European Transport \ Trasporti Europei (2017) Issue 65, Paper n° 3, ISSN 1825-3997

Performance Evaluation of Urban Links under Heterogeneous Traffic Condition

Krishnamurthy Karuppanagounder[1*], Muneera C P[2]

[1]*Associate Professor, Department of Civil Engineering, National Institute of Technology Calicut-673601, Kerala, INDIA. kk@nitc.ac.in*

[2]*Research Scholar, Department of Civil Engineering, National Institute of Technology Calicut -673601, Kerala, INDIA. muneeranit@gmail.com*

Abstract

Performance evaluation of roadway provides an information regarding quality of facilities and it reflects the satisfaction of the road users. Travel time based performance evaluation accounts the road user perception and traffic managers alike, provides information for the smooth flow on the roadway. The performance of vehicles under heterogeneous traffic condition is more complex compared to homogeneous traffic conditions. The present study aims to evaluate the performance of urban link under heterogeneous traffic conditions considering travel time based indices.Delay, planning time index, congestion index, and travel time index are the travel time based indices used for the performance evaluation of the urban link. Seven single carriage ways operating one way is selected as the study area. The data on roadway geometrics, traffic volume count and travel time on the selected urban links forms the data base for this study. Statistical analyses were carried out for the performance evaluation of urban link using travel time based indices. Models were developed and validated for the performance evaluation of the urban link by using the travel time based indices with variation in the characteristics of traffic flow rate.The research concludes that travel time based performance indices shows an exponential growth with traffic flow rate. The model developed in this study can be used to define the performance evaluation of urban link and the prior information about the performance indicators helps the road users to plan their trip well in advance.

Keywords: Delay; Planning time index; Congestion index; Travel time index; Regression model.

1. Introduction

The performance evaluation of urban link is a primary concern to traffic engineers, road users and the urban community as it holds million people using the system for their daily activities. Performance evaluation helps to analyses the quality and quantity parameters on urban transportation system and it is a component of public and personal service accountability (Shaw 2003).The rapid growth of vehicle in the urban link leading to congestion, and cause other negative impacts to transportation systems and

* Corresponding author: Krishnamurthy Karuppanagounder (kk@nitc.ac.in)

thus by deteriorating the traffic performances . Traffic system performance represents the functionality of the link and can be measured in different ways, two main emphasis are contained in which user perception and other part is regarding the improving the service. Both of this emphasis causes an increasing importance of evaluating the performance urban link using proper measuring tool.

The perusal of literature show that researchers have focused on the performance evaluation and operational effectiveness of the urban link. Researchers quantified the performance of urban link by means of performance indicators such as mean speed, speed indices, and volume capacity ratio. The traditional method, volume capacity ratio are used for evaluating the performance of urban links by traffic carrying capacity to demand level. HCM 2010 defined six level of service criteria (LOS), qualitative measure and that defines the performance of urban link (HCM-2010). The capacity analysis gives a quantitative measure of maximum traffic and passengers that can be accommodate in a roadway, due to its probabilistic nature of the occurrence on the link, it is not always possible to accurately estimate the capacity of an urban link from the field (Chandra, Mehar, and Velmurugan 2016),(Modi et al. 2014).

The average trip speed from origin to destination represents the quality of the system and it give an insight to the performance evaluation in the urban link (D'Este, Zito, and Taylor 1999),(Li et al. 2009),(Hashim and Abdel-Wahed 2011). For urban roads the maximum trip speed occurs when the flow is minimum and vice versa.The important speed indices used in the urban link for performance evaluations are quality of transmission index (Levinson and Lomax 1996), corridor mobility index(Lomax et al. 1997), speed performance index(He et al. 2016), and speed reduction index(Mohan Rao and Ramachandra Rao 2012). The speed based indicators may not be an appropriate method for microscopic performance evaluation since the vehicles with same mean speed may have totally different speed profiles with respect to their trips (Anjaneyulu and Nagaraj 2009).

Travel time is an important tool in the performance evaluation that can account for user perception and at the same time it provides a key input for the improvements for different facilities. Hence, this study focused on the performance evaluation of urban link using travel time based indices under heterogeneous traffic conditions. The important parameters which influence the overall performance of the transportation system is the variation characteristics of flow rate. Therefore, this study also focuses on the performance evaluation model by considering traffic flow as an independent variable.

2. Performance Measure for Urban link Using Travel time

Travel time is an important measure in quality analysis of urban links.In this research work,the performance evaluation of urban link was conducted based on travel time based indices such as delay,planning time index ,congestion index and travel time index.Travel time delay represents the difference between average travel time and free flow travel time(Lomax et al. 1997). It is the unexpected or excess time to spend on travel. For better traffic operation, the delay should be minimum for road users. Delay can be calculated by using the Eqn (1).

$$Delay = Average\,travel\,time - Free\ flow\,travel\,time \quad (1)$$

Planning time index (PTI) represents the ratio of the 95 th percentile travel time and free flow travel time. As the travel time along the stretch increases, planning time index also increases. Therefore, for better traffic operation, the planning time index should be a minimum value. Planning time index can be mathematically represented as in Eqn (2).

$$Planning\,Time\,Index = \frac{95^{th}\,Percentile\,travel\,time}{Free\ flow\,travel\,time} \quad (2)$$

Congestion Index (CI) is computed as the ratio of the difference between average travel time and free flow travel time to the free flow travel time(Levinson and Lomax 1996). For better traffic operation, average travel time for the passengers will be minimum. Hence, congestion index should be minimum The expression for congestion index is given in Eqn (3).

$$Congestion\,Index = \frac{Average\,travel\,time - Free\ flow\,travel\,time}{Free\ flow\,travel\,time} \quad (3)$$

Travel time index (TTI) is the ratio of the average travel time and free flow travel time For better performance of the link, the travel time index should be minimum and it can be expressed as in Eqn (4).

$$Travel\,Time\,Index = \frac{Average\ travel\,time}{Free\ flow\,travel\,time} \quad (4)$$

In order to predict the performance of urban links, the travel time based indices have to be estimated and for that purpose the study stretches were selected in the heterogeneous traffic scenario.

3. Data description

For performance evaluation model, seven single carriageways in Kerala state, in India operating at different traffic volume under heterogeneous traffic conditions were selected through a pilot survey. To understand the performance of urban link, three types of data were collected. The first one was geometric data. Geometric data such as length of road stretches and carriageway width were collected manually from the site. The selected site having varying length of 215 m to 679 m and carriageway width of 6.1 to 8 m.

The second one and third one was classified traffic volume count and travel time data for each link. Traffic parameters including traffic volume count and travel time data were collected through video graphic survey along a normal day. Traffic composition data were manually extracted from the video and the composition of vehicles on the

each study stretches is depicted in Figure 1.From the traffic composition plot, it can be inferred that two wheeler is predominant compared to other modes in the study sites. The presence of different composition of vehicles on the roadway and its physical dimensions necessitates the performance evaluation along the roadway is essential under mixed traffic conditions.

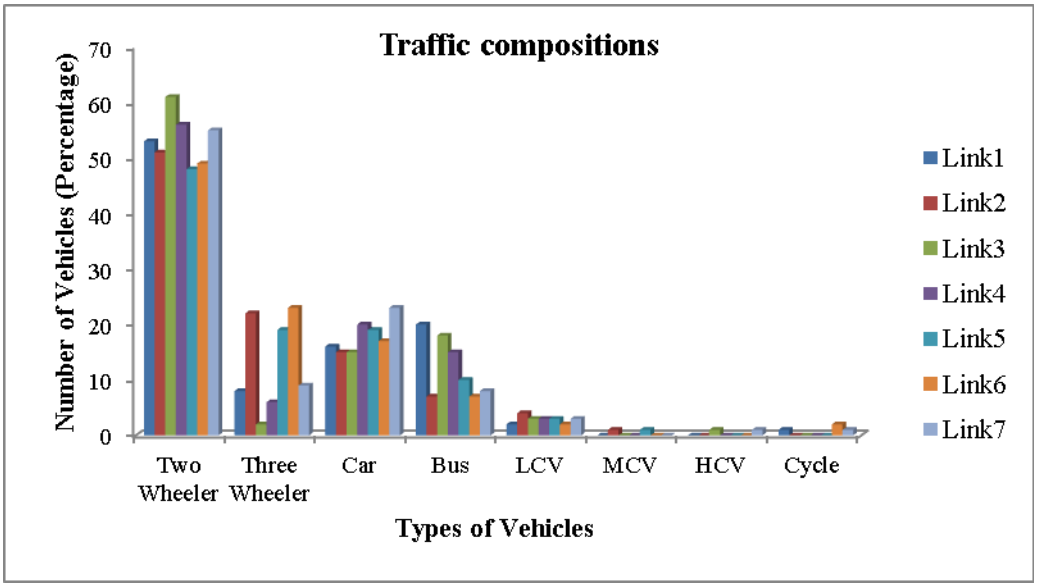

Figure1.Traffic composition characteristics along the study sites

Traffic volume data are observed from a camera that is fitted to the entry point of the link. The Data were collected from 7.00 AM to 6.00 PM , 5 minutes data were extracted manually from the video .Due to the different traffic composition of vehicles in the study sites, traffic volumes are converted to PCU by using IRC 86 -1983(IRC 83-1986). The minimum and maximum traffic flows of each stretch are depicted in Figure 2.The minimum traffic flow is observed in Link 4 and maximum traffic flow is observed in Link7.

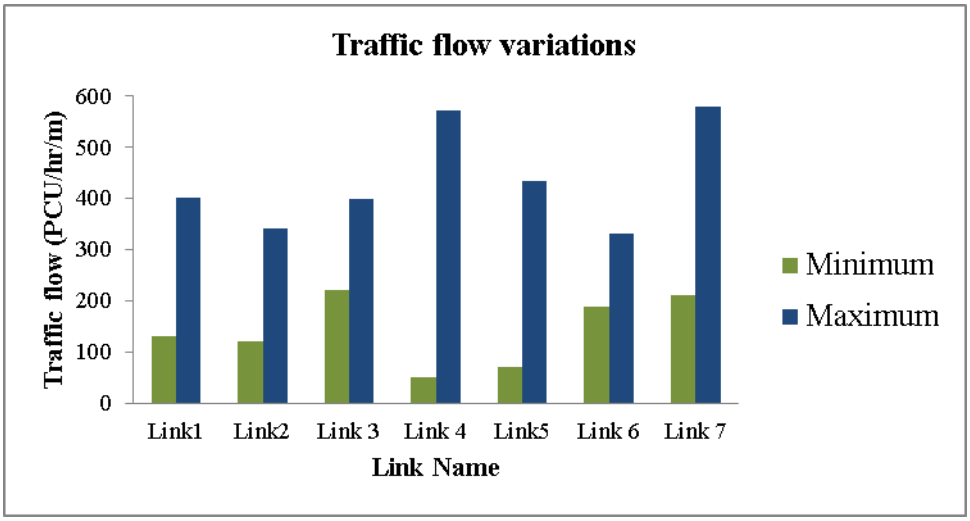

Figure 2.Traffic Flow Variation characteristics of urban link

The license plate matching technique was used to measure the travel time for the link. For this, video cameras are placed at the entry and exit location of the study area. By collecting vehicle license plate numbers for the entry point and exit point through the video and computing their time difference at exit and entry point gives the travel time for each vehicle. Free flow travel time was extracted manually from video in the early morning when the traffic flow was less. The travel time for the study stretches is varying from 11 sec to 254.5 sec and the minimum and maximum variation of traffic flow is depicted in Figure 3. The minimum travel time was observed in Link4 and maximum delay observed in the Link7.

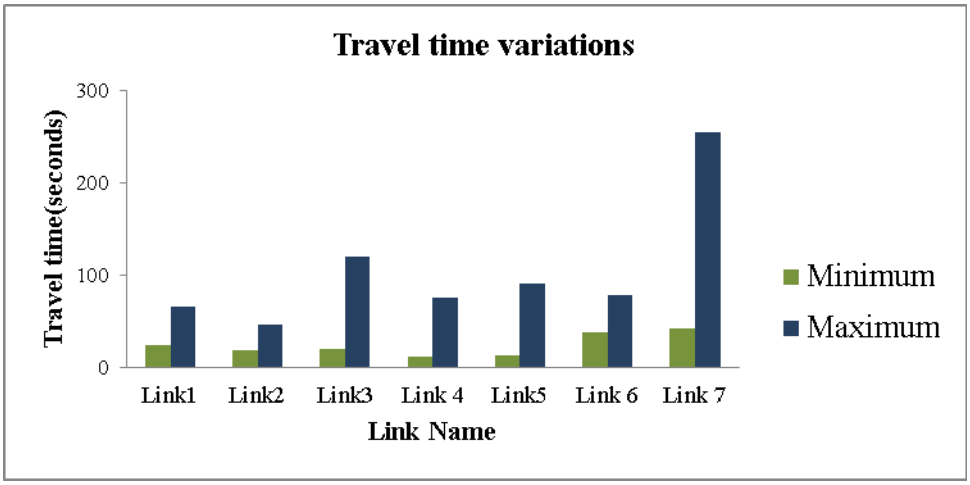

Figure 3.Travel time variation along the study sites

4. Performance evaluation of urban link

Evaluation of the quality of urban link has done by analysing the travel time based indices for each link. The summary statistics of the delay in seconds for the seven road links are shown in Table1. The value of the delay ranges from 1.12 to 249.4 seconds for the study stretches. The minimum delay observed in Link4 and maximum delay observed in the Link7. The high value on delay indicates that there is an increase in the average travel time for the link, hence the performances of the traffic operation decreases.

Table 1: Summary statistics for delay in seconds

Road name	*Minimum*	*Maximum*	*Mean*	*Standard deviation*
Link1	19.93	49.09	32.55	8.74
Link2	12.00	40.43	21.51	7.95
Link 3	14.08	114.75	45.8	23.92
Link 4	1.12	69.93	30.24	35.98
Link5	7.00	84.55	19.52	15.59
Link 6	21.2	62.05	30.37	8.67
Link7	36.4	249.4	96.30	76.76

The statistical evaluation of planning time index for each link is shown in Table 2. The planning index variation ranges from 1.52 to 50. The minimum planning time index

observed in Link4 and maximum delay observed in the Link7.Planning time index 50 means that, passengers should plan to allocate a travel time 50 times the free flow travel time in order to ensure on-time arrival 95% of the time. As the planning time index increases, the passenger allocate more time to travel through the road stretches. Therefore, an increase in the planning time index represents a decrease in the performance of the link.

Table 2: Summary statistics for planning time index

Road name	*Minimum*	*Maximum*	*Mean*	*Standard deviation*
Link1	1.88	5.31	3.45	0.89
Link2	3.30	13.41	6.77	2.12
Link 3	3.62	17.16	10.79	3.16
Link 4	1.52	8.33	3.79	2.85
Link5	3.49	49.50	13.43	12.22
Link 6	2.96	6.15	3.69	19.67
Link7	8.62	50.00	20.37	14.93

Congestion index for the seven urban links is estimated and the summary statistics were depicted in Table 3. The congestion index variation ranges from 0.031 to 48.90 for the study stretches. The minimum congestion index observed in Link4 and maximum congestion index was observed in the Link7. Congestion index 48.90 indicates that an extra time 48.90 times the free flow to be added to the free flow travel time to get the average travel time during that period. Congestion index increases, the performance of traffic operation on the link decreases.

Table 3 :Summary statistics for congestion index

Road name	*Minimum*	*Maximum*	*Mean*	*Standard deviation*
Link1	0.99	3.06	1.88	0.57
Link2	2.00	6.79	3.58	1.32
Link 3	2.34	19.12	7.75	4.07
Link 4	0.031	3.88	1.64	1.98
Link5	1.75	21.13	4.99	3.94
Link 6	1.32	2.97	1.81	0.36
Link7	7.13	48.9	18.88	15.05

The summary statistics of travel time index for the seven road links are shown in Table 4. The travel time index variation ranges from 1.03 to 49.9 for the study stretches. . The minimum travel time index observed in Link4 and maximum travel time index was observed in the Link7.

Table 4 :Summary statistics for Travel time index

Road name	*Minimum*	*Maximum*	*Mean*	*Standard deviation*
Link1	1.18	4.06	2.69	0.71
Link2	3.00	7.73	4.58	1.32
Link 3	2.51	20.12	8.41	4.21
Link 4	1.03	4.88	2.64	1.98
Link5	2.75	22.13	5.99	3.94
Link 6	2.32	3.97	2.81	0.36
Link7	8.13	49.9	19.88	15.05

From the analysis it is observed Link 4 having low values and link7 posses high values of travel time and traffic volume among the links in the study streches.Statistical analysis of travel time based indices on the study links shows that low values on link 4

and high values on link7.Therefore,link 4 contibute a good performance and on the other hand link7 posses least performances with observed traffic flow rate among the links.

The graph of the travel time based indices and traffic flow rate were examined in details to study their relationship for the measure of effectiveness of quality performances of urban links. Scatter plots were developed between indices and traffic flow rate and it is depicted in figure 4. From the scatter plots, it is observed that delay, planning time, congestion index and travel time index increases with increase in traffic flow. This is due to the fact that as the traffic volume increases, more number of vehicles accommodates in the roadway, interference among the vehicles leads to increase the travel time of vehicles.

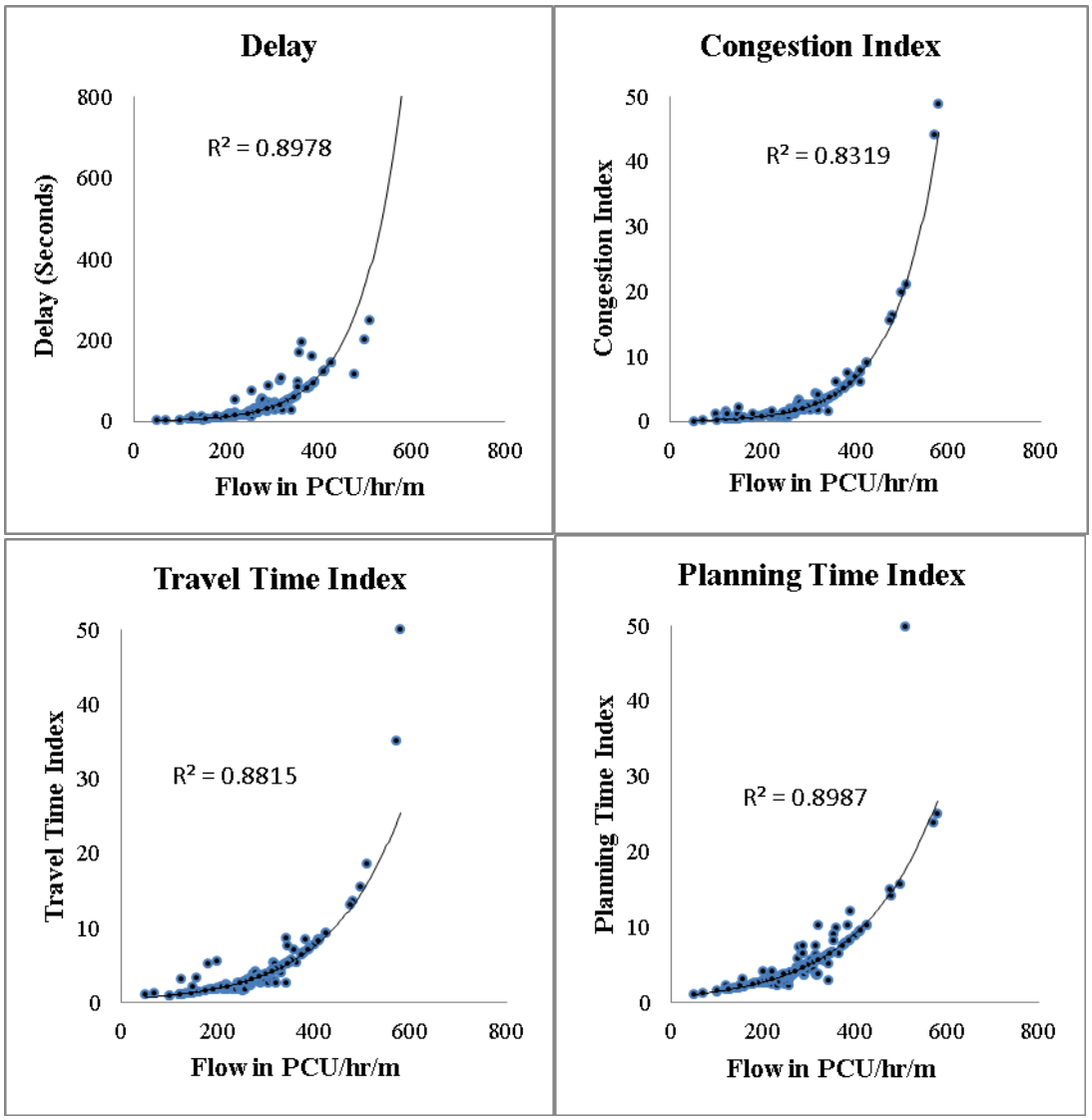

Figure 4.Variation of travel time based indices with traffic flow rate

5.Development of model for Performance evaluation on urban links

Models were developed to find the relationship between travel time based indices and traffic flow rate for urban links. A total of 250 data sets were taken for calibrating and validating the model. of the different model form tried, nonlinear regression model were developed for the performance evaluation of the urban links. The model form for predicting the travel time indices on the traffic flow rate is given in Eqn (5).

$$Travel\,Time\,Indices = a\ e^{b.V} \qquad (5)$$

Where a and b were estimated parameter for different indices and shown in Table 5. In this model, V is the traffic volume in PCU/hr/m width of the road.

Table 5.Models for Performance evaluation using travel time based indices

Si no	*Indices*	*Model*	R^2	*Standard error*		*RMSE*	
				Constant	*Coef of flow*	*CD*	*VD*
1	Planning time Index	$0.762e^{0.006v}$	0.572	0.036	0.001	2.80	2.66
2	Delay	$3.612e^{0.008v}$	0.789	0.046	0.001	46.31	45.90
3	Travel time Index	$0.239e^{0.009v}$	0.939	0.003	0.001	1.3	1.10
4	Congestion Index	$0.086e^{0.001v}$	0.993	0.017	0.001	2.33	2.17

Note: CD - calibration data set and VD - validation data set.

Statistical parameters for evaluating the travel time based indices with traffic flow rate are given in Table 5. Signs of the coefficents are logically correct. The standard error for the model parameters are less than 0.05 represents the coefficients are significant at 95% confident interval,which represents the predictability of the models.Considering R^2 value from the table, exponential model provide a fairly good prediction. The models were validated by estimating the RMSE value for both caliberated data set and validated data set.

The model explanis that the relation between travel time based indices and traffic flow rate is not linear, shows an exponential growth with traffic flow rate.This is also explains the fact that as the traffic flow rate increases,travel time of the vehicles in the heterogenous traffic condition also incraese,and it drops the reduction in the performace of urban link.

6.Conclusions

The study was an attempt for the performance evaluation of urban link under heterogeneous traffic operation. Travel time based indices comprising delay, planning time index, congestion index and travel time index were used to evaluate the performance of the urban link. The result of the analysis indicates that link having high value of travel time shows a high values of the performance indicators on urban link,which means that passengers allocate more time for their trip purposes.Therefore,the performance of urban link decreases as the travel time increases.

The relationship between the travel time indices and traffic flow rate is examined for the performance evaluation of urban link. Nonlinear regression models,exponential models were developed for the performance of urban link. The planning time index, travel time index, congestion index, and travel time delay shows a positive exponential trend with different traffic flow rates.

This study resulted in the usefulness of travel time based indices in the performance evaluation of the urban link. The scope of the study is limited to the heterogeneous urban single carriageway with observed traffic flow rate. This study is a novel approach to evaluate the performance evaluation of urban link under heterogeneous traffic conditions and can be used to predict the performance evaluation urban links under heterogeneous tarffic conditions.

Acknowledgement

The authors sincerely thank the support received from the Centre for Transportation Research, Department of Civil Engineering, National Institute of Technology Calicut, a Centre of Excellence setup under FAST Scheme of MHRD, Govt. of India.

Reference

Anjaneyulu, M. V. L. R. and B. N. Nagaraj. 2009. “Modelling Congestion on Urban Roads Using Speed Profile Data.” Journal of Indian Road Congress ,Paper (549):65–74.

Chandra, Satish, Arpan Mehar, and Senathipathi Velmurugan. 2016. “Effect of Traffic Composition on Capacity of Multilane Highways.” KSCE Journal of Civil Engineering 20(5):2033–40.

D’Este, Glen M., Rocco Zito, and Michael A. P. Taylor. 1999. “Using GPS to Measure Traffic System Performance.” Computer-Aided Civil and Infrastructure Engineering 14(4):255–65. Retrieved February 15, 2017 (http://doi.wiley.com/10.1111/0885-9507.00146).

Hashim, Ibrahim Hassan and Talaat Ali Abdel-Wahed. 2011. “Evaluation of Performance Measures for Rural Two-Lane Roads in Egypt.” Alexandria Engineering Journal 50(3):245–55.

He, Feifei, Xuedong Yan, Yang Liu, and Lu Ma. 2016. “A Traffic Congestion Assessment Method for Urban Road Networks Based on Speed Performance Index.” Procedia Engineering 137:425–33.

Highway Capacity Manual (2010).”Urban street facilities”. Transport Research Board, Washington D C.

H. Levinson and T. Lomax, “Developing a Travel Time Congestion Index,” *Transp.*

Res. Rec., vol. 1564, pp. 1–10, 1996.

Indian Road Congress 86.(1983),"Geometric Design Standards for Urban Roads in Plains",New delhi.

Levinson, Herbert and Timothy Lomax. 1996. “Developing a Travel Time Congestion Index.” Transportation Research Record 1564:1–10.

Li, Xu et al. 2009. “Performance Evaluation of Vehicle-Based Mobile Sensor Networks for Traffic Monitoring.” IEEE transactions on vehicular technology 58(4):1647–53.

Lomax, T. et al. 1997. “NCHRP Report 398: Quantifying Congestion.” NCHRP Report (398):102.

Modi, Vipul, Alexandra Kondyli, Scott S. Washburn, M.ASCE, and Douglas S. McLeod. 2014. “Freeway Capacity Estimation Method for Planning Applications.” Journal of Transportation Engineering 140(9):1–9. Retrieved (http://ascelibrary.org/doi/abs/10.1061/(ASCE)TE.1943-5436.0000699).

Mohan Rao, Amudapuram and Kalaga Ramachandra Rao. 2012. “Measuring Urban Traffic Congestion – a Review.” International Journal for Traffic and Transport Engineering 2(4):286–305.

Shaw, Terrel. 2003. NCHRP Synthesis 311: Performance Measures of Operational Effectiveness for Highway Segments and Systems.