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ANALYSIS OF SIDE FRICTION ON URBAN ARTERIALS

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The influence of the side friction activities on the speed has been analyzed in the present study by conducting series of traffic field surveys. Pedestrian movements, parked vehicles and entry-exit of vehicles from surroundings, and wrong way movements are observed from videos and analyzed to estimate weighing factors. To examine the combined effects of all the activities the weighing factors are used to determine total value of side friction on the road. The study suggests model to estimate average speed of vehicular stream with the effect of side friction and volume on the roads section. It was found that the vehicular speed decreases as side friction increases at all the levels of traffic volume. However, no change in the speed was observed at lower level side friction. Capacity value obtained for combined data based on Greenshield's theory that showed 9% reduction in the value considering with and without side friction.

Keywords: side friction, urban roads, capacity, speed

1. Introduction

Urban roads in India are operates under highly mixed traffic conditions. The traffic conditions some time become more chaotic when side friction plays on these roads. The side friction on a road also acts as bottleneck where the flow of the traffic stream found to be reduced with severity. The any roadway in city turns into congested state as side friction increases due to reduction in capacity. The capacity of roadway is used as an important parameter to measure congestion and level of service (HCM, 2010). The side friction is considered as one of the parameter that contributes in reduction of capacity. As per Highway Capacity Manual (HCM, 2010), capacity was defined as the maximum hourly flow rate at which vehicles or persons can traverse a point or a segment of the roadway under prevailing conditions. In developing countries like India, most of the activities occur at the side of the carriageway (on the shoulders) that creating disturbance to the directional traffic flow. Frequent pedestrian movements occur on the side of the roads especially at shopping malls, market areas etc. Frequent stopping of some vehicle category for picking up and dropping of the passengers on the road other than transit stops reduces the average speed and capacity. Entry and exit of the vehicles from the access points also causes disturbance in the traffic flow. The interaction of these activities with the traffic stream tends to slow down the vehicles which also reduce the capacity.

Many studies reported in the literature to assess the side friction on the urban roads and analyze the service performance of the roadways. HCM (2010) has given detailed guidelines for estimation of capacity and level of service based on speed and other criterion. Adjustment factors for estimating the capacity for various parameters provided HCM (2010) manual does not includes side friction parameters for determining capacity and level of service. Bang (1995) proposed various weighing factors for different type of side friction activities to examine speed-flow behaviour on the rural and urban highways in Indonesia. A significant change in the capacity of roadway was observed due to the side friction activities proven by statistical analysis. The findings from the study were included in Indonesian Highway Capacity Manual (IHCM, 1997) for general use of proposed factors. A detailed study was performed by Chiguma (2007) who assessed the impact of side friction on urban arterials in Dares-salaam, Indonesia. The study analyzed the impact of side friction on mean speed and capacity of sections. Multiple linear regression analysis was used to quantify the weighing factors of side friction elements. Rao A. and Rao K. (2015) evaluated the influence of road side friction on capacity in Indian capital and reported reduction in average speed of vehicles by 49-57% on the sections with bus stop locations and 45-67% on sections with provision of on-street parking facilities. Pal and Roy (2015) demonstrated a methodology for quantifying roadside friction by considering projected area and position of side friction elements.

Impact of side friction on travel speed was examined statistically and speed-flow curves were developed to understand the behaviour of the stream at different side friction levels. Munawar (2011) compared the values of IHCM (1997) with the values those were observed from the field data in Indonesia. He concluded that there was significant change in the capacity trend at high side friction values as proposed by IHCM (1997). Patel C.R. and Joshi G.J. (2014) used various parameters such as lane width, non-motorized vehicles and side friction elements to find capacity of urban arterials. Salini *et al*. (2016) also quantified the factors for estimating side friction with the effect of bus stops, pedestrians and on street parking. They found that the effect of side friction of combined factors is significant on reduction in average speed of the traffic stream. This study proposed speed prediction models for different levels of side friction. Chand *et al*. (2014), Koshy and Arasan (2005) studied the effect of bus stop on urban roads and found the reduction in capacity of urban mid-block sections with curbside bus stop. Based on IHCM (1997) another case study performed by Harison *et al*. (2016) in India aimed at traffic performance evaluation with the effect of side friction on roadways. Delay on road segment was observed due to side friction using VISSIM in the study performed by Irawati (2015). Guo *et al*. (2012) developed a model using simulation tool for finding the effect of on street parking on the traffic performance and found 35% reduction in capacity.

The quantification of side friction events has not been done earlier by considering the parked vehicles in terms of 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 the side friction. Therefore present study is aimed to analyze road side friction and its effects on average speed of vehicular traffic stream. The speeds and traffic volume relationship was develop to understand the behaviour of traffic flow steam in presence of different side friction levels. The analysis is performed with the field data collected on four-lane road sections in the Warangal city in India. The detailed methodology along with the analysis results and study outcomes is described under sections.

2. Field Data and Analysis

Field data was collected in Warangal city, Telangana state. Four different four lane divided road with mid-block sections were identified in urban areas with different characteristics for collection of traffic data. The traffic survey was performed for 4 hours in different days on selected sections covering both morning and evening periods. Video cameras are used to collect speed and volume data by recording the traffic operation by mounting it on elevated position near roadside. Trap length of 50 m was marked on road section to estimate the space mean speed of vehicles and traffic classified vehicle count made with some reference point in the observation section. The frequency of side friction events were observed and noted within observation section of roadway. Traffic volume, speed and side friction events types were extracted at 5min interval by playing the recorded video on a wide screen display. The geometrical and other details of the field sections as observed in the field are given in the Table 1.

Table 1. Details of selected road sections in the urban area

Sections	Name of the road section	Median width (m)	Carriageway width including shoulder (m)	Side friction factors
I	*Hanmakonda* road	0.5	7.0	Pedestrians Stopped vehicles Wrong movement of vehicles Entry/exit manoeuvres
II	*Subedari* road	1.2	8.6	Pedestrians Stopped vehicles Wrong movement of vehicles
III	*Bhadrakali temple* road	1.2	10.6	Pedestrians Stopped vehicles Wrong movement of vehicles
IV	*MGM* road		10.6	Pedestrians Stopped vehicles Wrong movement of vehicles

Traffic flow data was extracted from videos and required parameters such as traffic composition and volume, average speed and road side activities were extracted for the whole observation period. The observed vehicle composition and traffic volume on the sections are shown in the Table 2. The heterogeneous traffic volume as observed in the field was converted into passenger car units (PCU) using dynamic PCU method (Chandra and Sikdar, 2000). The equation (1) provides the expression for PCU estimation.

$$PCUi = \left(\frac{Vc}{Vi}\right) / \left(\frac{Ac}{Ai}\right), \qquad (1)$$

where, V_c is the speed of the passenger car, V_i is the speed of the subject vehicle 'i', A_c is the projected area of the passenger car, and A_i is the projected area of the subject vehicle 'i'.

Table 2. Traffic composition at all sections (%)

Sections	Vehicle type and composition (%)						Volume range (Veh/hr)	
	2w	3w	Car	Bus	LCV	NMT	Minimum	Maximum
I	58	25	11	2	3	1	1260	2974
II	60	17	18	2	2	1	2136	3348
III	60	29	8	1	1	1	1380	4644
IV	57	24	11	5	2	1	1416	3288

The method uses speed and area ratios of passenger cars and subject vehicle type. Here, passenger car is defined as the vehicle type with average length of 4.1m, width of 1.7m and with engine power 1200cc. The vehicle types other than passenger cars are subject vehicles those having different physical and operational characteristics.

2.1. Measurement of side friction

Side friction activities data were extracted from the recorded videos at different sites over 50m trap length. The pedestrian movements, stopped vehicles, entry and exit movements and wrong movement of vehicles are identified and frequency of each event type is noted. The data measured over the study section pertaining to event type is shown in Table 3.

Table 3. Side friction frequency on study section

Event type	Frequency (events/hr) at study sections			
	I	II	III	IV
Pedestrians	600	120	72	228
Parked vehicles	456	348	36	600
Entry-exit	48	NA	NA	NA
Wrong movement	24	36	24	24

For measurement of side friction, procedure followed by Pal and Roy (2016) is used in present study. This method uses the pedestrian influencing area as standard parameter to calculate equivalent pedestrian units for the events other than pedestrian. The stopped vehicles are converted into equivalent number of pedestrian units for standardizing the static side friction activity.

Table 4. Projected area and PEU for different mode

Mode	Projected area (m^2)	PEU
Pedestrian	0.50	1.00
2W	1.2	2.5
3W	3.9	7.8
Car	7.3	14.5
Bus	31.2	62.4
LCV	5.4	10.7
Jeep/Van	9.3	18.6
Bicycle	1.1	2.2

The frequency of all stopped vehicles was converted and added with frequency of pedestrians observed in the field. The equation (2) is used to estimate the Pedestrian equivalency unit (PEU) for converting all stopped vehicles into equivalent number of pedestrians. The PEU is multiplied with the frequency of events to convert the vehicles into pedestrian units. Projected area of pedestrians, vehicle type and PEU is shown in Table 4.

$$PEU_i = \frac{PA_i}{PA_p}, \tag{2}$$

where, PEU_i is the pedestrian equivalency unit of the subject vehicle, PA_i is the projected area of the subject vehicle and PA_p is the projected area of the pedestrian. The number of pedestrian events and stopped vehicles are added to calculate total static side friction frequency in terms of *PSPU* (events/hr) which is estimated by using the equation (3).

$$N_{PSPU} = N_p + \sum(PEU_I \times N_i), \tag{3}$$

where, N_P is the frequency of pedestrians, PEU_i is the pedestrian equivalency unit of the subject vehicle and N_i is the frequency of the subject vehicle. Entry-exit vehicular movement and wrong movement of vehicles those are moving activities that contribute to side friction on the road. Side friction (SF) was calculated by estimating weighing factors of the events observed on the road side. To estimate the weighing factor for each road side activity, Chiguma (2007) estimated the standardised coefficients and weighing factors using regression method by taking average stream speed as a performance measure variable. Similar methodology is adopted in the present study to find the relative weights of road side activities. By taking stream speed as a performance measure, the relative weighting factors of each activity was estimated for determining SF (Events/hr) on the selected road sections and the results are given in Table 5. The SF (Events/hr) for each section was calculated by using the equation (4). SF is the side friction which is the sum product of road side events frequency of different activities and their estimated weighing factors.

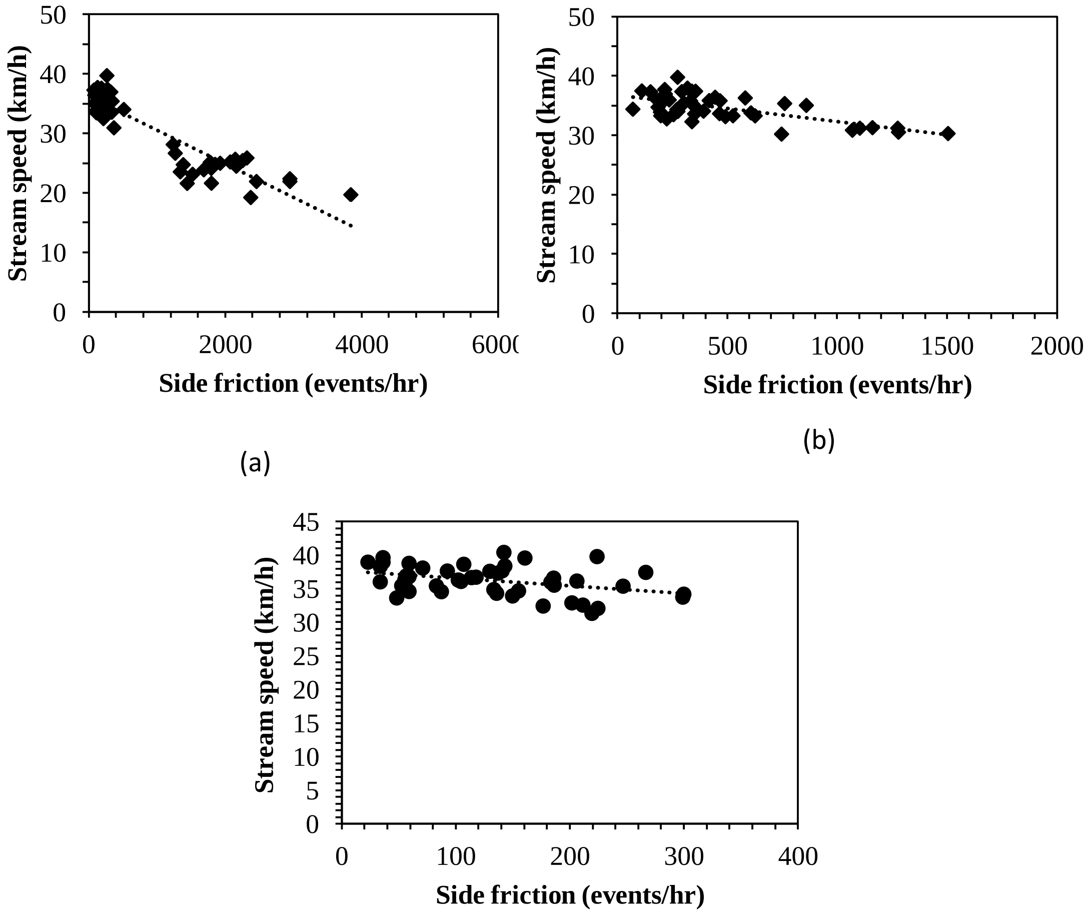
$$\mathrm{SF} = (RW_1 \times \mathrm{N}_{PSPU}) + (\mathrm{RW}_2 \times \mathrm{N}_{EE}) + (\mathrm{RW}_3 \times \mathrm{N}_{WM}), \tag{4}$$

where, N_{PSPU} is the frequency of pedestrians and parked vehicles in equivalent pedestrian units, N_{EE} is the frequency of entry-exit vehicles, N_{WM} is the frequency of wrong movement vehicles and RW is the relative weights of each activity type

Table 5. Result of regression analysis and relative weights

		Coefficients	**t- value**	**p-value**	**Relative weights**
Section I	constant	36.78	73.16	0.00	
	PSPU	-0.05	-8.78	0.00	1.00
	Entry-exit	-0.54	-4.22	0.00	0.48
	opposite	-0.11	-0.34	0.73	0.04
Section II	constant	37.15	72.82	0.00	
	PSPU	-0.05	-6.06	0.00	1.00
	opposite	-0.18	-1.56	0.12	0.30
Section III	constant	37.93	59.03	0.00	
	PSPU	-0.12	-2.35	0.23	1.00
	Opposite	-0.29	-2.31	0.25	0.98

The total side friction values were estimated for all sections and correlated to see the variation with average speed. It may be seen in the Figure 1; the average speed of vehicles is gradually reducing as the side friction increasing on all the sections.



(c)

Figure 1. Variation of speed with side friction at Section I (a), Section II (b), and Section III (c)

Side friction data obtained from all sections were combined (Section I, II and III) to measure relative weights of road side activities. The total side friction was determined by using the equation (4) based on combined data collected from the field sections. The relative weights were estimated based on regression analysis and the results are shown in Table 6.

Table 6. Regression analysis of combined data

	Coefficients	t-value	p-value	Relative weight
constant	37.06	138.39	0.00	
PSPU	-0.05	-11.88	0.00	1.0
Entry-exit	-0.53	-6.29	0.00	0.5
Wrong movement	-0.21	-2.52	0.01	0.1

After performing the whole analysis with combined data, the total side friction was calculated and varied with average speed as shown in Figure 2. Based on the variation in the speed data, the side friction was classified at four different levels. At very low level, side friction has not significant effect on the average speed of the vehicles. Between 500-1000 events/hr, there is significant reduction in the avg. speed was observed and. after, 1000 events/hr the percentage reduction in the average speed is very high. Classification of side friction level along with the percentage reduction of average speed for combined data is given in the Table 7. The reduction in the speed has been observed significantly at higher level of side friction which is about 51 percent.

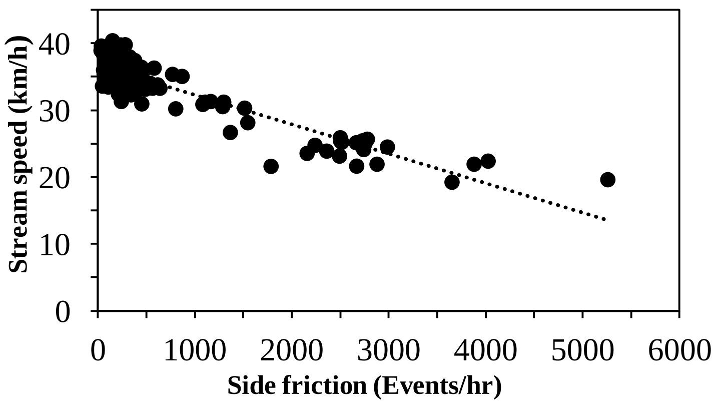


Figure 2. Speed at different side friction for the combined data

Table 7. Levels of side friction at different speeds

SF (Events/hr)	Level of side friction	Average stream speed (km /h)	Percentage reduction in average speed
0-500	Low	34	-
500-1000	Medium	31	20
1000-2000	High	24	38
>2000	Very high	19	51

2.2. Speed flow relation

Speed-volume relation was established to find the maximum volume on all the sections. Figure 3 shows speed-flow relationship on Section I, II and III. It may be seen that the section I is having the higher level of side friction which shows lesser average speed in compared to Section II and Section III. Capacity was estimated by using the Greenshield's speed- flow model. The capacity observed on the road i.e. with side friction was 2909 puce/hr. Again for no side friction case the speed was normalised by keeping the side friction as zero. A new speed flow curve was developed based on the speeds corresponding to no side friction case and the capacity was found as 3173 pcu/hr. After comparing two capacities, it was found that there was approximately 9% reduction in the capacity of the section of four lane divided road with medium level side friction

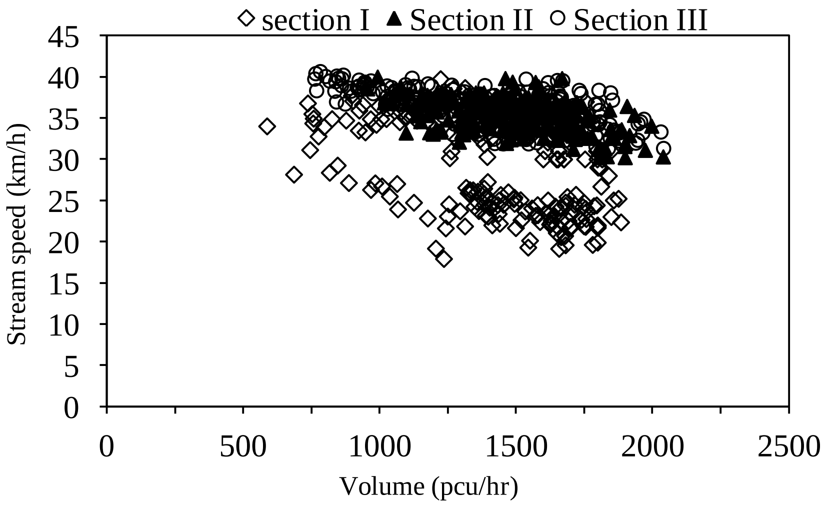


Figure 3. Speed-volume relationships on study sections

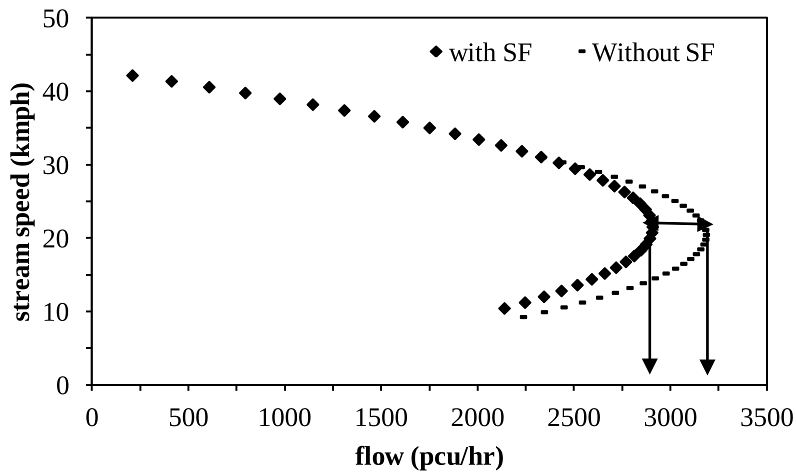


Figure 4. Speed- flow curve for with and without side friction

Figure 4 shows the Greenshield's speed flow curve with and without considering the side friction. The variation in the observed flow with the increase in side friction has been noticed on Section I, Section II and Section III which may be seen in the Figure 5.

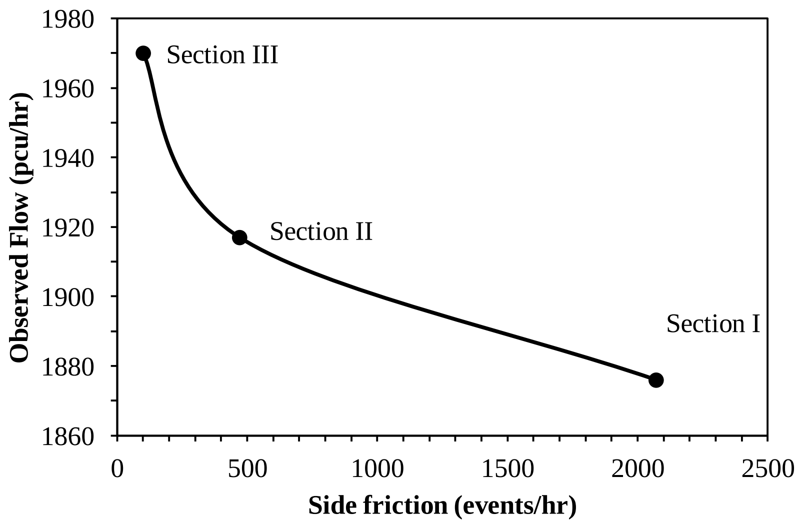


Figure 5. Variation of flow with side fiction at all sections

3. Development of Speed Model

The present study analyses the effect of side friction on avg. speed of vehicular traffic stream. MLR model is proposed to estimate avg. speed under varying traffic flow and side friction levels. The data collected on Section I, II, and III was used to perform multiple regression analysis for development of linear model. The results of analysis are given in the Table 8. It may be clear based on t-value obtained for variables that the value of estimated coefficients are statistically significant in changing in the average speed of traffic stream. The results suggest a linear expression as equation (5), for estimating average speed of the stream under varying side friction values and traffic volumes.

$$V = 45.0 - (0.04 \times SF) - (0.005 \times Q) \quad (5)$$

where, V is the stream speed (km/h), SF is the side friction (events/hr) and Q is the traffic flow (pcu/hr).

Table 8. Regression analysis for speed model (Dependent Variable: Speed)

	Coefficients	t-value	p-value	95% confidence interval	
				Lower bound	Upper bound
constant	45.00	73.43	0.00	42.80	45.16
flow	-0.005	-10.41	0.00	-0.005	-0.004
SF	-0.040	-12.25	0.00	-0.043	-0.029

The validation of the speed model was also performed by using observed traffic flow and speed data on Section IV. This section is also four-lane and having the similar operational characteristics as already mentioned in the Table 1. The data obtained from Section IV is used for calculating average speed by using field measured flow and side friction values at every 5 min interval. The average speed was estimated and compared with the actual speed measured in field in the same interval of observation. The plot between predicted and observed speed is shown in Figure 6.

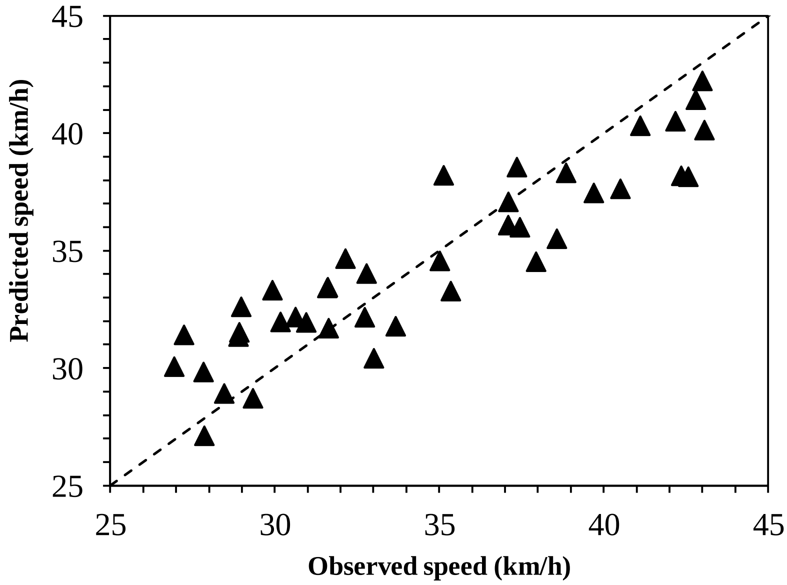


Figure 6. Validation of speed model on Section IV

RMSE value was calculated for comparing average speed for validation. The value of RMSE is estimated about 14% which is an acceptable limit under the given sets of observation. A non-parametric test such as Chi –square test was also applied to check whether the difference between the average speeds is significant. The theoretical chi-square value was obtained as 5.98 against the critical value (25.7) at 95% confidence level with 39 degree of freedom. Hence, null hypothesis was accepted as there is no significant difference between the modelled and observed average speeds of vehicular traffic stream. Average speed of the vehicular traffic estimated from the model was plotted with observed volume at different levels of side friction on Section IV. Upper limits of side friction estimated in the present study were used as input to the speed model. The variation in the speed with volume and side friction on section IV is shown in Figure 7. It is clearly understood that the average stream speed is having combined effect due to traffic volume and side road friction levels on the urban road section. However, the reduction of stream speed is not clearly seen with the flow due to limited range.

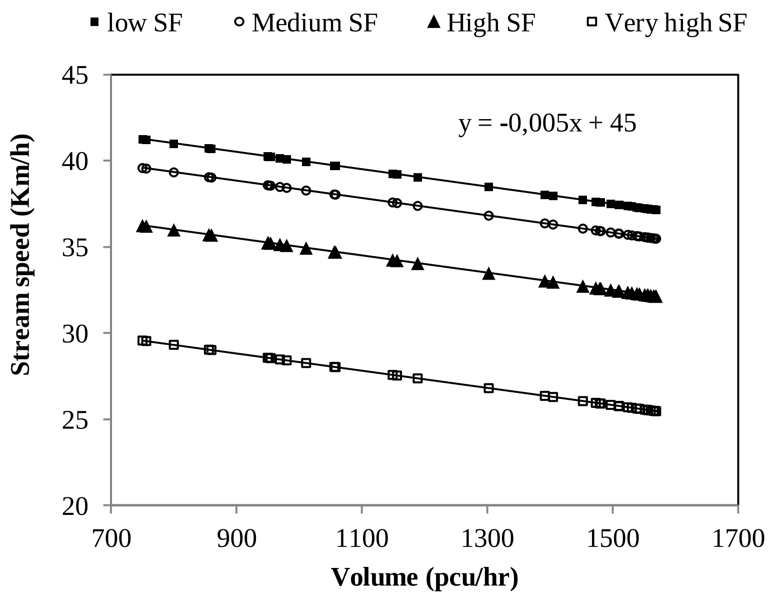


Figure 7. Variation of speed at different side friction levels for section IV

4. Conclusions

Following conclusions are drawn from the present study are discussed below.

- The pedestrian activity considered as one of the road side friction event is found to be most influencing average speed of the traffic stream on all the study sections.
- Pedestrian equivalency unit was estimated for converting frequency of vehicle type stopped on the road. Total side friction was calculated with the help of relative weights multiplied by frequency side friction. The effect of combined side friction was analyzed on the average speed which shows negative correlation.
- The average stream speed measured at low volume is lesser on Section I in compared to other two study sections. The amount of side friction measured on section I is the main reason of reducing the speeds.
- Side friction was defined into low to very high levels. At low level of side friction the average speed was observed as 34 km/h and at higher level the average speed was obtained as 19 km/h. Therefore, the reduction was measured as 51percent which is quite significant.
- The capacity was estimated as 2909pcu/hr from the speed-flow model for existing road conditions i.e. with side friction. And a capacity for no side friction case was observed as 3173pcu/hr after normalizing the speeds for no side friction case. Approximately 9% reduction in capacity was observed for the roads which was having the side friction.
- Speed prediction model was developed taking flow and side friction as independent parameters. RMSE found as 14% and Chi- square test was performed to validate the model on the test site and found the speeds predicted were statistically significant.

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