Travel Time Estimation Based on Intelligent Vehicle Infrastructure Cooperation System

Wenhui Fu, Jianming Hu, Qi Wang

National Laboratory for Information Science and Technology, Department of Automation, Tsinghua Univ, Beijing, 100084, China; Email: huiyier@gmail.com, hujm@mail. tsinghua.edu.cn, qi-wang06@mails.tsinghua.edu.cn

Keywords: travel time estimation (TTE); intelligent vehicle infrastructure cooperation system (IVICS); inter-vehicle communication; road-vehicle communication

Abstract

The paper proposed a travel time estimation (TTE) method based on the intelligent vehicle infrastructure cooperation system (IVICS), a new generation of intelligent transportation system (ITS) based on inter-vehicle and road-vehicle communication, utilizing the vehicle information gathered by vehicles which equipped with communication module in IVICS. A simulation platform of IVICS was set up using the traffic simulation software Paramics, database software MySQL and mathematical software MALAB. The TTE method was applied and validated on the platform and good results were achieved. The proposed TTE method was also validated with the NGSIM data and precise estimation were achieved: The MAPE can reach to approximately 7% when the equipped proportion is 0.2 and time interval of information collecting is 30 s. The influence of equipped proportion and time granularity is considered and the conclusion is that when equipped proportion increased or time granularity decreased, the accuracy of the estimation can be improved, but at the same time, the cost increased.

1 Introduction

As is well recognized, the traffic information is the most important factor for traffic management and control. The key point of ITS is how to get and use the traffic information to optimize the traffic. The first step of ITS is information extraction and many methods are developed to obtain the traffic information, from manual counting method to traffic flow sensors. There are different kinds of sensors, including magnetic loop sensor, vision sensor, FMCW radar, Infrared detector and some other sensors. With these fixed sensors, the traffic information we get are limited to some specific points; some sensors are badly affected while illuminations changes and the arrangements of some sensors are expensive; therefore, a flexible and comprehensive information gathering method is needed.

As the rapid development of inter-vehicle communication (IVC) technology and road-vehicle communication (RVC) technology, the ITS entered a new stage—intelligent vehicle infrastructure cooperation system (IVICS). In such a system, information can be exchanged among vehicles, traffic management centres, various elements of road infrastructure including traffic signals, message signs, bus stops, and other safety hardware[1]. Here the traffic information is gathered by vehicles equipped with wireless communication modules, which perform as moving sensors on road. With these moving sensors, all the information of certain vehicles along the entire road network can be collected. In US and some other countries, IVICS has been one major study, for example, vehicle infrastructure integration (VII) program in US, advanced safety vehicle (ASV) and advanced highway system (AHS) in Japan.

Here, we set up a simulation platform of IVICS by employing Paramics, Matlab and MySQL for further research. In the simulation system certain vehicles are equipped with communication modules so as to exchange information with each other and the road-side stations. In this way, the information of these vehicles such as location, velocity, and gap can be directly gathered in real time. Further studies such as traffic guidance, control and management on IVICS all base on the information collected. Here we use it to estimate the link travel time of vehicles starting at any past time.

Among all the traffic information, travel time is perhaps the most essential and valuable for traffic management and control. It's an indicator of the traffic condition. At the same time, travel times are difficult to obtain directly. As the development of technology many measurement methods are developed to estimate travel times directly or indirectly. Floating car (probe vehicle) is one way to measure travel times, but the information is far from sufficient. With recent advances in vehicle identification methods (i.e. video based vehicle identification and license plate recognition), more and more studies (i.e. Federal Highway Administration's (FHWA) Next Generation Simulation Program (NGSIM)) can provide travel times directly, but the identification methods are always associated with high costs.

As reported in the literature, many travel time estimation methods are studied to get travel times from other traffic data such as traffic flow data, which can be collected easily from common loop sensors or other detectors. Many works have been done in this area. Flow-based models[2–6] and Trajectory-based models[7–12] are two typical models which have been studied most.

In this article, a simulation platform has been set up. The information of vehicles with communication modules on the platform can be gathered in real time. Based on the platform and information, some work has been done in Wang's paper[13,14]. Our travel time estimation method is also based on the information (detail trajectory data of quipped vehicles) from the simulation platform. It's a kind of trajectory-based travel time estimation model based on IVICS.

The paper is organized as follows. In section II, we introduce the IVICS and our research based on the simulation platform. In section III, we present the travel time estimation method based on IVICS. Section IV is the empirical result. Conclusions and discussions are given in section V.

2 Simulation platform of IVICS

The development of wireless communication technology makes feasible the exploration of IVICS. A number of efforts are currently underway to investigate inter-vehicle communication (IVC) and road-vehicle communication (RVC) based on mobile wireless networking technology.

In IVICS, certain proportions of vehicles are equipped with communication modules, through which the traffic information of their own can be collected, including location, velocity and acceleration, etc. There are also infrastructures including Road-side Stations and some other elements installed by the transportation authorities. Vehicles equipped with communication modules and road infrastructures can exchange information with each other. The equipped vehicles act as moving sensors on road, and all the equipped vehicles on road network form a wireless sensor network. The road-side stations are used to collect the information from the vehicles in real time, and the information gathered by all the stations are centralized to the Traffic management centre. Based on the information, traffic management centre can guide traffic flow by controlling traffic signals, publishing guidance information on road side message board and disseminating road condition information to equipped vehicles. Such a communication system can be used to relay information of traffic conditions and transportation networks and could be helpful for improving safety and mobility of the transportation system. The schematic is showed as Figure 1.

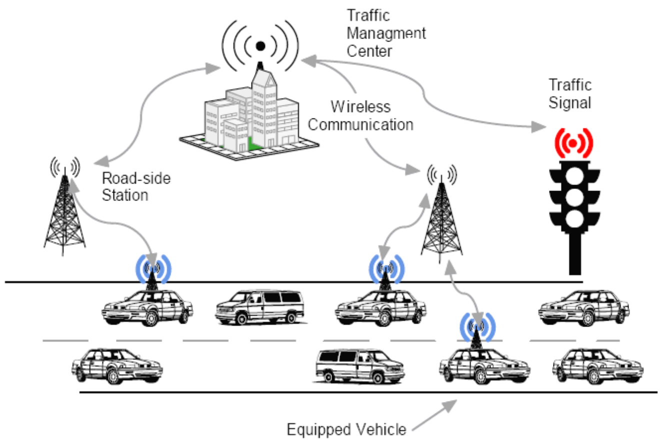

Figure 1: The simple schematic diagram of IVICS.

Compared to other information gathering methods such as camera, loop detector, there are many advantages of IVICS. First the information gathering process becomes more and more convenient and flexible; second, the information is more comprehensive. In IVICS, all the information of equipped vehicles along the entire journey can be collected in real time, and the other information can be derived from it. Besides, the data is more accurate and stable, because the wireless communication is not affected by the environment. It works well at night and under bad weather condition, different from the video-based method.

Based on the professional large-scale traffic simulation software "Paramics", a simulation platform of IVICS was set up for further study. The advantage of Paramics is that it provides plenty of APIs to support the data exchange with other applications.

The simulation platform is composed of four basic parts:

- Traffic Simulation Part based on Paramics
- Communication Simulation Part based on NS2
- Analysis Part based on awk and Matlab
- Data Sharing Part based on MySQL database

Illustration of simulation platform is shown in Figure 2.

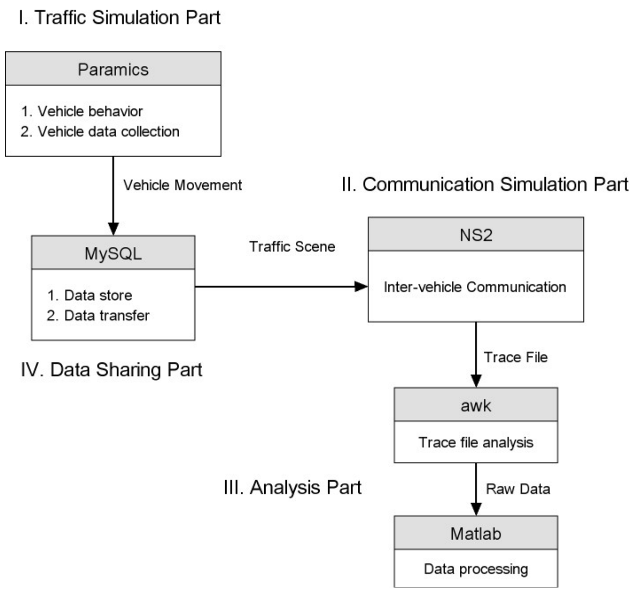

Figure 2: The composition of simulation platform.

The traffic simulation part is done in Paramics. And then NS2 (Network Simulator 2) is applied to simulate wireless communication on road. Simulation result which records entire process of communication is processed by awk script and Matlab is used to simplify simulation data and analyse the performance of inter-vehicle communication subsystem.

3 Travel time estimation based on IVICS

In this section, we proposed a travel time estimation method based on IVICS. In IVICS, the trajectory information of certain proportion of vehicles which equipped communication modules is known, so the travel time of these vehicles can be easily read directly. Our objective is to estimate the travel time starting journey at any time overpassed and from any given location on a link to the destination with the trajectory information.

The method considered variation of traffic condition in both space and time, making the estimation result more realistic. The travel time estimated can be shown on a given location on a link, maybe is a Variable Message Signs (VMS), which can give guidance to the travellers pass by.

3.1 Speed surface construction method

The best way to get travel time is read from the trajectory data directly. In order to estimate the travel time, we can imagine an imaginary vehicle driving from the given location to the destination at the given time and then construct the trajectory of imaginary vehicle from the equipped vehicles' trajectories.

Once we know the speed of imaginary vehicle at any time and any location, the movement of imaginary vehicle can be simulated step by step. Therefore the first step is constructing the speed surface so that the speed of any given location and time can be read from the surface.

We proposed a speed construction method to get the speed $v(t,x)$ at give location and time (t,x) . The equipped vehicles' trajectories are represented with a series of n-tuple point data $(t, vid, v, x, \cdots)$, including time, vehicle id, speed, location, etc. The point data has the equal time interval for the information collecting action is done at a given frequency.

We assume that the speed is continuous both in space and time on a given link, that is $v = v(t,x)$, so that the distribution of speed in space and time can be constructed using the interpolation method with the trajectory data of equipped vehicles.

Consider such a traffic scene: the imaginary vehicle is driving at point (t,x) with equipped vehicles around. We need to determine its speed $v(t,x)$. Assume points (t_1,x_{11}) , (t_1,x_{12}) , (t_2,x_{21}) , (t_2,x_{22}) around the point (t,x) are four points on the trajectories of equipped vehicles, so the speed of these 4 points is known from the trajectories. Speed $v(t,x)$ can be calculated using interpolation method.

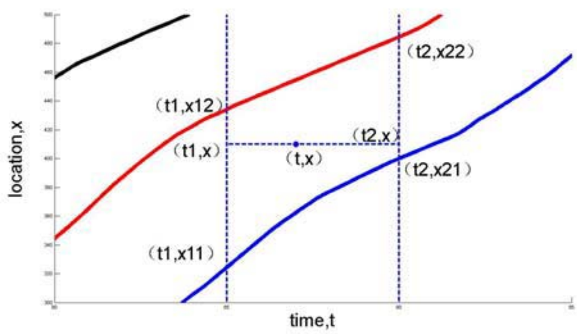

Figure 3: Interpolation method to construct the speed surface.

It is a kind of special two-dimensional interpolation problem because the space interval various so that the 4 points do not form a rectangle in $t-x$ plane, as shown in Figure 3. There are kinds of interpolation methods can be used here. The nearest neighbour interpolation is the simplest one. What it does is using the speed of the nearest point instead. Assume point (t_1,x_2) is the nearest point of point (t,x) , so the speed $v(t,x)$ can be replaced by $v(t_1, x_2)$. Other methods, such as bilinear interpolation, area-weighted interpolation, and distance-weighted interpolation also can be applied here.

Here we used a method similar to bilinear interpolation to determine $v(t,x)$ as follows:

First, using the linear interpolation method to determine the speed of point (t_1, x) at time t_1 and point (t_2, x) at time t_2 ;

$$v(t_1,x)=\frac{(x_{12}-x)v(t_1,x_{11})+(x-x_{11})v(t_1,x_{12})}{x_{12}-x_{11}}$$
$$v(t_2,x)=\frac{(x_{22}-x)v(t_2,x_{21})+(x-x_{21})v(t_2,x_{22})}{x_{22}-x_{21}} \quad (1)$$

Note that there might be no equipped vehicles before or behind the imaginary vehicle sometimes. Once this case happened, former linear interpolation method on space cannot be used as Eq. (1). The 1-dimensional nearest neighbour interpolation method can be applied here. If there are no equipped vehicles ahead, use the speed of back equipped vehicles directly.

Second, interpolate on time at location x to get speed $v(t,x)$;

$$v(t,x)=\frac{(t_2-t)v(t_1,x)+(t-t_1)v(t_2,x)}{t_2-t_1} \quad (2)$$

Then the speed surface is constructed in this way. What we should do next is using the speed surface to estimate the travel time of any given imaginary vehicle.

3.2 Travel time estimation method

Here we want to estimate the travel time of imaginary vehicle from a given location x_0 to the destination x_d. With the constructed speed surface, the movement (trajectory) of the imaginary vehicle can be constructed as follows.

First we cut the road segment $x_0 \sim x_d$ into N slices $(x_0, x_1, ...x_k, ..., x_N)$ equally, and $x_N = x_d$. Then travel time can be presented as Eq. (3):

$$T=\int dx/v(x)=\sum_{i=0}^{N-1}\Delta x/\overline{v}(x_i,x_{i+1}) \quad (3)$$

where $\overline{v}(x_i, x_{i+1})$ is the average velocity of slice (x_i, x_{i+1}), and

$$\Delta x=\tfrac{x_d-x_0}{N}$$

When N is sufficient large, the average velocity of slice (x_i, x_{i+1}) can be replaced by $v(t(x_i), x_i)$, $v(t(x_i), x_i)$ is the instantaneous velocity of point $(t(x_i), x_i)$, so Eq. (3) can be represented as Eq. (4):

$$T=\sum_{i=0}^{N-1}\Delta x/v(t(x_i),x_i) \quad (4)$$

After that the travel time estimation algorithm can be described as follows, in fact it's the simulation of the movement of imaginary vehicle start from location x_0 at t_0.

(1) Determines the initial status of the imaginary vehicle: $t = t_0, x = x_0$ and some parameters: time increment Δt , space increment Δx .

(2) Calculate the instantaneous velocity $v(t,x)$ of current point (t,x) using the interpolation method mentioned above.

(3) If $v(t,x) > v_{th}$, then imaginary vehicle move forward distance Δx at the speed $v(t,x)$,and update the status: $x' = x + \Delta x, t' = t + \Delta x / v(t,x)$, go to Step 5.

(4) Otherwise, stop for a while Δt , and update the status : $x' = x, t' = t + \Delta t$.

(5) Check current status. If $x' < x_d$, go to Step 2.

(6) Otherwise, using the linear interpolation method to get the exact time t_d crossing $x_d : t_d = t + \frac{x_d - x}{\Delta x} \Delta t$.

(7) Get the travel time $T = t_d - t_0$.

Notice that there is a threshold velocity v_{th} introduced in Step 3 in order to accurate the result and avoid the "divide by zero" error. If the velocity $v(t,x)$ is too small, large error may be introduced while Δx divided by $v(t,x)$, and if $v(t,x) = 0$, then "divide by zero" error happens.

4 Empirical results

In this section, the validation of the travel time estimation method based on IVICS is done with both the data produced by simulation platform and the real data from the NGSIM program and acceptable results are achieved. Because the simulation data is not so realistic, the validation is mainly done with the NGSIM data to test the performance in real world. The influence of equipped proportion and time granularity is investigated in the empirical validation.

4.1 Data and validation

We simulated a 2 km road segment on our simulation platform and a dataset containing trajectory data of all the 1,251 vehicles was produced. To get an overview of the data, the speed surface is shown in Figure 4.

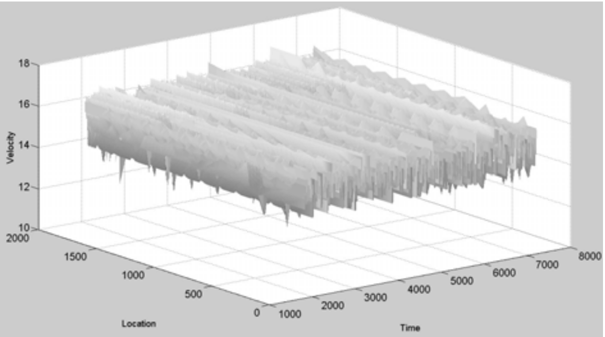

Figure 4: The overview simulation dataset.

Besides the simulation data from our platform, the datasets collected by the Federal Highway Administration's (FHWA) Next Generation Simulation Program (NGSIM) are used too. The detailed trajectory data of all the vehicles on the road segment is contained in the datasets.

The NGSIM datasets we chosen were collected on a segment of Interstate 80 in Emeryville (San Francisco), California on Wednesday, April 13th, 2005. The road segment is approximately 1650ft (503 m) long, with an on-ramp at Powell Street and a downstream off-ramp at Ashby Avenue. Three separate 15-min periods of data are available: (1)4:00-4:15 p.m., (2) 5:00-5:15 p.m., and (3) 5:15-5:30 p.m. Complete vehicle trajectories were transcribed at a resolution of ten frames per second.

Before the validation, the vehicles in the dataset are sampled with proportion p, which indicates the equipped proportion. The vehicles sampled denote the equipped vehicles, used to training the travel time estimation algorithm, and the rest vehicles are used as the test vehicles to validate the estimation accuracy. The validation can be done with various equipped proportion p and time granularity so that their influence to the estimation accuracy can be tested. The time granularity denotes the time interval of information collecting in the system. If the interval is too large, the information might be not sufficient, and if too small it will increase the load of the wireless communication system. So that choosing a proper time interval is very important.

Here we use the mean absolute percentage error (MAPE) to validate the performance of the travel time estimation method. It can be calculated as following Eq. (5):

$$MAPE(\%) = \frac{1}{N}\sum_{i=1}^{N}\frac{real(i) - estimated(i)}{real(i)} \times 100\% \qquad (5)$$

4.2 Validation results

First we validated our estimation method using the simulation data from IVICS platform. The equipped proportion is set to 20%, and the time interval of information collecting is 30s, that means we can get 20% of all vehicles' data every 30s. The validation result is shown in Figure 5.

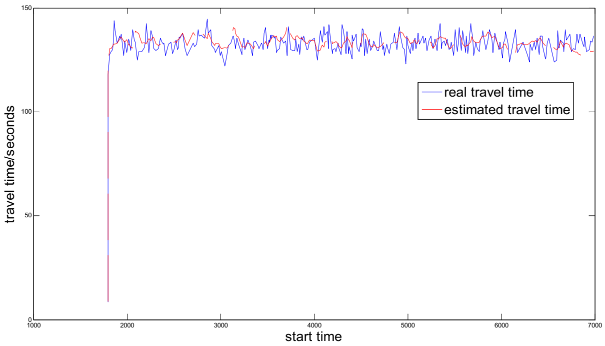

Figure 5: Validation result of simulation data.

As shown in the figure, the blue line denotes the real travel time while the red one denotes the estimated result. We can find that these two curves are quite close, and the MAPE here is 2.48, which indicates a good result.

The data from simulation platform is not so real, we. In order to examine the performance of this method in real traffic scene, the practical traffic data is necessary. Hence the validations below are done with the NGSIM data. Here 3 periods of NGSIM data are used here, and the results are shown below. The figures showed the variation of travel time with start time, and we can find that estimated travel time matches real travel time.

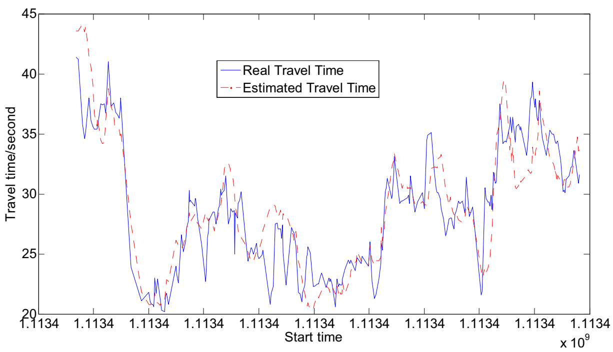

Figure 6: Validation result of NGSIM data (I-80, April 13, 2005 4:00–4:15 p.m., p=0.2, time granularity = 10 s).

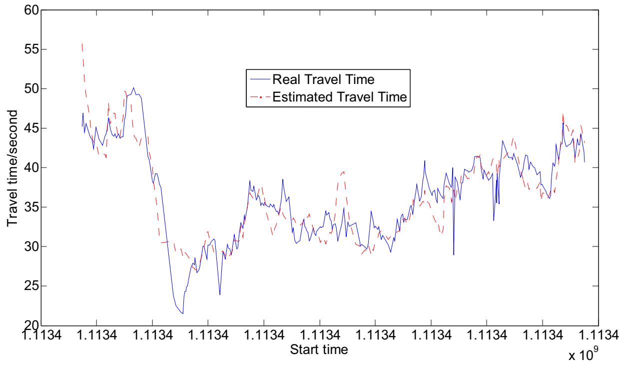

Figure 7: validation result of NGSIM data (I-80, April 13, 2005 5:00–5:15 p.m., p=0.2, time granularity = 10 s).

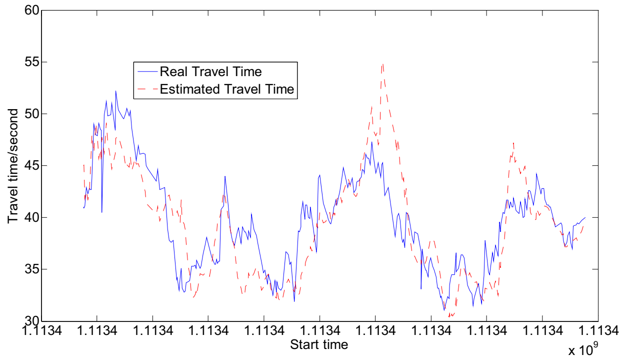

Figure 8: validation result of NGSIM data (I-80, April 13, 2005 5:15–5:30 p.m., p=0.2, time granularity = 10 s)

Table 1: Validation results with NGSIM datasets.

TIME	4:00–4:15	5:00–5:15	5:15–5:30
MAPE(%)	6.86	5.73	6.87

Table 2: Influence of equipped proportion.

Proportion	0.1	0.3	0.5
MAPE(%)	7.12	6.20	5.29

Beside the figures above, the MAPE data below also showed that the travel time estimation method based on IVICS performs very well with the real data from the NGSIM program.

In order to examine the influence of equipped proportion to the performance of the method, we can repeat the validation with different proportion on the same data. Here we use the period 5:00–5:15 p.m. data and 3 proportions are tested here: $p = 0.1, p = 0.3, p = 0.5$.

We find that the average MAPE decreases when the equipped proportion p increases. It can be explained that: when p increases, we collected more information, so the estimation base on the information is more accurate. But the equipped proportion is not the higher, the better. Besides the high cost, the data redundancy problem may be introduced when p gets higher.

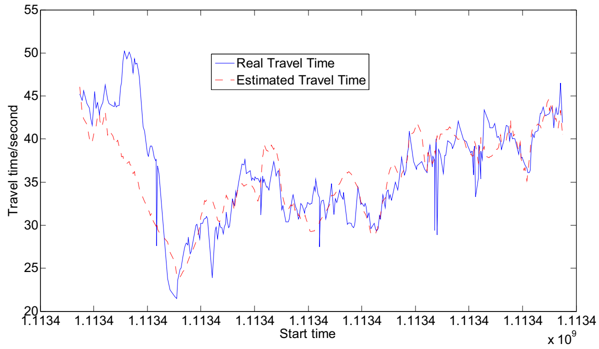

Figure 9: validation result of NGSIM data (I-80, April 13, 2005 5:00–5:15 p.m., p=0.1, time granularity = 10 s).

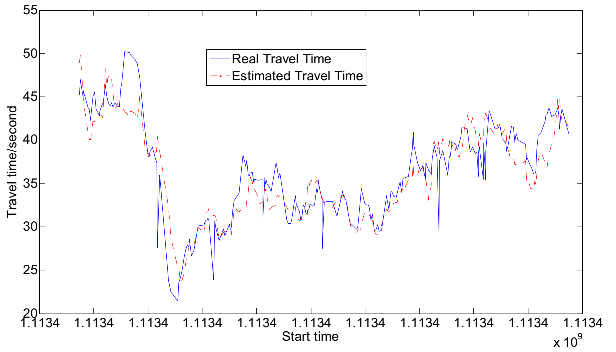

Figure 10: validation result of NGSIM data (I-80, April 13, 2005 5:00–5:15 p.m., p=0.3, time granularity = 10 s).

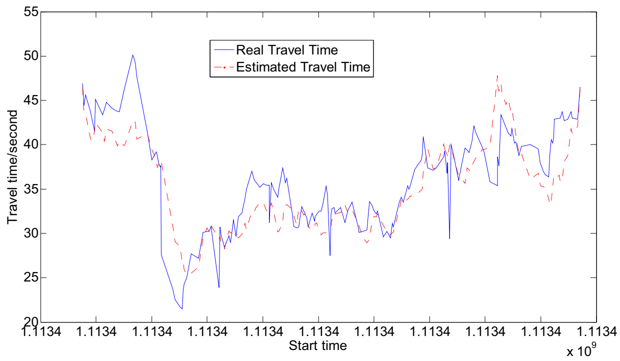

Figure 11: validation result of NGSIM data (I-80, April 13, 2005 5:00–5:15 p.m., p=0.5, time granularity = 10 s).

Consider the influence of time granularity. Repeat the experiment at two kinds of time granularity: 10 s and 50 s. The results are shown below.

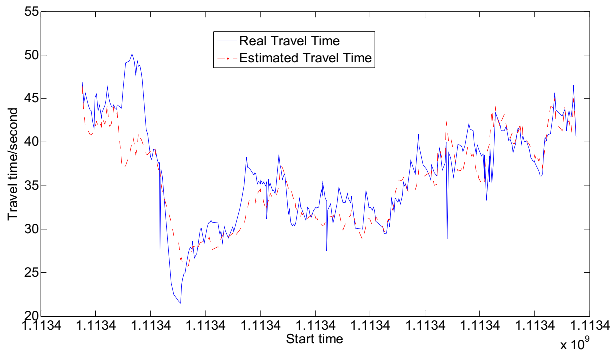

Figure 12: validation result of NGSIM data (I-80, April 13, 2005 5:00–5:15 p.m., p=0.2, time granularity = 10 s).

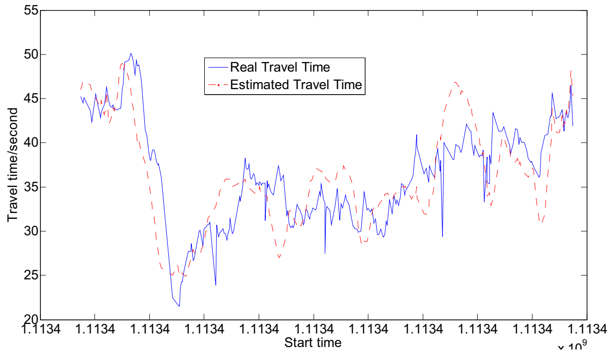

Figure 13: validation result of NGSIM data (I-80, April 13, 2005 5:15–5:30 p.m., p=0.2, time granularity = 30 s).

The MAPE (%) is 5.67 when time interval is 10 s and the MAPE is 8.68 when time interval is 30 s. And the explanation is same with the influence of equipped proportion. Therefore a proper proportion and time granularity is important.

5 Conclusions

In this article, we proposed a trajectory-based travel time estimation model based on IVICS. The IVICS is a new generation of intelligent transportation (ITS) based on inter-vehicle and road-vehicle communication. A percentage of vehicles in IVICS are equipped with communication modules so that the information of these vehicles such as location and speed can be collected for further information extraction and traffic optimization. We set up a simulation platform of IVICS for further research. The platform can simulate the research on IVICS, including the traffic simulation and wireless communication simulation, and also provide traffic data for study.

The proposed travel time estimation method is one example of the information extraction base on the vehicle information collected. The objective is to estimate the link travel time at any past time. The approach is that first we construct a speed surface as a function of location and time with these data collected so that the trajectory of vehicle which start one's journey from given location at given time can be constructed by simulating the movement of the vehicle on the speed surface step by step. In this way the travel time can be read from the trajectory.

The equipped proportion of vehicles and time granularity of collecting information is two important factors on IVICS, and their influences to the performance of proposed TTE method are examined in this article. The conclusion is that when equipped proportion increased or time granularity decreased, the accuracy of the estimation can be improved, for the information collected is increased. The number of equipped vehicles increasing when equipped proportion is increased and the time interval is decreasing when time granularity is decreased. Both that bring the increasing of collected information. While we get more information, data redundancy problem might be introduced and the noise data might influence the performance of proposed method. So how to find the optimal equipped proportion and time granularity will be a very interesting exploration.

In comparison with other models, the proposed model possesses many advantages. First it is designed for IVICS. It's an exploration of information extraction on the newly proposed ITS; Second the accuracy of the method is higher and more stable than the other method under the same condition. The MAPE can reach to approximately 7% when the equipped proportion is 0.2 and time interval of information collecting is 30s. The accuracy can be improved by optimizing the parameters. The TTE method can provide plenty of travel time data for further study such as travel time prediction.

The further study on IVICS is on-going. The travel time estimation method proposed can only estimate the link travel time passed, lagging behind the real time. It's not a real time estimation method. Therefore effort will be made to estimate the travel time in real time and predict the future travel time. And how to use this information in specific traffic scene is also a further research topic, for example controlling traffic lights at the intersection.

Acknowledgements

The work described in this paper is partially supported by the National Natural Science Foundation of China (No. 50708054), the National Basic Research Program of China (973Project) (No. 2006CB705506), the National Key Technology Research and the Development Program (No. 2006BAJ18B02), and the Henry Fok Foundation (No. 122010).

References

[1] W. L. Jin, H. J. Wang. "Modelling connectivity of inter-vehicle communication systems with road-side stations". *The Open Transportation Journal*, (2008).

[2] D. Dailey. "Travel-time estimation using cross-correlation techniques . *Transportation Research Part B*, Vol. 27, No. 2, pp. 97–107, (1993).

[3] Y. Liu, X. Lai, G. Chang. "Estimation of freeway travel time based on sparsely distributed detectors". Chicago : *9th International Conference on Applications of Advanced Technology*, (2006).

[4] D. Nam, D. Drew. "Traffic dynamics: method for estimating freeway travel times in real time from flow measurements". *Journal of Transportation Engineering*, Vol. 122, No. 3, pp. 185–191, (1996).

[5] N. Zou, J. W. Wang. "A hybrid model for reliable travel time estimation on a freeway with sparsely distributed detectors". Beijing: 11*th International IEEE Conference on Intelligent Transportation Systems*, (2008).

[6] K. Petty, P. Bickel, J. Jiang, *et al*. "Accurate estimation of travel times from single-loop detectors". *Transportation Research Part A*, Vol. 32, No. 1, pp. 1–17, (1993).

[7] B. Coifman. "Estimating travel times and vehicle trajectories on freeways using dual loop detectors". *Transportation Research Part A*, Vol. 36, No. 4, pp. 351–364, (2002).

[8] C. Cortés, R. Lavanya, J. Oh, "A general purpose methodology for link travel time estimation using multiple point detection of traffic". *Transportation Research Record*, pp. 181–189, (2002).

[9] C. Lindveld, R. Thijs, P. Bovy, *et al*. "Evaluation of online travel time estimators and predictors". *Transportation Research Record*, pp .45–53, (2000).

[10] D. H. Ni, H. Z. Wang. "Trajectory reconstruction for travel time estimation". *Journal of Intelligent Transportation Systems*, pp. 113–125, (2008).

[11] N. van Grol, S.Manfredi, M. Danech-Pajouh. "On-line network state estimation and short term prediction deliverable D05.2.". *Telematics Application Programme Project TR1017*, INRETS, Brussels, (1997).

[12] J. van Lint, N. van der Zijpp. "Improving a travel-time estimation algorithm by using dual loop detectors". *Transportation Research Record* 1855, pp. 41–48, (2003).

[13] Q. wang, J. M. Hu. "A simulation study for the communication subsystem of wireless traffic information service system". Macau: 7*th International Conference on Information, Communications & Signal Processing*, (2009).