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EVALUATION OF TRAFFIC SIDE FRICTION OF THE URBAN ROAD NETWORK

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ABSTRACT
Many city streets in developing countries suffer from traffic congestion as a result of human activities on the sides of the roads. The current study is to investigate the main side friction factors affecting traffic performance. The research aims to determine the overall factors affecting traffic side friction based on the previous studies. The study concluded that the main factors affecting road congestion due to traffic side friction are: (pedestrian flow (walking+ crossing), vehicle stops and parking maneuver, vehicles entering and exiting roadside premises, and slow-moving vehicles). However, determining the level of importance of these factors depends on the nature of the site under ex traffic side friction examination and the data for the case study.

Keywords: human activities; pedestrian flow; vehicle stops; parking maneuver; side friction.

1. INTRODUCTION
Road transport acts as a backbone for all activities, especially in urban areas [1]. The road system has been essential to the economic activities of the world's most developed cities [2]. At the same time, urban form and structure can influence not only the spatial growth of settlements, but also social and economic developments [3]. However, there is either recurring or non-recurring traffic congestion. Recurring congestion refers to the typical daily occurrences in which congestion begins as a result of growing flow rates within insufficient freeway bottleneck sections. Non-recurring congestion refers to occurrences in which congestion begins for a variety of causes, for example a severe weather, special events, and roadwork Federal Highway Administration (FHA) [4]. On the other hand, Side Friction (SF) refers to variables that describe activities that occur on or near the travelled roadway [5]. The SF on a roadway may acts as bottleneck where the traffic flow found to be severely impeded. However, if the SF increases any road in urban areas could turn into a congested situation as a result of capacity reduction Highway Capacity Manual (HCM) [6]. In addition, there are many different SF parameters, which are as follows [7]:

- On-street parking: These activities decrease the capacity in different approaches. Firstly, it reduces the roadway width. Secondly, repeated parking and unparking maneuvers produce complicated scenarios that exacerbate congestions;
- Temporary stopping: When the vehicles stop for a short time in the carriageway, it may make a block in the traffic stream and on the other hand, reduce the width of the street, resulting in speed reduction;
- Entry-exit maneuvers: Vehicles that enter or exit the street usually move at slow speed, interfering with the traffic stream and may force the cars to slow down.
- Pedestrian: Drivers tend to shy away when the pedestrians walking along the carriageway, for ensuring a safe distance from the pedestrians [7]. However, in the design of cities and public spaces, the hierarchy of importance for users should be taken into account by offering continuous, connected, safe, visible and well-maintained paths and facilities for walking and different transport system [8].

Purohit et al. [9] considered SF to be one of the criteria that contribute to capacity decline. Furthermore, it is worth noting that SF primarily impacts undivided streets because divided streets are expected to be more regulated. Biswas and colleagues [7]. On the other hand, HCM [6] provided detailed rules for capacity calculations and Level of Service (LOS) based on vehicle speed and other variables. However, the HCM [6] adjustments variables for estimating capacity and LOS do not incorporate SF characteristics. Furthermore, a number of research on the impact of SF on urban streets have been discussed in the literature.

Rao et al. [10] in India, the effect of SF on street capacity was explored. The speed of segments with bus stop areas was reduced by 49-57%, and segments with on-street parking were reduced by 45-67%.

Chiguma [11] the impact of SF factors on traffic performance, such as speed and capacity, was investigated. A new Friction 'FRIC' nomenclature was devised to account for the combined influence of all SF variables. While Biswas et al. [7] investigated the effects of SF on the capacity of undivided streets in metropolitan regions. The SF was calculated using on-street parking, pedestrians, and Non-Motorized Vehicle (NMV). The capacity was reduced by approximately 60.73% due to the SF effects.

Munawar [12] compared the Indonesian Highway Capacity Manual (IHCM) [13] values to what was observed in the fields in Indonesia. The capacity trend had changed significantly at high SF values, as indicated by IHCM [13]. Referring to IHCM [13], Harison et al. [14] conducted a case study in India with the aim of assessing traffic performance by taking SF on roadways into consideration. Using VISSIM program, Irawati [15] showed that SF caused a delay on a road segment. While Guoo et al. [16] built simulation model to assess street parking impact on the effectiveness of the traffic flow and indicated that the capacity was reduced by 35%. In the same context, for assessing the relation among the parking intensity and the Free Flow Speed (FFS) Yusuf [17] developed a new mathematical model. The study could not, however, explain the initial increase of the speed to 29 parked vehicles.

Kadalii et al. [18] and Kuttaam et al. [19] tried to ascertain the effect of pedestrians crossing volume on urban roads capacity. About 30% to 37% reduction in the capacity was observed by Kadalii et al. [18], the reduction was due to the high pedestrian crossing volume while about 32% was found by Kuttaam et al. [19]. Two more researches (Baak and Kiiec [20], Dhmaniya and Chandraa [21]) established a statistical model for correlating divided urban arterials capacity with pedestrian crossing volume, as it is shown in Eqs (1) and (2),

$$C = 1550e^{-\frac{(1.75x_2+4.24)x_1}{3600}} \quad (1)$$

$$PRC = 11.09 + 0.025 \cdot x_1 - 8 \cdot 10^{-8} \cdot x_1^2 \quad (2)$$

where C is the capacity (vehicle per hour); PRC is the percent of reductions in capacity; x_1 is the pedestrians crossing volume (pedestrian per hour); x_2 is the percentages of driver willing for giving the way to pedestrian.

Referring to Baak and Kiiec [20], this impact was entirely controlled by drivers' tendencies to give a way to pedestrians, which differs significantly among countries depending on driving culture. In addition, a delay model was developed by Pu et al. [22]. It indicates that an increase of about 1000 bicycles within the traffic flow increases the delay by 33 seconds per kilometre. In urban streets, typically the SF parameters are found in combinations. Consequently, the traffic flow is affected by a combined SF effect rather than individuals. Even though the fact those studies take into consideration multiple SF factors when building a speed model, none of them studied the effects as a combination on the capacity of urban streets in both undivided and divided streets.

2. STUDIES RELATED TO CAPACITY OF URBAN ROADS

There are several methods available in the literature to estimate the capacity of urban roads. Few of them are direct empirical methods and few of them are indirect methods. The direct empirical methods are estimated based on headways, traffic volume, speed and density etc. The indirect empirical methods are estimated based on the values/procedures suggested by capacity manuals such as IRC (106:1990) [23], HCM [24] and based on simulation techniques. including uniformed and mixed traffic conditions. It has been found that common factors such as geometry, traffic flow and environment are found to be influencing on capacity of urban roads. The study also discovered numerous evidences that any sort of roadside friction is another element for distracting driving behavior and reducing road capacity, particularly in mixed traffic scenarios. The next sections give a review of a sufficient number of past studies relating to the current subject. Road friction is another element for distracting driving behavior and influencing road capacity, particularly in mixed traffic conditions. The sections that follow give a review of a sufficient number of past studies linked to the current study.

HOMOGENEOUS TRAFFIC CONDITIONS

A linear relationship was fitted between stream speed and traffic density and suggested a polynomial fit curve between stream speed and traffic flow. The maximum flow, free flow speed and jamming density of the given roadway are suggested based on relations established between variables.

The study concluded that the capacity of the roadway depends on the intercept and slope of the fitted curve between speed and flow data.

Sinha et al. [25] estimated the capacity of four lane urban roads in Thailand using speed- flow relationship. Six different roadway sections are considered for the data collection and estimated static PCU values for different vehicle types as observed in Thailand [26]. Capacity of sections determined in the study is based on speed-flow relationship. The study found that the increase in percentage of motorcycles increases the capacity of selected road sections.

HETEROGENEOUS TRAFFIC CONDITIONS

Sarna et al. [27] estimated capacity of urban arterial using field data collected from 24 locations of both divided and undivided roads in Delhi and Mumbai cities. The fundamental speed-flow relationship was used to determine capacity values. The capacity value for the sections selected in

Mumbai city is reported as 930PCU/hr./lane for 2-lane, 1450PCU/hr./lane for4-lane and 1950PCU/hr./lane, for 6-lane roads. The capacity values of roads in Delhi city are reported as 880pcu/hr./lane, 950pcu/hr./lane and 114300pcu/hr./lane for 2-lane, 4-lane and 6-lane roads respectively.

IRC (106:1990) [23] suggests design service volumes all categories of urban roads such as arterials, sub arterials and collector streets. The guideline suggests, LOS C should be maintained on urban roads for better throughput and capacity. At LOS C, traffic volume is equal to 0.70 times the capacity which is known as design service volume.

Chandra and Prasad [28] estimated the capacity of multilane divided urban roads in India. The capacity values obtained from the field found to be quite higher (within the range of 28003000pcu/hr./lane) when compared to Korean Highway Capacity Manual and Indonesian Capacity Manual values. This is due to the presence of higher proportions of two wheelers in traffic composition. For every 10% increment in proportion of two-wheelers resulted in 9% increment in capacity of the urban roads. Arasan and Krishnamurthy [29] estimated the capacity of four lane urban roads in India using simulation approach. Field data collected on four lane urban roads was used as inputs for the simulation runs. The simulation model 'Heterosim' was used for simulating all cars traffic conditions and determined the capacity as 3250pcu/hr. for a width of 7.5m simulated section.

Patel and Joshi [30] studied capacity and LOS of the urban arterials under mixed traffic conditions. Field data was collected on six-lane urban arterial road in Surat city, India. The study established speed-volume relationship using field data. To obtain unobserved data for determining capacity, artificial neural network (ANN) technique was used for completing speed volume curve. The speed flow curve was divided into four regimes based on the traffic conditions two in free-flow and two in congested flow conditions. Different equations are proposed for each regime based on the relationship between speed and volume. Capacity estimated for the section based on the multi-regime modelling concept is 2480 vehicles per lane in one direction of travel. Further, LOS has been studied for the existing multi-regime capacity curve based on V/C ratio as threshold value. The division of LOS into different levels are done using K-means algorithm and is classified into 6 different LOS categories from A to F.

Dhamaniya and Chandra [31] analysed the speed characteristics of mixed traffic flow conditions on urban arterial roads. Different sections of four and six lane sections of in three metropolitan cities are considered for data collection. The analysis of speed distribution was carried out for individual vehicle type and for mixed traffic stream by establishing speed profiles. It is found that the speed data is following normal distribution in case of individual vehicle types but failed to fit for the mixed traffic. Therefore, authors estimated Speed Spread Ratio (SSR) to know the distribution of the speed data. The authors stated that speed data.

Biswas et al. [7] on urban roadways with mixed traffic, an artificial neural network-based speed prediction model was developed. In New Delhi, India, field data was collected on six-lane split mid-block road sections. In the absence of side friction elements, a speed model was created utilizing an ANN technique with traffic volume as an input variable and speed as an output variable. The anticipated speed values are compared to the existing models, which include the volume-based regression model and the density-based regression model. The suggested volume-based ANN model performs well for each vehicle category, according to the results.

2. STUDIES ON SIDE FRICTION

Side friction is a variable that represents actions that occur on or near the path of movement. The following are some examples of side friction activities: Vehicles stopping to pick up and drop off passengers, pedestrians crossing or moving along the roadside, non-motorized and slow-moving vehicles, on-street/road parking, vehicle maneuvers entering or exiting the traffic stream, wrong-way movements, and other roadside friction activities [5]. Roadside frictions are a result of increased vehicle density and limited urban road space. Roadside friction activities that disrupt traffic flow are common on urban highways in developing nations. [2]. In addition, certain road side-friction parameters are as follows [7]

- **On-street parking:** These activities decrease the capacity in two major ways. Firstly, it reduces the carriageway width by restraining the traffic flow. Thus, vehicles are compelled to maneuver into this narrower path, reducing the stream's speed. Secondly, frequent parking and un parking maneuvers create complex scenarios that cause congestion in congested urban streets.
- **Pedestrian:** Drivers like to slow down at undesignated midblock crossings for the safety of pedestrians. The overall stream speed reduces greatly as the pedestrian cross-volume climbs significantly. When pedestrians use the roadway while strolling down the road, cars prefer to back up to ensure a safe lateral distance from the walkers.
- **Wrong-way movements:** when there are a lot of vehicles countering the regular traffic stream, the driver tends to stop or reduce their speeds to avoid collision or conflict.
- **Temporary stopping:** when the vehicles stop for a short time in the carriageway, it may make a block in the street stream and, on the other hand, reduce the width of the street, resulting in speed reduction.
- **Entry-exit maneuvers:** vehicles entering or exiting the street normally travel slowly, interfering with traffic flow and causing motorists to slow down to avoid this vehicle.

Side friction is an important factor to consider when analyzing urban road capacity. It is worth noting that side friction is more common on undivided metropolitan streets. Because divided arterials are likely to be more controlled, with less opportunity for such actions [7]. The influence of side friction components on traffic flow varies depending on where they are on the road (on the side or in the center).

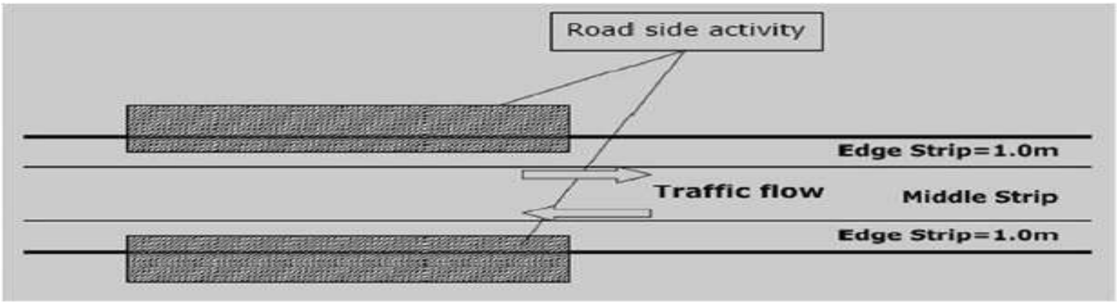

Figure 1 Details of edge and middle strip marked on the carriageway **(Pal and Roy, 2016). [33]**

The HCM clearly considers the roadside environment and the resulting traffic friction to be necessary, as they and their effects are discussed in general terms in several sections of the manual; for example, it is acknowledged that the "development environment has been found to affect the performance of multilane highways." These effects are often included intuitively into the highway classification system. Friction's effects are not explicitly quantified or directly referenced. However, the manual indirectly addresses the roadside environment by categorizing various facilities: Free-Flow Speed (FFS) is reduced for 'basic highway portions' if the shoulder's lateral clearance falls below the base standard of 1.8 m. This means that if there are items on the roadside or in the median that are closer than 1.8m from the road edge, the lateral clearance is reduced. The lateral clearance adjustment factors are provided in Table 2, and the greatest lateral clearance effect is reflected by an adjustment factor of 8.7 km/hr (reduction in FFS) for normal lanes with impediment at the carriageway edge of a four-lane (dual two-lane) highway.

Table 1 Adjustment for Lateral Clearance (HCM, 2000).

Four-lane highways		**Six-lane highways**	
LC (m)	FFS Reduction (km/hr)	LC (m)	FFS Reduction (km/hr)
3.60	0.00	3.60	0.00
3.00	0.60	3.00	0.60
2.40	1.50	2.40	1.50
1.80	2.10	1.80	2.10
1.20	3.00	1.20	2.70
0.60	5.80	0.60	4.50
0.00	8.70	0.00	6.30

HCM also observes that the level of traffic interference changes greatly depending on the 'development context,' which refers to the type and density of land use development. This is easily addressed by designating the facility as 'rural,' 'low-density suburban,' or 'high-density suburban.' There is no further quantification or explanation, and no direct sources are provided. HCM also understands that roadside construction on urban and suburban arterials (those with signals less than two miles apart) can be extensive, resulting in 'frictions' that limit drivers' speed choices. Parking, pedestrian circulation, and 'city population' have all been highlighted as factors influencing performance. Frictional effects are addressed by first categorizing arterials into functional and design-based types, as discussed earlier in this chapter. This classification involves friction indirectly through the degree of access control and frontage development [11].

A. LEVELS OF SIDE FRICTION

Side friction is graded based on average stream speed fluctuations and the amount of reduction caused; side friction levels are classified from very high to very low according to the Indonesian Highway Capacity Manual

(IHCM). At the most basic level, there is no discernible effect on average speed. Simultaneously, there is a large drop at very high side friction levels.

The Classification of side friction levels based on IHCM [32] is given in Table 6. Also, Chiguma [11] the observed FRIC data, along with their corresponding speed and flow data, were rearranged in ascending order and divided into three equal percentiles, with the upper, middle, and bottom percentiles representing low, medium, and high FRIC-levels, respectively.

Table 2 SF classes (IHCM, 1997).

SF Levels	Codes	SF events/hr.	Land-use conditions
Very-low	V-L	0-100	Residential location, no activities
Low	L	100-300	Residential location, in forms of public transportation.
Medium	M	301-500	Commercial location, very-high roadsides activities
High	H	501-900	Industrial location, many shops on the roadsides
Very- high	V-H	> 900	Commercial location, markets activities besides the roads

The Roadside Friction Index (RSFI) is calculated by multiplying the number of side friction elements by their weight. RSFI estimates took into account a number of roadside friction components. Among the items considered were pedestrian crossings, bicycles, and automobiles parked on the side of the road, whether permanently or temporarily. As shown in Eq 3, all of these elements were multiplied by a separate weight factor assigned to each element based on the severity of its effect on traffic characteristics **[33]**.

$$PSFIr = \sum_{i=1}^{n} WiXNi \qquad 3$$

Where:

RSFI = Road Side Friction Index

Ni = Number of (i) type friction elements in 100m road stretch

Wi = Weight factor for (i) type roadside friction parameter

Bang [35] developed a new unit called 'FRIC' that accounts for the weighted sum of side friction occurrences. It is later used to specify the side friction class for a specific route. He discovered a significant impact of side friction on traffic performance indicators such as speed and capacity and compared the results using the software Highway Design Maintenance Model (HDM-Q).

Chiguma [11] regression analysis was used to calculate weighting factors for various side friction activities. The term 'FRIC' was coined as a unit of measurement for side friction. The FRIC was calculated using the combined weighted side friction factors. As shown in Eq 4, side friction 'FRIC' was further modeled using four elements: pedestrian crossflow 'PED,' bicycle volume 'BIC,' non-motorized traffic volume 'NMV,' and parking and stopping vehicles 'PSV'. All of these variables were combined into a single unit of 'number/200 m/h'.

$$FEIC = PED + 0.45 * BIC + 0.08 * NMV + 0.37PSV \qquad .4$$

Where,

FRIC= Friction

PED= Pedestrians (No/200m/hr)

BIC=Bicycles (No/200m/hr)

NMV=Non-Motorized Vehicles (No./200m/hr)

PSV= the Parking and Stopping Vehicles (No/200m/hr)

Gulivindala [34] a model was proposed to assess the average stream speed with side friction and volume influence on the section of road. The quantification of side friction events has not previously been done by considering parked vehicles in terms of an equal number of pedestrians and pedestrians as one unit and other dynamic activities, i.e., entry-exit of vehicles from surroundings, and wrong way movements as individual parameters to estimate side friction. All halted cars' frequencies were converted and added to the frequency of pedestrians recorded in the field. Eq 5 calculates the Pedestrian Equivalency Unit (PEU) by transforming all stopped cars into the same number of pedestrians. To convert the vehicles, the PEU is multiplied by the frequency of incidents.

$$PEUI = \frac{PAi}{PAP} \qquad 5$$

Where:

The pedestrian equivalency unit of the subject vehicle is PEUi, while the projected area of the subject vehicle is PAi.

PAp: the pedestrian's predicted area

The overall static side friction frequency in terms of PSPU (events/hr) estimated using Eq 6 is calculated by adding the number of pedestrian events and stopped automobiles.

$$NPSPU = Np + \sum(PEUiXNi) \qquad 6$$

Where:

The frequency of pedestrians is NP, the pedestrian equivalency unit of the subject vehicle is PEUi, and the frequency of the subject vehicle is Ni.

Vehicle entry-exit movement and incorrect vehicle movement are moving activities that lead to side friction on the road. Side friction (SF) was determined by measuring the weighting factors of the events recorded along the road, as shown in Eq 7.

$$SF = (RW1XNPSPU) + (RW2XNEE) + (RW3XNWM) \qquad 7$$

Where,

NPSPU stands for the number of pedestrians and parked vehicles per equivalent pedestrian unit.

NEE: The number of entry-exit vehicles.

RW: The relative weights of each activity type and NWM: The frequency of improper movement vehicles

B. THE INFLUENCE OF SIDE-FRICTION ON CAPACITY

Various friction elements have different impacts on travel speed and capacity based on their static and dynamic characteristics and their position on the carriageway **[33].** Arterial streets in many developing countries display deterioration in capacity and weak operational performance. Therefore, Side friction is a necessary component to be considered in the capacity analysis of urban streets [10]**.** This roadside friction, along with varied traffic conditions, has a negative impact on the capacity of urban roads and poses a major threat to road users' safety. Traffic engineers face a difficult problem in quantifying these side friction variables. They have an impact on the speed flow characteristics, restrict road capacity, and endanger the safety of commuters and other road users **[2]**.

Bang [35] The effect of side friction on the speed-flow relationship on rural Indonesian highways was investigated. The study used regression analysis to determine relative weights, with space mean speed as a dependent variable and side friction parameters as independent variables. The study's findings were incorporated into the preparation of the Indonesian Highway Capacity Manual. It was discovered that when the level of side friction rose, the capacity value decreased. Furthermore, geometric design and pavement care management are viewed as influencing elements for increasing side friction and, as a result, reducing roadway speed and capacity. The weighting factors applied by the to various friction aspects. IHCM, [13] estimated relative weight for different friction elements for the urban roads and interurban roads as given in Table 3

Table 3 Relative Weights for Different Friction Elements (IHCM, 1995).

Event Type	**Code**	**Relative Weight**	
		Urban Roads	Interurban Roads
Pedestrian Flow (Walking+ Crossing)	PED	0.5	0.6
Vehicle Stops And Parking Maneuver	PSV	1.0	0.8
Vehicles Entering and Exiting Roadside Premises	EEV	0.7	1.0
Slow-Moving Vehicles	SMV	0.4	0.4

Heshen [35] developed a methodology to estimate the capacity of roads and intersections in China regarding side-friction factors. Field data were collected on 144 interurban and township road links to estimate PCU values and free flow speeds. The data is used for developing speed-flow density relationships for all roads. Eq 8 shows the relation for estimating the capacity.

$$C = COXFCCWXFCSPXFCSF \qquad 8$$

Where C: denotes the capacity (PCU/hr).

Co: is the starting capacity (PCU/hr).

FCCW: is the carriageway width adjustment factor. FCSP is the directional split adjustment factor, and FCSF is the side friction adjustment factor.

Munawar [12] the influence of side friction activities on speed and capacity on Indonesian roads was investigated, and the results were compared to IHCM (1997) capacity criteria. To assess the speed and capacity of the roadways, a multiple regression model is created. As independent parameters, side friction elements such as pedestrian mobility, on-street parking, the number of heavy vehicles, entry-exit vehicles, and stopped vehicles were examined. The study revealed that increased levels of side friction resulted in a considerable drop in stream speed. Additionally, parked/stopped vehicles and pedestrian movements have been seen to have a substantial impact on the speed and capacity of the roads.

Chand et al [36] the capacity loss on urban arterials owing to the presence of curbside bus stops was assessed. Field data were collected on seven sections of 6- lane-divided urban arterial roads in New Delhi. The study was performed with roadway sections with and without bus-stop locations. From the field data, the speed-flow relationship was developed, and capacity was estimated for both of the cases. The capacity estimated for the base condition i.e. without any side friction was 6314pcu/hr. The reduction in the base capacity was observed as 8 to 13% compared to the capacity of the sections with bus stops.

Rao et al. [10] the impact of side friction on capacity in the Indian capital was investigated. They discovered that the average speed of automobiles was reduced by 49-57% in portions with bus stop locations and 45-67% in segments with on-street parking. Furthermore, this study found that the severity of the impact of the side friction elements is affected by the volume of vehicles on the road. The influence of the side friction elements is at its lowest at low traffic volumes and at its highest at high traffic volumes and when the road speed reaches the lower free-flow speed.

Golakiya et al. [37] investigated the effect of a pedestrian crossing on capacity in urban mid-block areas. The authors investigated the capacities with and without pedestrian cross flow at 22 urban mid-block sections and found that while the pedestrian flow is up to 220 pph, there is no drop in capacity and a 32% reduction when the flow exceeds 1,550 pph.

Walaa [38] in Baghdad, researchers investigated the impact of side friction on speed and capacity. The data collected from study sites were spot speed, traffic volume, and side friction element values. The regression analysis was the main method used in the statistical analysis part by using the program SPSS Ver.26. The three main traffic relationships (speed-density-flow) are plotted for all the studied sites. The field free-flow speed was also extracted and compared with the empirical value, and the maximum difference percentage result in FFS to 29.13% in Palestine Street. The percentage reduction in capacity figures show that Palestine Street; Zayouna Region has the highest result, which was 33.92%. The combined side friction was not used in this study's analysis. Instead of assigning a weight to each element's influence on each site, they used the friction elements individually, which resulted in a hazy comprehension of the side friction effects.

C. IMPACT OF SIDE FRICTION ON SPEED

Aronsson [39] the speed characteristics of urban streets/roads were investigated. The impact of traffic flow on other road users was simulated at the macro and micro levels. Vehicle speed profiles were obtained in the field, and several variables impacting traffic flows from the several metropolitan streets analyzed were discovered. Traffic flow, pedestrians, bicycle activity, buses approaching and exiting the bus stop, and on-road/street parking were recognized as major influences. The microscopic simulation model was changed and certain behavioral traffic features were introduced. The results of the macro study revealed that the variable reduced speed by 1 to 6 km/hr, while the results of the microanalysis suggested a speed reduction of 1 to 4 km/hr.

Munawar [12] The Indonesian (IHCM) formula projected speed and actual observed speed in the Indonesian city of Yogyakarta during peak hours were compared. When side friction was substantial, the investigation discovered a considerable disparity between the speed predicted by the IHCM formular/standard and the observed vehicle speed and road capacity. The findings revealed that the values obtained for road capacity and vehicular speed in IHCM are consistent with a vast population of data collection sites. As a result, the study stated that additional research is required to include all of the elements excluded from the IHCM formula in order to improve the IHCM model and provide a fair comparison with actual observed speed.

D. IMPACT OF SIDE FRICTION ON LOS

Roadside friction (RSF) elements have become a major source of congestion and poor traffic operation in developing-country urban and rural road networks [2]; [14]; [33]). Many urban roads in developing nations have low levels of service (LOS) and thus poor performance as a result of certain activities on and alongside roadways [10]. Similarly:

(Pal and Roy) [33] The impact of side friction on travel speed and LOS on Indian rural roadways was quantified. As study portions, mid-block parts of three rural roadways near Kolkata were chosen. The presence of pedestrians, cyclists, and van-rikshaws on the carriageway is considered a friction feature in market districts, producing resistance through traffic movements. A trained enumerator collected classified traffic volume data, spot speed, and friction data (numbers of friction elements on the carriageway) during a field study. Speed-flow graphs were created for both the outside and inside of the market area scenarios. The impact of side friction on level of service (LOS) criteria was explored. The study's findings will assist policymakers in making decisions on stricter laws restricting the establishment of such roadside market areas and creating greater allowances for service roads and off-street market sites.

Bitangaza and Bwire [40] collected data from Kigali, Rwanda to investigate the impact of dynamic friction factors on vehicle performance on roads. The characteristics deemed affected in the study were speed and degree of service. Vehicle speed, road condition, and roadside items were among the data obtained. The data collection is regarded the busiest road in Kigali, the country's capital. The ANOVA analysis was used to determine the effect of roadside friction on speed and level of service. In addition, the dynamic nature of elements that generate roadside friction was taken into account when developing the relationship between speed, density, and flow. The report suggests establishing standards for motor traffic flow and limits in order to reduce or eliminate the ongoing increase of roadside friction throughout Kigali and beyond.

4. STUDIES RELATED ESTIMATION OF PCU

Vehicle, roadway, and environmental factors are thought to have a substantial impact on the PCUs of different vehicle types in both uniformed and mixed traffic scenarios. In previous research, different approaches for measuring PCU values on various highways and urban road sections were used, including the headway method, the homogeneous coefficient method (Permanent International Association of Road Congress (PIARC), and the walker's method [41]. multiple linear regression method [42], Huber method [43] and speed based method [7] These methods are proposed by collecting field data on various highways and urban roads using single or combination of parameters included flow rate,density [44], headway [45], volume to capacity ratio [46], average speed [42]; delay (Cunagin and Messer, 1983[47], size of vehicle types [48]. Recently, there are studies that proposed to estimat PCU based on area occupancy [49], time occupancy [50], level of service [51], effective area [52] and directional split [53]. Few of the studies that are carried out on homogeneous and heterogeneous traffic conditions are explained here.

HOMOGENEOUS TRAFFIC CONDITIONS

Huber [43] used the average travel time measure to estimate PCU of vehicle types under free flow conditions on multilane highways. The study compared the PCU values of two. different traffic streams such as a stream with trucks on one stream and with passenger cars only. It is found that the influence of slow moving vehicles have negligible effect at lower levels of traffic volume. However, increase in the volume levels increases interaction between the vehicles that results in increase in the PCU values of vehicles types such as truck. Equation (9) shows the estimation of PCU by Huber.

$$PCU = \left(\frac{1}{P}\right)\left[\frac{qb}{qm} - 1\right] + 1 \qquad 9$$

where, PCU is the passenger car unit, P is the proportion of trucks, q_b and q_m are the flow rates of base and mixed traffic conditions at common LOS.

Aerde and Yager [42] estimated PCU values of vehicle types based on relative speed of speed reduction for two lane highways. The study developed a methodology which involved multiple linear regression analysis to estimate the free speed of vehicle types and their corresponding speed reduction coefficients. The PCU of vehicle type is determined by calculating the ratio of coefficients of the subject vehicle types to the passenger car. Krammes and Crowley [54] used field data to estimate PCU value of trucks on urban freeways. PCUs were determined based on three approaches namely V/C ratio, equal density, and spatial headway. As the truck's physical size is larger than size of passenger cars, their impact is more on the nearby vehicles which leads to significance of position of trucks in the traffic stream. Therefore, actual position based on the headway analysis is an important parameter in estimating the PCU value which is carried out by the spatial headway approach. The authors compared the three methods and concluded that the spatial headway approach as the most appropriate approach in case of urban freeway.

Tanaboriboon and Aryal [55] estimated PCE factors based on the time headway observed between medium and large sized vehicles in Thailand. The study categorized size of the vehicles into small, medium and large and used reciprocal of time headway to estimate capacity value. It was observed that the medium sized vehicles did not influence the roadway capacity significantly. Finally, study concluded that the presence of large sized (trucks and buses) vehicles in large amount leads to increase in the headways between the other vehicles following it in the traffic stream causing a reduction in their PCU values.

Fan [46] estimated PCU of vehicle types using multiple linear regression technique for Singapore expressway. Traffic volume and speed data were collected from field using video recording method. The traffic volume is collected for 15-minute interval when v/c ratio is more than 0.7 only. The traffic flow rate was taken as independent variable in the regression equation. The PCU value of motor cycles was obtained as 0.4 which is lesser than 0.75 formerly used in Britain. And, the PCU values of light trucks, heavy trucks and buses were obtained as 1.3, 2.6 and 2.7 respectively those are found to be more than the values used in the countries US and Europe. The study concluded that the smaller size vehicles have lesser effect on the traffic in compared to bigger size vehicles.

Al-Kaisy et al [56] estimated PCU values of heavy vehicle type on both freeways and highways during the congestion. The study used both empirical data and simulation data generated by INTEGRATION tool for the estimation of PCU values. PCU values were analysed with different grades of the terrain during congestion. It is concluded that the PCU values were showing increasing trend with increase in magnitude of the grade percentage and length.

Rahman and Nakumara [57] proposed an equation to estimate PCU of non-motorized vehicles based on the speed data collected on urban mid-block sections in Dhaka city of Bangladesh. The study estimated speed ratio of the passenger cars to non-motorized vehicles under base and mixed traffic flow conditions. It is found that the average speed of the passenger car reduced significantly due to the presence of rickshaws in mixed traffic conditions. Equation (10) shows the expression to estimate PCU values of non-motorized vehicles.

$$PCUnmy = 1 + \frac{Sb - Sm}{SB} \qquad 10$$

where, PCU_{NMV} is the PCU of non-motorised vehicles, S_b is the average speed of passenger cars in base traffic flow conditions and S_m is the average speed of passenger cars in mixed traffic flow conditions. Figure 4 and Figure 5 shows the variation of PCU of rickshaws with flow rate and proportion of vehicles.

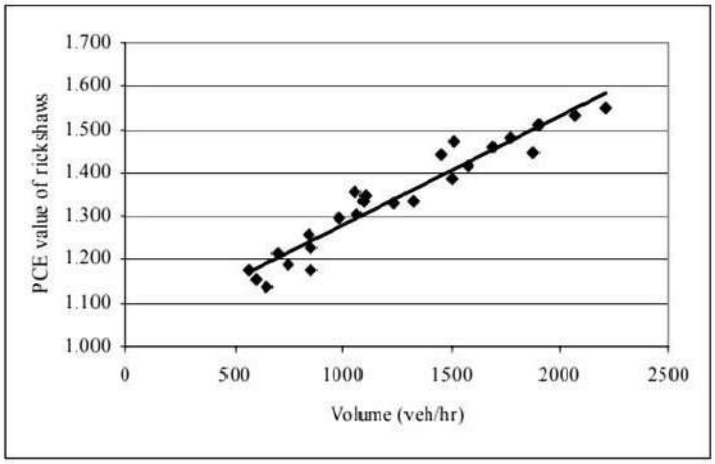

Figure 2 Variation of PCU of rickshaws and flow rate

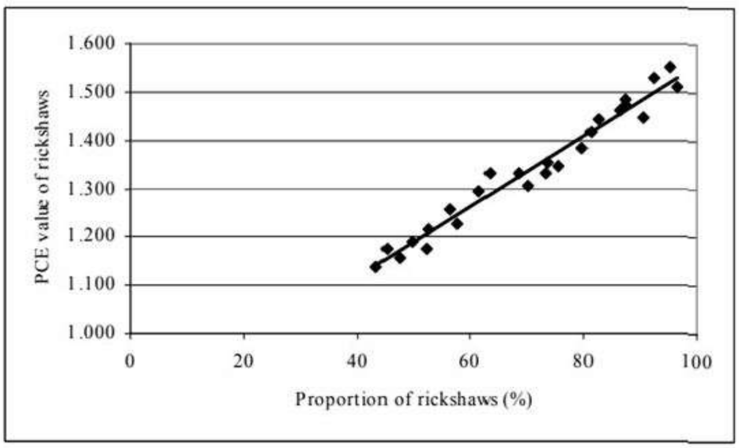

Figure3 Variation of PCU of rickshaws and its proportion

It is observed that PCU values of rickshaws increased with increase in flow rate and proportion of rickshaws. This is due to the increase in the speed difference between passenger cars and rickshaws at higher percentage.

Heterogeneous traffic conditions

Ramanayya [58] estimated PCU value of vehicle types namely motorized two-wheeler, truck and tractor-trailer on two-lane roadway sections through traffic simulation model i.e.

MORTAB (Model for depicting Road Traffic Behavior), developed for mixed traffic conditions. The study proposed PCU values of vehicle types based on proportional share of slow moving vehicles in terms of equivalent design vehicle units at different levels of service. As the LOS decreasing from A to C, the PCU of vehicle types were showing decreasing trend.

Indian Roads Congress (IRC 106: 1990) provided static PCU values of vehicle types based on traffic composition of the vehicle categories. PCU values were suggested based on the proportion of vehicles in the traffic stream. Table 4 gives the PCU values of the vehicle categories for Indian urban roads based on traffic composition.

Table 4 PCU values of different vehicle types (IRC 106: 1990)

Vehicle type	Equivalent PCU factors	
	Composition (%)	
	5%	10% and above
	Fast vehicle	
Two wheelers, motor cycle etc.	0.5	0.75
Passenger car, Pickup van	1.0	1.0
Auto-rickshaw	1.2	2.0
Light commercial vehicle	1.4	2.0
Truck or Bus	2.2	3.7
Agricultural tractor trailer	4.0	5.0
	Slow vehicle	
cycle	0.4	0.5
Cycle rickshaw	1.5	2.0
Tonga (Horse drawn vehicle)	1.5	2.0
Hand cart	2.0	3.0

Chandra et al. [59] derived a methodology to estimate PCU of vehicle types on the basis of space requirement of the vehicles. A mathematical equation to estimate the PCU of vehicle types is proposed. PCU of a vehicle type is calculated as shown in Equation (11)

$$PCU1 = \frac{VcVi}{Ac/Ai} \qquad 11$$

where, V_c and V_i are mean speed of the vehicle type car and subject vehicle type 'i' and A_c and A_i are projected area of the vehicle type car and subject vehicle type 'i'.

Chandra et al [59] estimated PCUs using different methods available in literature based on field data collected on two-lane highway in India. These methods include Walker's method, headway ratio method, homogenization coefficient method, multiple-linear regression method, and simultaneous equation method. Study compared all PCU methods and concluded that PCU values of vehicle types depend on the method of estimation used for particular traffic conditions.

Mallikarjuna and Rao [10] The PCU of vehicle types bus, truck, and motorized two-wheeler was evaluated using simulation techniques. The area occupancy method was used to calculate the PCU values. According to the study, when the proportion of vehicles increased, the PCU values of the vehicles decreased, regardless of the size of the vehicle types. Aggarwal (2008) [60] developed Fuzzy based model to estimate the PCU of Bus on highways. The study estimated PCU values by taking different carriageway and traffic characteristics such as width, type, conditions of shoulder, directional split and traffic composition and percentage of slow moving traffic. The study compared the results with the previous study available in the literature on PCU and concluded that the estimated PCUs are highly accurate.

Paul and Sarkar [61] estimated PCU values of several vehicle classifications on New Delhi, India's metropolitan roads. To estimate PCU values, the study used the dynamic PCU approach proposed by Chandra et al. [59]. For estimating PCU, the approach was modified by advocating the use of influencing area rather than predicted area of vehicles. The impact of the proportion of heavy vehicles and nonmotorized vehicles on various vehicle types is investigated. It has been discovered that as the fraction of heavy vehicles increases, the PCU of two wheelers decreases, but as the proportion of nonmotorized vehicles increases, the PCU of two wheelers falls. In the case of bus category PCU values, the situation is reversed. It was also discovered that the PCU of three-wheelers did not vary.

Mehar et al. [51] estimated PCU values of different vehicle types at different level of service on multilane highways in India. The study used simulation tool VISSIM to generate the speed and traffic volume based on field collected the data. With the generated data, speed- flow curves were drawn for traffic with cars and one more vehicle category from the available vehicle categories. The proportion of the other categories varied to analyses its influence on PCU values. It is concluded that with the increase in volume to capacity ratio, PCU of vehicle type decreases. The study suggested PCU values of vehicle types for four and six lane divided highways at different levels of service and traffic composition. Srikanth and Mehar [62] compared ANFIS, ANN and MLR methods by estimating PCU values using field data. The authors stated that the ANFIS is predicting PCU of vehicle types very accurately with the minimal root mean square error in comparison to the other two methods used in the study.

Pooja et al [63] in mixed traffic conditions, computed dynamic PCU values of vehicle types under the effect of nearby vehicles. Data obtained from two-lane undivided and four-lane metropolitan roadways in India are used to estimate PCU values. Vehicle PCU values were computed by taking the effective area and speed for six cases, taking into account the subject vehicle, adjacent vehicle, and leader vehicle. The PCU values of two-lane undivided highways are found to be greater than the PCU values of four-lane divided roads.

Pooja et al [63] also provided a detailed review of literature on PCU considering all types of roadway links and intersections. The study emphasized the influence of neighboring vehicle types on PCUs under six different traffic scenarios and suggested the use of effective area of vehicle types instead of projected area. The study also addressed a need for incorporating the effect of side frictions in determining PCU of vehicles.

5. STUDIES RELATED TO GIS

Jatisankar Bandyopadhyay, Indrajit Samanta, and Bijay Halder, [69] In this post, will look at the issue of traffic congestion in Midnapore. Midnapore municipality is one of the rising cities in West Midnapore, with a high rate of population growth, an increase in motorized transportation, and increased traffic congestion. The bulk of Midnapore's major crossroads are severely congested. Due to illegal parking and pavement encroachment, as well as inadequately designed road barriers, road widening area has been limited. Some of the causes of traffic congestion include a large number of on-road customized vehicles, two-wheelers, and automobiles, a problem with the traffic signaling system and traffic diversion, the size and weight of the car, the unscientific construction of the speed breaker, and the difficulty with the size and weight of the car.

Juan Salazar-Carrillo, Miguel Torres-Ruiz, Clodoveu A. Davis Jr., Rolando Quintero, Marco

Moreno-Ibarra and Giovanni Guzmán, [70] presented a method for geocoding traffic-related events collected on Twitter and discusses how to use the geocoded data to create a training dataset, use the Support Vector Machine approach, and build a prediction model. This method employs a spatiotemporal analysis to generate spatial data on traffic congestions. Furthermore, it is suggested that a Web-GIS application use a geographical distribution depicted by heat maps to describe the traffic pattern of specific and detected Mexico City locales.

Yasmany García-Ramírez, [71] Calibrate the equations for key parameters using Google traffic state indicators and compare them to real-world data. Six density-flow equations and six speed density equations were calibrated and some of them confirmed using power and linear curve. Other cities can use these equations to develop their own traffic congestion models. Drivers can use this model to plan their travels, choose the best routes to use during periods of low traffic, or use public transportation to travel, decongesting the city and lowering associated transportation costs. This comprehensive study broadens our understanding of how Google traffic data could be used in emerging cities. Kaisar alam sarkar [72] a method for efficiently identifying spatiotemporal patterns of traffic congestion at the network level was presented. The Metro Atlanta roadway system was used as a case study. The real-time traffic figures were provided by the Georgia Department of Transportation (GDOT) Navigator system. For a qualitative analysis, speed data was separated into three levels: low, middle, and high. Cluster analysis was performed on the classified speed data in the spatiotemporal domain to establish where, when, and for how long congestion occurred, as well as for how long, which indicates the severity of congestion.

This qualitative investigation was conducted each day of the week to identify any potential differences in congestion between weekdays and weekends. To highlight congestion patterns at a more precise level, real-time data was used to construct daily spatiotemporal maps, where congestion is depicted as a "cloud" in the spatiotemporal domain. Future study will focus on deep learning of congestion patterns using Convolutional Long Short-Term Memory (ConvLSTM) networks. Kerekes Anna-Hajnalka, [73] Estimate city of Cluj-Napoca, Romania's road network in order to create an ideal route model for a quicker and more dependable approach to medical services. The response time of ambulances for the city's districts can be determined by considering traffic as the primary speed constraint. Taiwo Olubunmi Adetiloye, PhD. Thesis, [74] developed a system for combining multimodal data in order to estimate traffic congestion on urban highway networks. It employs three fundamental strategies. The first method estimates traffic congestion on urban highway networks using data mining techniques. The two types of models that are considered are neural networks and random forest classifiers. Back propagation neural networks and deep belief networks are two neural network models. The second method estimates traffic congestion using social media data. To forecast traffic flow, sentiment analysis and cluster classification are applied to tweets about traffic delays on Twitter. A data fusion framework is the final technique we propose. It includes two basic ways. The homogeneous data fusion method combines data of similar types (quantitative or numerical) that have been analyzed using machine learning algorithms. The heterogeneous data fusion approach combines quantitative data from the homogeneous data fusion model with qualitative or categorical data (i.e., traffic tweet information) from the twitter data source using Mamdani fuzzy rule inferencing systems. The suggested work for route planning under interruption and traffic congestion monitoring, forecasting, and monitoring can be used by traffic planners and decision-makers. Mazloh Al-Enazi, [75] Using various GIS tools (network analyzer, shortest path, etc.), evaluate traffic congestion points during working daytime hours in line with road directions. The study area is a residential area in Jeddah, Saudi Arabia. A geo-database is being built to house the city of Jeddah's road network and driving instructions. ArcGIS 10.2 is used in this study for overlay analysis and network analyzer, among other GIS features. The priority findings are used to analyze congestion sites in relation to road directions. This can help planners rearrange traffic directions to reduce congestion points across Jeddah. Adebayo. H. Oluwasegun, [76] Uses geographic information system techniques to map the traffic conditions along a few key routes in the Lagos Metropolis, Nigeria. The Lagos Metropolitan Area Transport Authority (LAMATA) agency provided the study's data, while the Lagos metropolitan' topographical and road plan was provided by the Lagos state ministries of Land Management and Survey and of Transportation. Primary data also includes traffic counts along the corridors, observations of the type of vehicular traffic congestion, and geographic coordinates of the chosen traffic routes using the GPS (Global Positioning System). To create the traffic situation information system (TSIS), the data collected was input. Using ArcGIS 10, data was obtained and a spatial analysis of properties was displayed. The data were shown as maps, which facilitates fast comprehension and decision-making. An efficient method for displaying various levels of traffic congestion and vehicle volume along virtual traffic routes is the geographic information system. For the agencies in charge of managing and planning traffic conditions in Lagos State and throughout Nigeria, this will be very helpful. BIJIT KUMAR BANIK, MD. AKTARUL ISLAM CHOWDHURY &MD. SHAHJAHAN

KAISAR ALAM SARKAR, [77] A traffic volume count, a road geometry survey and flow capacity calculation, a pedestrian count, a home interview, and a questionnaire survey for tracking journey time and trip creation were all conducted as part of the study. Additionally, pertinent secondary data was gathered. According to the research, the Ambarkhana to Chowhatta connection, which runs through the center of the city, is the busiest link, while the Ambarkhana intersection, which sees the most traffic, has the highest PCU/h rate (9111). There were two traffic congestion peaks: one from 11:00 to 12:00, which was mostly caused by office, business, and educational journeys, and another from 17:00 to 18:00, which was caused by business and retail trips. Non-motorized vehicles (47%) such rickshaws and pushcarts were the biggest cause of traffic congestion, followed by tempo (15%) and private cars (14%) in that order. One of the main contributors to city traffic congestion (34%) was illegal roadside employment by hawkers, mobile businesses, etc. The Zindabazar to Chowhatta route, which passes through the sole bustling commercial area of the city, has the most pedestrian traffic. The Roadway Congestion Index (RCI) for Sylhet City was 2.36, which reflected how bad the traffic congestion was. This study presents a highly comprehensive scenario of the traffic paradigm of an urban agglomeration in a developing nation.

6.CONCLUSION

This study has identified key factors contributing to road congestion, including pedestrian flow, vehicle stops and parking maneuvers, vehicles entering and exiting roadside premises, and the presence of slow-moving vehicles. These factors, often overlooked in traditional traffic congestion studies, play a crucial role in the daily challenges faced by urban road networks.

The findings underscore the necessity for comprehensive urban planning and traffic management strategies that go beyond conventional approaches. The complexities introduced by traffic side friction demand a multi-faceted solution, integrating pedestrian safety, efficient parking management, and regulation of roadside activities. Specifically, the study highlights the need for designing urban spaces that balance the requirements of vehicular traffic and pedestrian activities, thereby reducing the instances of congestion caused by side friction. Moreover, the variability in the significance of these factors, depending on the specific location and context, calls for a localized approach to traffic management. Urban planners and policymakers must consider the unique characteristics of each urban area, tailoring solutions that address the specific challenges posed by traffic side friction.

In conclusion, this study tries to give a deeper understanding of urban traffic congestion, extending the discourse beyond the conventional factors of vehicle volume and road capacity. Future research should focus on developing specific strategies and policies tailored to mitigate the impact of traffic side friction, thereby enhancing the overall efficiency and safety of urban road networks.

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