Critical Analysis of Road Side Friction on an Urban Arterial Road

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ABSTRACT

This study reviews the impact of roadside friction on urban arterial roads in the published literature and aims to identify the various side frictional parameters that impact urban arterial roads. The side frictional parameters are non-motorized vehicles, pedestrian crossing or moving along the road, street vendors, on-street parking, animal movement, and land-use activity. The impact of all these parameters on traffic performance leads to a reduction in capacity, speed (instantaneous speed, journey speed, travel speed, time mean speed, and space mean speed), level of service, delay, travel time, and travel cost. This study considered online published studies from 1995 to 2022. The available effective width and the percentage reduction in road capacity are related. Road capacity is reduced by 3.37% when the effective width is reduced by 2.95%, while road capacity is reduced by 26.08% when the effective width is reduced by 21.81%.

Keywords-side friction; arterial road, speed; capacity; road capacity; level of service; non-motorized vehicles

I. INTRODUCTION

Efficient transportation infrastructure is essential and critical for economic development, particularly in developing countries. Economic development requires more movement of people and things. Rapid urbanization and population growth in urban areas in developing countries, such as India, have resulted in increased vehicular traffic. Vehicle growth is putting more pressure on the transportation infrastructure, particularly in the road transport system, and adversely affects smooth traffic flow. In India, as the road transport system handles more than 85% of passenger travel and 60% of freight flow, roads are dominantly used as a mode of transport and act as a lifeline for accessibility. Urban regions are experiencing more congestion, pollution, and accidents as a result of the increase in traffic. In old Indian cities, most arterial and sub-arterial roads face congestion due to the increase in vehicular population, heterogeneous traffic, and many side frictions.

Side friction is defined as any activity or action that occurs on the side of a road or on the road itself and interferes with the efficient flow of traffic. Side friction refers to activities that cause traffic congestion on the roadway or along its sides. In [1], the effects of side friction on an urban arterial road were explained and defined as any acts related to activities occurring on the roadside or sometimes within the road that obstruct traffic movement. Various side frictions include trading activities/street vendors/street trading, slow-moving cars, pedestrians crossing or walking along the road, non-motorized vehicles, turning movement, on-street parking/stopping, bus stops/bus bays, land use, animal movement, roadside accessibility, etc. Side friction alters the speed and flow characteristics and reduces the capacity of roads [2], as it significantly impacts traffic movement in various ways, such as reduction in road capacity and carriageway width, impact on travel speed, instantaneous speed/spot speed, Time Mean Speed (TMS), Space Mean Speed (SMS), affecting road performance. Side friction results in increased traveler discomfort, reduced speed behind stopped vehicles and abrupt volume rises on the roadway, traffic jams and time delays, loss of Level Of Service (LOS), and impacts travel time and cost.

The main objective of this study was to examine the side frictional parameters in urban roads as stated by different studies, This study also evaluates the various viewpoints on side friction, how they affect traffic on urban arterial roads, and shows that various side friction activities have different degrees of impact on traffic behavior characteristics.

II. RESEARCH LIMITATIONS

This study reviewed 90 studies from 1995 to 2022. However, most studies mainly focused on four side frictional parameters: non-motorized transport/slow-moving vehicle, pedestrian crossing (on or along the road), on-street parking, and street vendors/street traders. Less than 10% of the studies focused on other side frictional parameters, such as animal movement and land-use activity. Most studies mainly dealt with how 6 sid-frictional parameters, namely, non-motorized vehicle/transport and slow-moving vehicles, pedestrian crossing or moving along the road, on-street parking, street vendors/ traders, animal movement, and land use activity impact capacity, its estimation, and the level of congestion, the level of service, delay, and congestion factors. None of the studies dealt with the impact on travel time, the impact of travel speed on cost, journey speed, travel time, flow/capacity ratio, pedestrian activity, bicycle flow, TMS, and SMS. As a result, studies that aim to critically examine the side friction impact on Indian urban roads must incorporate multidimensional metrics. Due to inherent variations that may result in inaccurate conclusions, it is critical to separate the empirical research for developed and developing countries.

III. METHODOLOGY

This study systematically assessed the impact of side frictional in Indian urban roads through published studies in Elsevier Science Direct, IJIRSET, IJSRSET, IJSEAT, IJRTE, Doctoral Thesis, and JSTOR databases from 1995 to 2022. Data analysis was performed based on the aim and objectives, and the results are discussed in the result and discussion sections.

IV. LITERATURE REVIEW

The literature survey revealed that relatively little research has been conducted to date on the measurement of side friction and its detrimental effects on travel time, capacity, LOS, and other factors. Table I shows some Indian and international works that dealt with speed, capacity, LOS, travel time, etc. Although it is generally acknowledged that roadside activities impact the typical traffic stream's speed, capacity, and LOS and increase travel time, there are only a few studies recorded that make an effort to quantify these effects.

TABLE I. IDENTIFICATION OF SIDE FRICTION PARAMETERS

Parameter	Study
Pedestrian movement	[1-28]
On-street parking	[6, 9, 10, 12, 13, 23, 26, 28-47]
NMT/NMV/SMV	[1, 2, 6, 10, 13, 14, 22, 36, 38, 40, 46, 48-51]

V. PEDESTRIAN MOVEMENTS AS A SIDE FRICTIONAL PARAMETER

Pedestrian movements include crossing the street or walking along it. However, both negatively affect the traffic flow, as shown in Table II, and must be avoided. When pedestrians are forced to use the road alongside fast-moving cars because of no sidewalks, as is often the case on urban streets, the average speed of traffic on certain roads is slowed by 7.23km/hr [3].

VI. INFLUENCE OF PEDESTRIAN MOVEMENTS ON VEHICULAR SPEED

In [4], a pedestrian crossing traffic model was proposed for a city street. The volumes of traffic, speeds, and numbers of people crossing in and out of traffic are the inputs to the model (1) for calculating the average speed of a certain vehicle type:

$$v_j = a_0 - [\sum(a'i \frac{n_i}{v_i})] - (a'k\, n_{ped}/v_j) \quad (1)$$

where v_i is the speed of a particular vehicle (m/s), v_j is the speed of various types of vehicle, a_o is the regression coefficient for the free flow speed of the j_{th} type vehicle, $a'i$ and $a'k$ are regression coefficients for the impact of density of a particular vehicle type and pedestrians on the free flow speed of the j-th type vehicle, respectively, n_i is the number of vehicles (v/s), and n_{ped}/v_j is the pedestrian-vehicle interaction factor (m/s).

TABLE II. IMPACT OF PEDESTRIAN MOVEMENT ON SPEED

Study	Pedestrian crossing vol.	Speed Reduction
[1]	100 peds/h	2.5%
[3]	100 peds/h	7.23 km/h
[4]	100 peds/h	4.21%.
[5]	100 peds/h	3.52%.
[6]	100 peds/h	0.76 km/h
[7]	100 peds/h	5.2%
[8]	100 peds/h	5.9%
[12]	100 peds/h	3.9%
[15]	100 peds/h	2.9%
[17]	100 peds/h	4.44%
[18]	100 peds/h	4.8%
[19]	100 peds/h	5.20%
[20]	100 peds/h	3.33%
[21]	100 peds/h	4.65%

If traffic flow stays the same, this study shows that all vehicle classes, except large trucks, slow down due to an increase in pedestrian cross-volume. However, the model's iteration technique is a disadvantage because it takes a long time to predict the speed. Many studies that estimated traffic speeds on urban roads treated the variable "pedestrian motion" as binary, either missing or present. Only a small number of studies went further and created speed models to measure the speed reduction caused by increasing the intensity of pedestrian activity. This study used a mathematical model to estimate that when the degree of pedestrian crossing along the road is approximately 1360 peds/h, a six-lane divided urban road's capacity decreases by nearly half of what it should be according to IRC recommendations [5]. Furthermore, this study concluded that if the volume of pedestrian crossing volume is around 100 peds/h, it will reduce capacity by 3.52%. The rules of the IRC recognize the connection between a variety of frictional roadside activities on the road and capacity. It is clear from this study that no precise methodology or guidelines have been provided to analyze or quantify each side friction effect on urban streets. In [6], a weighting factor for pedestrian mobility was suggested in addition to other side frictional elements when designing urban roadways, as shown in Table III.

A. *Weightage Factors for Elements of Side Friction*

In [6], five unique categories were used to categorize the side friction index range, a weighted sum of the side friction components, as: very low, low, medium, high, and very high. Free flow speed was found to be lowered by 18Km/h for two-lane undivided urban roads and by 16Km/h for two-lane undivided interurban highways with significant side friction and short shoulders. On four-lane roads, it was discovered that the effect of side friction on the free flow speed was only somewhat alleviated. Other studies examined the impact of pedestrian crossings on the performance of an urban road segment.

TABLE III. SIDE FRICTIONAL PARAMETERS WEIGHTS

Event type	Weight factor (WF)
Rate of flow of pedestrian (W + C) (p/h/200m)	0.5
Parked vehicle and parking maneuvers (events/h/200m)	1.0
Entry & and exit of vehicle from road-side (veh/h/200m)	0.7
SMV (veh/h)	0.4

In [7], it was shown that if crossing maneuvers are carried out in an undesignated place, this has a greater impact on stream velocity. In [52], a video evaluation was carried out on two places on a split four-lane city street, where a median opening on one location allowed people to cross. This site's average speed was 7.7km/h slower than the other location, and it was also observed that friction on the sides of the road, such as parked automobiles and people waiting for buses or cars, can narrow the route and slow down the oncoming traffic. Compared to automobiles, pedestrians have less impact on the speed of two-wheelers due to their better maneuverability. This study found that pedestrian crossings caused a 2km/h drop in operational speed. Authors in [8] viewed "pedestrian cross movement" as a yes/no question, without investigating the slowed speed or the increased number of pedestrians crossing the road and without developing an adjustment factor or an empirical model. In [9], the usual speed on urban roads was calculated using the following mathematical model:

$$V_{sim} = 48.7 - 0.011 \times Flow - 0.015 \times Ped \quad (2)$$

$$V = 48.7 - 0.011x_1 - 0.015x_2$$

where V_{sim} is the average travel speed (km/h) from simulation runs, *Flow* is the traffic flow per hour in both directions of travel, and *Ped* is the number of crossing pedestrians per hour and km. In [1], a speed model was used, finding that, among all side friction factors, the pedestrian cross movement has the greatest impact on speed. In [10], the "Volume of pedestrian crossing" was considered a design variable in the speed model shown in (3), and another important aspect that affects how fast incoming vehicles approach is parking and stopping on the road:

$$V = 39.46 - 0.13x_2 - 0.13x_3 - 0.28x_4$$
$$-0.013x_5 - 0.15x_6 \quad (3)$$

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

In [11], a study was conducted to identify how pedestrian flow on/along highways impacts traffic flow speed, and to analyze aspects that affect the speed of four-lane urban roads in developing countries. This study used videography to conduct preliminary surveys in Mumbai, Bangalore, and Thiruvananthapuram, developed a speed model from the resulting footage, and determined the categorized volume and friction factors. The study was carried out in two different phases. In the first phase, side friction was considered individually, while the second examined the combined effect of all frictions. Multiple linear regression models were used to predict speed individually and in heterogeneous situations, and the analysis was completed using a speed prediction model to evaluate variations in the friction parameters. In addition, the speed prediction model was employed to examine the pedestrian side frictional influence in variations, showing that pedestrian movement is a critical element. This study generated the speed prediction model in which traffic flow speed that is exacerbated by additional pedestrian obstructions can be predicted by:

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

where V is the average speed (km/hr), n_{ped} is the number of pedestrians per minute, n_C, n_{2W}, n_{3W} are the number of cars, two-wheelers, and three-wheelers, respectively.

B. Speed Prediction Model for Stretches with Pedestrian Movement

In [12], a speed forecasting model was developed showing a 0.35Km/h reduction in speed for each additional pedestrian on the road per minute. Studies [2, 12, 52] investigated and analyzed how side friction variables affect travel time and capacity in urban environments, based on data obtained from numerous metropolitan regions, by performing macroscopic and microscopic analyses. These studies examined how every variable on side friction, such as pedestrians, bicycles, and stopped and parked vehicles, affected traffic flow, taking into account the distinct effects of each component. In [52], the relationship between various side friction parameters and the quality performance of traffic flow was investigated on different urban arterial roads, and the impact of varying side friction parameters on the speed-flow relationship was examined. This study delineated the study area roads based on the existence of extensive traffic flow situations using metrics such as the intensity of traffic flow, measured in volume/capacity ratio, traffic distribution based on direction, heterogeneous traffic scenarios, the proportion of heavy vehicles, and the extent of side friction. This study used ANOVA and regression models to determine the relationship between speed-flow and various side frictional characteristics and showed that side friction could affect speed and capacity. In [13], walking and crossing pedestrians were mixed with static roadside friction variables, such as vegetable markets, lay-bys, gas stations, mechanic shops, vulcanizing activities, and mini-marts, finding that T-junctions and bus stops are static features that contribute to traffic congestion. Static factors can be addressed by upgrading the geometric aspects of roads and this could increase the Level of Service (LOS). In [13-14, 29], road friction elements such as pedestrians, vehicles stopping on shoulders and highways, parking, and access to roadside premises were found on urban roads in Asian countries, and side friction classes were developed for urban and interurban roads based on the weights assigned to each side friction element.

C. Influence of Pedestrians Movement on Capacity

The studies [15-16] are among the few that attempted to determine the effect of pedestrian cross-traffic movement on the capacity of metropolitan roads, as shown in Table IV. A 30–37% decrease in capacity was observed as a result of pedestrian cross movements in [15], while a 32% decrease was discovered in [16]. In [17-18], empirical models that link the volume and capacity of pedestrian cross-traffic movement were presented, such as:

$$C = 1550e^{\frac{-(1.75x_7+4.24)x_2}{3600}} \quad (5)$$

where C is the capacity (veh/h), x_2 is the volume of pedestrian cross movement (ped/h), and x_7 is the percentage of drivers willing to give way to pedestrians.

TABLE IV. IMPACT OF PEDESTRIAN MOVEMENT ON CAPACITY

Reference	Ped-crossing volume	Capacity reduction
[4]	Upto 200 ped/h	No impact
[20]	200 ped/h	Negligible
[4]	1550 ped/h	32%
[1]	1550 ped/h	9%
[6]	1550 ped/h	20%
[7]	1550 ped/h	23%
[8]	1550 ped/h	25%
[12]	1550 ped/h	19%
[15]	1550 ped/h	27%
[17]	1550 ped/h	30–37%
[18]	1550 ped/h	32%
[19]	1550 ped/h	32%
[20]	1550 ped/h	33%
[21]	1550 ped/h	14%
[24]	1550 ped/h	11.05-60.73%

In [18], recommended techniques were employed to calculate the side friction factors. The area affected by pedestrian movement can be utilized as a quality variable to calculate Equivalent Pedestrian Units (EPU) for all activities other than walking and serves as a side friction parameter. A speed prediction model was developed to determine the relationship between traffic flow and the individuality of side friction characteristics. The Chi-square test was used to validate the model at the test site and the 14% RMSE test result showed that the predicted speeds were statistically significant. In [19], two urban and interurban arterial roads were surveyed. Various side friction parameters were investigated for urban roads, including pedestrian movement through highways (ped/h), pedestrians crossing highways (ped/h/km), vehicle stops concerning whether the vehicle was stopped on the shoulder or the highway, vehicle parking or unparking (veh/h/km), and vehicles entering or leaving the road. Additionally, several riding frictional factors were examined on interurban roads, such as the number of people walking through and crossing the road (ped/h/km). Furthermore, the study considered the number of vehicles stopping and parking maneuvers (veh/h/km), the number of vehicles entering or leaving the road premises, and the course of Slow Moving Vehicles (SMVs) (veh/h). After a detailed investigation, employing various parameters and providing their influence, the study showed that the free flow speed was reduced by a factor of 0.76 on interurban roads, and the capacity was reduced by 20%. Similarly, the rate on urban roads was reduced by 0.59. The study also improved the HDM-Q model for the prediction of speed and capacity with different side frictional characteristics. This study discussed several forms of roadside frictional parameters and their impact on urban road capacity, emphasizing the relationship between side frictional parameters, road capacity, and LOS. Studies [20, 21] showed that the decrease in the capacity of urban streets is influenced by the activity along the roadside and varies with the degree of side friction. Roadside activity, such as pedestrian movement, which is especially common in developing countries such as India, contributes to the loss of capacity on urban highways. In [13], static roadside friction factors were combined with pedestrians who were walking and crossing the street.

D. Influence of On-Street Parking on Vehicular Speed

On-street parking has primarily two effects on the capacity of a road. It initially narrows the highway by surrounding the traffic flow and vehicles squeeze into a smaller area slowing the streams, while frequent parking and unparking maneuvers complicate the problem, adding more congestion on the already congested metropolitan highways. These two effects of on-street parking ultimately reduce the capacity of metropolitan roads. The following subsections are devoted to presenting a range of findings on how and to what extent on-street parking affects the capacity of a road.

E. Reduction in the Average Speed due to the Presence of On-Street Parking on Urban Roads

The projected speed reduction due to on-street parking was reported to vary greatly, ranging from 15 to 44% or 5.1 to 21Km/h. This variation can be explained only by the existence of other elements that also significantly affect speed. Several studies investigated these variables and documented the way they alter the impact of on-street parking, as shown in Table V. In [28], it was found that larger roads were less likely to have side friction, in contrast to [6]. Several limitations apply to [6], as the roadside environment varied depending on the type of route, traffic data were collected over a brief period and there are some concerns about the sample size, the behavior of on-street parking was not explained, on-street parking was only taken into account as a categorical variable either as "presence" or "absence", there was no mathematical model to estimate this influence, and it was not evaluated with varied parking intensity. In [22], roadside parking occupancy was divided into three categories: (A) less than 30%, (B) 30-50%, and (C) 50-100% to address the problem, but there was no statistical difference between levels B and C on Free Flow Speed (FFS). Additionally, it was discovered that level A parking had little effect on FFS. Overall, the mean FFS of the streets without on-street parking was found to be 3.7kmph higher than the mean FFS of the streets with on-street parking up to 30% parking occupancy. As in previous investigations, the parking parameter was once again considered a categorical variable. Some recent studies investigated the variations in speed decrease throughout a wide range of parking intensity. In [23], the average speed was calculated at various volumes to capacity (v/c) levels, observing an almost steady decrease in speed with increasing parking density. This study noticed a pattern of definite speed increase at 75% parking density, but it was disregarded. In [30], the average speed and parking density were also related, finding a 13Km/h decrease in average speed for every 100 vehicles per Km increase in parking density.

TABLE V. IMPACT OF ON-STREET PARKING ON SPEED

Reference	Speed reduction
[6]	5.1km/h
[6]	32%
[10]	5.5km/h
[19]	36%
[43]	15%
[48]	22%
[49]	19%
[50]	27%
[51]	44%

In [31], a quadratic model was developed to describe the association between parking intensity and average FFS, but the study was unable to determine why FFS increased with parking intensity. In [1], the average speed *V* (km/h) was determined for two- and four-lane undivided urban roads as a function of *FLOW* (veh/h), carriageway width *CW* (m), shoulder width *SW* (m), and side friction *FRIC* separately. This study showed that there is a strong correlation between on-street parking and traffic congestion. Urban roads account for nearly 14% of all congestion incidents, with parked or parking-related maneuvering cars being the main causes [27].

$$\mathrm{V} = 79.6 - 0.008 \times \mathrm{Flow} - 0.028 \times \mathrm{FRIC} - 6.058 \times \mathrm{CW} + 11.8 \times \mathrm{SW} \quad (6)$$

$$\mathrm{V} = 46.465 - 0.015 \times \mathrm{Flow} - 0.011 \times \mathrm{FRIC} + 1.36 \times \mathrm{CW} + 5.393 \times \mathrm{SW} \quad (7)$$

where *V* is the average speed (km/h), *FLOW* is in lvu0/h, *CW* is carriageway width (m), *SW* is the shoulder width (m), and *FRIC* is side friction.

In [32, 41], simulation-based techniques were used to evaluate FFS on urban streets and show how, even at low densities, on-street parking can anticipate the change of traffic states from free to congested flow. A Monte Carlo simulation was run with a low traffic density to simulate a free-flow situation, finding that traffic volume significantly lowers when the proportion of parking maneuvers increases, as a 35% proportion of parking maneuvers can eventually cause a 35% reduction in capacity. Parked cars could be the sole source of congestion on urban roads if they are parked irregularly or carelessly. Even a very small number of vehicles might result in significant congestion if they are parked disruptively for an extended time. Additionally, even when every available spot is almost full, a sizable percentage of vehicles still prefer on-street parking, and instead of paying for off-street parking, they would rather continue looking until a spot opened up [4]. When these park-hunting vehicles are present in large numbers, they can significantly reduce both the capacity of urban roadways and stream transportation. Numerous studies investigated the capacity loss caused by on-street parking, and a significant capacity reduction of up to 90% was documented as a result of on-street parking. On-street parking is typically viewed as "missing" or "present", which is a common limitation of studies, while the effect of parking with varied capacity intensities has not been studied.

F. Decrease in Capacity Brought on by On-Street Parking on Urban Roadways

In [20-21], 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 a variety of factors, including roadside activity such as on-street parking, pedestrian movement, the presence of street vendors, a lack of lateral clearance and lane discipline, and diverse traffic, which is particularly prevalent in developing countries like India. In [53], a microscopic simulation model was developed to investigate the impact of bus stops on mixed traffic movement, focusing on reducing traffic flow rates. The model was validated by collecting traffic data at roadside bus stops and bus bays. 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 [20, 53]. In [10], 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 [21], three different side friction factors were used to conduct a survey and examine their impact on traffic quality performance: on-street parking, bus bay stops, and curbside bus stops. The results of 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. Due to the high percentage of heavy vehicles, this study used dynamic and static PCU values. As a result of using these two different types of PCU values, a 10-53% capacity reduction was observed in bus bays and bus stops and about 28-63% due to on-street parking. Authors in [1, 19, 24, 32, 52] investigated urban arterial roads, finding that parked and stopped vehicles act as frictional elements that majorly 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 the extensive analysis in [24-25], 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 21km/h. In [54], parking density was considered a side friction element, and after conducting a survey and analyzing the data, the results showed that parking density on urban arterial roads harms average traffic flow, with a decrease of around 13km/h for every 100 vehicles/km increase in parking density. In [12, 55], various types of roadside frictional activities on urban road links were examined, along with how these side frictional activities impact the speed and capacity of the urban roadway. Kerbside bus stops, bus bays, and on-street parking were some of the considered side frictional elements, and their impact on travel speed and reduction in capacity on urban arterial roads was investigated. The study concluded that the duration of the dwelling time of buses has an inverse impact on capacity, and more extended bus stops on the road act as interruptions for more extended time movement of traffic, affecting travel speed. In [34, 53] various types of side frictional activities were examined, using microscopic simulation models to evaluate how bus stops impact mixed traffic movement and its relation to the reduction in travel speed. In [24, 34], parked and stopped automobiles were studied, along wiuth various other factors. These studies showed that parked and stopped vehicles are critical side frictional elements, as they harm more the regular traffic flow, speed, capacity, and LOS than other side frictional factors, such as pedestrian movements, etc.

In [13-14, 29], T-junctions and bus stops were characterized as static features that contribute 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, such as pedestrians, vehicles stopping on shoulders and roads, parking, and access to roadside premises, were found along urban roads in Asian countries. Based on the weights assigned to each side friction element, side friction classes were developed for urban and interurban roads. In [35], motorcycle taxis were found to add another degree of friction when parking or loading and unloading passengers. In [13, 25, 35-37, 56], on-street parking produced a decrease in stream speed, ranging from 15 to 44% or 5.1 to 21km/h.

G. Non-Motorized Vehicles as a Side Frictional Parameter

All means of transportation that are not propelled by an engine or motor are referred to as Non-Motorized Transportation (NMT) or Non Motorized Vehicles (NMVs). While motorized vehicles are propelled by an engine, NMVs, including bicycles, e-rickshaws, cycle-rickshaws, hand-pulled vehicles, and animal carts, are propelled by humans or are dragged by animals.

H. Influence of Non-Motorized Vehicles on Vehicular Speed and Capacity

In [26], a 6-lane multi-directional road was investigated in Patna city and Pune city. Data were collected using videography to assess the speed variance in vehicle composition and traffic flow rate. This study presented a V-Q relationship for both sites, and variables of flow parameters at the mix flow level were acquired and correlated with the IRC standards. For each category, data on traffic characteristics, flow rate, peak hour factor, and spot speeds were reviewed. The results showed that the effective lane width in Patna city changed from 7.0 to 10.5m, resulting in a 57% capacity reduction and a 14% capacity decline due to the occurrence of NMVs, as shown in Table VI.

TABLE VI. IMPACT ON MNV ON SPEED & CAPACITY

Authors	NMV (%)	Capacity reduction (%)	Speed reduction in %
[2].	15-20%	55%	33%
[22]	14 %	57%	-
[48]	10%	-	20%

In [2], the influence of side friction on urban arterials was investigated. The authors examined numerous studies that characterized the effect of side friction in the decrease in urban arterial capacity, using NMV, passenger car unit, traffic, and shoulder activities as side friction parameters. The study concluded that the presence of side friction degrades the overall performance of traffic parameters, as an influence of NMT, up to 15-20% and reduced capacity and speed by 55% and 33%, respectively. Speed was identified as a critical issue affecting road capacity and LOS. This study showed that mixed traffic, composed of SMVs and NMVs, reduced the width of the effective road due to on-street parking, which acts as a barrier and reduces the road's qualitative performance. In [39], NMVs were also characterized as a source of side friction, and a speed model was proposed for this purpose, based on their ratio. According to the proposed model, a 10% rise in the NMV ratio would result in a 0.8mph (1.2kKm/h) reduction in average traffic flow speed. Furthermore, this study suggested including NMVs in the traffic volume classification because cycle rickshaws generate greater side friction than bicycles.

In [12], it was shown that when public transportation is poorly located or operates inefficiently, it forces the population to use their private vehicles, which causes an increase in heterogeneous traffic flow, slows down the speed of traffic flow, and increases travel time. The study showed that lateral clearance acts as a side friction activity on roads and affects the number of lanes in use and the average speed of vehicles. When traffic volumes are high, drivers tend to shift to the left lane more frequently, which means that the right lane is more likely to be affected by an obstruction. Road capacity and LOS may be affected by the narrowing of the roadway as the number of obstacles along the route increases [32]. Congestion and delays in traffic flow are often the result of poorly placed speed breakers, also known as "road friction" [52].

VII. DISCUSSION

This study examined the impact of various side frictional characteristics on the traffic performance of urban arterial roads, conducting a literature survey. The available literature was investigated under several constraints, such as various roadside activities which act as side frictional parameters and their impact on the traffic performance of urban roads. The side frictional parameters used in the literature are street vendors/traders, pedestrian crossings or moving along the road, NMTs including bicycles, on-street parking/stopping vehicles, land use, animal movement, and roadside accessibility. This study also focused on how various side friction parameters impact traffic performance, such as speed, capacity, and LOS. The considered studies were classified under different approaches, such as distribution by various side frictional parameters, impact on traffic performance, research methodology, and tools and techniques used for the analysis. These classifications identified various side friction parameters and examined their impacts. The side friction activities identified were NMV/NMT/SMV, pedestrian crossing, street vendors/traders, and on-street parking.

In [38, 48-51], NMT/NMV/SMV dominantly affected traffic performance among all side friction parameters, reducing speed (instantaneous, spot, travel, journey, running, time and space means), capacity, and LOS. These studies used speed prediction models, multiple linear regression models, Chi-square test, PV2 analyses, and Greenshields speed-flow model to evaluate these impacts, and the degree of correlation between NMV/NMT/SMV and traffic performance was identified. The NMVs were classified into various subcategories, using the proportions of NMVs, bicycles, cycle rickshaws, handcarts, and the percentage of NMVs traveling beyond 20% of the roadway width from the edge. The results showed that the correlation between N-3 and N-4 is the highest among all subcategories, while cycle rickshaws and handcarts impact traffic performance more than all NMV/NMT/SMV subcategories. All side friction elements have a direct impact on the traffic performance of urban arterial roads. The NMV parameters N-1 to N-3 and N-5 had a strong positive association. Increases in an individual or the aggregate NMV volume may increase their propensity to move away from the street's edge, resulting in a strong positive association between N-5 and N-1 to N-3. The NMV proportion of N-1 was chosen as the design variable because it had the strongest relationship with the output variable RC compared to the other NMV factors. As a result, N-1 NMVs significantly impact the arterial road capacity. Furthermore, there is a positive relationship between NMVs and on-street parking O-1 [51].

In [10, 16, 17, 19], pedestrian crossing was the second most impacting parameter on traffic performance of urban arterial roads. In [10, 27, 41], it was shown that side friction activities impact LOS. Based on the average delay per stop for any pedestrian crossing at the standard CFI geometries analyzed, the results showed an acceptable pedestrian LOS. Several criteria were related to pedestrian mobility within the roadway, which impacts urban road capacity. The effects of pedestrian crossings on capacity and the correlation value of pedestrian crossing on traffic performance were discovered. In increased pedestrian volumes, people tend to deviate away from the edge of the street, resulting in a strongly positive relationship. In [32], pedestrian volume was divided into pedestrian volume along the roadway and pedestrian cross volume.

On-street parking, legal or illegal, is the third most affecting parameter. This activity affects traffic congestion, which directly impacts LOS, reduces roadway width, and impacts traffic flow speed. The capacity of urban arterial roads decreases as parking maneuvers increase [13, 41-42]. In [11], a correlation was obtained between the available effective width and the capacity reduction percentage. The capacity decline was 3.37% at 2.95% reduction in effective width, and 26.08% at a 21.81% decrease in effective width. In [28, 43-45], on-street parking was correlated with traffic performance. On-street parking can be characterized by the following metrics: parking density O-1, effective parking width O-2, parking area O-3, number of parking maneuvers O-4, and number of unparking plots O-5. As all on-street parking metrics were found to have a substantial positive correlation (higher than 0.5), they aren't sufficiently independent to be used as integrated design variables. A choice of any parameter O-1 to O-5 can help in making a decision based on the correlation with RC, but O-2 is the best choice since it has the highest correlation with RC. The presence of street vendors and hawkers reduces road capacity, with delays that can exceed 30 minutes [46, 57].

VIII. CONCLUSION

This study critically reviewed the literature on three different side frictional parameters: NMV/NMT/SMV, pedestrian crossing, and on-street parking. The capacity of urban arterial highways decreases as the number of parking maneuvers increases. The effective width is connected with the capacity of a road. An increase in pedestrian volume walking along the road reduces road capacity. Similarly, the capacity of a road is reduced as the proportion of NMVs increases. Road capacity is reduced by 3.37% when the effective width of the road is reduced by 2.95%, while it is reduced by 26.08% when the effective width is reduced by 21.81%. Engineers can use the proposed models to estimate the section's capacity for any level of parking maneuvers in the traffic stream. Stretches with different side frictions and stretches with the combined effect of all components were tested for speed reduction. Side friction had a substantial impact on vehicle speed on urban roads and might also influence the extent to which individual elements influence speed. All traffic-related studies must include side friction factors for effective urban road planning. The capacity of the base and friction sections is determined using speed-volume data acquired from field data. Mathematically, there has been demonstrated that there is a link between pedestrian crossflow and capacity reduction. When the cross-flow of people is limited to 200pph, there is no influence on capacity, but when pedestrian cross-flow is increased to 1550pph, the capacity is reduced by 32%. The capacity figures in a segment that was only open to motorized traffic showed that a percentage of NMVs between 5-25% reduces the capacity of urban arterials by 3.60-35.82%. Rapid volume rises on a road result in congestion in traffic and time delays. LOS, vehicle speed, and capacity reduce while traffic volume and density increase before and after bus stops. Theoretical speed-volume curves are used to estimate the capacity, while the width of the road affects the base segment (PCU/h).

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