Analysis of travel time reliability of an urban corridor using micro simulation techniques

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The ever-increasing traffic congestion on urban roads leads to uncertainties in travel time necessitating the need to consider travel time reliability in measuring the efficiency of the transport system. In view of this, an attempt has been made in this study to examine the travel time reliability under the influence of various demand and supply side factors of the transportation system. For this purpose, an urban corridor of 2.5 km on National Highway 2 in the city of Delhi was considered. The traffic volume, speed and travel time data for one week were collected to analyse the travel time reliability on this stretch and estimated appropriate reliability measures. In order to assess the impact of various demand and supply side variations on travel time reliability, a microscopic traffic simulation model was developed using VISSIM software. The developed simulation model was successfully validated with the observed data and it was found from the analysis that travel time increases 5.3 and 6 times for the scenarios of increase in demand by 50% and lane closed for about 30 min respectively.

Keywords: Micro simulation, road network, traffic congestion, travel time reliability, urban corridor.

RELIABILITY is defined in system engineering as a probability of a device performing its purpose adequately for the period of time intended under the operating conditions encountered[1]. In road network, reliability is defined as the network which can guarantee an acceptable level of service for road traffic even if the functions of some links are physically damaged or large amount of travel demand is occasionally generated[2]. Road network problems related to travel-time variations are generally caused by uncertainties of traffic conditions of the network. In view of this, travel time reliability analysis has attracted the attention of researchers because of its importance compared with other network reliability measures such as connectivity reliability and capacity reliability[3]. The use of travel time reliability measures is growing in recent years in various developed countries like USA[4] and Japan[5,6]. These results will provide guidance in establishing travel time reliability for Indian road network. Travel time reliability is an important attribute for planning the urban transportation systems and it also significantly influences the mode and route choice of commuters[7]. Travel time reliability is a measure of roadway service quality and it is also a performance measure to assess the efficiency of congestion relief schemes[8].

In this study, fundamental characteristics of travel time reliability measures were examined for an urban arterial corridor on National Highway (NH) 2 in the city of Delhi. For this purpose, travel time data were collected from vehicle license plate survey on the selected urban arterial corridor of 2.5 km length on NH 2. The uncertainty parameters of travel time reliability on this corridor have been discussed. A micro simulation methodology is subsequently discussed to estimate travel time reliability under the influence of demand and supply side factors from the transportation system. Results from the micro simulation model are validated for the existing scenario. Further, travel time reliability measures are estimated for two different scenarios, i.e. variation in traffic volume as demand side and lane closure due to incident as supply side factors.

Review of travel time reliability studies

Travel time reliability is one of the indicators to measure the performance of road network. Iida and Wakabayashi[9] introduced connectivity reliability for the first time by defining connectivity reliability as the probability that the network nodes are connected or disconnected. The binary limitation of this reliability leads to development of various reliability indicators such as travel time reliability[2] and capacity reliability[10]. Out of these measures, travel time reliability aspects are useful to the system users as well as the system planners. From the literature, mainly two approaches are available for measuring travel time reliability of the road transportation system – mathematical-based travel time reliability measurements[2,11,12] and empirical-based measurements[4]. Mathematical-based reliability measurements were developed based on conventional user equilibrium (UE) route choice principle, whereas empirical-based reliability measures were developed based on travel time distribution which was obtained by travel time history of users' experience.

Asakura and Kashiwadani[2] introduced the concept of travel time reliability and defined it as the probability that a trip between a given origin and destination pair can be made successfully within a given time interval and speci-

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fied level of service. Recently, the US Federal Highway Administration (FHWA) has defined travel time reliability as the consistency or dependability in travel time, as measured from day-to-day and/or across different times of the day[4]. The planning time (PT), planning time index (PTI), buff time and buffer time index (BTI) were introduced as performance indicators. These indices are briefly discussed below.

- Planning time represents the total travel time expected or 'planned' before a trip starts with a given probability. It is the 95th percentile of the measured travel time. It represents travel time on some of the heaviest traffic days.
- Planning time index is the ratio of the planning time to the free-flow travel time. This index indicates the severity of traffic congestion as it represents the worst level of congestion at a given time of day in comparison with the free-flow traffic condition.
- Buffer time is defined as the difference between planning time and average travel time. It represents the extra time to ensure on-time arrival to the destination. This extra time accounts for any unexpected delay. In other words, the buffer time may be almost proportional to the variance of travel time.
- Buffer time index is defined as the ratio of buffer time to the average travel time.

Travel time variation is mainly caused due to individual or combined effect of demand side and supply side factors. FHWA[4] has identified seven source of events which causes travel time variation. Further, they are categorized into three main events such as traffic influence events, traffic demand events and physical highway features. Asakura[5] further categorized the sources of travel time fluctuation as a result of supply side, demand side and other external factors of transportation system. The Florida Department of Transportation[13] (Florida DOT) developed empirical travel time variability models as a function of frequency of incidents, work zones and weather conditions. For this, it has considered regression analysis for different scenarios of uncertainty sources. Ravi Sekhar and Asakura[14] modelled travel time distribution under the influence of various uncertain factors such as traffic volume, number of vehicle breakdowns, number of road accidents, intensity of rainfall and falling objects from the vehicles. They quantified sources of travel time parameters with the help of multiple linear regressions models. They used probabilistic model for travel time variation under the influence of continuous random variables such as traffic volume and amount of rainfall.

Higatani *et al.*[15] examined the fundamental characteristics of travel time reliability measures using the traffic flow data from the Hanshin Expressway road network in Japan. They have studied the differences in characteristics among five radial routes in the network. They also studied the characteristics of each route in terms of time and day-wise variation of traffic flow. Additionally, the effect of traffic incidents on travel time reliability measures was analysed on one radial route. The results show that the traffic incidents were the dominant factor for travel times during off-peak hours on the Hanshin Expressway road network. Haitham and Emam[16] introduced a methodology for estimating travel time reliability and capacity reliability under the effect of travel demand variation and link capacity degradation. They defined travel time reliability as the probability that the expected travel time at degraded capacity is less than the link free-flow travel time plus an acceptable tolerance. This tolerance is related to the level of service that should be maintained despite the capacity degradation.

Mehran and Nakamura[17] presented a methodology to estimate travel time reliability by modelling travel time variations as a function of demand, capacity and weather conditions. For a subject expressway segment, patterns of demand and capacity were generated for each 5 min interval over a year using the Monte-Carlo simulation technique. Entire year data were considered and analysis performed by comparing demand and available capacity for each scenario, and shockwave analysis was used to estimate the queue length at each time interval. Travel times were estimated from refined speed–flow relationships. Further, this travel time was considered for estimating buffer time index as a measure of travel time reliability.

It was observed from the above-mentioned studies that empirical analysis, linear regression and probability-based modelling techniques were generally used to develop relationship between travel time reliability and uncertainty parameters. However, all these were macroscopic models, neglecting the individual vehicle or driver behaviour under the different scenarios of traffic conditions. In the present study an attempt has been made to include individual vehicle behaviour by considering microscopic traffic simulation model to estimate the travel time and travel time reliability. The description of selected study area and data collection for this purpose is discussed in the next section.

Study area and data collection

Characteristics of study area

In the present study, an urban road corridor of 2.5 km length on NH 2 in the city of Delhi has been selected as the study area (Figure 1). The study corridor starts from Sarita Vihar and continues up to Aligoan village. This corridor is a six-lane, divided carriageway having one unsignalized *T*-intersection at Sarita Vihar side and one signalized intersection at Aligoan village. This corridor is one of the busiest and the most congested in Delhi and serves the intercity traffic from Delhi to Agra as well.

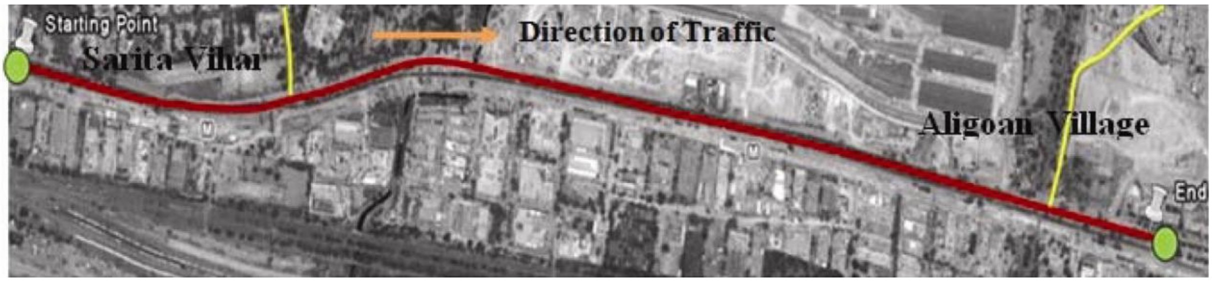

Figure 1. Study area on National Highway 2, Sarita Vihar to Aligoan village in Delhi.

Data collection

For evaluating operational efficiency of the selected urban corridor three types of survey, namely vehicle license plate survey, traffic volume count survey, and speed and delay survey have been carried out. These are briefly discussed in the following sections.

Vehicle license plate survey: This survey was carried out at entry and exit location of the study area from 11 November 2010 to 16 November 2010. The objective of this survey is to estimate travel time for the study area for the study period. In this survey, vehicle license plate numbers and their arrival times at entry and exit points of the section were collected. Subsequently, matching of the license plates at entry and exit points was done and travel time was calculated from the difference in arrival times at these points. Video cameras were installed at entry and exit location of the study area to record the vehicle license plate for all categories of vehicles. In the present study, only passenger cars data have been considered for estimating the travel time due to the paucity of time and resources. One week consistent data were collected in the morning hours between 8 : 30 and 10 : 30 am. It has been observed from the data that averages of 32% of vehicle license plate numbers were matched amounting to a sample size of 4313 for the study area during the study period. Travellers going from Delhi to Agra in this study stretch were considered to collect the data.

Traffic volume count survey: This survey was conducted in the morning peak hours for the same period, i.e. 8 : 30 to 10 : 30 am to assess the traffic volume and composition of traffic in the study area. Consistently one week data have been collected to know the day-to-day variation of traffic for the particular period. About 8000, 5500 and 2500 vehicles/h of traffic flow was observed during morning hours between 8 : 30 and 10 : 30 am in the direction of Sarita Vihar to Badarpur, Badarpur to Sarita Vihar, and from Aligoan village respectively. The following inferences were drawn from the observed data during morning hours:

- The average car traffic during morning hours is about 1675 and 1250 vehicles/h on working day and non-working days respectively.
- The average two-wheeler traffic during morning hours is about 1150 and 1350 vehicles/h on working day and non-working days respectively. Higher volume of two wheelers on non-working days was observed due to commercial shopping trips of commuters from Aligoan village and Badarpur boarder visiting Delhi on weekends.
- Almost the same number of auto rickshaws (about 3% of total traffic) was observed on working as well as non-working days.
- Composition of buses about 5% of the total traffic ply on working as well as non-working days in the study area.

Speed and delay using probe vehicle technique: In the present study, speed data were collected using probe vehicle technique. This technique utilises passive instrumented vehicle in the traffic stream and remote sensing devices to collect travel time. In this study probe vehicle technique such as velocity box (V-box) was considered for collecting speed and delay data. This was fitted in a test car to measure speed and delay on study corridor. A total of 3 runs/day starting just before peak hour (8 : 30 am), during peak hour (9 : 00 am to 10 : 00 am) and just after peak hour (after 10 : 00 am) were made in one directions of travel in the study area to assess the variations in journey and running speeds along with the delays. Figure 2 presents a typical speed profile for the direction from Sarita Vihar to Aligoan village. On working days, the maximum delays were encountered during morning hour between 9 : 00 and 10 : 00 am of 272 s, whereas it was 58 s before 9 : 00 am. The average journey speed before 9 : 00 am was about 25 kmph and after 9 : 00 am it reduced to 19 kmph. Apart from the journey speed data collection, spot speed surveys were also conducted with the help of laser speed guns to assess the spot speeds of vehicles on the study stretch.

Analysis of travel time reliability

As mentioned earlier, passenger car license plate method data are considered for examining travel time variation and manual transcription method has been considered in this study for noting the vehicle license plates. The statistical and reliability measures are estimated from the extracted data and findings are discussed in the following sections.

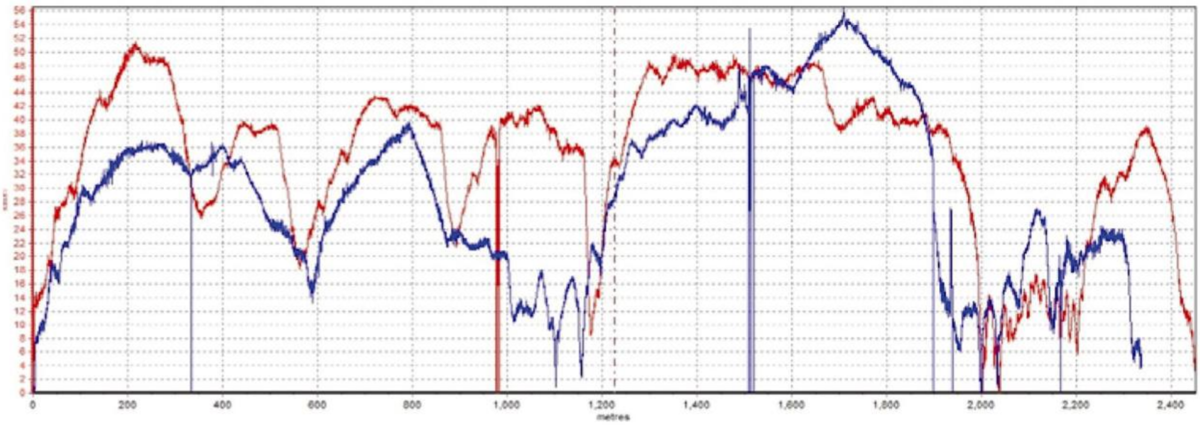

Figure 2. Speed profile before peak hour (red colour) and during peak hour (blue colour) on working days.

Table 1. Statistical measures during morning hours on working and non-working days

Time-period (am)	Sample size	Statistical measures (travel time (min))					
		Minimum	Maximum	Mean	Median	SD	CV
Working days							
8 : 30–8 : 45	445	5.8	33	10	9	3.4	0.34
8 : 45–9 : 00	375	7.2	37	13	11	5.0	0.38
9 : 00–9 : 15	291	7.0	36	14	10	6.5	0.46
9 : 15–9 : 30	330	7.0	34	14	10	7.0	0.49
9 : 30–9 : 45	312	6.0	36	14	16	6.9	0.48
9 : 45–10 : 00	474	5.6	39	13	8	7.9	0.60
10 : 00–10 : 15	220	5.6	36	15	8	11.3	0.73
10 : 15–10 : 30	445	5.8	33	10	9	3.4	0.34
Non-working day (Sunday)							
8 : 30–8 : 45	140	5.9	21	8	7	2.2	0.29
8 : 45–9 : 00	97	5.7	19	7	7	1.9	0.26
9 : 00–9 : 15	53	6.7	14	8	8	1.6	0.20
9 : 15–9 : 30	56	6.2	14	8	7	1.6	0.20
9 : 30–9 : 45	43	6.2	23	8	7	3.2	0.40
9 : 45–10 : 00	61	6.0	23	8	7	2.4	0.31
10 : 00–10 : 15	39	6.2	10	7	7	0.8	0.11
10 : 15–10 : 30	17	6.5	9	8	7	0.6	0.08

Statistical measures

The statistical parameters such as minimum, maximum, mean and median of travel time for the study area at various time intervals in the morning hours are presented in Table 1 for both working and non-working days. These statistical results were further utilized to estimate travel time reliability measures of the study area. From Table 1, it can be observed that the minimum travel time is about 7 min, which is the same for all the periods. However, wide difference between maximum travel time and mean travel time was observed. This indicates that travellers have suffered during peak hours due to unexpected delay.

Statistical measures such as standard deviation (SD) and coefficient of variation (CV) for all the time periods in morning peak hours for working and non-working days are also presented in Table 1. During morning peak hours on working days, SD values are higher (around 7 min) for the vehicles entering after 9 : 00 am. Similarly, CV values become higher for vehicles entering after 9 : 00 am and before 10 : 00 am in the morning peak hours. Whereas on non-working days, SD values are very low (around 2 min) compared to working days for the vehicles entering after 9 : 00 am in the study corridor.

Travel time reliability measures

To examine the performance of the study corridor, travel time reliability measures such as PT, PTI, BT and BTI were considered. The results during morning peak hours are presented in Table 2. From Table 2, it can be

Table 2. Reliability measures during morning hours on working and non-working days

Time-period (am)	Travel time reliability measures				
	Sample size	PT (95%)	PTI	BT	BTI (%)
For working days					
8 : 30–8 : 45	445	16	2.6	5.3	51
8 : 45–9 : 00	375	21	3.5	8.1	63
9 : 00–9 : 15	291	25	4.1	10.8	77
9 : 15–9 : 30	330	26	4.3	11.8	84
9 : 30–9 : 45	312	24	4.0	9.9	69
9 : 45–10 : 00	474	35	5.8	21.6	164
10 : 00–10 : 15	220	34	5.7	18.9	122
10 : 15–10 : 30	445	16	2.6	5.3	51
For non-working day (Sunday)					
8 : 30–8 : 45	140	12	2.1	4.6	59
8 : 45–9 : 00	97	11	1.9	4.2	58
9 : 00–9 : 15	53	12	2.0	4.0	50
9 : 15–9 : 30	56	11	1.8	3.3	43
9 : 30–9 : 45	43	14	2.4	6.2	77
9 : 45–10 : 00	61	11	1.8	3.3	43
10 : 00–10 : 15	39	9	1.4	1.3	18
10 : 15–10 : 30	17	9	1.4	1.0	13

observed that PTI values are about 5.8 for vehicles entering after 9 : 00 am. Similarly, BTI values become high for the vehicles entering after 9 : 45 am and before 10 : 15 am in the morning peak hours. Whereas on non-working days during morning peak hours, PTI values are as low as 2 compared to working days. Similarly, low variation of BTI values are observed during these hours on non-working days. Further, the mean 95th percentile travel time for this corridor was estimated by considering the length of the route for working and non-working days. Results indicated that the mean 95th % travel time/km for working days is a maximum of 9 min/km and minimum of 4 min/km during morning hours. Whereas, 95th percentile travel time/km for non-working days is maximum of 5.6 min/km and minimum of 3.6 min/km during peak hours.

Development of micro simulation model

General

In order to understand the travel time reliability of any transport facility/corridor, the analysis should appropriately consider different parameters such as roadway conditions, traffic conditions, driver behaviour characteristics, especially lane change and lane discipline characteristics, etc. All these conditions involve many complex situations. Analysis with traditional/analytical tools would be difficult and moreover, the accuracy of estimation is also important while taking policy decisions. On the other hand, the complex traffic behaviour can be easily considered in microscopic traffic simulation more precisely and realistically than other methods as it analyses individual vehicle/driver behaviour[18], although its accuracy and validity depend mainly on the quality of the underlying driver behaviour models. In the present study, assessment of travel time reliability has been carried out under various scenarios using VISSIM micro simulation software tool.

VISSIM is a stochastic, time-step-based microscopic traffic flow simulation program developed to model urban and highway operations. The model has two main internal components – traffic flow simulator that replicates vehicle movements and the signal state generator which determines the signal status based on detector information coming from the traffic simulator on time-step basis. The traffic flow model used by the traffic simulator relies mainly on two models, namely 'Wiedemann 74' car following model and the 'Wiedemann 99' car following model. Both the models are developed based on a psycho-physical car-following model and a rule-based algorithm for lateral movements. Wiedemann 74 defines the driver perception thresholds and the regimes formed by them. This model mainly focuses on three parameters – standstill distance, additive part of safety distance and multiplier part of safety distance. The Wiedemann 99 car-following model is similar to Wiedemann 74 car-following model, except that some of the thresholds in the former are defined in a different way to model freeway traffic better. This model employs ten different driver behaviour-related parameter sets (CC0 to CC9) to describe the different driving scenarios such as free-driving, approaching, following and braking[19]. In the present study, Wiedemann 99 model was adopted to model the driver behaviour under mixed traffic condition of the urban study corridor. The adopted methodology

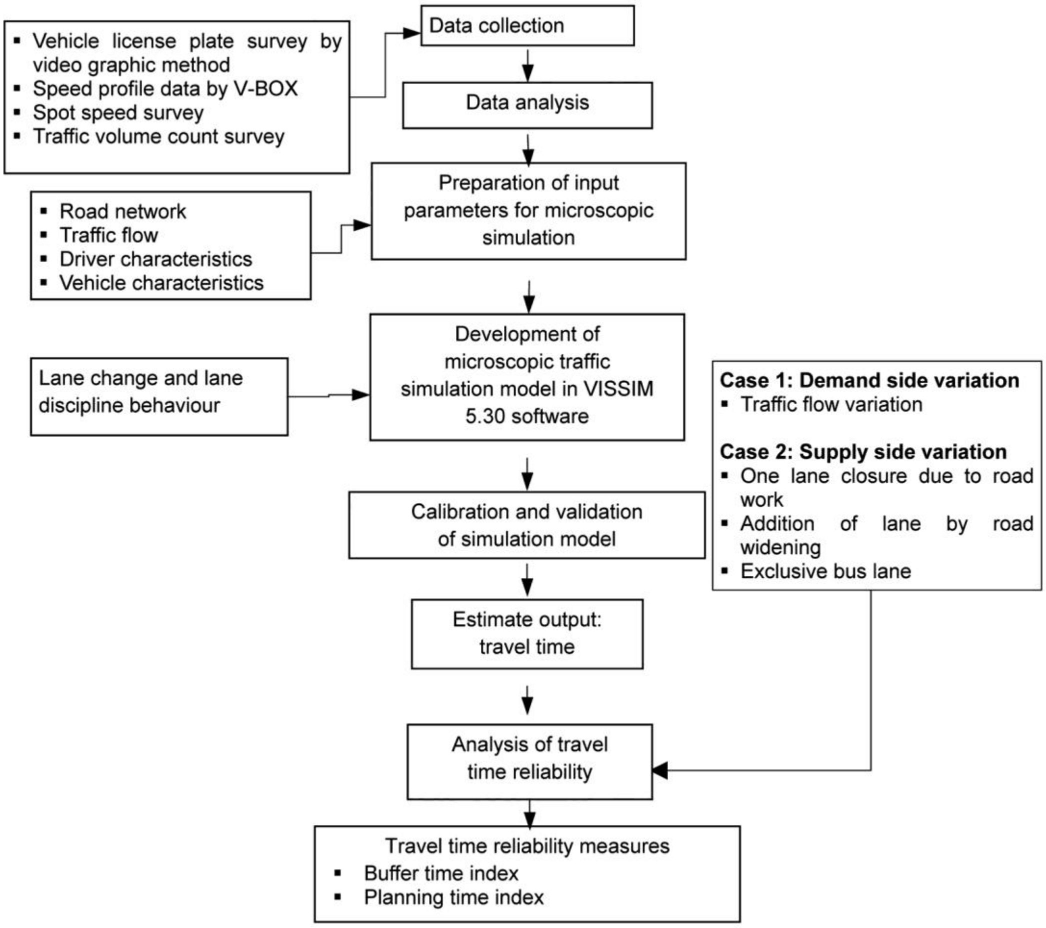

Figure 3. Adopted methodology for developing micro simulation model to analyse travel time reliability.

and input parameters considered in the VISSIM model have been discussed briefly in the following subsections.

Adopted methodology for micro simulation modelling

The methodology developed for analysing travel time variation in VISSIM in the present study is shown in the form of a flow chart in Figure 3. From Figure 3, it can be seen that data collection is the first and foremost activity of developing a simulation model. In the present study, traffic volume and speed data were collected from vehicle license plate survey, speed profile survey from V-Box, spot speed survey and traffic volume count. These data were appropriately analysed to provide input to the simulation model. The input parameters, namely road network, hourly traffic flow, vehicular characteristics for each vehicle type and driver characteristics have been prepared to provide input to develop microscopic simulation model. As the observed lane change and lane discipline behaviour of Indian drivers is more haphazard, this behaviour is appropriately considered in the simulation model. Then the model is calibrated adopting trial and error method by modifying the drivers' car-following and lane change parameters till the error between observed and estimated data is in the accepted limits. The developed simulation model is validated using the observed travel time and traffic volume data. Further, the validated simulation model was considered for estimation of travel time under different cases of uncertainty from demand side (variation of traffic flow) and supply side (variation due to lane closure for road maintenance and addition of extra lane). The travel time variation under these scenarios is further used to measure performance of the study area in terms of the travel time reliability measurement parameters.

Development of base network in VISSIM

The development of 'base model' which accurately represents the existing situation involves developing base network, defining model parameters, calibrating the network and validating the model. The development of base network is described in this section and rest discussed in the subsequent sections. Development of a base network that accurately determines the constraints of a road network is an important stage in the simulation model development process. The basic key network building components are links and connectors. Links are created by tracing the roadway over the study area map which serves as a background, and scale of the map has been provided. As mentioned earlier, the selected urban corridor of NH 2 is a six-lane divided carriageway and the lanes are accordingly created for the links to replicate the observed conditions on the road section. The developed road network in VISSIM is shown in Figure 4.

Defining model parameters

The input model parameters have to be appropriately defined while developing simulation model in VISSIM. These parameters mainly include vehicular characteristics, desired speed distribution, vehicle flow and composition, signal control parameters and driving behaviour parameters, namely car-following and lane change. These parameters are described below.

Vehicle parameters: These include dimensions of different vehicle types, namely width and length that are considered for the present simulation model according to the Indian conditions[20]. Other vehicle parameters include maximum acceleration, desired acceleration, maximum deceleration, desired deceleration and weight of the vehicle. In the simulation model, seven vehicle types are considered which include cars, motorized two-wheelers, auto rickshaws, buses, light commercial vehicles (LCV), heavy commercial vehicles (HCV) and multi-axle commercial vehicles (MCV). The above-mentioned parameters are appropriately considered for each vehicle type based on the available data; however, other vehicle characteristics are considered as default values.

Desired speed distribution: The desired speed distribution for each vehicle type has to be provided as input in VISSIM. These values include minimum speed, maximum speed and their distribution between the two. These values are provided in the simulation as an input based on the observed speed data from the spot speed survey conducted in the study stretch in order to accurately represent field conditions. The typical desired speed distribution is shown in Figure 5 for the vehicle type car.

Vehicle composition: The vehicle composition on this stretch based on the observed data is analysed as mentioned earlier, and provided as input to simulation model for different time intervals and directions. The typical traffic composition data are shown in Figure 6.

Vehicle flow: This is provided as input from the observed data for different time intervals and different directions collected from the traffic volume count survey. In VISSIM, vehicles would be randomly generated according to the given volume and composition. The observed vehicle inflow for the study stretch provided as input in VISSIM is shown in Figure 7.

Driving behaviour characteristics: This plays an important role in the development of simulation model. The driving behaviour in VISSIM mainly includes car-following, lane change and later distance model. In these models, safety distance during standstill in case of car-following, and minimum gap in the lane to carry out lane change in the lane change model have to be appropriately provided as input. In the lateral model, the location of the vehicle on a lane, minimum lateral distance at different speeds, etc. have to be given as input. This model mainly

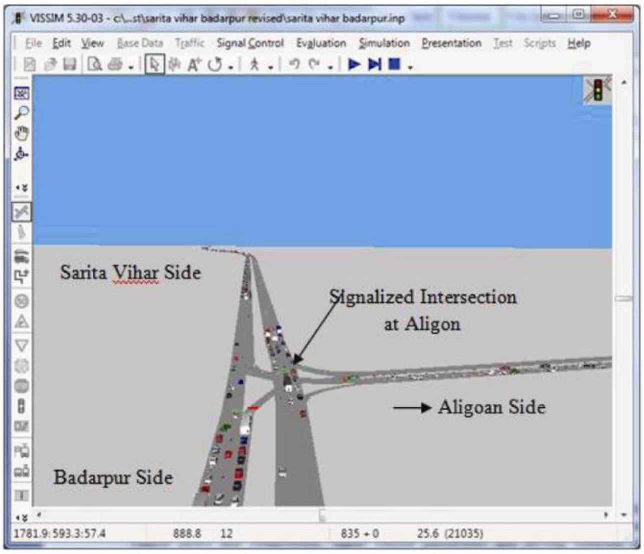

Figure 4. Developed road network in VISSIM for the study corridor.

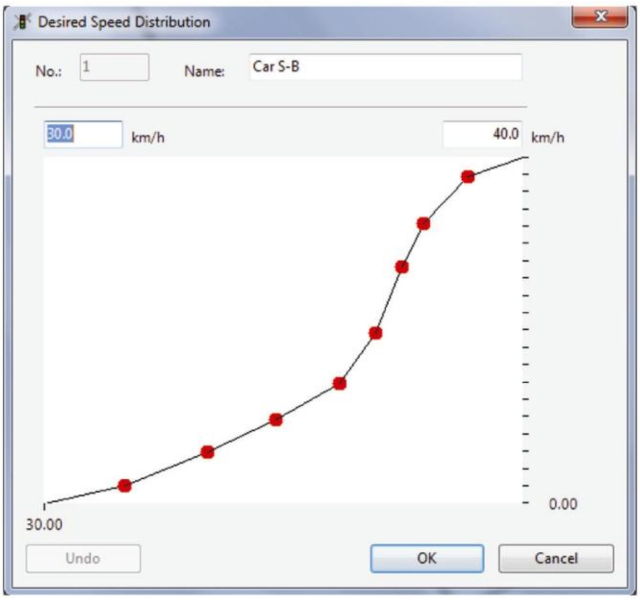

Figure 5. Typical desired speed distribution for car given in VISSIM.

dictates the lane discipline while travelling on that particular link of the simulation model.

Signal control: In case of any signalized intersection to be considered in VISSIM, the number of phases and phase timings specifying green, amber and red times have to be given as input in VISSIM. On the study stretch, one three-arm signalized intersection exists at Aligoan village. These signal control parameters data for the Aligoan intersection were collected and provided as input to the simulation model.

Calibration of the simulation model

After creating base network and defining model parameters, calibration process was carried out in VISSIM. As mentioned earlier, trial and error method was adopted in this process by adjusting the model parameters to reflect and represent observed conditions. The following parameters of vehicle and driver characteristics are appropriately considered to adjust till the accepted level of accuracy as found in the estimations from the simulation model:

- Desired speed distributions
- Maximum acceleration of vehicle
- Desired acceleration of vehicle
- Maximum deceleration of vehicle
- Desired deceleration of vehicle
- Minimum safety distance
- Minimum lateral distance
- Minimum gap distance in the other lanes
- Observation of vehicles in the same and other lanes.

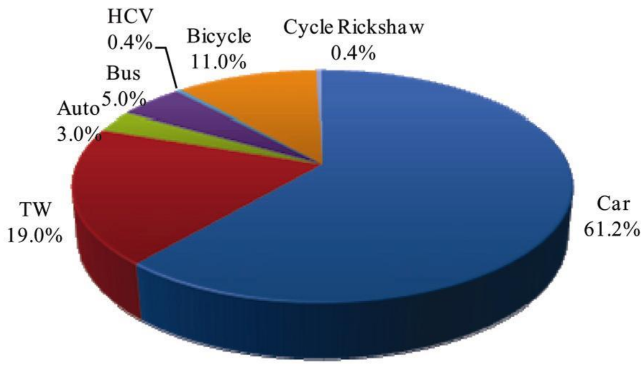

Figure 6. Typical traffic composition on study stretch in the direction of Sarita Vihar to Badarpur (9 : 30–10 : 00 am) given in VISSIM.

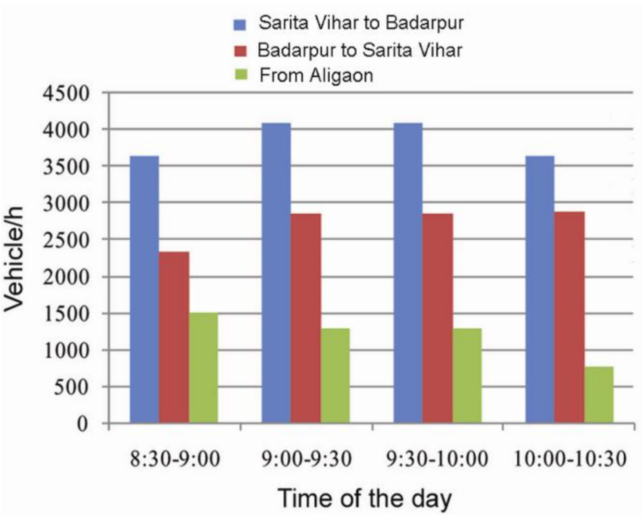

Figure 7. Vehicle flow provided as input in VISSIM.

Wiedemann 99 VISSIM car-following model involves 10 tunable driving behaviour parameters – CC0–CC9. In this study standstill distance parameter (CC0), in VISSIM model was modified accordingly to the study area. The value of CC0 was considered as 0.50 m instead of 1.50 m based on free-flow speed and jam density conditions observed in urban arterial conditions in Delhi. For all other parameters from CC1 to CC9, the default values of VISSIM were considered. Table 3 presents the driving behaviour parameter sets considered in model calibration. By giving these parameters as input, simulation runs have been carried out and the output estimated. In the present simulation model, travel times of vehicles are considered as output since the observed data on this parameter were collected in the field for validation of the developed simulation model. Comparison of estimated with observed values is carried out and error is estimated. Based on the estimated error, modification of the parameters has been done and simulation runs are carried out. This process is carried out and simulation runs are made till the error is at the satisfactory level.

Model validation

Validation is the process of checking the developed simulation model in terms of predicted traffic performance of a road system against field measurements such as traffic volume, travel time, average speed, lane change, etc.[21]. In the present study, validation process was carried out comparing the observed (from field data) and estimated (from simulation model) travel time and traffic volume. From the results of comparison, it was observed that travel time obtained by simulation model is well distributed between 7 and 25 min, which closely follows observed travel time distribution. It was also observed that the error in observed and estimated travel time is about 7%. Further, estimated travel time obtained from simulation model considered to estimate the reliability measures such as PT and PTI are presented in Table 4. From Table 4, it can be observed that the average PTI value for the peak hour is about 4.25 for the observed travel time and is 3.9 for simulated travel time.

Table 3. Driving behaviour parameter set

VISSIM code	Description of the parameter	Considered model calibration
CC0	Standstill distance: desired distance between lead and following vehicle at $v = 0$ kmph	0.50 m
CC1	Headway time: desired time (s) between lead and following vehicle	0.90 s
CC2	Following variation: additional distance over safety distance that a vehicle requires	4.0 m
CC3	Threshold for entering 'following' state: time (s) before a vehicle starts to decelerate to reach safety distance (negative)	–8.0 s
CC4	Negative 'following' threshold: specifies variation in speed between lead and following vehicle	–0.35
CC5	Positive 'following' threshold: specifies variation in speed between lead and following vehicle	0.35
CC6	Speed dependency of oscillation: influence of distance on speed oscillation	11.44
CC7	Oscillation acceleration: acceleration during the oscillation process	0.25 m/s^2
CC8	Standstill acceleration: desired acceleration starting from standstill	3.5 m/s^2
CC9	Acceleration at 80 kmph: desired acceleration at 80 kmph	1.5 m/s^2

Table 4. Comparison of reliability measures

Time period (am)	Reliability measure (measured)		Reliability measure (simulated)	
	PT (95%)	PTI	PT (95%)	PTI
8 : 45–9 : 00	21	3.5	18	3.0
9 : 00–9 : 15	25	4.1	19	3.2
9 : 15–9 : 30	26	4.3	21	3.5
9 : 30–9 : 45	29	4.0	24	4.0
9 : 45–10 : 00	35	5.8	25	4.1
10 : 00–10 : 15	34	5.7	25	4.1

Comparison between modelled and observed traffic volume was also made using Geoffrey E. Havers (GEH) statistics, widely used in traffic simulation models to compare two sets of traffic volume. The formula for estimation of GEH statistics is given in eq. (1).

$$\text{GEH} = \sqrt{\frac{2(M-C)^2}{(M+C)}}, \tag{1}$$

where M is the traffic volume obtained from simulation model and C is the observed traffic volume. In this study average GEH statistics value of 2.94 was obtained for the direction from Sarita Vihar to Aligoan village direction of flow. This indicates a good fit between modelled and observed traffic volume. Thus, it can be concluded that micro simulation models are able to predict the results more realistically compared to regression and other aggregated models. Further the base model has been considered for studying the influence of uncertainties from demand and supply side on travel time, which is discussed in the next section.

Influence of demand side variation on travel time

Influence of demand side factors on travel time was examined through validated simulation model. For this the same input parameters discussed earlier were considered and traffic flow parameters considered as demand side variation. The influence of traffic flow on travel time is estimated for two realistic scenarios (10% increase and 10% decrease in demand) and two hypothetical scenarios (50% increase and 50% decrease) in traffic demand variation. The average travel time for exiting demand on the study corridor is 19.02 min. In the case of 10% increase in demand, the average travel time will be increased to 24.60 min and if 10% demand is reduced, the travel time will be reduced to 17.2 min for vehicles entering during the study period. The average PTI for study period is about 4.0, which indicates that if 10% increase in traffic demand situation arises, road users should plan their travel for about four times the travel time as against free-flow travel time. If the demand is reduced by 10%, PTI also reduces to 3.0.

Micro simulation has been also been carried out for hypothetical scenarios and travel time obtained for such a scenario using VISSIM presented as a cumulative travel time distribution in Figure 8 for two hypothetical cases along with observed traffic condition. From Figure 8, steep gradient of cumulative distribution curve for the case of 50% increment of traffic demand can be observed. Further travel time reliability indices such as PT and PTI have been estimated for the two cases for different time-periods and are presented in Table 5. The average PTI for peak hour is about 5.5, which indicates that if 50% increase in traffic demand situation arises, road users should plan their travel for about 5.5 times the travel time as against free-flow travel time. If the demand is reduced by 50%, PTI reduces to 2.3. From Table 5, it can be observed that the PTI value is as high as around 7.4 for the period between 9 : 45 am and 10 : 00 am during the peak hour period. Whereas in the case of 50% less demand, PTI value is 2.6 for the period between 9:15 and to 9:30 am.

Influence of supply side variation on travel time

Subsequently, influence of supply side factors on travel time was examined by considering three scenarios using

Table 5. Variance of travel time reliability under the influence of demand side and supply side variation

Time-period (am)	Variance of reliability measures due to demand side variation				Variance of reliability measures due to supply side variation			
	50% more demand		50% less demand		Lane closer due road work		Provision of one extra lane	
	PT (95%)	PTI	PT (95%)	PTI	PT (95%)	PTI	PT (95%)	PTI
8 : 45–9 : 00	17	2.9	13	2.1	20	3.3	15	2.6
9 : 00–9 : 15	23	3.9	16	2.6	29	4.9	16	2.7
9 : 15–9 : 30	30	5.0	14	2.3	37	6.2	18	3.0
9 : 30–9 : 45	35	5.8	13	2.2	40	6.6	22	3.7
9 : 45–10 : 00	44	7.4	14	2.3	36	5.9	23	3.8
10 : 00–10 : 15	42	7.0	12	2.0	30	4.7	21	3.5

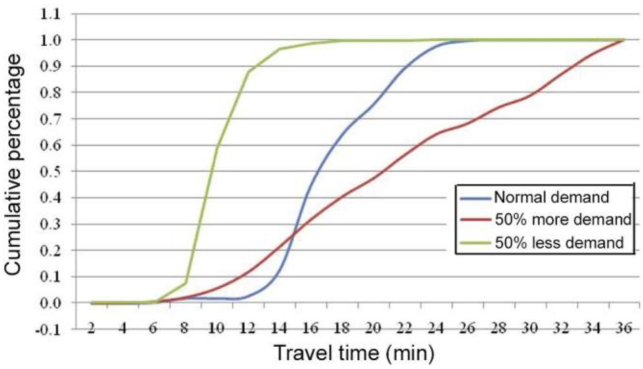

Figure 8. Travel time distribution under uncertainties from demand side variation.

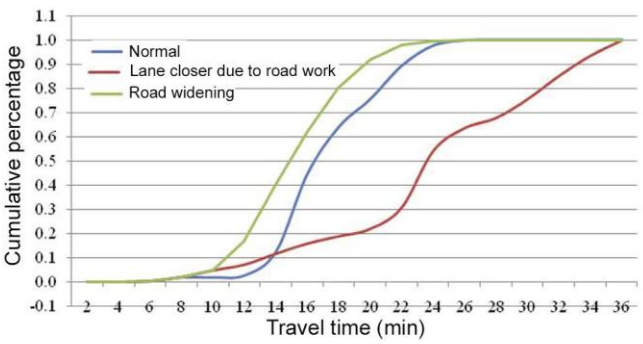

Figure 9. Travel time distribution under uncertainties from supply side variation.

the developed simulation model. These include: exclusive bus lane (one lane is reserved for buses), one lane closure of about 200 m out of three lanes due to road work condition for 30 min, and providing extra lane of 3.5 m width along the entire corridor. In the case of exclusive bus lane, the average travel time will reduce from 19.02 min (existing) to 16.50 min. The average PTI for study period is about 2.7, which indicates that if there is provision of exclusive bus lane situation, road users should plan their travel for about 2.7 times the travel time as against free-flow travel time. The behaviour of traffic during road working condition and extra lane conditions has been simulated for morning peak hours and the travel time estimated for the same has been presented in Figure 9. From Figure 9, it can be observed that there is a steep gradient of cumulative distribution for the case of extra lane condition. Reliability measures such as PT and PTI for different time-periods are estimated and presented in Table 5. The average PTI for peak hour is about 5.9, which indicates that if the one lane is blocked for 30 min during the peak hour, road users should plan their travel for about six times the travel time as against free-flow travel time. Highest PTI value around 6.6 was observed for the period between 9 : 30 am and 9 : 45 am during the peak hour period.

As mentioned earlier, provision of one extra lane per direction option has been investigated using the simulation model. The behaviour of traffic and travel time due to this provision has been simulated for morning peak hours and the travel time estimated for the same is presented in Figure 9. From Figure 9, it can be observed that the gradient of cumulative distribution for this case has been shifted to the left side to normal situations (blue colour profile). The area between the observed and simulated curves will be the total time savings of the road users. Further, reliability measures such as PT and PTI for various time-periods are estimated and presented in Table 5. The average PTI for the peak hour is about 3.5, which indicates that if one extra lane is provided for the entire corridor, road users should plan their travel for about three times the travel time as against free-flow travel time. Highest PTI value around 3.8 was observed between 9 : 45 am and 10 : 00 am during the peak hour period.

Conclusion

This study has identified the requirement of travel time reliability measurements for measuring performance of transportation network compared to the traditional measures for Indian roads. Travel time reliability measures such as BTI are more useful to business-trip users. Whereas PT and PTI are more suitable for normal traffic and working trips. The observed data on NH 2 section in the city of Delhi during morning peak hours, that revealed PTI values are about 3.5 for vehicles entering after

9 : 00 am. Similarly, BTI values become high for the vehicles entering after 9 : 15 am and before 10 : 15 am in the morning peak hours. For non-working days during morning peak hours, PTI values were 2.4.

In this study with the help of micro simulation models travel time was estimated under the influence of demand side variation by considering a traffic flow and supply side variation by considering a random event such as one lane being closed due to road maintenance and provision of providing one extra lane. Travel time obtained by simulation model is well distributed between travel time 7 min and 25 min and follows observed travel time distribution. If 50% increase in traffic demand situation arises road users should plan about 5.5 times the travel time as against free-flow travel time and PTI is about 2.2 in case of 50% reduction of flow in the study area. In the case of one lane being closed for 30 min during peak hours, road users should plan about six times travel time as against free-flow travel time. Road users should plan about three times the travel time as against free-flow travel time if the study area is widened from three lanes to four lanes. These results can be validated on statistical grounds. Further research is required to study the behaviour of various travel time reliability measures and their relation with congestion measures for road networks in India.

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ACKNOWLEDGEMENT. This work is a part of CSIR EMPOWER Project funded by Council of Scientific and Industrial Research, New Delhi.

Received 16 October 2012; revised accepted 4 June 2013