The Impact of Road Side Friction on the Traffic Flow of Arterial Roads in Varanasi

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ABSTRACT

Varanasi's prominence as a cultural and historical center means it receives visitors from all over the world. The city's tourism industry is a boon to the local economy. Better transportation infrastructure is crucial to attracting more tourists and increasing revenue. Varanasi is currently experiencing terrible difficulties due to various roadside frictional activities. Vehicle ownership grows in tandem with population growth. The increase in the number of vehicles on the road significantly impacts the reliability of the transportation network since land availability is fixed. The various roadside frictional activities usually found in the streets of Varanasi are on-street parking, pedestrian crossing, and Non-Motorized Vehicles (NMVs). There are not enough legal on-street parking and segregated lanes for NMVs/slow-moving vehicles or demarcation for pedestrian movements in the old city of Varanasi. Vehicles in Varanasi are traditionally parked on the street due to the narrow carriageways. Slow-moving vehicles are forced to move with fast-moving vehicles, and pedestrian crossings affect traffic flow. Integrated movement of slow-moving vehicles and rapid-moving vehicles affects traffic speed, pedestrian crossings impact the Level of Service (LOS), and on-street parking results in the reduction of the effective carriageway width and, hence, road capacity. This paper aims to identify the impact of pedestrian crossings, NMVs, and on-street parking on the traffic flow, speed, capacity, and LOS of urban arterial roads in Varanasi. To achieve this objective, two case studies were considered: the base section (with minimum side friction) and the friction section (with maximum side friction). The videography method was used for data collection. Nine hours of data were collected from 9:30 am to 6:30 pm. The video was played on the screen for data extraction. The speed model was developed by using fundamental diagram methods. Speed-density curve was drawn using Greenshield's model. The speed-flow curve was derived from the speed-density curve to estimate the capacity at the base and friction sections. Reduction in capacity was determined by comparing friction section capacity with base section capacity. V/C ratio of a particular road compared with the V/C value provided by IRC 106 to predict LOS. A correlation model was developed between the percentage reduction in capacity and road width. Increase in parking, the proportion of NMVs, and pedestrian crossing frequency reduce the traffic flow. It was observed that a 34.10% capacity loss occurs at a 29.31% reduction in effective width, and a 40.54% loss occurs at a 40.98% reduction in effective width. Roads with frictional activities affected its level of service up to LOS-E (for the Bhelupur section).

Keywords-side friction; speed; capacity; level of service; non-motorized vehicles; on-street parking; pedestrian crossing; traffic flow; linear regression; correlation

I. INTRODUCTION

Side frictional activities take place on or along the road and disrupt traffic flow. Varanasi, the cultural capital of India, attracts visitors from all over the globe. On-street parking, non-motorized transportation, and pedestrian crossing are all activities that add friction to the streets of Varanasi. These activities affect traffic flow characteristics in several ways: they result in road capacity reduction, impact speed, and affect the Level of Service (LOS). A vehicle requires parking space at the start and end of its journey. The significant growth in vehicular traffic has increased the need for parking in urban centers. Scarce parking can interrupt traffic flow and produce congestion. In Varanasi, on-street parking is a commonality, since there simply aren't enough legal on-street parking places, so people use to park their vehicles on the street, hence inducing a reduction in effective carriageway width. Also, there is no segregated lane for non-motorized transport, which forces slow- and fast-moving vehicles to flow in the same lane, which causes a reduction in traffic flow speed and LOS. Pedestrian crossing is another common problem in Varanasi.

II. LITERATURE REVIEW

In [1], various side friction elements were considered, such as on-street parking, city buses stopping on the roadway, exit/entry vehicles, and vehicles about to turn. The study proposed a novel formula to update the Indonesian highway capacity manual to estimate the speed and capacity of urban highways with significant side friction. In [2, 3], several forms of roadside frictional parameters were discussed along with their impact on urban road capacity, highlighting the relationship between side friction parameters, road capacity, and LOS. These studies showed that capacity reduction in urban streets depends on roadside activity and varies with side friction. Loss of capacity on urban highways is caused by various factors, including roadside activity such as on-street parking, pedestrian movement, the presence of street vendors, the lack of lateral clearance and lane discipline, and diverse traffic, which is particularly prevalent in developing countries like India. In [4], a microscopic simulation model was developed to investigate the impact of bus stops on mixed traffic movement, focusing on reducing traffic flow rates. This study evaluated the impact of bus stops, which act as side friction on urban traffic. Based on the collected data, several areas for further work were recommended, as very few studies examine mixed traffic situations [5, 6]. In [7], three different side friction factors were used in a survey (on-street parking, bus bay stops, and curbside bus stops) and their impact on traffic quality performance was examined. This study showed an average speed drop due to side friction, a reduction in stream speed of 49-57% due to bus stops and bays, and a loss of 45-67% in speed due to on-street parking. This study used dynamic and static PCU (Passenger Car Unit) values. As a result of using these two different types of PCU values resulted in a 10-53% capacity reduction in bus bays and bus stops and about 28-63% due to on-street parking. Authors in [8-10] investigated urban arterial roads, finding that parked and stopped vehicles act as frictional elements that impact traffic flow, LOS, speed, and delay. On-street parking has been highlighted as a substantial source of side friction in urban arterial roads, and there is a relationship between the presence of on-street parking and the reduction in stream speed. According to [11-13], the impact of on-street parking as a side friction element on urban arterial roads results in a slowdown in traffic flow ranging from 15 to 44% or 5.1 to 21 km/h. In [13], parking density was considered a side friction element. The survey results showed that parking density on urban arterial roads harms average traffic flow, with a decrease of around 13 km/h for every 100 vehicles/km increase in parking density. In [15], various types of side frictional activities were examined, using small simulation models to evaluate how bus stops impact mixed traffic movement and their relation to the reduction in travel speed. In [2, 8], parked and stopped automobiles were studied, along with various other factors. These studies showed that parked and stopped vehicles are critical side frictional elements, as they harm the regular traffic flow, speed, capacity, and LOS more than other side frictional factors, such as pedestrian movements.

In [9, 14], T-junctions and bus stops were characterized as static features contributing to traffic congestion. On the other hand, static factors can be addressed by upgrading the geometric aspects of roadways to increase LOS. Roadside friction elements found in urban roads in Asian countries were pedestrians, stopped vehicles, parking, and access to roadside premises. Based on the weights assigned to each side friction element, side friction classes were developed for urban and interurban roads. In [16], motorcycle taxis were found to add another degree of friction when parking or loading and unloading passengers. In [17], on-street parking produced a decrease in stream speed, ranging from 15 to 44% or 5.1 to 21 km/h. In [18], speed–flow diagrams at various flow levels were plotted to analyze the collective effect of all these factors. The capacity of urban motorways and four-lane two ways were found as 4600 PCU/ and 5700 PCU/h, which further matched with the capacity values recognized in the South Korean manual and US HCM. The study concluded that Indonesian roads function poorer than those in the USA and South Korea.

Drivers' speed choices are expressively affected by crossing pedestrians, engaged curbside bus stops and confrontation with vehicles in the opposing direction [19]. The effect of crossing pedestrians on stream speed was analyzed using the network-based speed–flow relationships by [20]. Authors in [21] established a microscopic simulation model in VISSIM to simulate pedestrian flow properties by coding pedestrians as a vehicle that follows the pedestrian flow characteristics despite many issues related to pedestrian behavior, pedestrian route choice decisions, and multidirectional flow. Authors in [22] demonstrated the effect of operating speed on the capacity of a midblock section of urban road using field data collected at 12 midblock sections in India. Authors in [23] evaluated the effect of the pedestrian refuge island on the speed of vehicles and, accordingly, the effects on the probability variations of fatal accidents. Authors in [24] used the simulation approach to study pedestrian crossing behaviors. They concluded that pedestrians show more tolerance in waiting time in developing countries as compared to developed countries. Due to the high percentage of heavy vehicles, this study used dynamic and static PCU values. As a result, a 10-53% capacity reduction was observed in bus bays and bus stops and about 28-63% was attributed to on-street parking. Authors in [25] included NMVs (Non-Motorized Vehicles) as a source of side friction. He created a speed model for this purpose, which is based on the ratio of NMVs. A 10% rise in the NMV ratio, according to the model, would result in a 0.8 mile per hour (1.29 km/h) reduction in average traffic flow speed. The inclusion of NMVs in the traffic volume classification was suggested because cycle rickshaws generate greater side friction than bicycles. Authors in [26, 27] identified the degree of correlation between NMVs and traffic performance. The side frictional element (NMVs) is further divided into various subcategories, such as the proportion of NMVs, the proportion of bicycles, the proportion of cycle rickshaws, the proportion of handcarts, and the percentage of NMVs that travel beyond 20% of the roadway width from the edge. The correlation values of N-3 and N-4 were the highest among all the subcategories.

The literature review reveals that most researchers tried to find the impact of various side frictional activities on traffic characteristics individually. Only some studies have been carried out on more than one and maximum two side friction parameters combined. To the best of our knowledge, no study related to the combined effect of on-street parking, NMV, and pedestrian crossing on traffic flow, speed, capacity, and LOS has been attempted for mixed traffic conditions. The present research attempts to identify the impact of these 3 side frictional parameters on various traffic characteristics like traffic flow, speed, capacity, and LOS.

III. RESEARCH OBJECTIVES

The present work aims to study the impact of on-street parking, pedestrian crossing, and NMVs on traffic flow, traffic speed, road capacity, and LOS on the urban arterial roads of Varanasi.

IV. METHODOLOGY

Study stretch selection: To achieve the objective of this research, firstly, two types of study stretches were chosen: Base Section (BS), with minimum side friction and Friction Section (FS), with maximum side friction. These sections are away from the intersection to avoid its effect. Seven BSs and seven FSs were selected based on the similarity of road characteristics.

Planning phase: in this stage, two survey methods were prepared. The first one is a manual survey to collect geometric details of the road. The survey format (traffic volume count, parking, speed, and pedestrian movements) were prepared to observe data manually. The second is the videographic method. A 60 m stretch was marked to be captured in the video. The camera was mounted at a certain height and the time of survey was recorded.

Data collection: Data were collected on both stretches for 9 hours per day, from 9:30 am to 6:30 pm. The data were collected from 14 mid-block sections (7 BSs and 7 FSs) of a 2-lane urban arterial road. Data regarding classified traffic volume count, peak hour volume, peak hour duration, number of on-street parking, parking duration, speed of traffic flow, traffic density, and to examine the LOS were extracted from the recorded videos.

Data extraction: The recorded videos were played on screen, Individual vehicles were counted at an interval of 15 min. These data were used to calculate the classified traffic volume count, proportion of non-motorized vehicles, peak hour volume, peak hour factors, peak hour duration and heterogeneous traffic flow. To understand the on-street parking demand during peak hours, the parking vehicles were counted and the parking duration was noted. The pedestrian crossings during peak hours were counted. The video data were used for speed measurements. The entry and exit times of every vehicle over a 60 m trap length were observed. Speed was calculated for the individual vehicles by dividing the 60 m trap length with the entry-exit time difference of a vehicle.

Data analysis: By using peak hour factor, traffic flows at BSs and FSs were calculated. The FS traffic flow rate was compared with BSs' to determine the reduction in traffic flow rate. The video data were used for speed measurement. Individual vehicles' entry and exit times over a 60 m trap length were observed. Speed was calculated for individual vehicles by dividing the entry-exit time difference of a vehicle by 60 m trap length. The obtained space mean speed of the vehicles was used to calculate the traffic speed. The data set of speed and flow for all base and friction sections were pooled together and a speed prediction model was developed. By using the speed-flow curve, the capacity for each parking number and NMV proportion was determined. All the observed capacities at the base and friction sections were compared, and the reduced capacity due to on-street parking and NMVs is calculated. After this, the parking numbers were correlated with the available effective width and a relationship between capacity reduction and available effective width was developed. Finally, the volume/capacity (V/C) ratios were calculated for the FS. The value obtained from the V/C ratio was compared with the V/C ratio provided by the Indian Road Congress (IRC) to measure the LOS.

V. DATA COLLECTION

This study focuses on the impact of on-street parking on road capacity, speed, and LOS, the result of non-motorized transport on traffic flow speed and LOS, and the effect of pedestrian crossings on rate and LOS. To achieve the objective, seven midblock 2-lane arterial sections with minimum side frictions were selected. Indiranagar, Bisesarganj, Sonia, Salarpur, Lahurabeer, DLW campus and BHU (A_1, B_1, C_1, D_1, E_1, F_1 and G_1), were named as the BSs. Similarly, seven midblock 2-lane arterial sections, with side frictions, were selected with different levels of parking maneuvers, NMV, and pedestrian crossing. Chitaipur, Godowlia, Benia, Sarnath, Sigra, DLW and Bhelupur (A_2, B_2, C_2, D_2, E_2, F_2 and G_2), respectively, were named as the FSs. Both manual and videographic methods were used for data collection. The data were collected for 9 hours, from 9:30 am to 6:30 pm, on both types of stretches (BS and FS) on weekdays only. A 60 m stretch was chosen for data collection. The global coordinates of each roads are: Indira nagar (25°16'25.77" N, 82°58'7.34" E), Bisesarganj (25°19'26.89" N, 82°59'30.05" E, Sonia (25°21'14.49" N, 83°1'25.04" E), Salarpur (25°21'12.07" N, 83°2'19.76" E), Lahurabeer (25°19'8.44" N, 83°0'5.23" E), DLW campus (25°17'11.05" N, 82°58'9.21" E), BHU(25°16'3.79" N, 82°59'28.53" E), Chitaipur (25°16'18.72" N, 82°58'3.47" E), Godowlia (25°18'36.27" N, 83°0'34.74" E), Benia (25°19'3.28" N, 83°0'15.89" E), Sarnath (25°22'34.2" N, 83°1'21.76" E), Sigra (25°18'39.89" N, 82°59'11.19" E), DLW (25°17'11.05" N, 82°58'9.21" E), and Bhelupur (25°18'14.29" N, 82°59'24.03" E). From the inventory survey, geometric details of the road section, carriageway width, right of way, on-street parking, road surface quality, street vendors etc., were obtained. The classified traffic volume count survey was conducted manually (survey format) and by videographic survey. The data were collected at 15 min intervals. From the traffic volume count survey, traffic composition, peak hour traffic, peak hour volume, directional split, peak hour factor, and proportion of motorized and non-motorized vehicles were all measured to learn more about the traffic characteristics of each place. For counting flow, a video is played, and each vehicle category is counted per min. The video data were used for speed measurements for a 60 m trap length entry and the exit time of vehicles was noted. In order to calculate the speed of individual vehicles, the 60 m trap length was divided by the interval exit time – entry time. The same procedure was applied for both BS and FS. From the parking survey, the number of parking maneuvers was calculated for the peak hours of the respective sections, the parking duration, the types of parked vehicles, the peak hour parking demand, the occupancy level, and the proportion of the road occupied by on-street parking were noted. From the pedestrian survey, the number of pedestrian crossings during peak hours was observed in 15 min intervals.

Tables I and II represent the vehicular composition of the BSs and FSs chosen in this study. The percentages of motorized and NMVs are calculated from these data and are used in further analysis. As the traffic is heterogeneous, in order to convert the stream into homogenous traffic, the data were used with PCU to get homogenous traffic conditions. This process simplifies the analysis phase. Tables III and IV represent the traffic volume count at the BSs and FSs. The collected data were used to calculate peak hour (from 9:30 am to 11:30 am) volume, as shown in Table XI. A parking survey was conducted at both sections by videographic survey from 9:30 am to 6:30 pm. It can be observed in Table V that all roads have on-street parking issues. The parking location on each road shows all roads having an unauthorized type of parking. They determine the on-street parking demand during peak hours and identify its impact on speed, capacity, and LOS. The parking maneuvers during peak hours in various vehicle categories are shown in Table VI.

VI. RESULTS AND DISCUSSION

A. *Impact of On-street parking, NMV, and Pedestrian crossing on Traffic Flow*

The peak time of the BS (the hour of the day with the highest traffic volume for that section) can be seen in Tables III-IV. The peak hour volumes of the BSs and the FSs are shown in TableVII.

TABLE I. VEHICULAR COMPOSITION AT THE BASE SECTIONS

BS	Name	Vehicular composition (in % age)							
		Car	2W	3W	Bus/truck	SGV	LGV	Cycle	Others
A_1	Indira nagar	23.97	36.03	22.37	3.26	7.63	4.74	0.33	1.67
B_1	Bisesarganj	18.69	39.37	19.32	5.68	6.21	7.23	1.47	2.03
C_1	Sonia	18.36	41.12	20.87	4.96	5.26	6.66	1.33	1.98
D_1	Salarpur	24.32	39.67	19.46	5.32	4.21	4.66	1.20	1.16
E_1	Lahurabeer	22.96	40.48	17.56	5.03	4.52	5.72	1.60	2.09
F_1	DLWcampus	28.66	42.39	15.23	2.01	5.62	0.92	3.37	1.83
G_1	BHU	22.84	42.98	18.76	3.20	3.96	1.82	5.23	1.21

** SGV = small goods vehicle, LGV = large goods vehicle*

TABLE II. VEHICULAR COMPOSITION AT THE FRICTION SECTIONS

FS	Name	Vehicular composition (in % age)							
		Car	2W	3W	Bus/truck	SGV	LGV	Cycle	Others
A_2	Chitaipur	25.34	38.66	20.09	4.91	3.26	4.74	0.87	2.13
B_2	Godowlia	13.86	42.24	21.14	2.00	8.76	7.29	1.83	2.88
C_2	Benia	17.28	43.13	22.18	2.90	7.87	2.10	1.60	2.40
D_2	Sarnath	26.21	38.97	19.23	4.77	3.97	5.03	0.80	1.20
E_2	Sigra	23.07	37.93	20.91	6.09	3.26	5.74	1.76	1.24
F_2	DLW	29.87	41.13	13.66	2.34	7.98	1.03	2.02	1.97
G_2	Bhelupur	21.07	44.93	19.02	2.79	4.21	1.90	4.98	1.10

TABLE III. TRAFFIC VOLUME COUNTS AT THE BASE SECTION

BS	9:30-9:45	9:46-10:00	10:01-10:15	10:16-10:30	10:31-10:45	10:46-11:00	11:01-11:15	11:16-11:30
A_1	277	232	201	211	159	248	152	176
B_1	348	346	350	337	232	221	388	279
C_1	233	247	242	239	198	202	187	203
D_1	339	347	350	344	336	297	252	289
E_1	296	289	250	232	249	286	192	132
F_1	342	375	326	266	298	287	232	198
G_1	226	268	275	266	295	286	176	145

TABLE IV. TRAFFIC VOLUME COUNT AT THE FRICTION SECTION

FS	9:30-9:45	9:46-10:00	10:01-10:15	10:16-10:30	10:31-10:45	10:46-11:00	11:01-11:15	11:16-11:30
A_2	154	146	186	183	198	181	163	159
B_2	282	276	206	216	211	211	142	144
C_2	186	158	142	153	182	182	127	113
D_2	289	248	252	244	179	191	188	136
E_2	141	137	143	141	139	127	132	138
F_2	214	273	268	152	189	197	157	196
G_2	108	113	137	109	111	88	98	108

TABLE V. ON-STREET PARKING LOCATIONS

BS	Place		Type	FS	Place		Type
	LHS	RHS			LHS	RHS	
A_1		*	Un-Authorized	A_2	*		Un-Authorized
B_1		*	Un-Authorized	B_2	*		Un-Authorized
C_1	*		Un-Authorized	C_2	*		Un-Authorized
D_1	*		Un-Authorized	D_2		*	Un-Authorized
E_1			Un-Authorized	E_2		*	Un-Authorized
F_1	*	*	Un-Authorized	F_2		*	Un-Authorized
G_1	*		Un-Authorized	G_2	*		Un-Authorized

** LHS = left hand side, RHS = right hand side*

TABLE VI. PARKING MANOEUVRES

BS	Parking manoeuvres (Peak hours)						
	Car	2w	Auto	LCV	Truck	Other	Total
A_1	1	2	2	-	-	2	7
B_1	-	4		1	-	-	5
C_1	1	1	-	-	-	1	3
D_1	1	3	1	-	-	2	7
E_1	-	1	-	-	-	-	1
F_1	-	1	1	-	-	-	2
G_1	-	1	-	-	-	1	2
A_2	13	36	17	3	1	6	76
B_2	18	27	17	7	-	4	73
C_2	8	24	32	12	-	8	84
D_2	12	32	16	9	2	6	80
E_2	16	36	18	3	2	9	84
F_2	18	32	21	7	-	11	89
G_2	16	28	15	5	-	9	73

TABLE VII. PEAK HOUR VOLUME

BS	Peak hour volume	FS	Peak hour volume
A_1	921	A_2	748
B_1	1381	B_2	980
C_1	961	C_2	639
D_1	1380	D_2	1033
E_1	1067	E_2	562
F_1	1309	F_2	907
G_1	1122	G_2	470

B. Peak Hour Factor (PHF)

PHF is the hourly volume during the analysis hour divided by the 4 × peak 15-minute flow rate within the analysis hour. The PHF is also considered a measure to estimate traffic demand fluctuations and traffic flow rate within the peak hour. PHF is used to calculate the base and friction section traffic flow rate during peak hours. As shown in Table IX, the traffic flow rate can be calculated by peak hour volume with the PHF. Table X shows that due to side frictional activities, the reduction percentage in traffic flow ranged from 36.67% to 66.13%. Bhelupur stretch is majorly impacted by side frictional activities as a reduction in traffic flow is 66.13%, while the Chitaipur stretch is the least affected with a reduction in traffic flow of 36.67%. As shown in Figure 1, due to various side frictional activities at the FS with respect to the BS (free from any side friction), the reduction in traffic flow can be observed due to on-street parking, NMVs and pedestrian crossing are directly proportional to the reduction percentage in traffic flow. The R^2 value of 0. 896 for the created model indicates high dependability.

TABLE VIII. TRAFFIC FLOW RATE

BS	PHF at the BS	Traffic flow rate at the BS (Veh/hr)
A_1	0.83	1110
B_1	0.98	1410
C_1	0.97	991
D_1	0.98	1409
E_1	0.90	1186
F_1	0.87	1505
G_1	0.95	1181
FS	**PHF at the FS**	**Traffic flow rate at the FS (Veh/hr)**
A_2	0.94	703
B_2	0.86	843
C_2	0.85	543
D_2	0.89	919
E_2	0.98	551
F_2	0.83	753
G_2	0.85	400

TABLE IX. REDUCTION PERCENTAGE IN TRAFFIC FLOW DUE TO FRICTIONAL ACTIVITIES

Reduction in traffic flow (Veh/h)r	Traffic flow reduction percentage (%)
407	36.67
567	40.21
448	45.20
490	34.78
635	53.54
750	49.83
781	66.13

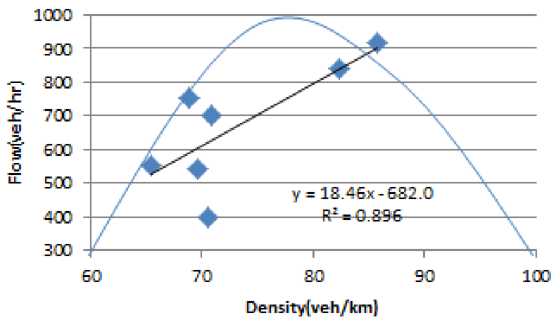

Fig. 1. Flow-density relationship at FS

C. Speed-Density Relationship

Three fundamental parameters, traffic flow, speed and density, were used to develop the relationship between traffic speed and density of the 14 sections. Space mean speed data extracted from videography were used to predict traffic speed. The speed of traffic flow in each section was determined using the 85[th] percentile cumulative method as in (1). Traffic volume data were converted into passenger car units to develop a speed-flow relationship. Each vehicle type was found in mixed traffic conditions, so it was more challenging to predict the density and capacity of the road. To analyze the mixed scenario space, the mean speed used in this research. Space Mean Speed (SMS) of vehicles was noted in the presence of on-street parking and NMVs. The SMS for the Indiranagar section (A_1) is shown in Table XI. The values of the speed of traffic flow at the BS and the FS in the presence of on-street parking and NMVs are shown in Table XII. Table XIII and Figure 2 show the reduction in speed in the FSs. The R^2 value of 0.865 for the created model indicates high dependability. These speed data were further used in the prediction of road capacity.

TABLE X. TRAFFIC SPEED AT BASE AND FRICTION SECTION

BS	Traffic speed at BS	FS	Traffic speed at FS
A_1	29.081 km/hr	A_2	13.392 km/hr
B_1	32.173 km/hr	B_2	14.637 km/hr
C_1	32.112 km/hr	C_2	13.338 km/hr
D_1	30.694 km/hr	D_2	14.194 km/hr
E_1	29.963 km/hr	E_2	16.196 km/hr
F_1	27.252 km/hr	F_2	16.826 km/hr
G_1	29.246 km/hr	G_2	14.324 km/hr

TABLE XI. TRAFFIC FLOW SPEED

Parking manoeuvres at BS	Pedestrian crossing at BS	NMV at BS	Parking manoeuvres at FS	NMV at FS	Traffic speed (Km/hr)	
					BS	FS
7	11	9	76	23	29.081	13.392
5	8	4	73	46	32.173	14.637
3	13	12	84	26	32.112	13.338
7	9	7	80	21	30.693	14.194
1	9	11	84	17	29.963	16.196
2	2	13	89	36	27.252	16.826
2	7	19	73	47	29.246	14.324

$$SMS = \frac{n}{\sum \frac{1}{Vi}} \quad (1)$$

where *SMS* is the space mean speed, *n* is the number of vehicles, and *Vi* is the speed of an individual vehicle.

TABLE XII. REDUCTION IN SPEED AT THE FS DUE TO ON-STREET PARKING AND NMVs

FS	Speed reduction (kmph)	Speed reduction percentage
A_2	15.689	53.94
B_2	17.536	54.50
C_2	18.774	58.46
D_2	16.499	53.75
E_2	13.767	45.94
F_2	10.426	38.25
G_2	14.922	51.02

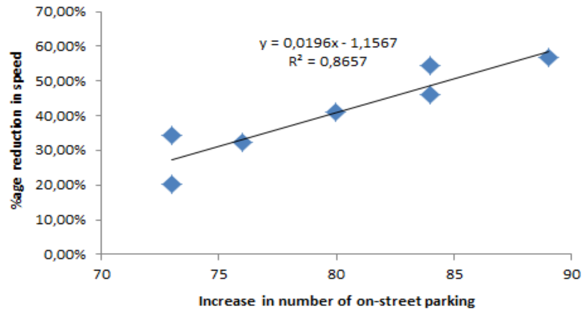

Fig. 2. Speed reduction percentage in traffic speed at the FSs.

D. Impact of On-street Parking and NMVs on Road Capacity

Two types of data were used to determine the road section capacity at both sections: SMS and classified volume data. Data were extracted by the videography method at intervals of 15 min. A 60 m trap length was chosen for all 14 sections to collect data regarding speed and classified traffic volume count. A video camera was fixed 5.2 m above the ground, and 9 hours of video were recorded. The fundamental diagram method was used to establish the speed-flow relationship. Volume data (veh/h) were recorded in the video, which need to be converted into PCU as it was mixed traffic. Highway capacity manual categorized vehicle types should be considered as motorized and NMVs (cycles, cycle rikshaws, and animal-drawn vehicles). The PCU factors for individual vehicle categories given by IRC 106 (for urban streets) were used. Using PCU factors, each 15 min traffic count (veh/h) was converted into PCU/h and was multiplied by 4 to get the hourly volume. The flow (PCU/hr) at the BSs and FSs is shown in Table XIV. The density of each section was calculated by:

$$Q = KV \quad (2)$$

where $K = Q/V$, Q is the traffic flow (veh/hr), K is the traffic density (veh/km), and V is thee traffic speed (km/hr).

By using the Greenshield's Model (3), speed and density graphs were designed to estimate the section capacity. Figure 3 shows the speed-density curve for the BSs.

TABLE XIII. FLOW (PCU/H)

BS/FS	Vehicular composition in percentage								
	Car	2W	3W	Bus/truck	SGV	LGV	Cycle	Others	Total
A_1	66	75	124	31.5	42	28.6	0.4	10	377.5
B_1	65	103.5	136	38.5	44	55	2	14	458
C_1	45	76.5	104	42	26	35.2	1.2	10	339.9
D_1	85	104.25	136	49	46	33	0.4	8	461.65
E_1	68	90	104	35	52	50.6	2.8	12	414.4
F_1	96	119.25	82	45.5	38	46.2	2.4	16	445.35
G_1	67	94.5	110	59.5	42	41.8	1.6	9	425.4
A_2	48	57	78	10.5	26	15.4	0.4	2	237.3
B_2	43	73.5	102	17.5	30	28.6	0.8	6	301.4
C_2	26	57	78	24.5	18	24.2	0.4	4	232.1
D_2	63	76.5	102	14	26	19.8	0.8	2	304.1
E_2	49	64.5	66	7	24	26	2.4	6	244.9
F_2	76	99	58	14	18	15.4	1.6	8	290
G_2	52	72	70	21	16	17.6	0.4	4	253

TABLE XIV. FLOW, SPEED, AND DENSITY

BS	Flow (PCU /h)	Stream speed (km/h)	Density (PCU/km)	FS	Flow (PCU/h)	Stream speed (km/h)	Density (PCU/km)
A_1	1510	29.081	51.92	A_2	950	13.392	70.93
B_1	1832	32.173	56.94	B_2	1206	14.637	82.39
C_1	1360	32.112	43.71	C_2	929	13.338	69.65
D_1	1847	30.693	60.17	D_2	1217	14.194	85.74
E_1	1658	29.963	55.33	E_2	980	16.196	65.50
F_1	1782	27.252	65.38	F_2	1160	16.826	68.94
G_1	1702	29.246	58.19	G_2	1012	14.324	70.65

Greenshield's straight line can be seen in the graph, best fitted on the basis of the R^2 value. Similarly, Figure 4 shows the speed-density graph for the FSs, while also the Greenshield's straight line can be observed, which is best fitted on the basis of the R^2 value.

$$v = a - b * K \quad (3)$$

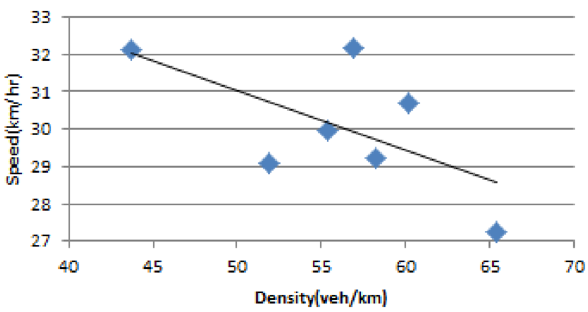

Fig. 3. Speed-density relationship at the BS.

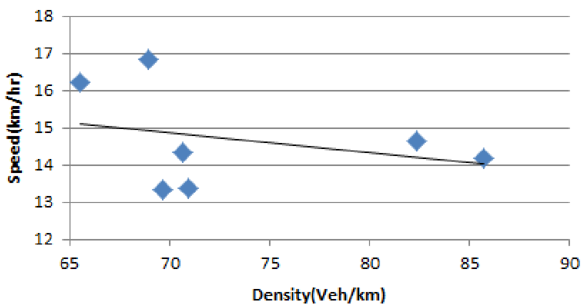

Fig. 4. Speed-density relationship at the FS.

Table XV, shows the traffic flow, speed, and density at the BSs and FSs. To determine the capacity, the developed model (speed-density model) was used to generate the speed-flow curve shown in Figure 5. The speed-flow curve will give the capacity of the respective sections. The generated capacity is shown in Table XVI. The reduction percentage in the capacity due to on-street parking and NMV on the FS are shown in Table XVII. The LOS of each section was calculated by dividing the road volume with the capacity. The volume/capacity ratio was compared with the values provided by IRC 106. Table XVIII represents the impact of on-street parking, NMV, and pedestrian crossing on LOS at the FS.

According to the IRC guidelines for urban roads, a road will lie in LOS A if its V/C value lies in 0-0.60 (free flow), similarly for LOS B, it should be in 0.61-0.70 (reasonable free flow), for LOS C 0.71-0.80 (near free flow), for LOS D 0.81-0.90 (medium flow), for LOS E 0.91-1.00 (capacity flow), and LOS F values should be greater than 1 (congested flow). It can be observed from Table XVIII, that frictional activity affects the service level of Sarnath road up to LOS-B, while the level of service of Bhelupur road is impacted up to LOS-E.

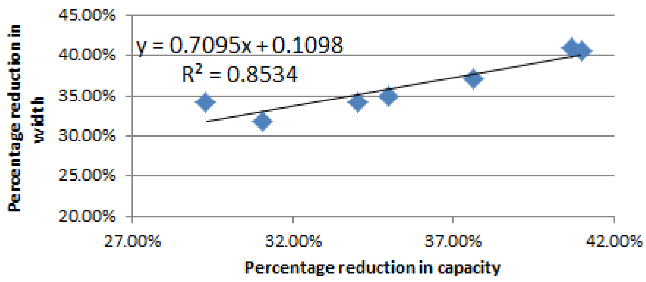

Fig. 5. Correlation between the reduction percentage, effective width, and capacity.

TABLE XV. CAPACITY REDUCTION PERCENTAGE DUE TO NMVS

Capacity at BS (PCU/hr/2lane)	Capacity at FS (PCU/hr/2lane)	Reduction in capacity (PCU/hr/2lane)	Reduction percentage (%)
1510	950	560	37.08
1832	1206	626	34.17
1360	929	431	31.69
1847	1217	630	34.10
1658	980	678	40.86
1782	1160	622	34.90
1702	1012	690	40.54

TABLE XVI. CAPACITY REDUCTION PERCENTAGE DUE TO ON-STREET PARKING

Parking manoeuvres/hr	NMT	Reduction percentage (%)
76	23	37.08
73	46	34.17
84	26	31.69
80	21	34.10
84	17	40.86
89	36	34.90
73	47	40.54

TABLE XVII. IMPACT ON LOS AT FS

FS	V/C at FS	LOS as per IRC	Remarks
A_2	0.787	LOS C	Near free flow
B_2	0.812	LOS D	Medium flow
C_2	0.687	LOS D	Medium flow
D_2	0.848	LOS B	Reasonable free flow
E_2	0.873	LOS D	Medium flow
F_2	0.781	LOS C	Mear free flow
G_2	0.902	LOS E	Capacity flow

E. Correlation of Capacity Reduction with the Effective Width of the Carriageway

On-street parking along the roads led to a loss of carriageway width, resulting in loss of road capacity. A correlation model was developed between the effective carriageway width and the capacity of the FS. The available effective width is the width of the carriageway available at any instance for traffic movement. On-street parking reduces the available effective width, and the capacity of the friction section decreases, as shown in Table XIX.

TABLE XVIII. RELATIONSHIP BETWEEN PARKING MANEUVERS PER HOUR, CAPACITY REDUCTION, AND EFFECTIVE WIDTH

FS	Parking manoeuvres per hour	Capacity reduction (pcu/hr)	Capacity Reduction percentage	Flow at BS (veh./ 5 min.)
A_2	76	560	37.08%	126
B_2	73	626	34.17%	153
C_2	84	431	31.69%	113
D_2	80	630	34.10%	154
E2	84	678	40.86%	138
F_2	89	622	34.90%	149
G_2	73	690	40.54%	142

For data extraction, the BS (ex: A_1) with minimum (as possible) and the FS (ex: A_2) with the maximum number of on-street parking maneuver issues were selected. The flow ratio (veh / 5 min) at these two sections for each interval is determined with the corresponding number of parking maneuvers. The ratio of flow at section A_1 to section A_2 directly gives the effective width factor for each 5 min interval, as shown in (4). These effective width factors for various sections at different parking maneuvers were multiplied with the actual width of the road to get the available effective width, as shown in (5). The reduction in width can be calculated by deducting the available effective width for various parking maneuvers from the actual width of the road.

$$\text{EWF}=\frac{F(A_2)}{F(A_1)} \quad (4)$$

$$\text{AEW}=\text{EWF}\times\text{AW} \quad (5)$$

where EWF is the effective width factor, $F(A_1)$ is the traffic flow at A_1, $F(A_2)$ the traffic flow at A_2, AEW is the available effective width, and AW the actual width of the road.

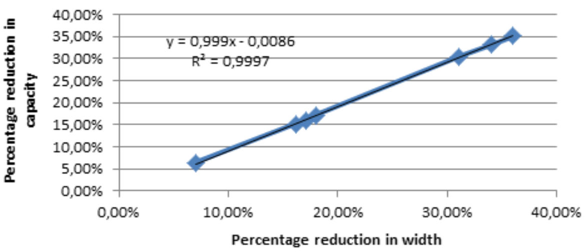

Fig. 6. Correlation between the reduction percentage, effective width, and capacity.

As shown in Figure 6, a linear relationship exists between width decreases and capacity reductions, with an R^2 value of 0.853. It is determined that a 34.10% capacity loss occurs at a 29.31% reduction in effective width, and a 40.54% loss occurs at a 40.98% reduction in effective width. Reduced effective width and capacity are related, as demonstrated in (6).

Percentage reduction in width = 0.709 × *percentage reduction in capacity* + 0.109 (6)

with $R^2 = 0.853$.

VII. CONCLUSION

Roadside frictional activities are prevalent in developing countries like India. This study focused on the urban arterial roads in Varanasi. It is observed that the presence of side frictional activities such as on-street parking, NMVs, and pedestrian crossing reduces the traffic flow, speed, and road capacity and impacts LOS. In this study, two types of roads were considered: base section (with minimum side friction) and friction section (with maximum side friction). Data were collected from 7 base and 7 friction sections to analyze the effects of the considered fractional activities on the friction section. A correlation model was developed at the friction section and was compared with the base section to understand the impact of on-street parking, NMV, and pedestrian crossing on traffic flow. The speed-density model was developed using three fundamental parameters, which were further used to develop the speed-flow model. The speed-flow curve is plotted using the model's speed at various flow levels. The speed-flow curve is used to estimate the capacities of respective roads. Capacities at each parking maneuver and the proportion of NMV were determined and compared with the base section capacity. The capacity obtained for different roads was used to calculate the V/C ratio to understand the quality of the respective roads' service levels. The values obtained from the V/C ratio were compared with those suggested by IRC 106 guidelines. The main conclusions of this study are:

- Traffic flow of two-lane divided friction urban arterial midblock sections decreases with the increase in the influence of on-street parking, NMV, and pedestrian crossing, compared to the base section. The R^2 value obtained from the developed model indicates high dependability.
- The reduction percentage in traffic flow ranged from 34.78% to 66.13%. Bhelupur stretch is majorly impacted by side frictional activity as the reduction in traffic flow is 66.13%, while the Sarnath stretch is least affected with a reduction in traffic flow of 34.78%.
- The R^2 value obtained from flow-density relationship at BS is 0.576, at FS it is 0.896, showing high dependability between traffic flow rate and side frictional parameters.
- The reduction percentage in speed at friction section ranged from 38.25% to 58.46%. From the developed model between % age reduction in speed and parking maneuvers per hour, the value of R^2 (0.865) indicates high dependability.

- A correlation is obtained between the available effective width and percentage reduction in capacity.
- It is observed that a 34.10% capacity loss occurs at a 29.31% reduction in effective width, and a 40.54% loss occurs at a 40.98% reduction in effective width.
- The capacity of Indira nagar road (A_1) is 1510 PCU/hr/2lane, while the capacity of Chitaipur Road (A_2) is reduced to 950 PCU/hr/2lane due to on-street parking and NMV.
- Similarly, the capacity of Lahurabeer road (E_1) is 1658 PCU/hr/2lane, while the capacity of Sigra road (E_2) is reduced to 980 PCU/hr/2lane due to the influence of frictional activities.

REFERENCES

[1] A. Munawar, "Speed and Capacity for Urban Roads, Indonesian Experience," *Procedia - Social and Behavioral Sciences*, vol. 16, pp. 382–387, Jan. 2011, https://doi.org/10.1016/j.sbspro.2011.04.459.

[2] Y. Xiaobao, H. Mei, and G. Ziyou, "Car Delay Model near Bus Stops with Mixed Traffic Flow," *Journal of Applied Mathematics*, vol. 2013, May 2013, Art. no. e437637, https://doi.org/10.1155/2013/437637.

[3] M. A. Lim, E. L. Hallare, and J. G. Briones, "Modeling the impact of on-street parking on vehicular traffic," in *5st Atrans Symposium Student Chapter Session*, Bangkok, Thailand, Aug. 2012, pp. 47–57.

[4] W. E. Marshall, N. W. Garrick, and G. Hansen, "Reassessing On-Street Parking," *Transportation Research Record*, vol. 2046, no. 1, pp. 45–52, Jan. 2008, https://doi.org/10.3141/2046-06.

[5] S. Biswas, S. Chandra, and I. Ghosh, "Effects of On-Street Parking in Urban Context: A Critical Review," *Transportation in Developing Economies*, vol. 3, no. 1, Apr. 2017, Art. no. 10, https://doi.org/10.1007/s40890-017-0040-2.

[6] S. Chand and S. Chandra, "Impact of bus stop on urban traffic characteristics–a review of recent findings," *Journal of Society for Transportation and Traffic Studies*, vol. 5, no. 2, pp. 57–72, 2014.

[7] M. Patkar and A. Dhamaniya, "Effect of On-street parking on Effective Carriageway Width and Capacity of Urban Arterial Roads in India," *European Transport*, no. 73, 2019, Art. no. 1.

[8] R. Khatawkar and C. Kumar N T, "Impact of Road Side Bus Stops on Capacity of Roadway," *International Journal of Avanced Technology in Engineering and Science*, vol. 3, no. 7, pp. 147–157, 2015.

[9] H. Guo, Z. Gao, X. Yang, X. Zhao, and W. Wang, "Modeling Travel Time under the Influence of On-Street Parking," *Journal of Transportation Engineering*, vol. 138, no. 2, pp. 229–235, Feb. 2012, https://doi.org/10.1061/(ASCE)TE.1943-5436.0000319.

[10] R. Z. Koshy and V. T. Arasan, "Influence of Bus Stops on Flow Characteristics of Mixed Traffic," *Journal of Transportation Engineering*, vol. 131, no. 8, pp. 640–643, Aug. 2005, https://doi.org/10.1061/(ASCE)0733-947X(2005)131:8(640).

[11] Y. Cao, Z. Z. Yang, and Z. Y. Zuo, "The effect of curb parking on road capacity and traffic safety," *European Transport Research Review*, vol. 9, no. 1, pp. 1–10, Mar. 2017, https://doi.org/10.1007/s12544-016-0219-3.

[12] S. Biswas, S. Chandra, and I. Ghosh, "Side friction parameters and their influences on capacity of Indian undivided urban streets," *International Journal of Transportation Science and Technology*, vol. 10, no. 1, pp. 1–19, Mar. 2021, https://doi.org/10.1016/j.ijtst.2020.03.007.

[13] K. A. Madhu and H. N. Rajakumara, "Effect of Improper Bus Stop Locations on Capacity and Speed-Flow Relations on Urban Roads," *International Journal of Recent Technology and Engineering*, vol. 8, no. 3, pp. 1489–1494, Sep. 2019, https://doi.org/10.35940/ijrte.C4148.098319.

[14] A. M. Rao, S. Velmurugan, and K. M. V. N. Lakshmi, "Evaluation of Influence of Roadside Frictions on the Capacity of Roads in Delhi, India," *Transportation Research Procedia*, vol. 25, pp. 4771–4782, Jan. 2017, https://doi.org/10.1016/j.trpro.2017.05.489.

[15] M. L. M. Chiguma, "Analysis of side friction impacts on urban roads links," Ph.D. dissertation, KTH Royal Institute of Technology, Stockholm, Sweden, 2007.

[16] Nahry, H. R. Agah, A. Thohirin, and N. H. A. Hamid, "Modeling the Relationship between On-Street Parking Characteristics and through Traffic Delay: Parking and Traffic Delay Relationship," *Proceedings of the Pakistan Academy of Sciences: A. Physical and Computational Sciences*, vol. 56, no. 2, pp. 29–36, 2019.

[17] I. Adinarayana and N. C. Anil, "The Study Exploration towards Side Friction Influences by traffic performance measures on roads," *International Journal of Science Engineering and Advance Technology*, vol. 5, no. 11, pp. 1024–1031, Dec. 2017.

[18] K. L. Bang, "Impact of Side Friction On Speed-Flow Relationships for Rural and Urban Highways," SWEROAD, Indonesia, HDM4 project report, 1995.

[19] K. F. Aronsson and K. L. Bang, "Influence on vehicle speed profiles of interactions with other road users," in *European Transport Conference*, Strasbourg , France, Sep. 2006, pp. 1–14.

[20] B. R. Kadali, T. Chiranjeevi, and R. Rajesh, "Effect of pedestrians un-signalized mid-block crossing on vehicular speed," *International journal for traffic and transport engineering*, vol. 5, no. 2, pp. 170–183, 2015, https://doi.org/10.7708/ijtte.2015.5(2).07.

[21] M. O. Kuttan, S. Babu, and G. Asaithambi, "Impact of Pedestrian Road Crossing on Capacity and Level of Service of Urban Undivided Roads in Indian Traffic Conditions," in *Transportation Research Board 96th Annual Meeting*, Washington, DC, USA, Jan. 2017, pp. 1–17.

[22] A. Dhamaniya and S. Chandra, "Influence of Undesignated Pedestrian Crossings on Midblock Capacity of Urban Roads," *Transportation Research Record*, vol. 2461, no. 1, pp. 137–144, Jan. 2014, https://doi.org/10.3141/2461-17.

[23] M. Angın and S. I. A. Ali, "Analysis of Factors Affecting Road Traffic Accidents in North Cyprus," *Engineering, Technology & Applied Science Research*, vol. 11, no. 6, pp. 7938–7943, Dec. 2021, https://doi.org/10.48084/etasr.4547.

[24] S. Ranjan and V. Singh, "HEC-HMS based rainfall-runoff model for Punpun river basin," *Water Practice and Technology*, vol. 17, no. 5, pp. 986–1001, Apr. 2022, https://doi.org/10.2166/wpt.2022.033.

[25] S. Ranjan and V. Singh, "ANN and GRNN-Based Coupled Model for Flood Inundation Mapping of the Punpun River Basin," *Engineering, Technology & Applied Science Research*, vol. 13, no. 1, pp. 9941–9946, Feb. 2023, https://doi.org/10.48084/etasr.5483.

[26] A. Jawed, M. a. H. Talpur, I. A. Chandio, and P. N. Mahesar, "Impacts of In-Accessible and Poor Public Transportation System on Urban Enviroment: Evidence from Hyderabad, Pakistan," *Engineering, Technology & Applied Science Research*, vol. 9, no. 2, pp. 3896–3899, Apr. 2019, https://doi.org/10.48084/etasr.2482.

[27] K. Srivastava and A. Kumar, "Critical Analysis of Road Side Friction on an Urban Arterial Road," *Engineering, Technology & Applied Science Research*, vol. 13, no. 2, pp. 10261–10269, Apr. 2023, https://doi.org/10.48084/etasr.5603.