

INFLUENCE OF SIDE FRICTION AND ROADWAY WIDTH ON CAPACITY OF MULTILANE URBAN DIVIDED ROADS

Pallavi Gulivindala^{*} and Arpan Mehar

Received: April 17, 2019; Revised: August 20, 2019; Accepted: August 31, 2019

Abstract

Urban arterials exhibit deteriorated capacity and poor level of service in many developing countries in recent times. Because of increased social and commercial land use, there are several factors that affect performance of the road in which one significant parameter is side friction. Side friction is defined as the activities prevail on the side of the road such as pedestrian movement, curb side busstops, parking maneuvers etc. The present study deals with effect of road side friction on capacity of the urban roads, also attempted to relate roadway width with the capacity. The objective of the study is to derive the adjustment factors for side friction and roadway width which are used to develop a model for estimating the capacity at the urban mid block sections. For this, data was collected from six different sections. Capacity is estimated by using the speed flow relationship for each section. And regression equations are developed to derive the adjustment factors for side friction and roadway width. Further capacity model is proposed by using these adjustment factors. The study finds that there is 21% reduction in capacity of the road under medium to higher level of side friction. It is also observed that the percentage reduction in capacity has been increased by 3.2% with every 2% increase in the side friction activities. The capacity model proposed in the study is simple as well as provides a good estimate of capacity of urban road under prevailing roadway and side-friction conditions.

Keywords: Side friction, urban road, capacity, adjustment factors

Department of Civil Engineering, National Institute of Technology Warangal-506004, Telangana, India,

E-mail: pallavi.gulivindala@gmail.com, arpanmehr400@gmail.com

.^{*} Corresponding author

Introduction

The increase in vehicular population on urban roads specifically in developing countries results in congestion which exhibits a picture that the roadway is not able to cater the higher demand. In addition to the vehicular population, the interference of the road side activities with the ongoing traffic flow is one of the major causes deteriorating service quality performance on the roads. These road side activities usually occur on edge of the road or on the shoulder or sometimes on the carriageway itself at dense urban streets which is referred as side friction. Side friction includes several activities such as street vendors, busstops, auto-stands, on street parking etc. These elements attract the people to buy the things from the street vendors which leads to the movement of the pedestrians along and across the side of the road. Also, slow moving vehicles come to the street vendors for delivering of the goods. Bus-stops and auto-stands are the points where the vehicles stop and go to pick up the passengers. Parking maneuvers prevail on the road due to the on-street parking facility also due to the absence of parking facilities near shopping malls and other commercial elements. Moreover, the lack of traffic discipline on the roadway often causes a chance for intending wrongway movements which influences the traffic performance and reduces the safety.

Some of these activities occur for short duration but lead to encroachment by occupying portion of the roadway width. The interaction of these activities with the ongoing vehicular stream affects the traffic flow behaviour, reduces the actual capacity and causes congestion on a part of urban roads. The difference between estimated capacity and actual capacity may lead to improper judgement of service performance or level of service on urban roads. Therefore, a proper methodology is needed that incorporates the side friction to quantify actual capacity. Although, there are several side friction factors that influence the traffic performance but few of them are considered to be dominating for the present study such as pedestrian movement,

parking maneuvers, entry-exit vehicles and wrong movement vehicles.

To overcome difficulties, present study defines the objectives as to derive the adjustment factors for side friction and propose a simple model to find capacity of mid block section on multilane divided urban roads under mixed traffic conditions.

Past studies show that the roadway, environmental and traffic factors influence the capacity of roads very significantly. The influence of these factors on capacity has been studied by many authors under uniform and mixed traffic conditions. Ramanayya (1988) stated that the capacity specifications developed by the western countries are applicable only for homogeneous conditions and cannot be directly adopted for countries with heterogeneous traffic conditions. Bang (1995) proposed the weights for different type of side friction factors and investigated their impact on traffic flow behaviour on rural and urban roadways in Indonesia. The results obtained from the study were included in the development of Indonesian Highway Capacity Manual (IHCM, 1997). Chandra and Sinha (2001) studied the effect of directional split of the two lane roads on capacity and stated that the capacity reduces significantly when the directional split moves away from 50/50. They concluded that the capacity decreases with the increase in proportion of slow moving vehicles in the stream. Chandra and Kumar (2003) studied the effect of lane width on the capacity under mixed traffic conditions and presented a relationship between capacity and lane width. Author proposed the adjustment factors for lane width to calculate the capacity. Chandra and Prasad (2006) stated that the capacity of the urban multilane divided roads increases significantly with the increase in the proportion of two wheelers into mixed traffic stream.

In a detailed study, Chiguma (2007) examined the impact of side friction on urban arterials in Indonesia. Macroscopic and microscopic analysis was performed by the

author and analyzed the effect of side friction on traffic flow performance. The study estimates weighing factors for different side friction activities. Munawar (2011) analyzed the effect of side friction activities on speed and capacity on Indonesian roads and compared the results from HCM (1997) capacity standard. A comparative study was done by Patel *et al.* (2014) on urban arterials and found lane width, non-motorized vehicles and side friction are the main parameters affecting capacity significantly. Rao *et al.* (2014) evaluated the influence of road side friction on capacity in Delhi and found the reduction in speed as 49 to 57% on the sections having bus stops and 45 to 67% reduction in stream speed with presence of on-street parking. Salini *et al.* (2014) quantified the significance of combined effect of side friction factors on stream speed on urban road by considering bus stops, pedestrians and on street parking as side friction elements. Chand *et al.* (2014) estimated the capacity of various urban road sections under mixed traffic conditions. They observed the reduction in the capacity of sections with curb side bus stops is more in compared to the bus stops with bus bay conditions.

Pal *et al.* (2016) demonstrated a methodology to quantify road side friction by considering the projected area and position of side friction elements present on carriageway. The impact on side friction elements on travel speed was examined by speed-flow curves developed at different side friction levels. A detailed study was done by Salini (2018) for developing the speed prediction models based on the most influencing side friction parameters such as curb side bus stop, pedestrians, on street parking. The author found the reduction in capacity and speed is due to the side friction activities. Pal *et al.* (2019) studied the impact of side friction on traffic performance of the highways. The study mainly focused on the analysis of the side friction on stream speed, capacity and levels of service. By using the V/C ratio and percentage speed reduction, the authors recommended five threshold limits for level of service. Golakiya *et al.* (2019) analysed the impact of pedestrian crossing on capacity at urban mid block sections. Author compared

the capacities with and without pedestrian cross flow at 22 urban mid block sections and stated that there is no reduction in the capacity when the pedestrian flow is upto 220 pph and 32% reduction is observed when the flow 1,550 pph.

Although, there are several studies done to investigate the effect of side friction factors on capacity but they are limited to the specific traffic and roadway conditions. Many studies use existing guidelines for calculating side friction by choosing predefined values. In fact, there is no research found on derivation of adjustment factor for side friction to directly find actual capacity of urban roads under highly mixed traffic conditions like India. Present study proposes a methodology to find the actual capacity that do not requires development of fundamental relationship using speed and volume data. It provides direct and quick estimation of field capacity by incorporating major factors related to roadway width and traffic conditions.

Methodology

The present study aims to relate the roadway configuration and side friction factors to find capacity of the multilane divided urban roads. Six study sections were identified for the data collection having varying width of roadways prevailing with more or less side friction activity on the roads. First, the traffic volume was measured in terms of PCU/hr and average stream speed was determined. Later, speed-volume plots are drawn to estimate the capacity of each selected sections. Further, regression equations are developed between maximum volume and roadway width, and between maximum volume and side friction. The regression equations are used to derive adjustment factors for different range of side friction and roadway width. Finally, capacity model is developed by applying adjustment factors to the base capacity for estimating actual capacity of multilane divided urban roads. Figure 1 shows the complete research frame work for the present study.

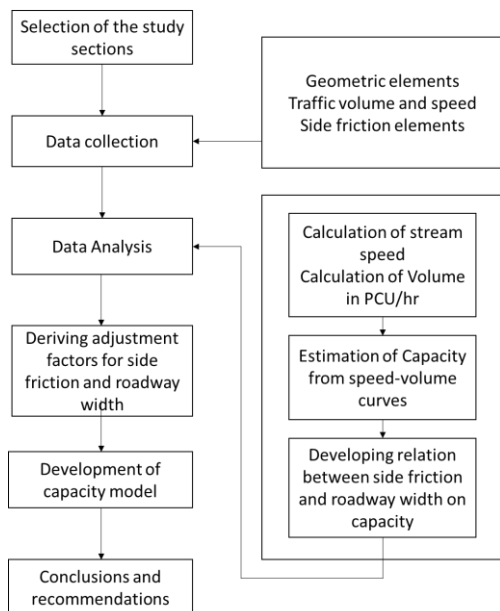


Figure 1. Research methodology

Field Data and Analysis

Field data was collected on the six different identified locations in Warangal city, India. The sections for the study were identified on basis of varying roadway configurations such as carriageway width and shoulders, comprising road side activity on either side. Video-graphic method was used to collect the data from all sections in which three study sections are four lane divided roads having carriageway width from 7.0 to 8.5 m on either side and the remaining three study sections are six-lane divided roads having width of 10.5 m on either side. Figure 2 shows the location of the selected study sections. Section I, Hanmankonda road which is very dense urban area with commercial buildings on both sides of the carriageway and street vendors which attracts more number of pedestrians. Section II, Subedari road consists of street vendors, fruit shops, and on street parking facility. Section III, NITW road which is a semi-urban road having negligible side friction activity compared to other sections. Section IV, MGM hospital road which is having curbside busstop which allows

frequent stopping of the buses and pedestrian movement along and across the side of the road. Section V, D-mart road is a commercial road with on street parking activities. Section VI, Temple road is a semi urban road which is almost free from side friction activity. The details of the selected roadway sections are given in Table 1.

Traffic video recording was performed at selected sections for a period of 6 h from 6.00 AM to 9.00 AM and from 2.00 PM to 5.00 PM covering peak and off-peak periods during clear weather conditions on a flat terrain. The recorded videos were replayed in the laboratory to extract the traffic volume and speed data. A trap length of 30 m was marked on the road section to estimate space mean speed of vehicles. Six different vehicle types were observed at study section such as Car, 2w (motorized two wheelers), 3w (motorized three wheelers), Bus, LCV (light commercial vehicle), NMV (non-motorized vehicle such as bicycles). Side friction frequency was also extracted from video recording by counting the frequency of the events observed within 50 m length of the roadway sections. Traffic composition was observed at each section are given in Table 2 along with the range of observed traffic volume. The proportion of two wheelers is more than 50% and slow moving traffic such as NMV are having 1 % traffic share at all the study sections.

Analysis of Side Friction

In the present study, side friction was observed on all of the sections that include parking manoeuvres near shopping malls, street vendor encroachment, curb side bus stops, pedestrian movement, on-street parking

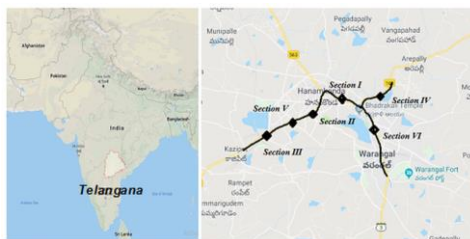


Figure 2. Location of the study sections

Table 1. Details of selected road sections in Warangal city

Sections	Name	Median width(m)	Carriageway width (m)	Side friction factors
I	Hanmakonda road	0.5	7.0	Pedestrians Stopped vehicles Wrong movement of vehicles
II	Subedari road	1.2	8.5	Entry/exit manoeuvres Pedestrians Stopped vehicles Wrong movement of vehicles
III	NITW Road	1.2	7.0	Pedestrians
IV	MGM road	1.2	10.5	Pedestrians Stopped vehicles Wrong movement of vehicles
V	Dmart Road	1.2	10.5	Pedestrians Stopped vehicles Wrong movement of vehicles
VI	Bhadrakali temple road	1.2	10.5	Pedestrians Stopped vehicles

Table 2. Vehicle composition and average stream speed on study sections

Sections	Vehicle type and composition (%)						Volume range (Veh/h)		Average stream speed (Kmph)	No. of observations N
	2w	3w	Car	Bus	LCV	NMV	Minimum	Maximum		
I	60	29	8	1	1	1	684	2,976	31.89	1,934
II	60	17	18	2	2	1	612	3,348	35.56	2,678
III	58	25	11	2	3	1	456	4,068	43.56	3,112
IV	56	23	18	2	1	1	780	3,288	37.92	2,630
V	59	22	12	5	1	1	444	4,140	34.34	3,064
VI	57	24	11	5	2	1	1380	4,644	36.02	3,204

Table 3. Weightage factors for individual side friction

Side friction type	Relative weight
Pedestrian movement	1.0
Parked vehicles	1.0
Entry-exit manoeuvres	0.5
Wrong way movement	0.1

and wrong vehicular movements (opposite direction). The high pedestrian movement along and across the road dominates over other side friction events being as a most vulnerable road user. Hence, high weightage has been given for the pedestrian activity than the other factors for quantifying the total side friction. The total side friction is calculated as per the method suggested by Gulivindala and Mehar (2018). In this method, the weightages are estimated for each side friction activity by

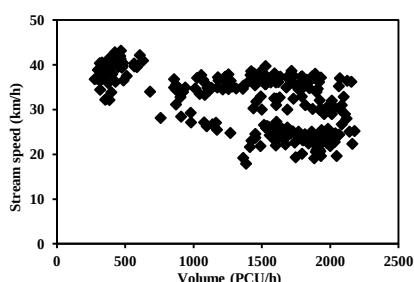
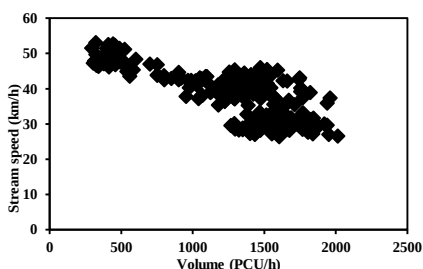
regression analysis using average stream speed as dependent variable and side friction elements as independent variables. The values of the weightage for each side friction activity are given in Table 3. These weightages are used in the present study to estimate the total side friction. The side friction amounts as calculated after using weightage are given in Table 4, with their defined levels.

Speed and Volume Relationship

Speed and volume data obtained from the field are used to develop fundamental relationship. Heterogeneous traffic volume was converted to Passenger Car Equivalent Units (PCU) by using Dynamic PCU method proposed by Chandra and Sikdar (2000). Average stream speed was calculated as weighted mean speed of vehicles observed at field sections based on volume counts. Then the relationship between

Table 4 Details of the side friction for all the sections

Sections	Max Side friction (Events/h)	Min Side friction (Events/h)	Side friction Level
I	3912	72	High
II	1521	95	Medium
III	137	12	Low
IV	4420	370	Very High
V	1176	176	Medium
VI	302	24	Low

**Figure 3. Speed –flow curve for study section I****Figure 4. Speed –flow curve for study section IV**

average stream speed and traffic volume was plotted for all the sections to observe the maximum volume. Maximum volume was obtained as the highest volume observed in the speed-volume diagram. The speed flow curves developed for Section I and Section IV are shown in Figures 3 and 4 respectively.

Similarly, speed-volume relationship was developed for other study sections and maximum volume was mentioned in the Table 5. It also shows the critical speed which explains the speed at maximum volume. From

Table 5. Maximum volume Q_{max} and speed at Q_{max} on study sections

Section	Q_{max} (PCU/h)	Critical speed (Km/h)
I	2023	25.2
II	2508	30.3
III	2674	30.1
IV	2012	26.6
V	3408	29.5
VI	3217	31.3

the Table 4, It is clear that the maximum volume obtained at the Sections I and Sections IV are relatively lesser than the other sections which may be due to the higher side friction observed at these sections.

Development of Capacity Model

This section deals with the development of model to estimate capacity by finding the adjustment factors for carriageway width and side friction as they are found to be significant in determining the capacity.

Adjustment Factor for Carriageway Width

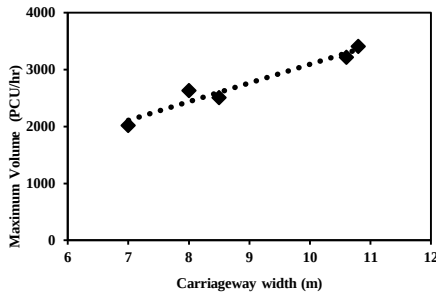
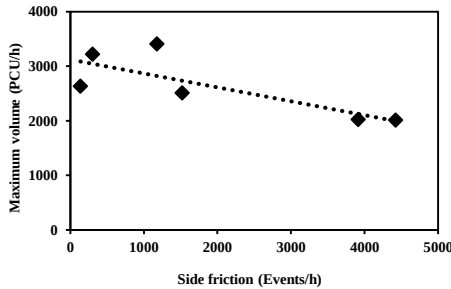
The relationship between maximum volume diagram and carriageway width was established and the Equation (1) is proposed. The relationship between maximum volume and carriageway width is shown in Figure 5.

$$Q_{max} = 308 \times cw \quad , (if \ cw \geq 7.0m) \quad (1)$$

Where Q_{max} = Maximum volume (PCU/h) on multilane divided urban road

Table 6. Adjustment factors for carriageway width

Carriageway width (m)	7.0	8.5	10.5	14.0
Adjustment factor	1.0	1.2	1.5	2.0

**Figure 5. Variation of the capacity with carriageway width****Figure 6. Variation of the capacity with side friction**

CW = Carriageway width of the road (m)

The study further uses Equation (1) to estimate adjustment factors for carriageway width. The relationship proposed to estimate the adjustment factors for carriageway width is shown in Equation (2).

$$f_{cw} = \frac{Q_{max,i}}{Q_{max,s}} \quad (2)$$

Where f_{cw} = Adjustment factor for carriageway width

$Q_{max,i}$ = Maximum volume at carriageway width i

$Q_{max,s}$ = Maximum volume at 7 m carriageway width

Here, $Q_{max,s}$ is taken as 2,633 PCU/h in the present study. This is a maximum volume obtained at study section III for 7 m carriageway width with the low side friction level. This value is used as ideal capacity for estimating adjustment factors for carriageway width. The calculated adjustment factors are given in Table 6.

Adjustment Factor for Side Friction

The relationship between the side friction and the maximum volume obtained at each section was developed and an Equation (3) is proposed. It is very clear that the maximum volume decreases with the increase in side friction events. A linear relationship between maximum volume and side friction is shown in Figure 6.

$$Q_{2max} = 3117 - 0.253 \times SF \quad (3)$$

Where Q_{2max} = Maximum volume (PCU/h)

SF = Side friction (Events/h)

Based on the Equation (3) the adjustment factors were estimated at different side friction levels. The relationship to estimate the adjustment factors for side friction is shown in Equation (4).

$$f_{sf} = \frac{Q_{2max,i}}{Q_{2max,s}} \quad (4)$$

Where, f_{sf} is the adjustment factor for side friction

$Q_{2max,i}$ is the maximum volume observed at study section i

$Q_{2max,s}$ is the maximum volume at low side friction section Here,

$Q_{2max,s}$ is again taken as 2633 PCU/h in the present study as it represents the maximum volume under ideal roadway conditions. The calculated

Table 7. Adjustment factors at different side friction range

Side friction range (events/h)	0-500	500-2000	2,000-3,000	3,000-4,500
Adjustment factor	1.0	0.9	0.8	0.7

adjustment factors are given in Table 7.

The adjustment factors proposed for carriageway width and side friction are used for determining capacity of divided multi-lane urban roads. These adjustment factors will be used to adjust the base capacity of multilane divided road under mixed traffic conditions. A general relationship is proposed by Equation (5) incorporating adjustment factors to find actual capacity. The base capacity of multi-lane divided urban road is adopted from Indo-HCM (2017) as 2700 PCU/h.

$$C = c_0 \times f_{sf} \times f_{cw} \quad (5)$$

Where C = Capacity of the study section (PCU/h)

C_0 = base capacity (PCU/h)

f_{sf} = adjustment factor for side friction

f_{cw} = adjustment factor for carriageway width

Conclusions

The present study demonstrates a methodology for estimating actual capacity of multilane divided urban roads by suggesting adjustment factors of side friction and roadway width. Average reduction in capacity of multilane divided urban road is found to be increased as 21% and the average reduction in the speed has been observed up to 36%. The reduction in the capacity is increased by 3.2% with every 2% increase in side friction events. Also, it is observed that the values of adjustment factors are increasing with the increase in the roadway width. This is due to the increment of capacity with the increase in the roadway width. And, the adjustment factors are decreasing with the increase in the side friction range as it deteriorates

the capacity. Hence, the side friction problem has very negative effect on capacity which needs to be fixed for providing better level of service. Moreover, the reduction was found to be higher at the sections having curb-side bus stop and shopping malls. Therefore, proper parking facilities, foot paths and provision for bus bays must be planned to reduce the side friction. The study finds significance of only two parameters to develop a capacity model. The adjustment factors for various other parameters such as city size, traffic composition, heavy vehicle percentage etc., may also be included by performing sensitivity analysis. The present study performed with only six sections in level terrains and the effect of geometric conditions has not been discussed. The proposed method is simple which may be readily used by field traffic engineers for quick estimation of capacity with limited available data under any range of road width and side friction level under mixed traffic conditions.

References

- Bang, K.L. (1995). Impact of side friction on speed-flow relationship for rural and urban highways. HDM 4 Project Report, SWEROAD Indonesia, p. 1-27.
- Chandra, S. and Sikdar, P. K. (2000). Factors affecting PCU in mixed traffic on urban roads. Road Transportation Research, 9(3):40–50.
- Chandra, S. and Kumar, U (2003). Effect of lane width on capacity under mixed traffic conditions in India. J. Transport. Eng., ASCE, 129(2):155-160.
- Chandra, S. and Sinha, S. (2001). Effect of directional split and slow-moving vehicles on two lane capacity. Road and Transport Research, ARRB Transport Ltd., Victoria, Australia, 10(4).
- Chandra, S. and Prasad, Vishnu N. (2006). Capacity of multilane divided urban roads under mixed traffic conditions. Highway Research Bulletin 75, Indian Roads Congress, New Delhi, p. 97-103.
- Chand S., Chandra S., and Dhamaniya A. (2014). Capacity drop of urban arterial due to a curb side bus Stop. International conference on sustainable civil infrastructure, ASCE India section.

- Chiguma L.M.M. (2007). Analysis of side friction impacts on urban road links. Doctoral Thesis in Traffic and Transport Planning, Infrastructure and Planning, Royal Institute of Technology Stockholm, Sweden.
- Gulivindala, P. and Mehar, A. (2018). Analysis of side friction on urban arterials. *J. Transport Telecom.*, 19(1):21–30.
- Golakiya, H.D., Patkar, M. and Dhamaniya, A. (2019), Impact of midblock pedestrian crossing on speed characteristics and capacity of urban arterials. *Arabian J. Sci. Eng.*, p. 1-15.
- Highway Capacity Manual. (2010). Transportation Research Board, National Research Council, Washington, DC.
- Indian Highway Capacity Manual. (2017). Council of Scientific and Industrial Research (CSIR), New Delhi.
- Indonesian Highway Capacity Manual. (1997), Directorate General of Highways, Republic Indonesia, Jakarta.
- Munawar, A. (2011). Speed and Capacity for Urban Roads, Indonesian Experience. *Procedia - Social and Behavioural Sciences*, 16:382-387.
- Patel, C.R. and Joshi, G.J. (2014). Mixed traffic speed–flow behavior under influence of road side friction and non-motorized vehicles: A comparative study of arterial roads in India. *Int. J. Civil Environ. Struct. Const. Arch. Eng.*, 8(11):1,198-1,204.
- Pal, S. and Roy, S. (2016). Impact of roadside friction on Travel Speed and LOS of rural highways in India. *Transportation in Developing Economics*, 2(9):1-12.
- Pal, S. And Roy S. (2019). Impact of roadside friction on performance of rural highways in India. *J. Infrastruc. Sys.*, 25(2):1-14.
- Rao A. and Rao K. (2014). Free Speed Modelling for Urban Arterials - A case study on Delhi. *Procedia - social and behavioural sciences*, 43(3):111-119.
- Ramanayya, T.V. (1988). Highway capacity under mixed traffic conditions. *Traffic Eng. Control*, 29(5):284–287.
- Salini, S., George, S., and Ashalatha, R. (2014), Effect of Side frictions on Traffic Characteristics of urban arterials. *Transportation research procedia*, 17:636-643.
- Salini, S. and Ashalatha, R. (2018). Analysis of Traffic Characteristics of urban roads under the influence of roadside frictions. Case studies on Transport Policy (*In Press*).
- Transportation Research Board. (1965). Highway capacity manual, Special Rep. 209, National Research Council, Washington, DC.
- Transportation Research Board. (2010). Highway capacity manual, National Research Council, Washington, DC.