n_{2W}}{V_{2W}}\right) - 134.80\left(\frac{n_{3W}}{V_{3W}}\right) - 23.04\left(\frac{n_{SC}}{V_{SC}}\right) - 34.88\left(\frac{n_{BC}}{V_{BC}}\right) - 157.44\left(\frac{n_{HCV}}{V_{HCV}}\right) - 502.66\left(\frac{n_{park}}{V_{HCV}}\right) \quad (7)$$

(4.98) (3.34) (3.35) (3.31) (15.45) (4.11) R^2 =0.968

In above equations, ‘t’ values of all coefficients are more than 1.96, which shows that all coefficients are significant at 95 percent level of confidence.Signs of all the coefficients are negative which shows that at increase of the density of any category of vehicle, speed decreases from free flow speed. In all model equations, value of R^2 is appreciably high which indicates that the model is more compatible for predicting speed. As the speed parameter is on both sides of the model equation, it can solve by the iterative process. A small program was written in MATLAB software to solve these simultaneous equations.

8. Capacity Estimation for Different Parking Manoeuvres

The speed flow curve helps us to predict the roadway capacity at different assumed scenarios. These curves are obtained by solving simultaneous equations at various flow levels by keeping fixed proportion of each category of vehicles. In this study, Eq.(3) to (7) are solved for traffic flow varying from 500 vehicles/hr to 6000 vehicles/hr and number of parking manoeuvres varies from 60 parking manoeuvres/hr to 240 parking manoeuvres/hr. On an average, minimum one parking manoeuvre per minute and maximum four parking manoeuvres per minute are observed in the field so in this study, the number of parking manoeuvres (Npark) are kept from 60 parking manoeuvres/hr to 240 parking manoeuvres/hr in steps of 30 parking manoeuvres/hr. The composition of vehicles in traffic stream is kept fixed with 2W, 3W, SC, BC and HCV/Bus as 45%, 12%, 30%, 8% and 5% respectively. Figure 2 shows the speed-flow relationships at different flow levels and at different numbers of parking manoeuvres.

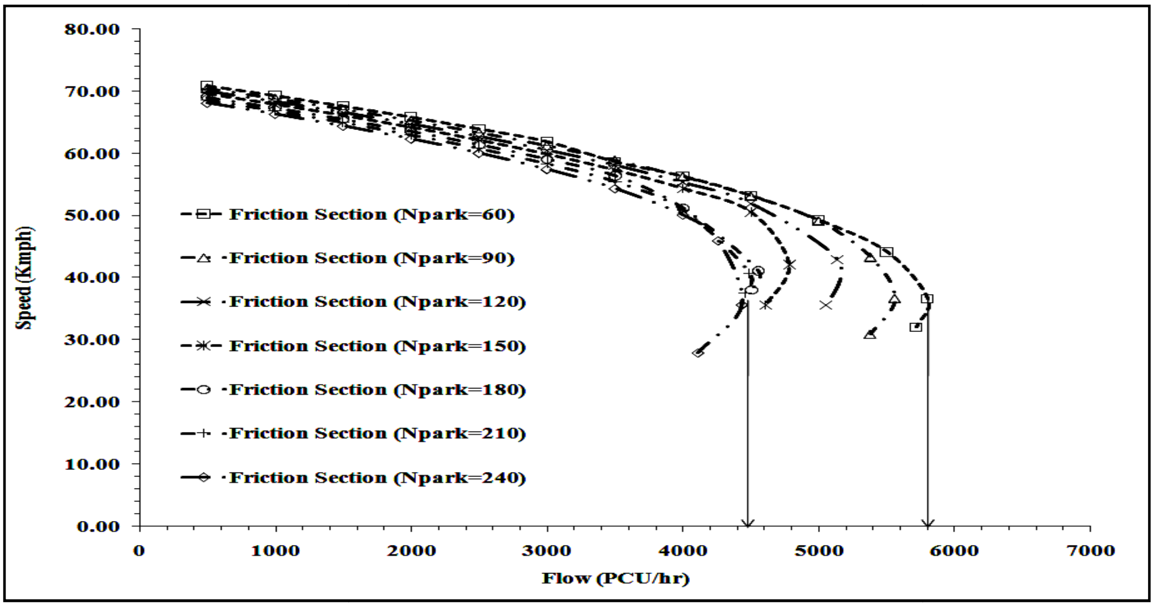

Figure 2: Speed-Flow Curves for Friction Condition

It is observed from Figure 2 that speed decreases with increase in traffic flow at constant vehicular composition. Also at the constant vehicular composition, when the number of parking manoeuvres on carriageway increases, capacity reduction continued up to certain values of parking manoeuvres after that reduction in capacity becomes nearly constant.

It is observed from speed-flow curves that capacity of urban midblock section decreases due to on-street parking. An effort has been made to relate number of parking manoeuvres per hour with respective capacity reduction. For fixed proportion of vehicular composition, number of parking manoeuvres are varied from 60 parking manoeuvres/ hr to 240 parking manoeuvres/hr and capacity flow is observed as 5798 PCU/hr to 4435 PCU/hr respectively. The capacity values at various parking manoeuvres are represented in Table 4 (column 3). All these capacity values are compared with base capacity (i.e. 6000 PCU/hr) to obtain capacity reductions at different parking manoeuvres per hour. This capacity reduction may represent in terms of percentage reduction in capacity. Table 4 represents the capacity reduction due to on-street parking.

Table 4: Capacity Reduction due to On-street Parking

Sr. No.	*Number of Parking Manoeuvres per hour*	*Capacity Flow (PCU/hr)*	*Capacity Reduction (PCU/hr)*	*Percentage Reduction in Capacity*
1	60	5798	202	3.37
2	90	5559	441	7.35
3	120	5135	865	14.42
4	150	4781	1219	20.32
5	180	4552	1448	24.13
6	210	4487	1513	25.22
7	240	4435	1565	26.08

From Table 4, it is observed that for 60 parking manoeuvres per hour, the capacity reduction is 3.37% and at 240 parking manoeuvres per hour capacity reduces up to 26.08%.

Figure 3 shows the relationship between parking manoeuvres per hour and percentage capacity reduction.

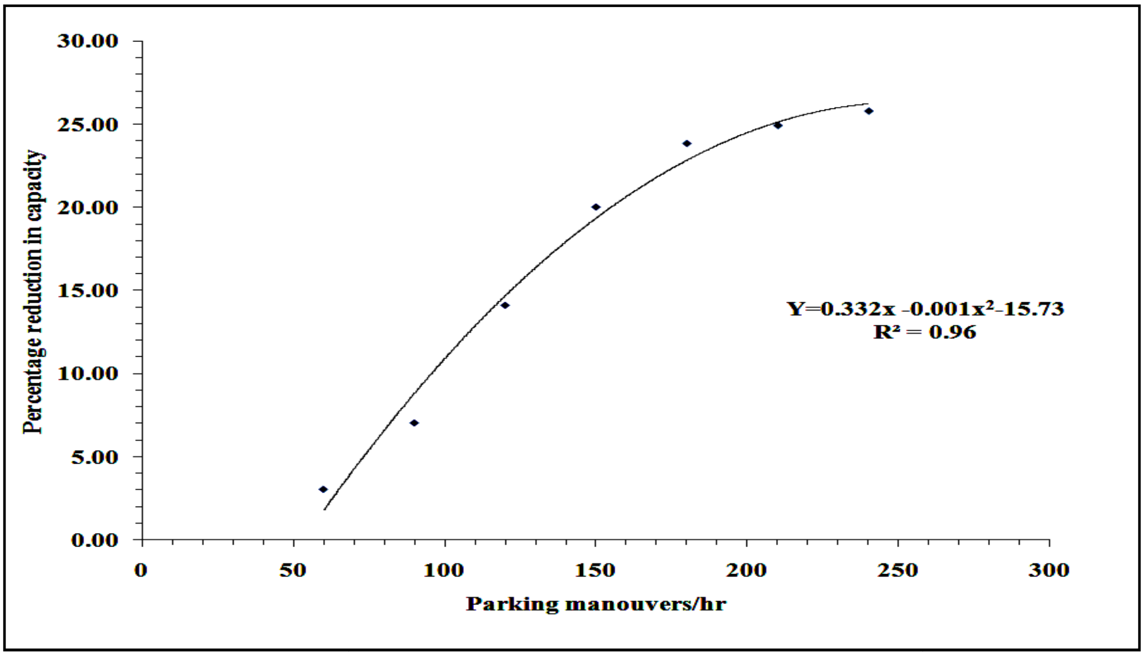

Figure 3: Relationship between Parking Manoeuvres per hour and Percentage Capacity Reduction

Figure 3 shows that there is a polynomial relation between parking manoeuvres per hour and percentage capacity reduction. The developed model shows good reliability with R^2 value of 0.96. It is concluded from Figure 3 that capacity of urban arterial midblock sections continuously decreases with increase in number of on-street parking manoeuvres from 60 parking manoeuvres per hour to 240 parking manoeuvres per hour and after that reduction in capacity becomes nearly constant. The relationship between parking manoeuvres per hour and capacity reduction is obtained as shown in Eq.(8). This relationship can be used to estimate capacity reduction for more than 60 parking manoeuvres per hour.

$$\%\ \text{Capacity Reduction}=0.332(\text{parking manoeuvres /hour})-0.001(\text{parking manoeuvres /hour})^2-15.73 \quad (8)$$

$$R^2=0.96$$

9. Validation of Speed Models

In order to check the results obtained from speed models for friction condition, data from one more friction section are collected in Surat having six lane divided road with on-street parking. Data sets of five minutes classified traffic volume count, parking manoeuvres and average speed are extracted from video recording and Eq. (3) to (7) are solved for observed traffic volume, proportion of vehicles and corresponding parking manoeuvres per hour for each five-minute interval. The speeds obtained by solving above mentioned equations are termed as estimated speeds. The estimated speeds are compared with observed speeds for each category of vehicle as shown in Figure 4. It is seen that speed values for various categories of vehicles lie on a line drawn at an angle of 45degree which shows the good agreement between estimated and observed speed values.

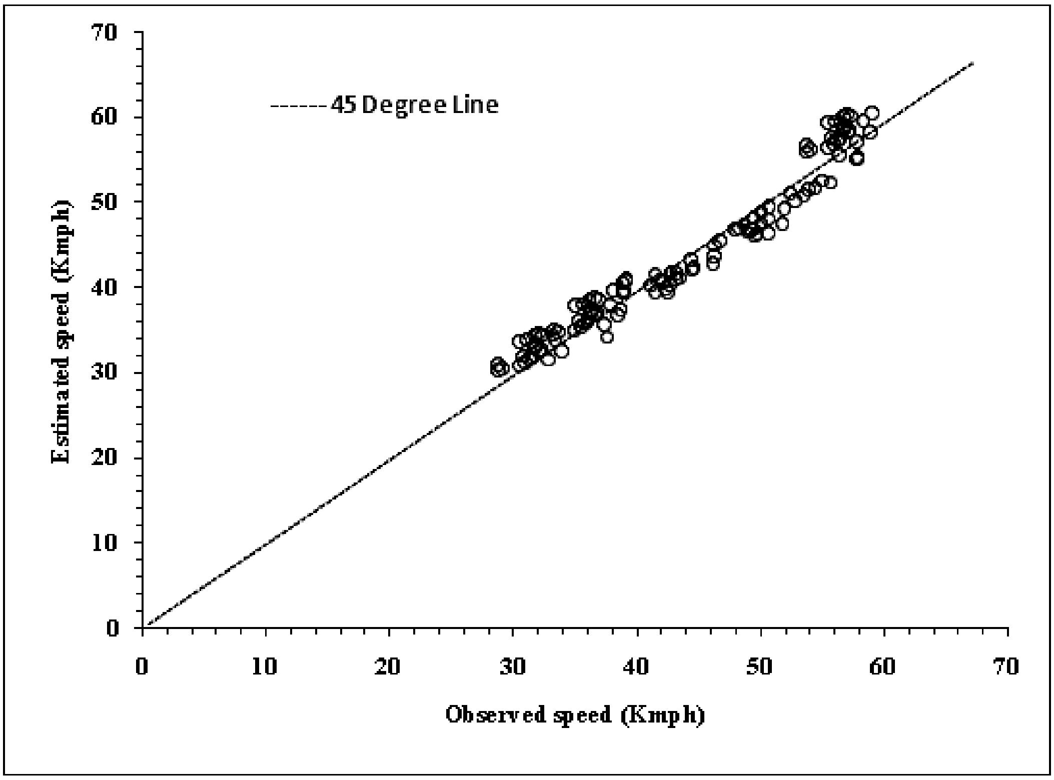

Figure 4: Comparison between Observed and Estimated Speeds

Further to check the statistical significance between observed and estimated speed values for each vehicle category, a paired t-test is conducted. It is found that the value of t-statistics for observed data is 1.98 at 5% significance level and 76 degree of freedom. The critical value of t-statistics obtained from standard t-test is 2.00 that confirm there is no statistical significant difference between estimated and observed speed values.

10. Correlation of Capacity Reduction with Effective Width of Carriageway

On-street parking which takes place around road side result in the loss of the carriage way width which results in loss of capacity of the road and also increases the chances of accidents. Here an attempt is made to correlate the reduction in width due to on-street parking with the capacity of the road.

Available effective width is the width of carriageway available at any instance for the traffic movement. On- street parking reduces the available effective width which reduces the capacity of roadway. As parking manoeuvres increases, available effective width decreases and capacity of roadway decreases. Figure 5 given below shows the reduction in effective width available for traffic flow due to parking manoeuvre.

To correlate the parking manoeuvres with effective width, data are extracted for available effective width. One previously considered friction section, Surat session court, Surat is taken for data extraction. For data extraction, two sections AA and BB are selected within study stretch of 50m length. These two sections are selected in such a way that at one section AA there is no parking and at other section BB maximum number of parking manoeuvres are found as shown in Figure 5.

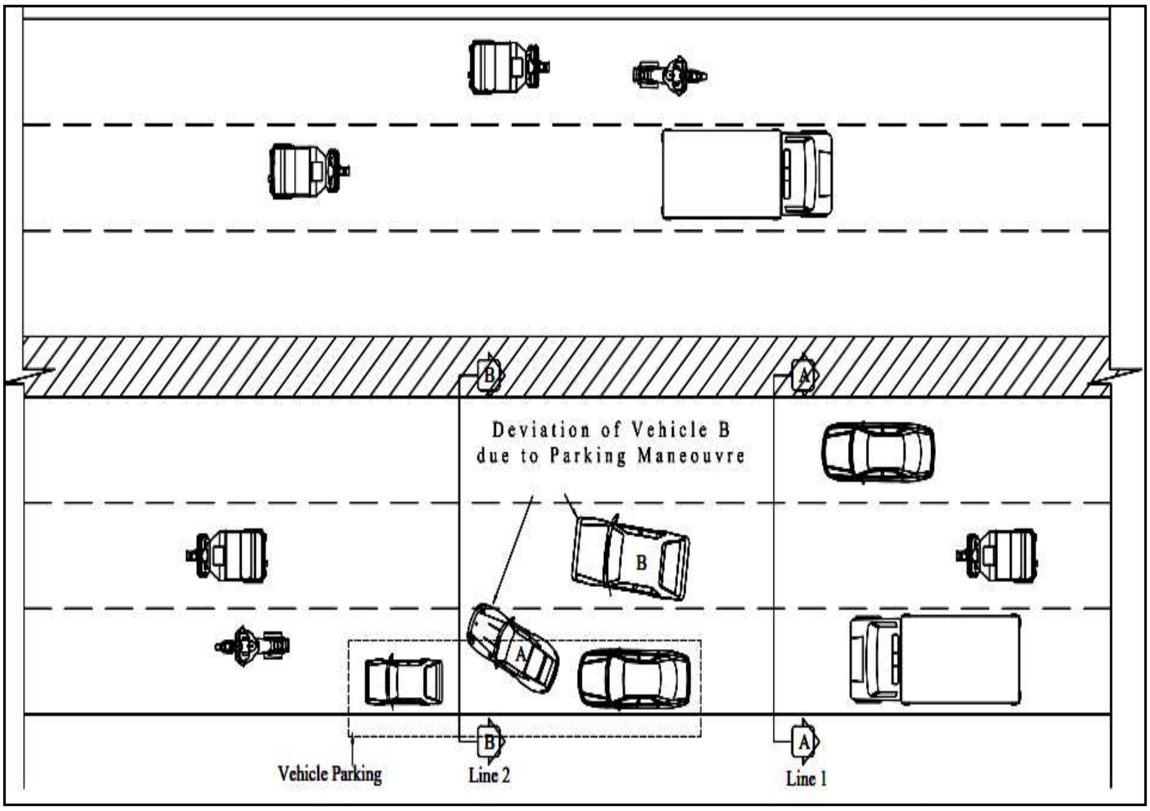

Figure 5: Reduction in Available Effective Width due to Parking Manoeuvre

For each five-minute interval, the ratio of flow (Vehicles/5 min.) at these two sections is determined with corresponding number of parking manoeuvres. This ratio of flow at section BB to at section AA directly gives the effective width factor with corresponding parking manoeuvres for each five-minute interval. Data sets of same number of parking manoeuvres are combined and average effective width factor is taken. These effective width factors for various parking manoeuvres are multiplied by actual width of road (i.e. 10.5m) to get available effective width. Reduction in width can be calculated by deducting available effective width for various parking manoeuvres from actual width of road. Table 5 given below shows the correlation between parking manoeuvres per hour, capacity reduction and effective width available for traffic flow.

Table 5: Relationship between Parking Manoeuvres per hour, Capacity Reduction and Effective Width

Sr. No.	*Parking Manoeuvres per hour*	*Capacity Reduction (PCU/hr)*	*Percentage Reduction in Capacity*	*Flow at Section AA (Veh./ 5 min.)*	*Flow at Section BB (Veh./ 5 min.)*	*Effective Width Factor*	*Available Effective Width (m)*	*Reduction in Width (m)*	*Percentage Reduction in Width*
1	0	0	0.00	613	613	1.00	10.5	0.000	0.00
2	60	202	3.37	522	507	0.97	10.19	0.030	2.95
3	90	441	7.35	412	386	0.94	9.83	0.064	6.38
4	120	865	14.42	386	333	0.86	9.07	0.136	13.62
5	150	1219	20.32	468	383	0.82	8.6	0.181	18.10
6	180	1448	24.13	342	273	0.80	8.38	0.202	20.19
7	210	1513	25.22	489	387	0.79	8.3	0.210	20.95
8	240	1565	26.08	437	342	0.78	8.21	0.218	21.81

From above Table, a relationship may be established between parking manoeuvres per hour and available effective width. Figure 6 given below shows the relation between parking manoeuvres per hour and available effective width.

Figure 6: Relationship between Parking Manoeuvres per hour and Available Effective Width in meter

The above figure shows that there is a linear relation between parking manoeuvres per hour and effective width. The developed model shows good reliability with R^2 value of 0.931. From above, it is concluded that as number of parking manoeuvres per hour increases, available effective width for traffic movement decreases. When there is no on-street parking, the available effective width is 10.5m that reduces up to 10.19m at 60 parking manoeuvres pr hour and 8.21m at 240 parking manoeuvres per hour. The relationship between parking manoeuvres per hour and effective width is obtained as shown in Eq. 9.

Effective Width (m)= 10.58 -0.011(parking manoeuvres per hour) R^2=0.93 (9)

A correlation can be established between percentage reduction in effective width and percentage reduction in capacity as shown in Figure 7.

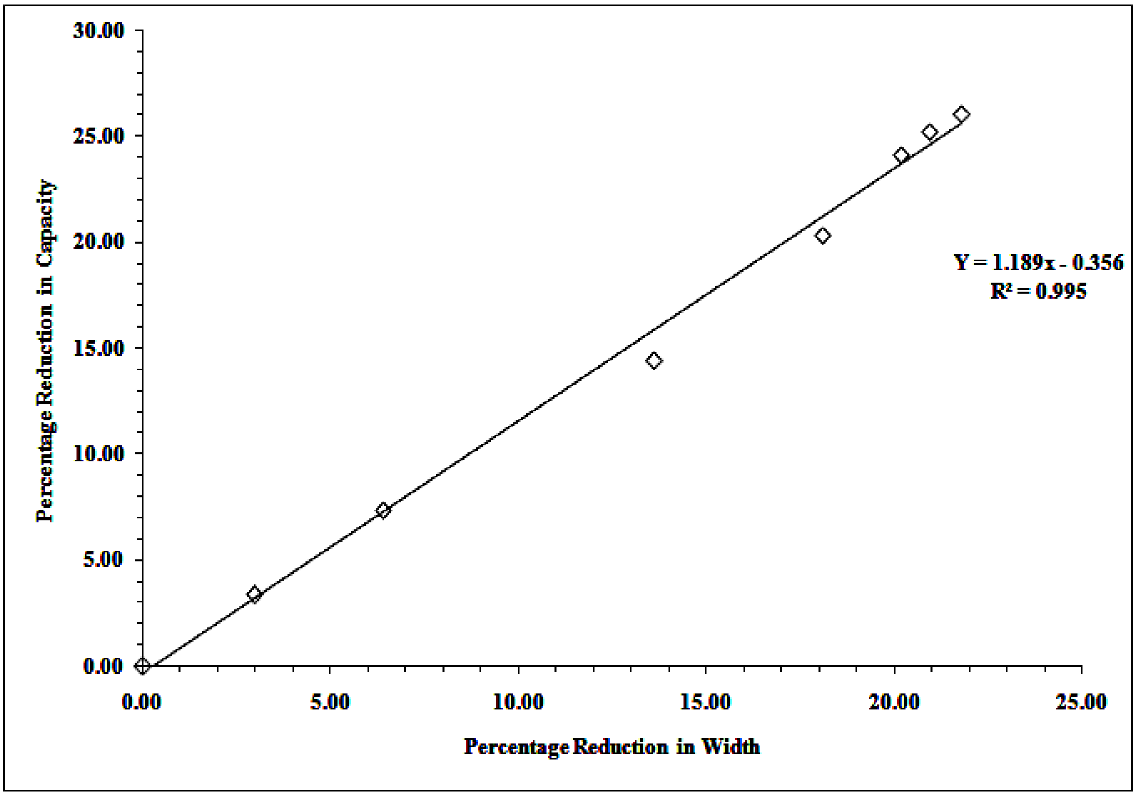

Figure 7: Relation between Percentage Reduction in Effective Width and Percentage Reduction in Capacity

From above Figure, it is observed that there is a linear relation between percentage reductions in width to the percentage reduction in capacity with R^2 value of 0.995. It is concluded that at 2.95% reduction in effective width, the capacity reduction is 3.37% and at 21.81% reduction in effective width, the capacity reduction is 26.08%. The relationship between percentage reduction in effective width and percentage reduction in capacity obtained is represented as shown in Eq. 10.

Percentage reduction in capacity=1.189 (percentage reduction in width)- 0.356R^2=0.99 (10)

11. Conclusions

On- street parking is very common in developing countries like India. It is observed that the presence of on-street parking significantly reduces the stream speed and capacity of the roads. This reduction in capacity depends on the frequency of on-street parking. To analyze the effects of on-street parking, data are collected from three friction sections and speed models are developed for friction condition. Further speed-flow curves are plotted by using speed obtained from speed models at various flow levels. From those speed flow curves, capacities for varying levels of parking manoeuvres are determined and these capacities for friction condition are compared with base capacity. That gives percentage capacity reduction for number of parking manoeuvres varying from 60 parking manoeuvres per hour to 240 parking manoeuvres per hour. Finally, capacity reduction is also correlated with effective road width available for traffic movement. The various conclusions made from this study are

1. The capacity of six lane divided urban arterial midblock sections decreases with increase in parking manoeuvres.
2. During data extraction, maximum numbers of parking manoeuvres in field are observed as 20 parking manoeuvres per five minutes so the reduction in capacity is found out for maximum 240 parking manoeuvres per hours.
3. For 60 parking manoeuvres per hour, the capacity reduction is 3.37% and at 240 parking manoeuvres per hour capacity reduces up to 26.08%.
4. A correlation is obtained between available effective width and percentage reduction in capacity. It is observed that at 2.95% reduction in effective width, the capacity reduction is 3.37% and at 21.81% reduction in effective width, the capacity reduction is 26.08%.
5. The developed model can be used by the practicing engineers to estimate capacity of the section for any levels of parking manoeuvres in traffic stream and subsequently planned the urban roadway policy and design.

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