VALIDATION OF LINK TRAVEL TIME USING GPS DATA: A Case Study of Western Expressway, Mumbai

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Abstract

Traffic congestion is the most visible manifestation of the failures in urban traffic operations. It is a widely recognised that relief from providing more roadway space in urban areas has been only temporary and the concept of traffic management has not been successfully adopted. A considerable amount of traffic congestion in cities is caused not by the sheer volume of traffic, but by poor information about optimal routing. Some of this is due to ignorance of where and when congestion is occurring and hence the inability to avoid. More efficient use of existing road network using emerging technologies like GPS and reliable information system seem to be the most acceptable answer to such problems. Many innovations are often discussed; like variable message signs (VMS) which respond dynamically to traffic congestion that can give information to users. The whole concept of VMS is based on the link travel time, which is the core of any traffic management system. On the application front, a large network with VMS's can be integrated with Geospatial information to empower commuters to act and decide which corridor to follow leading to less congestion. Keeping this in view, this paper investigates the technique of estimating link travel time using the model proposed by Coifman (2002) from the spot speeds. To investigate its suitability for heterogeneous traffic a case study was undertaken on the western expressway in Mumbai, India and compared the travel time estimated from the spot speed with the actual travel time obtained by a probe vehicle mounted with a GPS receiver. The study established the use of sophisticated travel time prediction algorithm for heterogeneous traffic. Further, GPS has emerged as a valuable tool in the validation of travel time estimation algorithm.

Introduction

Road transport is by far the most versatile and commonly used mode of transportation and have constituted the fundamental elements in structure of a society. Population explosion, suburbanisation and growth of motor vehicles with the expanding economy have led to the rapid increase in the traffic congestion, degradation of environment and safety on the roads. Traditional solutions to these problems are no longer effective by planning piece-meal improvement schemes. Isolated solutions such as widening, improvements of junctions, etc, can only touch the edge of the problems.

This lead to the expressway culture, constructed both between urban centres and within them. However, expressway travel reduces travel times but high speeds involved tend to increase the fatlity rates. Besides, development many kilometres away from jobs and services, there has been sustantial growth in traffic. Thus, expressways designed for safe, comfortable and congestion- free travel, are facing congetion as before. Further, new expressway segments cannot be build in most of the metropolitan areas, due to high cost and political opposition. Moreover, it is a well established fact that new traffic will grow anyway, whether or not the expnasion of roadways are carrid out. Thereby, offering new challenges to Traffic Management Unit (TMC) to manage traffic.

There are opportunities offered by the timely application of technical innovations like VMS to address the above-identified challenges. It responds dynamically to traffic congestion and can give information to commuters based on the estimation of link travel time. In order to provide this service effectively, we need all-time traffic information and surveillance of links to avoid losing time in congestion and incidents. However, algorithms available are developed for homogeneous traffic conditions and algorithms that are more effective are needed for mixed traffic conditions.

Keeping this view, a more recent model by Coifman (2002) for estimating link travel time was investigated. Finally, in the process of understanding the behaviour of the algorithm, a study was conducted on one of the expressway corridors in Mumbai, India. A comparative evaluation was carried out by estimating the link travel time from the above model and was validated using actual travel time obtained from a probe vehicle mounted with GPS a receiver. The study is concluded by illustrating an application of VMS as traveler information system and it can be used to empower the commuters to know the information about the corridor conditions and can be the solution to the problems that are resistant to traditional methods.

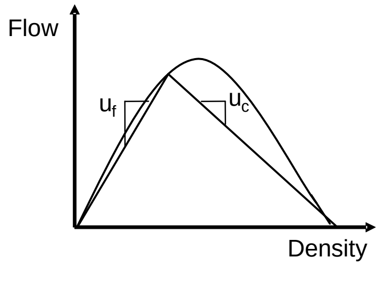
Background

Conventional algorithms of travel time estimation averaged velocity sampled at detector locations at the entry of the link. This assumes that the vehicle will continue to travel with the same speed for the entire link. This assumption, however, is not correct especially when there is variation in the traffic leading to local congestion. The actual link travel time for vehicle reflects traffic conditions averaged over a fixed distance and a variable amount of time. The present model uses a new algorithm based on the application of traffic flow theory to yield the accurate estimate of link travel time from the point data.

This study by Coifman, (2002) illustrated the fact that travel time is considered to be more informative to users than local velocity measurements at a detector station. However, direct travel time measurement requires the correlation of vehicle observations at multiple locations, which in turn requires new communications infrastructure and/or new detector hardware. He presented a method of estimating link travel time using data from an individual dual loop detector, without requiring any new hardware. The estimation technique exploits basic traffic flow theory to extrapolate local conditions to an extended link. Further, Newell (1993) proposed a simplified flow density relationship, as shown below and said if the traffic state remains on one leg of the triangle, than u_f represents free flow or u_c for congested condition. Windover and Cassidy (2001) have verified empirically that this simplification is reasonably accurate. If we postulate, that traffic velocity, *v*, over time, *t*, and space, *x*, has the functional form:

$$v(x,t) = f(x + u * t) \qquad (1)$$

where *u* is either u_f or u_c , then, the level sets of function *f* are straight lines and thus, *v* is completely determined by observing this parameter over time at a single point in space, i.e. at a detector station. The evolution of vehicle trajectories in the time-space plane is defined by the differential equation:



$$\frac{dx}{dt} = v(x,t) \qquad (2)$$

and vehicle’s link travel time is simply the time it takes the corresponding trajectory to propagate from one detector station to other. His work demonstrates that the travel time estimates are very good, provided there are no sources of delay, such as an incident within a link.

Methodology

The present study adopted the following methodology to understand the performance of the model. First, travel time is estimated by a naïve approach.

Travel Time Estimation from Naïve

Link travel time is estimated conventionally by a naïve approach. This approach assumes the velocity is constant over the link, which captured at the detector location. The link travel time is estimated from the length of the link by assuming that the vehicle will traverse the entire link with the same speed. Thus:

$$tt_n^j = \frac{L}{v_j} \tag{3}$$

where tt_n^j is the travel time of j^{th} vehicle, L is the link length, and v_j is the spot speed of j^{th} vehicle at the detector location. The spot speeds of successive vehicles are derived from video by assuming a small strip of 25-30m or loop detector, across the single lane roadway under investigation as illustrated in Fig 1.

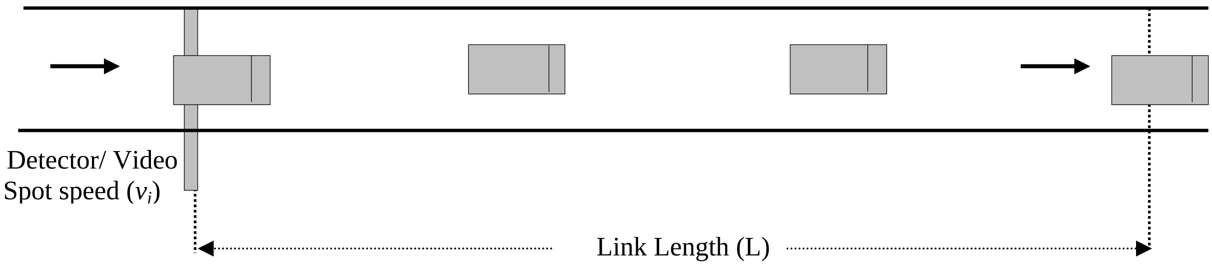


Fig. 1. Schematic showing intercepting vehicles (single lane traffic) for spot speeds

Travel Time Estimation Model

As discussed above the present model uses a new algorithm based on application of traffic flow theory to yield accurate estimate of link travel time from point data. Fig. 2 shows the relationships between u_c, the vehicle velocity, v_j, the headway, h_j, the travel time, τ_j, and the distance traveled, x_j, for j^{th} truncated chord, where a cord is simply a representative of a traffic regime in the time-space plane. Finally, link travel time, T_k, of the j^{th} vehicle is calculated by the empirical eq. (4).

$$T_k = p * \tau_{k+N_k+1} + \sum_{j=k}^{k+N_k} \tau_j \tag{4}$$

where N_{k+1} represents as estimate of the number of vehicles that pass the detector while the k^{th} vehicle traverses the link and p is weight factor for each vehicle. However, one of the critical parameter in the model was u_c. Newell (1993), suggested u_c of 6.25m/sec from freeways in US. However, the traffic characteristics are different here and were calibrated with GPS data and discussed in the next section.

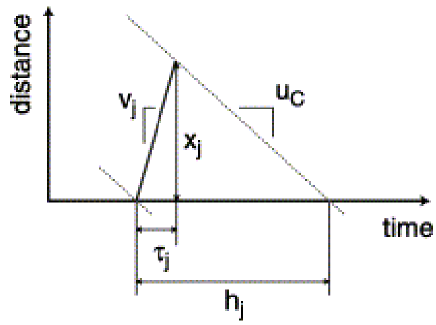


Fig. 2. Schematic showing the relationships between signal velocity, u_C, vehicle velocity, v_j, headway, h_j, travel time, τ_j, and distance traveled, x_j, for the j^{th} vehicle (Coifman, 2002).

Comparison of the Naïve approach and Model

In order to compare the performance of the model and the naive approach, the average travel time estimation error with respect to the actual travel time (tt_a) is computed. The actual travel time are estimated by a probe vehicle with GPS receiver. The average travel time estimation error (e_n) for the naïve approach is computed by eq. (5), (Gupta, 2005)

$$e_n = \frac{\sum_{j=1}^{k} | tt_a^j - tt_n^j |}{k} \tag{5}$$

where tt_a^j is the actual travel time of the j^{th} vehicle, tt_n^j is the travel time of the j^{th} vehicle computed by eq. (3), and k is the sample size of vehicles intercepted. Similarly, the average travel time estimation error for the model (e_m) is computed by eq. (6), (Gupta, 2005)

$$e_m = \frac{\sum_{j=1}^{k} | tt_a^j - tt_m^j |}{k} \tag{6}$$

where tt_m^j is the travel time of the j^{th} vehicle computed by the eq. (4).

Study Area and Field Survey Analysis

A study was carried out on Western Expressway (Mumbai, India) to test the model in the real time situation. To get the accurate travel time of the vehicles traversing the study link, a GPS receiver with its antenna mounted on a pilot car was used. The traffic was captured using the video while the pilot car made several runs along with traffic stream on the study link. A computer program was developed to analyze the vehicle data extracted the video data (Gundaliya, et. al., 2005). Video technique was used because it was the most suitable method for short-term traffic data collection compared to inaccurate manual or costly detectors.

A 400m stretch, three lane divided road of a flyover was identified near Kandivali, on the Western Expressway as shown in Fig 3. The site was chosen because of two reasons: (a) it offers a long stretch of uninterrupted traffic, (b) the location was suitable for video recording from a high-rise building, to get the unbiased data set. Further, lane adjacent to the median was considered for study to minimize the effect of lane change. The survey was carried out for one-hour duration, and 12 minutes of video, synchronizing with the GPS vehicle in the traffic stream was extracted for the present analysis.

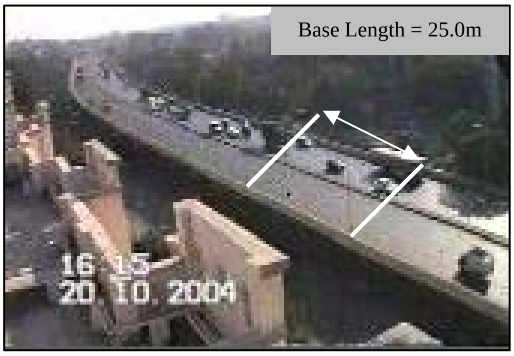


Fig. 3 Video clipping of the survey for Spot Speed and Headway measurement

Micro and Macroscopic Traffic Parameters

As discussed a computer program was developed to extract the recorded data from the video manually, by watching the video recording. The program records time of the pass when the vehicle crossed the reference marking on the road as shown in Fig. 3. The video is played with the normal speed and each vehicle is closely observed on the computer screen. As soon as the front-wheels of a vehicle cross the first reference point, appropriate key is pressed and headways are calculated for successive vehicles. e.g., when the first car crosses the first reference line, press key 1 (for car), and when the next car crosses the first reference line, press key 1 again and the program will calculate the time headway between the two cars. Similarly, appropriate key is pressed when vehicle passes the second reference point, the program records the time required to cross the marked base length (25m in the present case) on the road and calculates the spot speed. Similarly, for each mode appropriate key is pressed when it crosses the reference line.

Once the program computes the headways and spot speeds for the desired duration of traffic flow, it becomes input for the other program developed for computing link travel time. The output of this program is in the form of spreadsheet showing the computation for successive vehicles using the eq. (4). Various values of u_c were tested and value of 9.41m/sec is found to be optimum and the results are shown in Table 1.

Table 1. Travel Time Estimation by Model (tt_m), Naïve approach (tt_n) and GPS (tt_m)

u_c (9.41m/sec)		**Link Length** (400m)		**Model**	**Naïve**	**GPS**
j	**Time (sec)**	**Headway (sec)**	**Speed (m/sec)**	**tt_m (sec)**	**tt_n (sec)**	**tt_a (sec)**
1	0.88	0.88	11.44	25.03	34.97	
2	2.32	1.44	13.22	24.36	30.26	
-	-	-	-	-	-	-
6	8.92	1.27	15.51	23.87	25.79	
7	11.94	3.02	22.7	24.63	17.62	30.00
-	-	-	-	-	-	
306	642.13	1.39	13.11	25.18	30.51	
307	643.01	0.88	14.28	24.24	28.01	

The Trimble GeoXT (2004) GPS receiver was used for computing the actual travel time (tt_a) and four data sets were available for comparison. Trimble GeoXT GPS receiver is a full time, all weather, high precision instrument for navigation services for air, sea, and land based operations. After differential correction, the accuracy of the location information given by this instrument is within one meter. Accurate travel time and speed values are tagged to the digital map of the study stretch every second as the probe vehicle moves in the desired traffic stream.

The comparative evaluation of the link travel time for vehicles (representing pilot car with GPS) from the model (tt_m), naïve approach (tt_n), and GPS (tt_a) are summarized in Table 2. The plot of travel time estimation of vehicles by Model (tt_m) with four corresponding estimates by GPS (tt_a) is shown in Fig. 4. The avg. error in estimation of travel time from model (e_m) is less than 4 seconds, whereas from naïve approach (e_n) is more than 10 seconds as observed from Table 2. Although the estimations from model are not perfect, it is reasonably accurate. The average deviation from the actual travel time is less than 10%.

Table 2. Comparative Evaluation of estimated travel times by Model, Naïve approach & GPS

Vehicle ID No.	**Estimation by Model (tt_m), sec.**	**Estimation by GPS(tt_a), sec.**	**Estimation by Naïve Approach (tt_n), sec.**	**$e_m = \lvert tt_a - tt_m \rvert$**	**$e_n = \lvert tt_a - tt_n \rvert$**
7th	24.63	30	17.62	5.37	12.38
85th	24.69	26.3	31.25	1.61	4.95
188th	26.52	32.16	17.11	5.64	15.05
299th	25.86	28.2	18.6	2.34	9.6

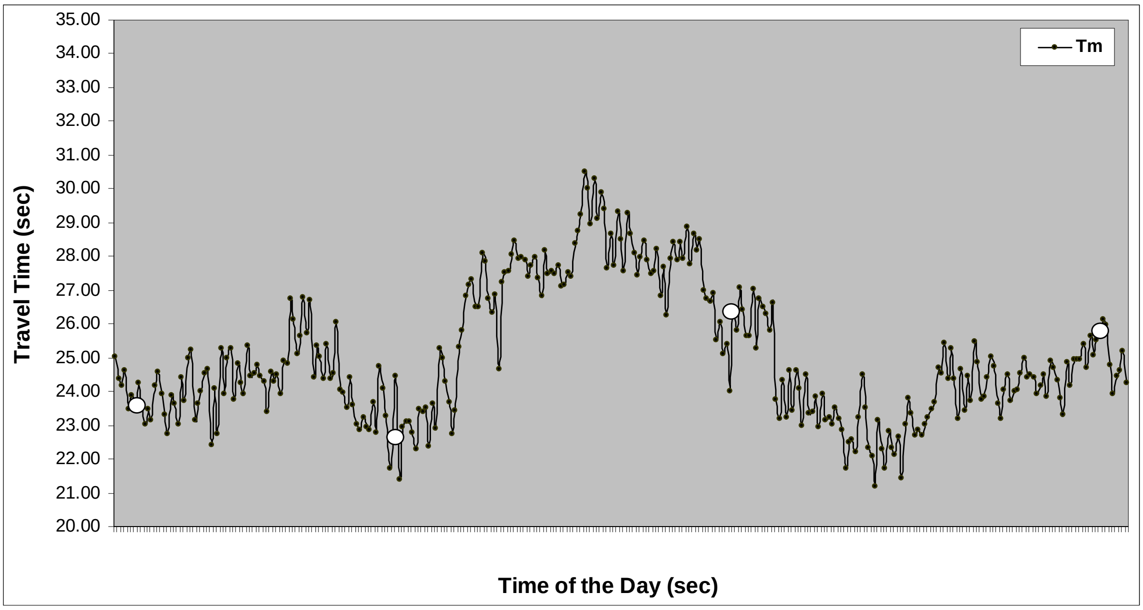


Fig. 4. Plot of Travel Time estimation of successive vehicles by Model (*tt_m*) with four corresponding estimates by GPS (*tt_a*)

With the model giving encouraging results, it was further investigated for multiple links. However, since it is not always possible to collect data at a large scale in field, traffic simulation software (VISSIM) was used to simulate a 7.0 km network for a heterogeneous traffic, volume of 1600vec./hr. as shown in Fig 5. Link travel times for successive vehicles traversing the each link were estimated from the model (tt_m), naïve approach (tt_n), actual travel time from VISSIM (tt_a) and are summarized in Table 3.

Table 3 Summary for Heterogeneous Traffic Stream

Volume: 1600 vec/hr.	**Network Simulation for 15 minutes**			
Link Travel Time	**Link 1**	**Link 2**	**Link 3**	**Link 4**
Length (km)	2.00	2.00	2.00	1.00
Naïve approach (e_n)	18.04	15.67	22.76	15.85
Model approach (e_m)	15.06	5.86	10.77	2.54
Actual Travel Time (tt_a), sec	112.66	123.67	131.92	60.86
tt_m (sec) for u_c = 6.25 m/sec	**99.65**	**130.89**	**135.57**	**66.88**
tt_m (sec) for u_c = 9.41 m/sec	**103.19**	**129.38**	**129.91**	**62.23**
Minimum speed, m/sec	15.66	13.21	14.53	2.89
Maximum speed, m/sec	27.20	25.06	26.69	26.59

Thus, from the table above it can be concluded that the model gives better estimates than the naïve approach, However, when the traffic fluctuation is more and estimates are even better with the calibrated value of u_c = 9.41m/sec.

VMS Application

A considerable amount of traffic congestion is caused due to poor information of where and when congestion is occurring and hence the inability to avoid adding it. Thus, traveler information system is the most widely implemented application among all ITS applications. VMS, one such traveler information system respond dynamically to traffic congestion and can give information to commuters based on the link travel time estimation, which is the core of any ITS applications. The algorithm can be integrated with VMS to give information to the commuters about the link wise travel time as shown in Fig. 5. Information compiled from number of VMS with spatial data can be further helpful for the TMC to know the congested routes, delays, incidents in a large urban network.

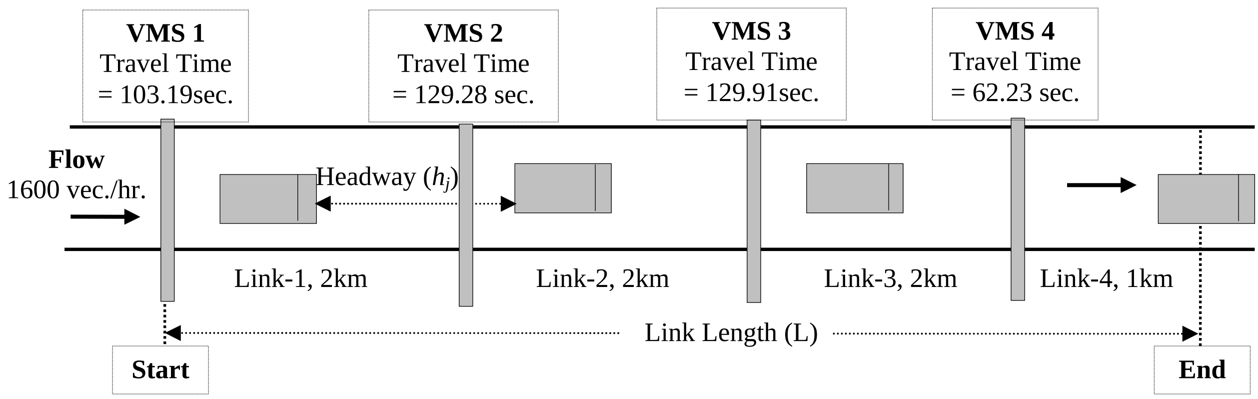


Fig. 5 Schematic Representation of VMS application as Traveler Information System

Conclusion

This study investigated a more recent link travel time algorithm and its suitability to heterogeneous traffic by studying one of the expressways in Mumbai and calibrating using Trimble GPS receiver. It was observed that travel time estimates are within 10 percent of the true values and quite good considering the fact that it is based on spot speed and the traffic stream is heterogeneous in nature. On the application front, the algorithm is integrated with VMS to give information to the commuters about the link wise travel time, in a network. Besides, information compiled from number of VMS with spatial data can be further helpful for the TMC to know the congested routes, delays, incidents in a large urban network. Further, technologies like GPS have emerged as a valuable tool in validation of the travel time estimation algorithm.

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