Travel Time Estimation Modelling under Heterogeneous Traffic: A Case Study of Urban Traffic Corridor in Surat, India

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Abstract

Achievement of fast and reliable travel time on urban road network is one of the major objectives for a transport planner against the enormous growth in vehicle population and urban traffic in most of the metropolitan cities in India. Urban arterials or main city corridors are subjected to heavy traffic flow resulting in degradation of traffic quality in terms of vehicular delays and increase in travel time. Since the Indian roadway traffic is characterized by heterogeneity with dominance of 2Ws (Two wheelers) and 3Ws (Auto rickshaw), travel times are varying significantly. With this in background, the present paper focuses on identification of travel time attributes such as heterogeneous traffic, road side friction and corridor intersections for recurrent traffic condition and to develop an appropriate Corridor Travel Time Estimation Model using Multi-Linear Regression (MLR) approach. The model is further subjected to sensitivity analysis with reference to identified attributes to realize the impact of the identified attributes on travel time so as to suggest certain measures for improvement.

Keywords

heterogeneous traffic, travel time, travel time attributes, road side friction, intersection factor, travel time model

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1 Introduction

Fast and reliable movement of people and goods is one of the key functions of the Arterial and Sub-Arterial roads in urban areas (Yang, 2005). Traffic pressure owing to the significant growth in vehicle population on such roads in most of the metropolitan cities, particularly in developing countries, has reached alarming proportion due to increased economic activities resulting in a longer and unreliable travel time. Travel time is affected by various attributes besides traffic and physical characteristics of corridors (Lin et al., 2005). Pedestrian encroachments and haphazard road side parkings are further adding to the congestion level. Travel time variation and longer travel time not only add to the anxiety and stress of the commuters but also result in waste of productive time (Ravi Shekhar et al., 2012). These attributes vary from place to place with time. Keeping this in view, an urban traffic corridor has been considered to probe into the major travel time attributes for recurrent congestion conditions, so as to develop a suitable travel time estimation model. The model finds application in urban transportation planning and traffic management apart from assessment of corridor traffic performance. The study corridor belongs to Surat, the second largest city in the state of Gujarat in India as a typical case of corridor travel time studies.

2 Literature Base

Travel time is one of the basic parameters for the transport planning, management and operation and this depends upon various factors such as driver's behaviour, traffic and physical characteristics of urban corridors. Traffic characteristics refer to traffic flow and density under heterogeneous conditions, whereas physical characteristics are concerned with road width, geometry, intersection controls. Wang et al. (2016) recognizes that lane width and numbers of traffic stream have significant impact on travel time along with traffic volume. Impact of signalized system on travel time has been dealt by Liu et al. (2005) in their study travel time prediction in Adelaide, Australia. They found that travel time is considerably affected by signal system. Other factors that can be considered are certain events such as accidents, processions, repair work and weather conditions

as part of non-recurring conditions. Chakrabarty et al. (2014) have mentioned about the likely effect of extreme weather conditions on speed profiles in Delhi. In view of the number of factors involved in corridor traffic flow, the travel time estimation modelling becomes a challenging task. Many research workers have attempted to build travel time estimation models using various techniques such as analytical method, time series method, soft computing and simulation technique. Skabardonis and Geroliminis (2008) developed travel time estimation model based on kinematic wave theory using loop detectors data as well as signal system. Bhaskar et al. (2007) has also used analytical method for travel time estimation based on cumulative plots using stop-line loop detector and signal controller data. Travel time modelling has been reported by Yang (2005) using time series data with GPS test vehicle technique. Khoei et al. (2013) have developed travel time prediction on signalized urban arterials by applying Seasonal Auto Regressive Integrated Moving Average (SARIMA) modelling on Bluetooth data. Dharia and Adeli (2003); Jiang and Zhang (2001) for Artificial Neural Network (ANN) approach in their modelling. Travel time forecasting model using ANN with cluster method has been developed by Lee (2009). Microscopic simulation analysis on arterial has been reported by Liu et al. (2005). In his model, total travel time has been divided into two components link cruising times and intersection delays. Hu and Ho (2010) has also employed the simulation approach for travel time estimation of urban networks and compared the same with time series models.

Multi-linear Regression modelling approach also bears equal importance in dealing with travel time estimation modelling for its simplicity and the technique has been adopted for travel time prediction by many research institutes (Sisiopiku et al., 1994; Fils, 2012). Bhaskar et al. (2009) suggested that regression based models are fast to compute and favourable for transport planning and policy applications. However, the data collection is quite laborious in license plate techniques or videography approach. Zhang and He (1998) proposed regression models based on spot speed and the degree of saturation of corresponding links. Ravi Shekhar et al. (2012) employed regression approach for travel time model using road traffic volume on loop detectors basis. Yang et al. (2011) has made effort to develop a model for car travel time estimation for uncongested condition of an arterial road using data mining technique.

Very limited research has been carried out on travel time modelling in Indian context to address the mix traffic impact on travel time variations incorporating number of associated attributes. Rushikesh (2013) reported in his study on the travel time variations for a corridor with reference mainly to traffic volume on license plate data base under mixed traffic conditions of Surat in India. The present study focuses on travel time attributes of not only traffic flow and composition but also intersection and road side friction to cover both hazardous parking and

pedestrian using GPS laden Probe vehicle technique and videography and Travel Time Estimation Model has been developed employing Multi-Linear Regression (MLR) approach.

3 Study Approach

Study approach comprises of four stages beginning with the selection of suitable study corridor and to note the physiographic features including curb parking, intersection & lane configuration and interspacing of intersections, etc. Various field studies were carried out in second stage with focus on traffic volume & composition survey employing videography technique and curb parking & pedestrian disturbance followed by speed profile survey to note travel time through probe vehicles. Expert rating technique has been adopted for curb parking and pedestrian disturbance prevailing along the corridor at various spots. All three surveys were carried out simultaneously. Data analysis in terms of traffic volume & composition, road side friction incorporating both parking and pedestrian impact and intersection impacts has been carried segment wise in third stage. The fourth stage covers building of Travel Time Estimation Model through multi-linear regression approach and sensitivity analysis.

4 Study Corridor and Surveys
4.1 Corridor Location

An arterial corridor of length 5.8 km known as Udhana–Sachin Corridor situated in South Zone of Surat has been considered for the present study. The corridor passes through commercial and industrial area and as an entry road to the city. Corridor has six lanes inclusive of two lanes of BRTS at the centre and two lanes are available for the mixed traffic flow on either side. The study stretch has been divided into three segments of nearly 2 km each having number of intersections. Fig. 1 (a) provides the location diagram whereas schematic diagram of study corridor indicating the location of Intersections as C_2 to C_8 is shown in Fig. 1 (b). C_2 (Canal Cross Road), C_6 (Dindoli Cross), (Batliboy Circle) (C_8) are crossed intersections whereas others are three legged intersections. None of the intersections have signal system. C_3, C_4 and C_5 are major intersections in Segment I.

Segment I is recognized for heavy commercial activities on front side of the corridor with highly residential area behind and also a Railway Station. Other two segments are dominated by manufacturing industries.

The intersections are uncontrolled and inter-space of the same is as in Table 1.
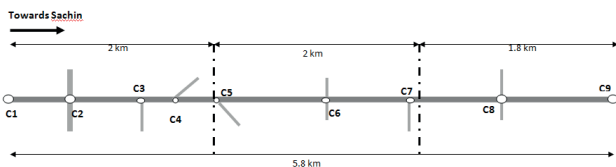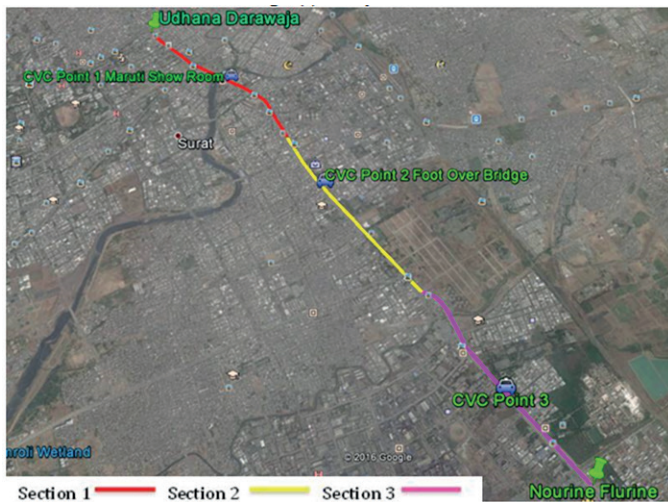
4.2 Field Surveys

The following field surveys were carried out to note the necessary traffic data for this study.
- Traffic Volume and Composition Survey
- Speed Profile Survey
- Road Side Friction Survey (RSF).

Table 1 Inter-space of Intersection							
C1-C2	C2-C3	C3-C4	C4-C5	C5-C6	C6-C7	C7-C8	C8-C9
600 (m)	700 (m)	300 (m)	400 (m)	1000 (m)	800 (m)	900 (m)	1100 (m)

Fig. 2 Platoon Flow Behaviour

Fig. 1 (a) Study Corridor (b) Schematic Diagram of Study Corridor

Surveys were planned for the morning and evening peak and off peak hours based on pilot surveys of eight hours.

4.2.1 Traffic Volume and Composition Survey

The video-graphic survey stations were established one in each segment at midway to capture the traffic volume and composition views. Surveys were conducted simultaneously with other surveys at all three locations. The classified volume data is extracted at the interval of 5 minutes. Vehicles are divided in four categories namely 2Ws (Two Wheelers), 3Ws (Auto Rickshaws), 4Ws (Car) and Commercial Vehicles (CVs). Commercial vehicles include Light Commercial Vehicles (LCVs), trucks and buses as it is mixed traffic flow.

4.2.2 Speed profile Survey

Speed profiles survey was conducted using GPS laden 3Ws i.e. V Box survey which provides moment to moment or spot to spot speed. This technique provides speed traverse of the corridor stretch to include study segments. The surveys were carried out during both peak and off peak time of morning and evening period. The sample size in such type of V-Box survey results in lower value compared with license plate method but has the merit of spot to spot speed particulars. Moreover, the speed profile of the probe vehicle mostly represents for the vehicle platoons during the peak traffic flow i.e. reasonable sample size (Fig. 2).

4.2.3 Road Side Friction Survey (RSF)

Haphazard parking has been observed in certain parts of segments. Similarly varied pedestrian interruptions also prevail. These two factors form the attribute of RSF and have an impact on effective width and traffic flow to reduce traffic capacity eventually. These attributes have been noted by three trained enumerators during V-BOX speed profile survey in terms of rating 1 to 5 in qualitative terms where 1 is for lowest and 5 for highest RSF. The ratings were averaged for the three persons and two attributes and converted to 0 to 1 scale i.e. larger the value higher the RSF. **Chinguma (2007)** measured road side frictions in three levels i.e. low side friction, medium friction and high friction in his study.

5 Attribute Analysis
5.1 Traffic variation

Average hourly mixed traffic volume Segment-wise for various periods is shown in Fig. 3. During morning peak hour (9:30 to 10:30) nearly 5900 vehicles/hour are plying in Segment I whereas 4100 vehicles/hour and 4000 vehicles/hour are plying in Segments II and III respectively in one direction. Segment I has quite a high traffic volume due to the presence of high residential and commercial density area along it. It is almost 1.5 times in comparison to Segments II and III.

5.2 Traffic Composition

Traffic composition is an important factor in mixed traffic condition for its significant travel impedance. Traffic composition of each Segment on average basis is shown in Table 2. Two wheelers (2Ws) are the dominating mode of traffic to an extent of 53 % to 60 %, followed by 3Ws 28 %. In case of Segment I, share of 2Ws is higher whereas share of 4Ws and CVs is on higher side in Segments II and III. Traffic flow behaviour under such heterogeneous condition plays vital role in vehicular
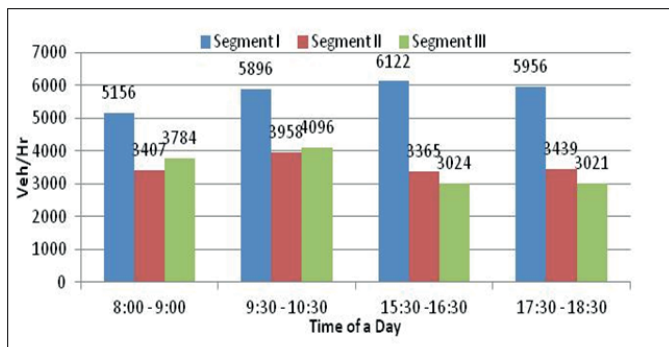
Fig. 3 Hourly Traffic Volume

movement but very few studies have reported the impact of such mixed traffic flow on speed profiles which are eventually interpreted to travel time variation and reliability.

Table 2 Mixed Traffic Composition

	2W	3W	4W	CV
Segment I	60 %	27 %	9 %	4 %
Segment II	53 %	28 %	13 %	6 %
Segment III	53 %	28 %	13 %	6 %

5.3 Road Side Friction (RSF)

RSF observed in terms of road side parked vehicles and pedestrian encroachment is rated in each trip on 1 to 5 scale and is averaged out as mentioned earlier. The average rated RSF for various durations for all the three segments are shown below. Higher RSF value has been observed in the morning and evening peak hours for all the three Segments. Among the three, Segment I bears very high RSF during peak hours (Table 3).

Table 3 Observed Road Side Frictions (RSF)

Time	Period	Segment I	Segment II	Segment III
8:00 - 8:15		0.63	0.47	0.43
8:15 - 8:30	Morning off	0.77	0.57	0.37
8:30 - 8:45	peak Period	0.60	0.60	0.40
8:45 - 9:00		0.70	0.57	0.43
9:30 - 9:50		0.80	0.77	0.50
9:50 - 10:10	Morning Peak Period	0.83	0.73	0.40
10:10 - 10:30		0.83	0.65	0.45
15:45 - 16:00		1.00	0.47	0.40
16:00 - 16:15	Noon Period	0.80	0.57	0.40
16:15 - 16:30		0.73	0.60	0.33
17:30 - 17:45		0.70	0.57	0.47
17:45 - 18:00	Evening Peak Period	0.87	0.67	0.63
18:00 - 18:15		0.93	0.60	0.47
18:15 - 18:30		0.88	0.67	0.53

The statistical observations are presented below in Table 4.

Table 4 Statistical observations of RSF

	Segment I	Segment II	Segment III
Average	0.79	0.61	0.44
Std Dev	0.112	0.086	0.076
Minimum	0.60	0.47	0.33
Maximum	1.00	0.77	0.63

5.4 Intersection Factor (IF)

The study Segments have number of uncontrolled intersections as discussed earlier. They do have impact on traffic flow to result in higher impedance. This fact has been reasonably addressed by defining IF as the ratio of average speed to dropdown speed at the intersection for the main road and these are added if more number of intersections are present in the segment. The dropdown speeds are observed form the Speedo-graph obtained in V-Box Survey. The observed IF for the Segments is shown in Table 5. A typical space-speed profile of evening peak hour during 17:30 to 17:45 hours is indicated in Fig. 4. The speed drop can be noted at intersections C_2, C_3, C_4, C_5 at 600, 1300, 1600 and 2000 m respectively for the Segment I at 17:45 to 18:00 hrs.

Table 5 Segmental Intersection Factors

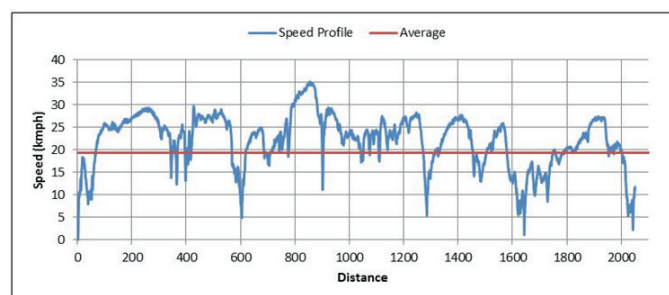| Time	Period	Segment I	Segment II	Segment III
8:00 - 8:15		7.64	9.41	28.00
8:15 - 8:30	Morning off	10.57	3.80	1.66
8:30 - 8:45	peak Period	8.53	8.02	1.72
8:45 - 9:00		31.32	14.93	1.51
9:30 - 9:50		31.41	5.34	2.00
9:50 - 10:10	Morning Peak Period	20.50	16.82	1.56
10:10 - 10:30		21.80	4.11	1.42
15:45 - 16:00		38.68	17.38	1.19
16:00 - 16:15	Noon Period	11.75	3.20	1.60
16:15 - 16:30		15.21	2.89	1.52
17:30 - 17:45		8.26	3.29	1.41
17:45 - 18:00	Evening Peak Period	24.73	3.68	28.16
18:00 - 18:15		10.57	18.41	2.28
18:15 - 18:30		15.54	9.35	28.52

Fig. 4 Space -Speed Profile of Segment I (17:45-18:00)

6 Observed Travel Time

Observed Travel time per km for different period of the day for all three Segments is noted based on Segmental speeds as shown in Table 6. Statistics of the same is summarized in Table 7. Travel time is observed to be higher in Segment I as compared to Segment II and III for the prevailing lower traffic volume. Higher standard deviation is also observed in Segment I owing to considerable fluctuations in speed because of significant traffic interruptions through road side parking and pedestrian movements.

Table 6 Observed Travel Time/Km (min)

Time	Period	Segment I	Segment II	Segment III
8:00 - 8:15		2.60	2.07	2.15
8:15 - 8:30	Morning off	2.60	2.03	2.01
8:30 - 8:45	peak Period	2.20	1.87	1.67
8:45 - 9:00		2.84	2.19	1.81
9:30 - 9:50		2.18	1.80	2.00
9:50 - 10:10	Morning Peak Period	2.81	1.91	1.83
10:10 - 10:30		2.82	1.77	1.69
15:45 - 16:00		3.24	1.86	1.73
16:00 - 16:15	Noon Period	2.54	1.87	1.71
16:15 - 16:30		2.83	1.98	2.07
17:30 - 17:45		2.64	1.84	1.71
17:45 - 18:00	Evening	3.23	2.04	2.11
18:00 - 18:15	Peak Period	2.64	1.90	1.76
18:15 - 18:30		3.03	2.06	2.01

Table 7 Observed Travel Time/ kM (min) – Statistics Measures

	Segment I	Segment II	Segment III
Min	2.18	1.77	1.67
Max	3.24	2.19	2.15
Avg	2.73	1.95	1.9
Std Dev	0.32	0.12	0.18

7 Development of Travel Time Estimation Model (TRATIM)
7.1 Model Structure

A multi-linear regression (MLR) has been developed with reference to traffic characteristics covering the various modes of 2Ws, 3Ws, 4Ws, and CVs in the mix traffic stream. The model also incorporates the impact of intersections and RSF which has been explained in preceding paragraph. Most of the models reported in the literature have addressed traffic as the main factor to reflect on the congestion level for the recurrent conditions. Here, an effort is made to understand the implications of mixed mode with varied characteristics as well as the uncontrolled access, haphazard parking and pedestrian interruption prevailing on Indian roads. The developed TRATIM model to estimate Travel Time min/km (TT) is as by Eq. (1).

$$TT = 0.980 + 0.122 \ (2W) + 0.502 \ (3W) - 0.734 \ (4W)$$
$$+ 0.895 \ (CV) + 0.560 \ (RSF) + 0.012 \ (IF)$$
$$(R^2 - 0.82) \ -----$$

$$(1)$$

The regression is satisfactory to the extent of 0.82 and other statistics are as shown in Table 8. It is interesting to note that a negative impact is associated with 4Ws. The major impact has been in the case of CVs and 3Ws. RSF and IF have positive bearing on travel time.

Table 8 Regression Model:–Statistical Measures

	Coeff.	*Std Error*	*t Stat*	*P-value*
Intercept	0.980	0.153	6.425	0.000
2W Vol*	0.112	0.086	1.304	0.201
3W Vol*	0.502	0.271	1.851	0.073
4W Vol*	-0.734	0.299	-2.457	0.019
CV Vol*	0.895	0.332	2.693	0.011
RSF	0.560	0.291	1.927	0.062
IF	0.012	0.004	3.494	0.001

*Volume in (000)

7.2 Model Validation

Estimated travel time obtained from the above developed model is plotted against the observed travel time as presented in Fig. 5 indicating good agreement between them. The t-statistics test is also satisfactory for its value of 0.108 which is extremely less than t-critical (2).

Other three parameters MPE, MAPE and RMSE have been checked and found satisfactory as in Table 9.

Table 9 Model Performance Evaluation Parameters

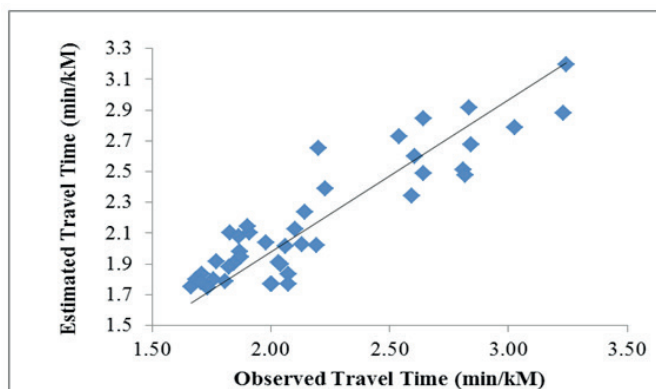| Parameter	Value
Root Mean Square Error (RMSE) min	0.18
Mean Percentage Error (MPE) %	-0.25
Mean Absolute Percentage Error (MAPE) %	7.02

Fig. 5 Observed and Estimated Travel Time

8 Sensitivity Analysis

Model TRATIM is further subjected to realize its sensitivity by varying inputs in possible range. At a time one input is to be varying assuming that other inputs are not varying. The inputs of traffic volume, composition, RSF and IF are part of the sensitivity analysis carried out as under.

8.1 Traffic Volume

Travel time variation with reference to increase in hourly traffic volume from 4000 to 7000 vehicles while maintaining composition of 2W, 3W, 4W and CV are 55 %, 30 %, 10 % and 5 % respectively and keeping RSF and IF as 0.6 and 11.5 respectively is shown in Fig. 6 (a). The fixed share of composition is assumed based on field observation of fixed traffic. It shows that travel time per Km increases by 26 % with increment of 75 % in hourly volume.

8.2 Traffic Composition

Travel time variation with reference to mode wise variation keeping other components fixed at a time as under is shown in Fig. 6 (b).

  a) 2W from 2500 to 4000 vehicles/hour
  b) 3W from 1500 to 3000 vehicles/hour
  c) 4W from 750 to 2250 vehicles/hour
  d) CV from 250 to 1750 vehicles/hour.
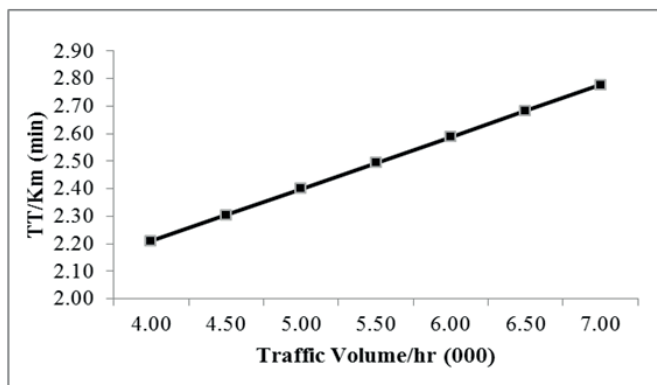
Increment for each mode is 250 vehicles/hour. Here Road Side Friction (RSF) and Intersection Factor (IF) as 0.6 and 11.5 respectively are assumed to be as constant. Total traffic varies from 5000 vehicles/hour to 6500 vehicles/hour. The initial traffic of 5000 comprises of 2500 2Ws, 1500 3Ws, 450 4Ws and 250 CVs. With increase in modes of 2Ws, 3Ws and CVs, the travel time increases at different rates and being higher for the Commercial Vehicles (CVs). As expected, the travel time reduces with increase in 4Ws as the probe vehicle follows the speedier mode in mixed flow.

8.3 Road Side Friction (RSF) and Intersection Factor (IF)

As anticipated, when RSF or IF increase, the speeds reduce and travel times are bound to increase because of increase in traffic impedance as shown in Fig. 6 (c) and 6 (d). Here, traffic composition of 2W, 3W, 4W and CV is maintained 55 %, 30 %, 10 % and 5 % respectively in both cases. The impact of IF is slightly higher to the RSF. In case of sensitivity analysis with reference to RSF, IF is assumed to be constant at 11.5 whereas RSF is 0.6 for sensitivity effect of IF.

9 Conclusions and recommendations

Travel time is the most significant factor from both trip makers and transport planners point of view. The traffic composition of
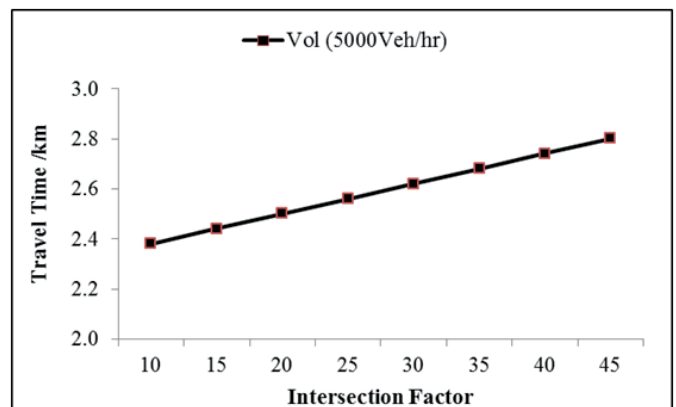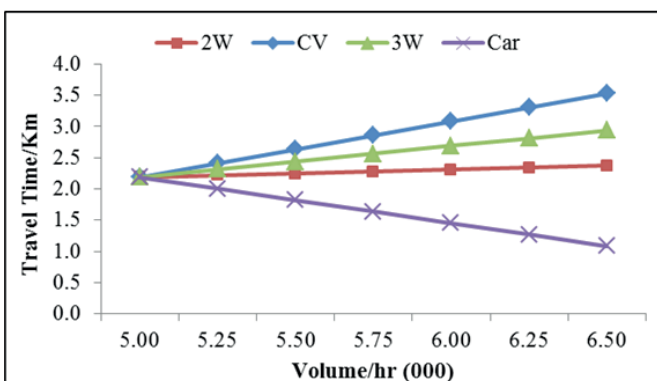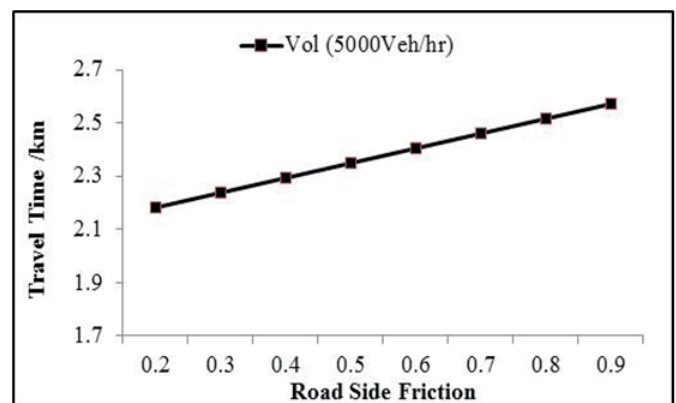

Fig. 6 (a) TT/Km with variation in hourly Traffic Volume **(b)** TT/km with respect to Mode-Wise Variation **(c)** TT/km with variation Road Side Friction **(d)** TT/km with variation in Intersection Factor

2Ws, 3Ws and CVs matters much in travel time as part of heterogeneous traffic volume, as observed in the present study, apart from the increase in traffic volume. In addition to the heterogeneous traffic characteristics, significant role has been observed by RSF on travel time. RSF covers both curb parking and pedestrian interruption at various spots along the corridor related with road side commercial activities. Similar is the case of IF along the route and is considered in the present study as ratio of average speed to the drop down in speed at the intersection and the same is aggregated for number of intersection in study stretch.

These varying attributes are part of the multi-liners regression model developed (TRATIM) here. The model indicates that 3Ws, CVs, RSF and IF are significant additive attributes, whereas 4Ws indicate negative impact in heterogeneous traffic on travel time on account of high speed consideration. The result of sensitivity analysis of the model clearly indicates mixed traffic and its composition has considerable impact along with RSF and IF. 2Ws are observed better mode compared to 3Ws in the mixed traffic flow. Certain mitigation strategies can be considered on the basis of present study to improve the travel time on urban corridors by controlling the travel impedances: restriction on heavy vehicles, access control at intersection of high intersection factor, regulating parking and pedestrians with provision of necessary facilities.

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