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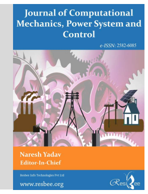

Estimating The Delay Caused by Side Friction Near 'School Zones'

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Abstract:Side friction of a road can be defined as all the actions related to the activities taking place by the sides of the road and sometimes within the road, which interfere with the mainstream traffic flow on the arterial roads. It includes pedestrians on the road, parked vehicles, entry and exit of vehicles from the mainstream, wrong movement of vehicles, etc., Even though these factors are random and sparse in developed countries makesless research interest.Normally it was very frequent in densely populated areas like school zones in developing countries. Finally, this side friction takes a huge time waste and has a considerable negative impact on the gross domestic product of the country. This research defines a universal side friction index incorporating all possible side friction components thatcan be seen near school zones in a developing country. It accounts dynamic or static nature of the side friction elements, their position, and overall dimensions and includes the dimension of the road. A speed prediction model was developed incorporating the side friction index and the road density using a multiple linear regression method. Graphs associating the side friction were developed and pointed out that there is a considerable impact created by the side friction near school zones showing a necessity to impose mitigation measures. The key feature of this research is its universal side friction index which is taking the effect coming from almost all the side friction elementsthat are partially addressed by other researchers.The other main feature is this side friction index can be not only used for schools but also for any place where side friction plays a major role.The outcomes of this researchmake a quantitative value for the effect of the side friction (That is the average speed).Also,the outcome of this research can be used to compare and find the places where the side friction is maximum which will help in city planning and town development.

Keywords: Side friction index,Gross domestic product, School zone,Equivalent pedestrian units, Process Control Unit

Nomenclature

Abbreviation	Expansion
GDP	Gross Domestic Product
SFI	Side Friction Index
RSFI	Road Side Friction Index
AR	Area Ratio
DR	Distance Ratio
PCU	Process Control Unit
EPU	Equivalent Pedestrian Unit

1. Introduction

Smooth traffic flow in a transportation network is the expectation of all stakeholders. However, due to numerous reasons, such smooth traffic flows cannot be achieved in road networks. Accidents, junction controls, driver behavior, and mixed traffic situations are some such influencing factors toward non-uniform traffic flow in the road network. On top of that roadside activities also contribute significantly tothe non-uniform traffic flows. Among such roadside activities, on-street parked vehicles, bus stops, walking pedestrians, pedestrian crossings, roadside vendors, left-side overtaking, etc., contribute heavily tomainstream traffic characteristics. Such roadside disturbances are defined as "Side Friction" and they can be categorized as shown in Fig.1. The gravity of side friction depends mainly on the geographical location. While urban centers exemplifyvery high side friction, rural areas have only very few.

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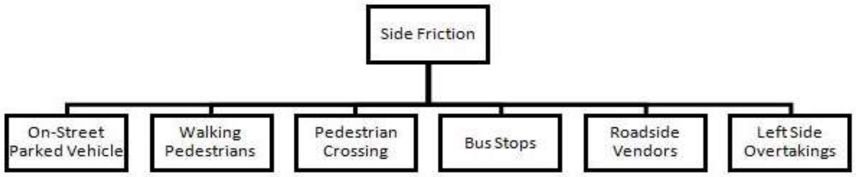

Fig.1. *Categories of side friction*

School zones are places where such side friction is very significant. Most of the schools in major cities are located by the side of arterial roads. Due to this, a noticeable disturbance can be witnessed inthe mainstream traffic within school zones. The causes for such disturbances are due to roadside parked vehicles, walking pedestrians, bus stops, left-side overtaking, etc, Roadside parked vehicles will narrow the roadway width and mainstream vehicles are forced to maneuver into this narrower space. In cases when pedestrians use the roadway whilewalking on the road, vehicles tend to keep away making certain a secure lateral distance from the pedestrians and thereby overall stream speed will be drastically reduced. Therefore, these activities will result in a negative impact on the overall performance of the road. Some of the activities are shown in Fig.2. Unless this side friction is kept under some allowable limit, excessive delays will occur in the mainstream traffic flow and finally cause a significant reduction in GDP and ultimately reduce the economy of the country.

Fig.2. *Presence of side friction near school zone*

The main aim of this research is to analyzethe impact created by sidefriction on mainstream traffic in the vicinity of schools located along undivided main arterial roads. There are two objectives accomplished when achieving the aim.

- Estimating the reduction of travel speed and roadway capacities with different intensities of side-frictions.
- Applying modifications to existing traffic flow theories by applying factors incorporating side friction are them.

Past researchers have tried to include different side friction components in their study but none of them were able to incorporate allof those side friction components without any errors in their research. Further, most of them were not able to get a quantitative value instead they could address the side friction matter qualitatively only.In this research, the SFI has been developed incorporating all the side friction parameters that can be seen in a developing country.According to their projected areas compared to the standard projected area of a single pedestrian.Further,this SFI has incorporatedthe dynamic or static nature of side friction components. Vehicles in the mainstream are more cautious of moving pedestrians rather than stationary pedestrians. This research is based on quantifying the delay due to the side friction near school zones. So that the outcome of this research can be used to compare delays caused due to side friction among different schools in the country and can provide sufficient measures to reduce the side friction.

The paper is organized as follows: Section 2 covers the Literature review. Section 3 details the Methodology, and Section 4 emphasizes the Results and Discussion. Section 5 mentions the Advantages and Disadvantages of the proposed method. The conclusion is recapitulated in Section 5.

2. Literature Review

There are many studies available regarding the influence of roadside frictions on traffic characteristics of urban arterials. Most of them were conducted under mixed traffic conditions. Since Sri Lanka has a mixed traffic situation, this section is focused on literature related to the analysis of side friction under mixed traffic situations. Although it is generally known that roadside friction activities reduce usual traffic flow speed and hence increase travel time, it is a very critical scenario to quantify that influence. There have been only a few studies that attempt to quantify this influence.

In 2008, Gulivindala, P. and Mehar, A., [3]haveperformed a study to analyzethe side friction with the field data collected on a four-lane divided road section in India. Side friction elements were identified such as on-street parked vehicles, pedestrian movements, entry and exit movements of vehicles, and wrong movements of vehicles were identified and the frequency of each element wasrecorded. After that, each sort of side friction element was given a relative weight, and the overall amount of side friction was calculated by multiplying the weights by the frequency of side friction. Here, relative weights were calculated using a multiple linear regression analysis method. Finally, the authors used multiple linear regression analysis to construct a speed prediction model to calculate the average speed under changing traffic flow rates and side friction levels.

In 2021, Singh and Kumar., [5] have developed speed models incorporating various side friction parameters by using regression analysis. The video recording technique was used as the data collection method.There are only a few studies from India that attempted to examine how bus stops affect different types of traffic. They had done research on the type of mode-wise speed variation due to the presence of side friction.

In2014, Salini *et al.,*[4]have used quantitative analysis of the impact of bus bays and curbside bus stops on traffic flow characteristics of urban roads and found that reduction in capacity is more in the case of curbside bus stops compared to bus bays in which the reduction is negligible. They had taken into account frictional factors such as the length of time buses stayed at bus stops, the number of people strolling along the sides of the roads, the number of parked cars, the influence of parking operations, and the number of parking manoeuvres for on-street parking. Other variables, such as the frequency of buses stopping at bus stops, the number of random pedestrian crossings, and the style of parking, were left out of the analysis because it was determined that their fluctuations were small and hence considered to be relatively less significant. Regression analysis was used to create the speed model and incorporate the side friction components.

In 2016, Rao *et al.,* [8] have focused on the dwell time of buses and frequency of buses in addition to the accumulation of on-street parked vehicles to analyze effect of the roadside friction on travel speed and capacity of urban arterials in Delhi. To gather information about the flow of traffic and the amount of on-street parking, video cameras were deployed. Using the floating automobile technique, GPS was used to collect segmental speeds over the chosen region. Then, both static and dynamic PCUs were used to create speed-density models. For further determining the speed-flow connection and predicted capacity, the best-fitting Speed-Flow model was chosen. The study concluded that bus bays and bus stops resulted in a significant reduction in travel speed and road capacity compared to without side friction condition and the dwell time of buses have a significant impact on capacity.

In 2019,Naghawi *etal.,*[10] have used AIMSUN microscopic simulation software to evaluate side friction impacts on traffic stream performance. In that research, a hypothetical base model and eighteen hypothetical alternative scenarios were created to study several side friction components such as pedestrians walking parallel to the road, parked vehicles, and the presence of trucks. The impact from the side friction in each scenario was evaluated using speed flow models. Data were entered, scatter graphs of speedflow were generated using Microsoft Excel software, and equations were developed using best-fitting curves. Finally, a considerable negative shift in the speed-flow graphs with the effect of side friction resulted from all the above-mentioned studies.

In 2017, Patel *et al.,* [17]have carried out asix-lane divided urban road in Pune and Patna city of India. Data was taken every minute from videos, which were chosen as the major data-gathering method. For both types of roads, speed flow density correlations were created, and parameters for mixed flow conditions were derived and compared to IRC. Instead of the Passenger car unit, they have chosen the Dynamic car unit. In Patna city, side parking causes the effective lane width to drop from 10.5 meters to 7.0 meters, which results in a 57% reduction in capacity. In addition, a 14% slower speed is seen in Patna City compared to Pune City, which is caused by the NMV.

In 2012, Ponnu *et al.,*[12]haveimplemented a microsimulation model VISSIM was suitable for simulating heterogeneous traffic in expressways. He found that the estimated PCU values of the heterogeneous traffic are accurate at a 5% level of significance and decrease with increases in volume capacity ratio. This was due to decreasing speed difference as volume increases from free flow to that at capacity. Due to the platooning effect of trucks, the PCU value of vehicles decreases when traffic stream.

It was found that due to the complex nature of the interaction between vehicles under heterogeneous traffic conditions.The PCU estimates made through simulation for different types of vehicles of heterogeneous traffic significantly change with a change in traffic volume level.

In 2015, Pal *et al.,* [9]have performed two different research to find the influence of roadside friction on the capacity of roads in Delhi, India, and find the Impact of Roadside Friction on Travel Speed and LOS of Rural Highways in India respectively.

2.2 Research Gap

- In most research, regression analysis simply considered the average speed of the traffic stream, and mode-wise speed variation was not addressed. However, the impact of side friction on the speeds of various vehicle categories is important especially in Asian countries as each vehicle category exhibits different speed characteristics on urban roads.
- Most of the research, when developing speed models by using multiple linear regression, did not pay much attention tothe multicollinearity problem which means the presence of substantial correlation among the independent variables.
- In [3], the authors did not even disclose the R2 and p values, simply the regression model. Even when R2 is given, sometimes it is relatively lower than 0.7. Similarly, the p values of independent variables were frequently more than 0.05, which means that the coefficient is equal to zero and has no effect. But still, those variables have been considered in that research. The presence of substantial correlation among the independent variables is one of the main reasons for not reaching high R2 and significant p values (0.05). Thus, the correlation among independent variables or multicollinearity is one of the major problems faced by researchers while doing regression analysis.
- The author [5]considered how to identify whether multicollinearity exists in the data set when analyzing the side friction and if so, how to overcome it. When developing regression models, the dependent variable was taken as the speed of a particular category of vehicle and the independent variables were speeds of other vehicle categories, class-wise traffic flow, and side friction elements like the number of parked vehicles, pedestrians (crossing and walking on carriageway), wrong movement and dwell time of buses in seconds were considered. They found that there were multicollinearity issues with some independent variables. Therefore, the research effort primarily added to the issue by introducing a simple and robust strategy for overcoming the multicollinearity problem in regression analysis. Although this method is complex with other common methods such as ridge regression, multicollinearity has been removed without dropping any subject variables.
- In [5] [9]havedefined an indexto account for the side friction components and quantify them.
- The author [5] implemented SFI which can be calculated using the formula given as follows. The SFI was calculated for each vehicle type separately as their speeds are different in urban heterogeneous traffic environments. However, the contribution from numerous side friction elements wasnot specified in this definition.

$$SFI_{VehType} = \frac{Average\ speed\ with\ side\ friction}{Average\ speed\ without\ side\ friction}$$

While they used those indexes,[9]proposed an index called RSFI and it has been also proposed to quantify the side friction effect. The number of friction elements present in the form of pedestrians, bicycles, and van-rickshaws standing or crossing the carriageway within a 100-meter stretch has been multiplied by a weight factor to calculate anRSFI for that specific instance. The weight factor concept was created to apply various weights to each friction element depending on their contribution toward traffic disturbance. Weight factors were determined based on the predicted area of each friction element and their distance from the carriageway edge. Side friction was treated as a combination of the physical dimensions of friction elements and their location on the roadway. The carriageway was divided into three strips in a longitudinal direction for a representative length of 100 m. The edge strip was a 1-meter strip on either side of the carriageway, while the center strip was the remainder of the carriageway as shown in Fig. 3. Side friction data was collected from video photographic data and counted number of friction elements presented on the middle and edge strip of the carriageway manually for each 5 min interval.

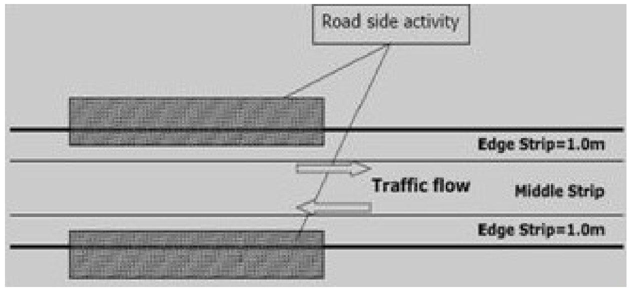

Fig.3. *Details of the edge and middle strip marked on the carriageway [9]*

- In the above study, pedestrians standing on a carriageway edge strip are considered as units of side friction. Area effect was estimated as the ratio of the projected area of a particular type of friction element and the area of a pedestrian which is referred to as AR. This concept was also used by [3]when converting parked vehicles into the equivalent number of pedestrians. The disturbance in traffic flow also depends on the position of the friction element on the carriageway. This effect was estimated as the ratio of distance to the particular midpoint of the strip from the carriageway edge on which the friction element currently stands to the midpoint of the edge strip and presented as DR. Then weight factors were obtained by summing up those ratios and scaled considering pedestrian standing on edge strip as a unit of side friction. Finally, it was concluded that for initial values of RSFI, speed reduced rapidly and beyond a certain level (RSFI = 40) speed reduced at a much lower rate with the increase of RSFI. This is due to the speed of moving vehicles within the study region decreased drastically as side friction increased, and they were forced to follow a platoon-like behavior. Further increases in friction level or traffic volume have a lower impact on travel speed as the same has already come down to a lower level.
- While [10]have used AIMSON microsimulation software to simulate the results, [11] have used VISSIM traffic simulation software for the same purpose. [6] have also conducted the same type of research by developing speed flow graphs to evaluate roadside friction and its effect on the reduction of capacity of urban arterial roads. However, in this research, simulation was not conducted.

3. Methodology

3.1 Site Selection and data collection

For this research, schools in major cities located by the side of the arterial roads were selected for data collection which is having side frictional influence. According to the scope of the research, schools were selected based on undivided two-lane municipal arterials situated away from major pedestrian activity centers, signalized intersections, and such obstacles nearby to eliminate those influences.School zones in Kurunegala, Sri Lanka were selected for the study. Figures 4 and5 show the location of selected school zones in Kurunegala.At each stretch, drone surveys were used to record the side friction details and traffic flow metrics. Then vehicular speeds were extracted by tracking software, called 'Tracker', and side friction parameters were counted manually.

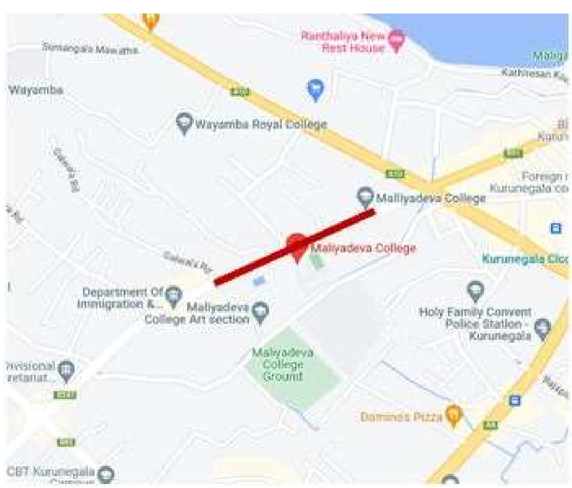

Fig.4.*Location of selected school zone*

Fig.5.*Drone view of selected school zone*

3.2 Data Analysis

In this research, on-street parked vehicles, curbside bus stoppings, entry and exit vehicles, left-side overtaking vehicles, and pedestrians who were stationary, walking along and crossing the roads were considered as the side friction components. An SFIwas created on a length along the main road of a 10m stretch. For calculating the SFI, an imaginary grid was generated on the influencing area of the road section which was symmetric to the road center line and each grid cell was assigned with a weight factor whichwere increasing towards the road center.

3.3 Weight Factors

The entire road was divided into 10m stretches along the longitudinal directions. For a 10m stretch, it was subdivided into 3 sections along the transverse direction namely grid 1, grid2, and grid 3 as shown in Fig.6. Grid 1 lies between the end of the pedestrian sidewalk and the edge line of the road. It is inclusive with the hard and soft shoulders but exclusive with the pedestrian sidewalk. Then the lane is divided into two equal sections namely grid 2 and grid 3. When defining the weights, it was taken that negative impact occurs due to a pedestrian was directly proportional to the distance traveled from the edge of the pedestrian sidewalk. The effect created by a pedestrian standingat the center of grid 1 was taken as 1 unit and relative weights were calculated relative to that effect.

- 'a' is the distance between the center of grid 1 and the edge of the pedestrian sidewalk.
- 'b' is the distance between the center of grid 2 and the edge of the pedestrian sidewalk.
- 'c' is the distance between the center of grid 3 and the edge of the pedestrian sidewalk.
- Weight for Grid 1 = $\frac{a}{a} = 1 = W_1$
- Weight for Grid 2 = $\frac{b}{a} = W_2$
- Weight for Grid 3 = $\frac{c}{a} = W_3$

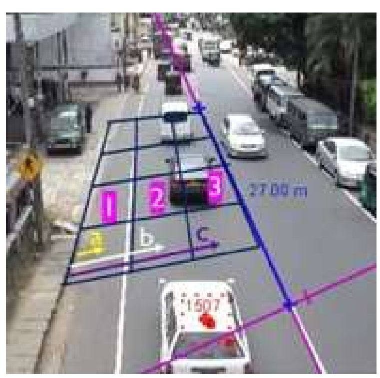

Fig.6.*Grid system used in the study*

3.4 EPU

All identified side friction components were converted into EPU which is defined to standardize the side friction unit. The EPU value is from dividing the projected area of the side friction component by the standard projected area of a pedestrian and multiplied with a coefficient (C_0) which is based on the static or dynamic condition of the side friction activity as shown in equation (1). Here, the coefficient for static activities was assumed as 1.0 and for the dynamic activities, the same coefficient was found as 1.41 from the analysisof the data.

$$EPU = \frac{\text{Projected area of the side friction componennt}}{\text{Standard projected area of a pedestrian}} \times C_0 \tag{1}$$

Where C_0 measures the negative influence created on a vehicle thatis moving on the mainstream by the dynamic nature of certain side friction components over its stationary state.C_0 is 1.0 for static side friction components and 1.41 for dynamic side friction components.

3.5SFI

To calculate the SFI, three grid cells were selected ina transverse direction as shown in Fig.7, and the total EPU value of each grid cell was multiplied bythe relevant weight factor. Then the cumulative value of all the above three values represents the side friction index for a particular transverse section which is 10m in length. Thereby, SFI values for each transverse section along the longitudinal direction can be estimated. Equation 2 will be used to estimate the side friction index.

$$SFI = \sum_{i=1}^{3} \left(\sum EPU\right)_i \times W_i \tag{2}$$

Where i refer to the ith grid cell in the transverse direction (i=1,2,3)
$\sum EPU$ are the total equivalent pedestrian units presented in a grid cell and W_i is the weight factor of ith grid cell.

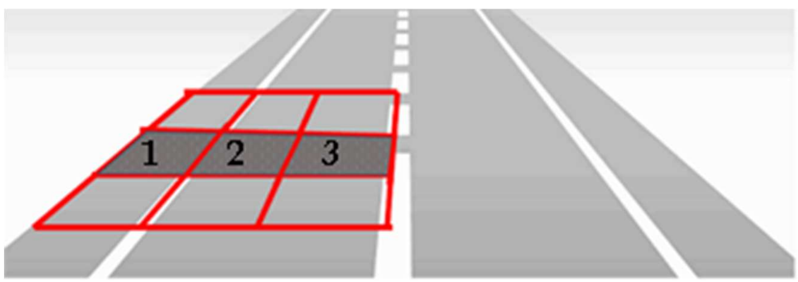

Fig.7. *Selection of grid cells when estimating SFI*

3.6Data Extraction

Vehicles maintaining average speeds inside 10m stretches were extracted through the tracking software and at the same timethe road densities were recorded. The side friction indices when the vehicle is at the beginning and halfway of the 10m stretch were recorded. The average of these represents the side friction index experiencedby the vehicle in which the average speed inside the 10m stretch is extracted through the tracking software. When the side friction components are presentin multiple transverse grids (mostly due to pedestrianscrossing the road, wrong movement of vehicles, vehicle entry and exit), the cumulative effect of it is taken into consideration. When there are influences by nearby 10mstretches due to side friction events occurring at them that effect is also included in the side friction index.

4. Results and Discussion

4.1 Speed Prediction Model

Multiple linear regression analysis was performed making the density of the road and the SFI as the independent variables while keeping the average speed as the dependent variable. The coefficient (C_0) used to define the EPU value, which is based on the static or dynamic condition of the side friction activity was determined by adjusting it till the R square value of the regression becomes the maximum as shown in Table 1. The R square value became maximum when C_0 equals 1.41. Significance F in Table 2 represents the statically independent variables forecast the dependent variable. Therefore, the regression model is a good fit for the data.

Table 1: *Regression Statistics*

Parameter	Value
Multiple R	0.751553
R Square	0.564831
Adjusted R Square	0.561112
Standard Error	1.667266
Observations	300

Table 2: *Analysis of variance (ANOVA)*

	df	SS	MS	F	Significance F
Regression	2	844.28	422.14	151.8612	5.28395E-43
Residual	234	650.4675	2.779776		
Total	236	1494.748			

Table 3:*Regression outcomes*

	Coefficient	Standard Error	t Stat	p-value	Lower 95%	Upper 95%
Intercept	28.92	0.7793	37.1177	4.96E-100	27.3936	30.4646
Density (PCU/km)	-0.1078	0.00829	-12.9995	1.915E-29	-0.1242	-0.0915
Side Friction Index	-0.08112	0.01279	-6.3379	1.185E-09	-0.10634	-0.0559

The p values for the independent variables are well below the significance value of 0.05 as shown in Table 3, indicating that side friction has an impact on the average speed of the vehicle. From the results obtained from the regression analysis, Equation 3 can be used for predicting the speed for different side friction conditions.

$$\mathbf{V} = -\,\mathbf{0.1078K} - \mathbf{0.08112(SFI)} + \mathbf{28.92} \tag{3}$$

Where

- V=Average vehicular speed (km/h)
- K=Density on the road (PCU/km)
- SFI=Side friction index

4.2 Average Speed vs. Density Graphs

The average speed maintained inside 10m stretches wasplotted against the density of the road with different side friction ranges in Fig.8. When the side friction increases, the curves get shifted downwards showing that side friction has some negative impact on vehicular speeds.

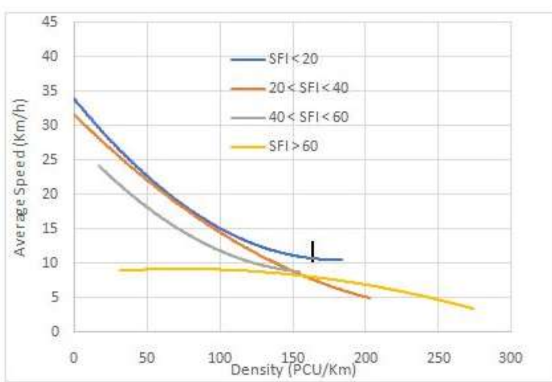

Fig.8.*Average speed vs. density graph*

4.3 Average Speed vs SFI Graphs

Fig.9 shows the variation of average speed vs. SFI under different road density ranges. With the increment of SFI, the average speed gets reduced.

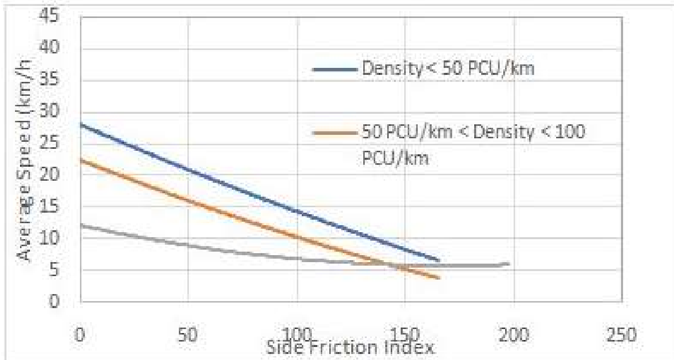

Fig.9.*Average speed vs SFI*

When the road density is below 100 PCU/km, side friction has a greater influence on mainstream vehicles. With a small increment of side friction condition on the road, a noticeable speed reduction can be expected when the road density is below 100 PCU/km as seen in Fig.9.When the mainstream density goes beyond 100 PCU/km, the platoon effect becomes dominant over the effect of the side friction. Therefore, a large increment of side friction gives a small speed reduction on the mainstream vehicles as seen in Fig.9, and when after the SFI becomes 125, the speed tends to be constant emphasizing that the platoon effect is dominant.

5. Advantages and Disadvantages

Advantage

This research helps to find the schools where side friction affects the most in the allocated budget and can be used more effectively and efficiently. When reducing the effect of side friction on those identified schools using this research, we can do some land acquisitions and direct vehicles to them, or simply impose parking restrictions, restricting curbside bus stoppings, etc.,

Disadvantages

- The paper does not conduct any simulation to validate the results, unlike some previous studies that have used micro-simulation software for this purpose.
- The presence of multicollinearity among independent variables is not adequately addressed, which can affect the accuracy of the regression analysis.
- The research focuses specifically on side friction near school zones in developing countries, potentially limiting the generalizability of the findings to other contexts.
- The paper does not provide information on the sample size or specific data collection methods used, which may affect the reliability and replicability of the study findings.

5. Conclusion

By observing the results obtained, there is a significant influence on mainstream vehicular speeds due to the side friction near school zones. Further that impact increases when the prevailing side friction increases. When the density of the road exceeds a certain level (100 PCU/km), the side friction cannot make much impact on the vehicular speed as it is governed by the prevailing road traffic conditions. (i.e., Effect of the platoon). On the other hand, when considering uncongested situations, the vehicular speeds are decided by the side friction effect. According to the resulting average speed vs density graphs, the GreenShields modelis slightly deviating when low side friction conditionsare present and highly deviating when the side frictionincreases.

Average speed (V) maintained by the mainstream traffic near school zones with side friction index (SFI) given by V = - 0.1078K - 0.08112(SFI) + 28.92. Using it, the most influenced school by the side friction should be identified and should provide sufficient measures according to the allocated budget, to reduce the side friction near them by imposing parking restrictions, land acquisitions, directing vehicles to them, etc.

This research can be further extended to other congested areas like markets, shopping malls,etc. where different side friction componentscannot be seen near schools. Further, micro-simulation can be done using “VISSIM” traffic simulation software to improve the accuracy of the results.

Compliance with Ethical Standards

Conflicts of interest: Authors declared that they have no conflict of interest.

Human participants: The conducted research follows the ethical standards and the authors ensured that they have not conducted any studies with human participants or animals.

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