Performance Evaluation of Urban Arterial in Delhi Using Travel Time Reliability

Anish Kumar BHARTI[a], Satish CHANDRA[b], Ravi Sekhar CHALUMURI[c],

[a,b]*Deapartment of Civil Engineering, Indian Institute of Technology Roorkee, Roorkee, 267667, India*
[a]*E-mail: bharti09.iitr@gmail.com*
[b]*E-mail: satisfce@iitr.ernet.in*
[c]*Transportation Planning Division, CSIR-CRRI, New Delhi, 110025, India;*
[c] *E-mail: chalumuri.ravisekhar@gmail.com*

Abstract: The present study demonstrates the application and usefulness of concept of travel time reliability on Indian roads. Travel time data collected on an urban arterial in New Delhi during morning and evening peak periods are analyzed and various reliability and congestion measures are evaluated. Attempt is also made to correlate reliability measures such as planning time index (PTI) with congestion measures like travel time index (TTI). Analysis of results indicates that the PTI for the subject corridor varies from 1.63 to 2.63 with a maximum of 2.63 during 8.45 to 9.00 AM. Highest value during evening peak is 2.21 indicating travel time of a traveler during evening peak would be 2.21 times its free flow travel time. Other parameters of reliability like planning time and buffer time index are also evaluated and their values for different range of volume-capacity ratio are presented.

Keywords: Travel Time Reliability, Urban Arterial, License Plate, Travel Time Index, Capacity, Buffer Time Index.

1. INTRODUCTION

Travel time reliability is most useful indicator to measure performance of transportation system. Since 1991, travel time reliability has attracted many researchers in the studies of transport network reliability because of its importance as compared with other network reliability measures such as connectivity reliability or capacity reliability. Asakura and Kashiwadani (1991) introduced the concept of travel time reliability. Since then various mathematical models have been developed to measure the travel time reliability of a road transportation system. The empirical based studies are initiated by Federal Highway Administration (FHWA) and defined travel time reliability is consistency or dependability in travel time, as a measure from day to day and or across different times of the day (FHWA Report 2006; Margiotta 2002). The advantage of travel time reliability is that, it is more useful to transport system planner as well as the users (PATH Report 2005). It can be used in policy assessment as a new evaluation technique and may be used as a new travel time related information to the users (Asakura 2006). Chen et al. (2003) stated that travel time reliability is “an important measure of service quality for travelers”.

Level of service (LOS) is a quantitative stratification of a performance measure or measures that represent quality of service (HCM 2010). Thus LOS is spatially a localized measure and this is used to analyze the operation of specific locations of highway sections (Chen et al. 2003). Highway Capacity Manual (HCM) defines six levels of service, ranging from A to F for each service measure. The HCM often uses speed as the service measure for urban street segment and this speed depends on volume to capacity (v/c) ratio (Highway Capacity Manual 2010). Other service measures considered for various system elements in HCM 2010 such as, freeway segment, multilane segment and urban are density, percent time spent following and speed. These measures do not capture the variability in travel time. Although travel time, LOS, and delay are all related and provide different summaries of the underlying traffic conditions, only travel time based statistics capture the variability experienced by individual drivers.

Travel time variation is especially more in urban arterial corridors irrespective of the segment of the network flow being interrupted or uninterrupted. The variation in travel time is mainly due supply side, demand side and other external factors. The objective of this study is to evaluate the performance of the urban arterial corridor in Delhi using travel time reliability indices such as Planning Time Index and Buffer Time Index (FHWA 2006). These measures are compared with volume-capacity ratio of the study section. The capacity of the study corridor has been estimated through empirical data and the relation between V/C ratio and reliability indices is also discussed.

2. LITERATURE REVIEW

Two approaches are mainly available in the literature for measuring travel time reliability of road transportation system. These include mathematical based travel time reliability measurements (Asakura and Kashiwadhani, 1991; Lee et.al, 2000; Chen et.al.2003) and empirical measures (FHWA Report 2006). Mathematical reliability measurements are developed based on conventional User Equilibrium (UE) route choice principle, where as empirical measures are developed based on travel time distribution which is obtained by travel time history of users' experience for the particular link/road. The empirical measures are relatively easy to understand by non technical road users also, Federal Highway Administration (FHWA) has defined travel time reliability a consistency or dependability in travel time, as a measure from day to day and or across different times of the day (FHWA Report 2006; Margiotta 2002). Performance indicators such as 95thpercentile travel time, Buffer Index (BI) and Planning Time Index (PTI) were developed under this category. Travel time distribution is the base for development of all these indices. These indices are discussed defined below. (FHWA Report 2006)

- 95th Percentile Travel Time: It is the 95th percentile travel time of the measured travel time distribution on a route. It represents travel time on some of the heaviest traffic days.
- Buffer Time Index (BTI): It is the ratio of buffer time (extra budget time) to average travel time. The buffer time is the difference between 95thpercentiletravel time and the average travel time.
- Planning time Index (PTI): It is the ratio of 95th percentile travel time to free flow travel time.

Studies carried out in USA, Europe and Japan are briefly discussed in the following paragraphs.

Travel Time Reliability Studies in USA

Several agencies in the US have already begun using empirical data based reliability measures in various applications. Initially, FHWA launched a National traffic monitoring programme to track reliability measures such as Buffer Time Index (BTI) and Planning Time Index (PTI) in more than 30 cities and this information is communicated to key decision makers as a monthly dashboard report. In another programme named as Measuring travel time reliability in freight significant corridor, FHWA derived BTI for five significant corridors. From BTI, commercial vehicle operators can estimate buffer time to ensure 95thpercentile confidence that driver would arrive on time. Minnesota Department of Transportation (Mn/DOT) used travel time reliability measures such as 95th percentile travel time to study the effects of a ramp meter shutdown on Minneapolis-St. Paul freeways in USA. Lyman (2007) used travel time reliability measures for prioritizing Portland freeway road network, Oregon, USA. This study recommended metropolitan planning organisation to use travel time reliability measures for evaluating and prioritizing the roadway segments.

Travel Time Reliability Studies in Europe

Lint et al. (2004) studied on monitoring and predicting freeway travel time reliability using travel distributions for Netherland roads. They suggested that when travel time distribution is not symmetric, both the width and the skew of the travel time distribution can provide a more robust estimate of reliability. Avariation of buffer time index takes into account distributional skewness. This study further suggested that the skew of the distribution can be measured as the ratio of the difference between the 90thand 50thpercentile to the difference between the 50thand 10thpercentile. Tu et al. (2007) studied influence of road geometry on travel time variability. This study considered the influence of number of ramps per unit road length on densely used freeways stretches in Netherlands.

Travel Time Reliability Studies in Japan

Asakura and Kashiwadanni (1991) studied road network reliability considering day to day fluctuation of traffic flow using user equilibrium based mathematical models. They proposed reliability measures including travel time reliability and suggested that time reliability is suitable for evaluating network performance under normal conditions in which a driver meets traffic congestion caused by heavy travel demand. Asakura (2006) compared statistical measures and reliability measures and concluded that statistical measures such as coefficient of variation have some similarities with reliability measures such as buffer time index. Ravi Sekhar and Asakura (2008) carried out a comparative evaluation of various travel time reliability indices between different corridors of the Hanshin expressway road network. They suggested that travel time reliability measures like BI is much more useful to the commercial vehicle users and freight significant corridors, whereas planning time and planning time index are more suitable for personal traffic. Mehran and Nakamura (2009) on considered travel time reliability and safety for evaluation of congestion relief schemes on expressway segments in Japan. This study proposed a methodology to estimate travel time reliability based on modeling travel time variations as a function of demand, capacity and weather conditions by using stochastic simulation techniques. Wakabayashi and Matsumoto (2012) compared travel time reliability indexes for highway users and operators. This study discuss the merits and demerits of the various travel time reliability indices with respect to highway user and operator and this study proposes two indices based on acceptable travel time variation and desired travel time variation.

3. STUDY AREA AND DATA COLLECTION

A case study of uninterrupted urban arterial corridor of 1.7 km length on Lala Lajpat Rai Road in New Delhi has been considered. This section is 6-lane divided carriageway having 10.5 m road width in each direction. There is no major merging and diverging within the selected 1.7 km of the road section. Separate facility for pedestrian walking (raised kerb) is available on both side of the road. Traffic leaving from Oberoi Hotel to Lajpat nagar metro station was considered in this study (Figure 1). This arterial corridor serves the traffic coming from main city towards South Delhi. From earlier studies it was observed that Peak Traffic volume along this section is 9 AM to 10 AM and from 5 PM to 6 PM. Data collection in this study was mainly focused during morning hours between 8 AM and 10 AM and evening hours of 4 PM to 7 PM. It is to ensure that travel time would vary due to traffic volume alone. .

Figure 1 Study area: Urban arterial corridor on Lala Lajpat Rai Road in Delhi

License plate matching technique has been considered for measuring the travel time in the study area. For this Video cameras were installed at entry and exit locations of the study area to capture the vehicle license plate for all categories of vehicles. Traffic volume data and classified traffic speed (50 m trap length) was estimated through third video camera installed at the entry point of the section. Three days continuous data from 5th July 2012 to 7th July 2012 in the morning (8.00 to 10.00 AM) and evening hours (4.00 pm to 7.00 pm) have been collected. Seven categories of vehicles were identified during the study period on this corridor. The vehicular composition on the study section for morning hours and evening hours of a typical day is presented in Figure 2. From the figure it can be observed most predominant composition is car and the average composition is 47% in morning hours and 60% in the evening hours. After that 2- wheelers composition is about 36% in morning hours and 25% in the evening hours.

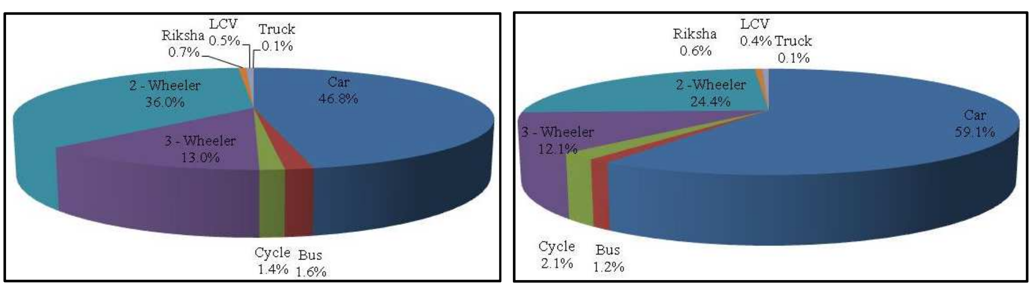


Figure 2. Traffic Compositions on Study Corridor during Morning and Evening Hours

License plate matching techniques was considered for measuring travel time on the study section. This method consists of collecting vehicle license plate numbers and arrival times at entry and exit points of the section, matching the license plate between entry and exit points and computing travel time from the difference in arrival times. The study mainly focused on travel time variation of cars which includes both small and big cars. On an average 30% of vehicle license plate numbers were matched for cars. License plate of two-wheelers could not be identified properly from the video and hence analysis is restricted to cars only. The statistical parameters such as minimum, maximum, mean, standard deviation of travel time data for the study area at various time intervals in the morning and evening hour were calculated and presented in Table 1 (a) and (b). The large variations in travel time data are mainly due to change in traffic volume and its composition in different time intervals.

Table 1. (a) Statistical Summary of Travel Time Data for Cars in Morning Hour

Time Interval	Travel Time Parameters				
	Minimum (sec)	Maximum (sec)	Average (sec)	Std. Dev. (sec)	Coefficient of Variation
8:15 – 8:30	119	337	144.76	38.29	0.26
8:30 – 8:45	107	285	137.49	26.62	0.19
8:45 – 9:00	117	306	156.85	38.96	0.25
9:00 – 9:15	117	336	152.32	32.14	0.21
9:15 – 9:30	111	312	153.44	38.13	0.25
9:30 – 9:45	115	339	151.92	29.70	0.20
9:45 – 10:00	106	166	148.61	14.35	0.10

Table 1. (b) Statistical Summary of Travel Time Data for Cars in Evening Hour

Time Interval	Travel Time Parameters				
	Minimum (sec)	Maximum (sec)	Average (sec)	Std. Dev. (sec)	Coefficient of Variation
16:15 – 16:30	115	171	143.98	11.31	0.08
16:30 – 16:45	81	284	156.14	21.22	0.14
16:45 – 17:00	83	310	149.19	27.49	0.18
17:00 – 17:15	117	345	152.29	30.33	0.20
17:15 – 17:30	118	338	160.09	31.21	0.19
17:30 – 17:45	114	328	158.78	29.01	0.18
17:45 – 18:00	130	357	175.55	37.68	0.21
18:00 – 18:15	79	325	161.20	29.95	0.19
18:15 – 18:30	128	349	162.56	42.71	0.26
18:30 – 18:45	140	170	153.22	10.11	0.07
18:45 – 19:00	134	314	163.52	35.75	0.22

4. PERFORMANCE EVALUATION BASED ON TRAVEL TIME RELIABILITY

The performance of uninterrupted urban arterial corridor is evaluated through travel time reliability analysis. Capacity of the road is also estimated separately and Travel Time Reliability based on volume-capacity is considered to evaluate the performance of the test section.

4.1 Analysis of Travel Time Reliability

Travel time curves were plotted for each 15 minute time interval and reliability and congestion measures were evaluated during morning peak and evening peak. These are given in Table 2. It is observed from the reliability measures that during morning peak hour PTI values are about 2.6 for vehicles enter after 8.45 AM. Similarly BTI values become larger for the vehicles between 8.45 AM and 9 AM. The 95th percentile travel for urban section is maximum 268 seconds and minimum 166 seconds in the morning hours. During evening peak hours the maximum PT was observed is 225 seconds and minimum is 158 seconds. Highest

PTI is observed between 5:45 PM and 6:00 PM.

Travel Time Index (TTI) is a performance measure for congestion and it is defined as the ratio of average travel time to the free flow travel time (Turner et al. 2004). It was attempted to observe if there exists some correlation between congestion measure (TTI) and reliability measure (PTI). Figure 3 shows a plot between these two parameters for evening peak data. As may be seen, a good correlation exists between the two measures. However, similar trend could not be obtained for morning hours. It can be attributed to the fact that is made to find the correlation among the reliability and measurements and TTI. Particularly, congestion level practiced in literature is compared with performance measure of travel time reliability with respect of PTI. From Table 2a and 2b, it can be identified that the severity order of congestion represented by the congestion index (TTI) consistently not followed with that of PTI. This is mainly because of the congestion measure depends on average travel time of the route, whereas travel time reliability indices such as BTI and PTI considers the travel time variation. Therefore, two parameters are to be interpreted separately.

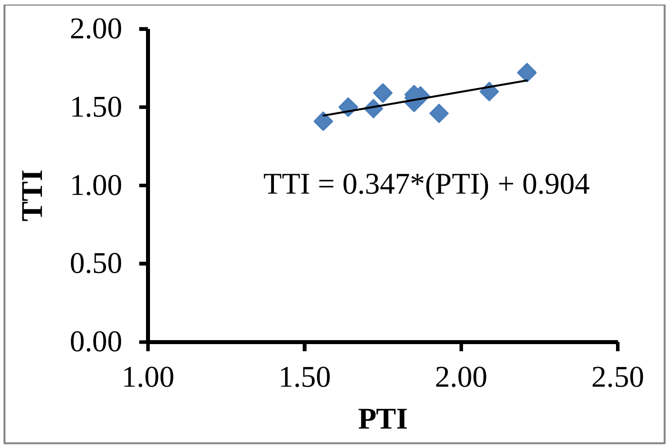


Figure 3. Relation between PTI and TTI

Table 2a.Travel Time Reliability of Uninterrupted Urban Corridor in Delhi (Morning)

Time Period	**Sample Size**	**Reliability Measures**					**Congestion Measure**
		PT (95%)	PTI	BTI	λ_{skew}	$\lambda_{var.}$	TTI
		Morning Hours (8:15 AM to 10:00 AM)					
8:15 – 8:30	34	191.25	1.88	0.32	1.97	0.28	1.42
8:30 – 8:45	90	172.65	1.69	0.26	2.12	0.26	1.35
8:45 – 9:00	91	268.50	2.63	0.71	3.06	0.50	1.54
9:00 – 9:15	81	185.00	1.81	0.21	1.31	0.21	1.49
9:15 – 9:30	82	257.45	2.52	0.68	1.55	0.26	1.50
9:30 – 9:45	100	174.30	1.71	0.15	1.99	0.17	1.49
9:45 – 10:00	18	166.00	1.63	0.12	1.41	0.18	1.46

Table 2b.Travel Time Reliability of Uninterrupted Urban Corridor in Delhi (Evening)

Time Period	**Sample Size**	**Reliability Measures**					**Congestion Measure**
		PT (95%)	PTI	BTI	λ_{skew}	$\lambda_{var.}$	TTI
		Evening Hours (4:15 PM to 7:00 PM)					
16:15 – 16:30	45	158.80	1.56	0.10	0.64	0.19	1.41
16:30 – 16:45	84	188.35	1.85	0.21	1.25	0.22	1.53
16:45 – 17:00	97	196.60	1.93	0.32	0.94	0.26	1.46
17:00 – 17:15	109	175.80	1.72	0.15	1.35	0.21	1.49
17:15 – 17:30	127	191.20	1.87	0.19	1.42	0.26	1.57
17:30 – 17:45	138	188.90	1.85	0.19	1.28	0.26	1.56
17:45 – 18:00	119	225.20	2.21	0.28	1.31	0.45	1.72
18:00 – 18:15	54	188.75	1.85	0.17	1.27	0.29	1.58
18:15 – 18:30	41	179.00	1.75	0.10	1.13	0.21	1.59
18:30 – 18:45	9	166.80	1.64	0.09	0.73	0.15	1.50
18:45 – 19:00	25	212.80	2.09	0.30	0.63	0.21	1.60

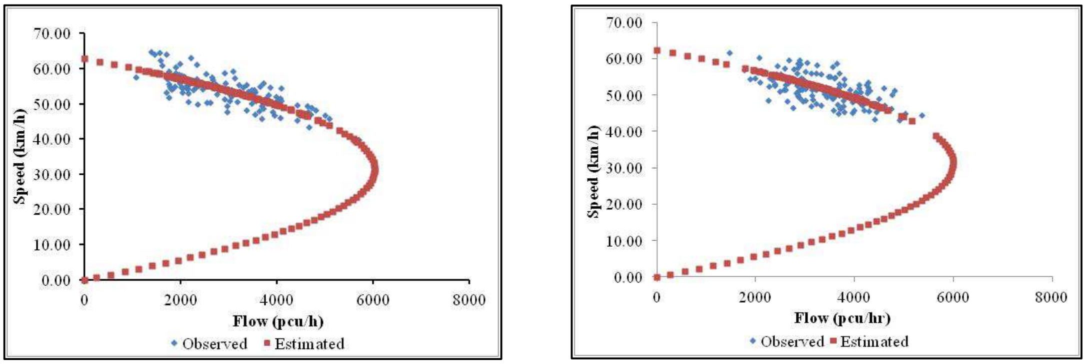
4.2 Estimation of Capacity of Study Section

The main problem in developing the analytical speed-flow relationship on Indian road is the heterogeneity of traffic. The vehicles in the mix produce different impedance due to their varied static and dynamic characteristics. Hence simply adding the number of vehicles does not give the authentic speed flow relationship. For this reason, the vehicles are normally presented in terms of standard type of vehicle using certain conversion factors. Generally, passenger car is adopted as standard vehicle and therefore the factor is known as passenger car unit (PCU). Many researchers have developed methods to estimate PCU for a vehicle type. There exists large variation in PCU values being adopted in different parts of the world. In the present study, vehicles of different types were converted into equivalent number of standard cars by using PCU factors as given by Equation (1) (Chandra and Kumar 2003).

$$PCU_i = \frac{V_c / V_i}{A_c / A_i} \qquad Equation\ (1)$$

Where PCU_i is the passenger car unit value of i^{th} type of vehicle V_c/V_i is speed ratio of standard car to i^{th} vehicle and A_c/A_i is physical rectangular area ratio of standard car to the i^{th} vehicle.

In India ITS technologies are yet to be implementing on highway road network therefore in a traditional way; measurement of density in the field is difficult. Hence speed and volume data collected using video camera as explained in section 3, were used to calculate traffic density using the fundamental relationship between speed, flow and density. This relationship was used to develop the complete theoretical speed-volume curves as presented in Figure 4. The capacity of the section selected for the present study is estimated to be 6032 pcu/hr/dir in the morning hours and 5995 pcu/h/dir in the evening hours. Both of these values are taken same indicating that there is no change in the capacity of the road with time of the day.



a) Morning hours b)Evening Hours

Figure 4. Speed Volume Relationships from field data

5. TRAVEL TIME RELIABILITY ESTIMATION BASED ON V/C RATIO

HCM (2010) has defined level of service (LOS) on urban street facilities based on travel speed as a percentage of free flow speed. As per the manual, LOS E occurs when travel speed is 30-40%. However, in a mixed traffic situation speed flow curve stars falling down right from the beginning and travel speed at capacity (LOS E) around 50% of free speed as shown in Figure 4. Therefore, limits of travel time as suggested in HCM (2010) cannot be applied to mixed traffic conditions. Instead, Indian specifications which are based on volume-capacity ratio are used and reliability measures at different volume-capacity (V/C) ratios as observed from field data are given in Table 3. As may be seen PTI and TTI increases as the ratio increases on the road. It is quite obvious also.

Table 3: Travel Time Reliability Measures Vs Volume to Capacity Ratio (V/C)

V/C	PT	PTI	BTI	λ_{skew}	$\lambda_{var.}$	TTI
		Morning Hours (8:15 AM to 10:00 AM)				
≤ 0.3	162.60	1.59	0.16	0.70	0.18	1.38
0.3 – 0.5	205.25	2.01	0.41	1.80	0.31	1.43
0.5 – 0.7	218.10	2.14	0.42	1.58	0.21	1.51
		Evening Hours (4:15 PM to 7:00 PM)				
0.3 – 0.5	192.00	1.88	0.23	1.48	0.34	1.53
0.5 – 0.7	211.00	2.07	0.32	1.89	0.34	1.57

6. CONCLUSIONS

The present study is an attempt to measure travel time reliability on an urban corridor in India. Travel time has been estimated by vehicle license plate matching method using video graphic data for an urban arterial in Delhi and the travel time reliability analysis has been carried out. The results of travel time analysis indicate that the planning time index (PTI) is highest (2.63) during 8.45 AM – 9.00 AM. It means that the travel time on the study corridor during this is 2.63 times more than free flow travel time. This is an important conclusion for travelers and planners. A road user should plan his travel in such a manner that he does not enter the subject corridor during 8.45 to 9.00 AM to avoid long delays. Minimum PTI is during 16.15-16.30 hours and a driver entering the test corridors during this period will experiences the shortest travel time. Another important result is buffer time index (BTI) which is also higher (0.71) during 8.45 - 9.00 AM. It suggests that travelers should budget an additional 111 seconds buffer time to ensure 95% on-time arrival at the destination on study corridor. The mean 95th % travel time for urban corridor varies between 166 and 268 sec during morning hour and 159 to 225 sec in the evening hours.

Travel time reliability is currently not used in transportation planning or for performance evaluation of corridor/network in India. This study demonstrates its usefulness and importance of the travel time reliability for road transportation communities in India. Further study is required to investigate the Level of Service (LOS) based on Travel Time Reliability measures and their comparison with services measures considered in HCM 2010 for urban arterial corridors.

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