Travel Time Estimation for Short-highway in Pre-timed Systems

Arthit Buranasing

Abstract— A travel time is important detailed measures for evaluating the performance of the traffic network system and only a single CCTV camera is installed on the highway is cause of difficulties to the automated estimate the travel time because there are many factors are hidden from the data input, for example, arrival-flow/departure-flow rates, traffic light cycles and etc. This paper studies the effect of primary hidden factors to travel times on a single CCTV camera. Some characteristics are revealed with significance to the estimation of travel time. A model for travel time is proposed. Comprehensive experiments are presented. The technique can estimate travel time for real-time system with low error rate.

Keywords — Travel Time Estimation; Queue Length Estimation; Intelligent Transportation System (ITS); Highway Engineering; Traffic Signal Management System

I. INTRODUCTION

Travel time is one of the most important detailed measures for evaluating the performance of the traffic network system and also important information for traveler to decide the travel choices and avoid unnecessary delay. Nevertheless, most of travel time estimation works are on freeway, which has no traffic light is included in the system. Highway, On the contrary, is more complicated as traffic light cycles play an important role and many factors that affect the travel time are hidden in the system [1, 2].

So far, highway travel time estimation has been conducted with different techniques and constraints of input data. For example, Liu and Ma [3] developed a virtual probe travel time model by using a single camera and traffic signal data to estimate travel time, but the model requires queue length estimation which the traditional queue length estimation method cannot handle congested situations with a long queue and so far, no reliable method is available to estimate travel time with a long queue. (Note that long queue is defined here as that the queue length is longer than distance from intersection or traffic light stop-bar to CCTV camera position and traffic signal data is often used to predict departure-flow rate.) [3].

Recently, Arthit Buranasing and Akara Prayote [4] developed travel time estimation model for highway by using only flow rate and average velocity in each minute from a single CCTV camera which is installed in the middle of the road without using traffic signal data or departure-flow rate on the pre-timed system.

However, the model could only predict travel time on uncongested condition, but could not predict travel time on congested condition.

Hence, so far to the best of our knowledge, travel time estimation on highway requires at least two types of raw data, one is the data from a CCTV camera which some work requires at least two cameras and the others is traffic signal data or departure-flow rate. Although, Buranasing and Prayote attempted to develop travel time estimation model for highway by using only a single camera for saving cost, but the model could not predict travel time on congested condition. Therefore, in this paper, the proposed model are able to estimate travel time on short-highway by using only flow rate and average velocity from a single camera which is installed at the beginning of the road by without using traffic signal data or departure-flow rate on the pre-timed system and the model are able to predict travel time in any traffic condition (both congested and un-congested condition). This paper is organized into the following sections: Section II simulation software and experiment setting. Traditional travel time estimation model and the other related model in section III. Travel time estimation model with adaptation for Short-highway in section IV. Travel time estimation for Short-highway model and the performance in section V and a conclusion and remark is drawn in section VI.

II. SIMULATION SOFTWARE AND EXPERIMENT SETTING

Quadstone Paramics Simulation Software [5] was used for the experiment testing and used some major simulation setting which was derived from Buranasing and Prayote. (Quadstone Paramics Simulation Software was also used in theirs proposes.)

In this propose, the experiments were defined as follows; used 2 type of roads which each road had length 0.5 km. and 1.0 km. with 1 lane, set vehicle only 4 wheels cars which each car had 4 meters length and 1 meter for suitable gap, maximum vehicle speed was 120 km/h, traffic was controlled by pre-timed system which each experiment had a cycle length 60, 120 and 240 seconds and used green time per red time 25%, 50% and 75% in each cycle length experiment. (For instance, green time 25% of 120 seconds cycle length, means green time 30 seconds and red time 90 seconds. Yellow time was included in green time, about 5 seconds in each green time). In simulation, collection data was derived from a single...
CCTV camera which was installed at the beginning of the road and detected average velocity in each minute and also detected average travel time by using function of simulator. Then, launched simulator by started from empty road and released vehicles to the road and controlled arrival-flow rate more than departure-flow rate until road was full (road had a maximum congestion) within first 180 minutes and next 180 minutes later controlled arrival-flow less than departure-flow until the road was empty again, each experiment had the same this scenario. In simulation excluded exception-event such as accident, using siren of vehicle, human cross a road and etc., vehicles flows were run normally. The data from simulation experiment will be used for testing all of the rest in this paper.

Where AVL is the length of space a vehicle occupies when stopping, and can be calculated as follows.

\[
AVL = \left(\sum_{i=1}^{N} LVT_i + \sum_{i=1}^{N} MG_i\right)/N \tag{4}
\]

Where LVT is a length of vehicle in each type, MG is minimum gap between 2 vehicles, N is number of vehicle’s type in the system.

Thirdly, amount of vehicle between CCTV-flow and departure-flow in each minute are much different. Thus, some characteristics of freeway are applied by using macroscopic property which is methods that measures larger scale than usual. Therefore, the model expended time window size at least 15 minutes and equivalent flow can be calculated as follows.

\[
K = Q AVL = \sum_{i=1}^{T} V_{CCTV} / T \tag{1}
\]

Where \( V_{CCTV} \) is velocity from CCTV camera in each minute, \( V_{ma} \) is an average velocity which is computed in time window size of \( T=15 \) minutes, \( T \) is time window size.

\[
Q = C \sqrt{1 - (V_{ma}/V_{max})} \tag{2}
\]

Where \( Q \) is an equivalent queue length, \( C \) is CCTV position (In addition, \( C \) in this paper means road length or can replace by \( L \)), \( V_{max} \) is a maximum speed a vehicle can reach on an empty road.

A queue’s length can be translated into the amount of vehicles accumulated or congestion by

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In case empty vehicle on road (\( K=0 \)) travel time can be calculated in generally form by using motion of movement as follows.

\[
T = R / V_{max} \tag{7}
\]

Where \( R \) is road length, \( V_{max} \) is a maximum speed that a vehicle can reach on an empty road.

Thirdly, amount of vehicle between CCTV-flow and departure-flow in each minute are much different. Thus, some characteristics of freeway are applied by using macroscopic property which is methods that measures larger scale than usual. Therefore, the model expended time window size at least 15 minutes and equivalent flow can be calculated as follows. \[9\]

\[
F_{ma} \approx \left(\sum_{i=1}^{T} F_{CCTV} / T\right) \approx \left(\sum_{i=1}^{T} F_{departure} / T\right) \tag{8}
\]

Where \( F_{ma} \) is equivalent departure-flow rate at time window size \( T \), \( T \) is time window size, \( F_{CCTV} \) is amount of vehicle that pass CCTV camera in each minute, \( F_{departure} \) is amount of vehicle that departure from a road in each minute.

Fourthly, whenever queue length has a maximum congestion, vehicles that pass CCTV in this period will pass in same pattern as departure-flow rate. Therefore, maximum travel time on any road in pre-timed system can be calculated as follows.

\[
T_{max} = K_{max} / F_{max} \tag{9}
\]

Where \( T_{max} \) is maximum travel time, \( K_{max} \) is maximum congestion on a road and \( F_{max} \) is maximum departure-flow rate, which is stated in a following section.

Fifth, the maximum velocity’s vehicle (\( V_{max} \)) down to 90% of maximum velocity’s vehicle or called effect point (\( \alpha \)) \[4\] were a period that equivalent queue length is not longer than ability of departures rate in 1 cycle length. Thus, CCTV-flow rate can be calculated by using only CCTV-velocity as follows.

Fig. 1. Traffic Simulations on Quadstone Paramics.

Fig. 2. Sample’s data from CCTV camera.

III. TRADITIONAL TRAVEL TIME ESTIMATION MODEL AND THE OTHER RELATED MODEL

The techniques and equation of traditional travel time estimation model which was proposed by Arthit Buranasing and Akara Prayote was involved and adapted by travel time estimation model for short-highway in this paper and the model will be briefly introduced in sequence as follows. Firstly, the equivalent queue length can be estimated in sequence as follows.

\[
V_{ma} = \sum_{i=1}^{T} V_{CCTV} / T \tag{1}
\]

Where \( V_{CCTV} \) is velocity from CCTV camera in each minute, \( V_{ma} \) is an average velocity which is computed in time window size of \( T=15 \) minutes, \( T \) is time window size.

\[
Q = C \sqrt{1 - (V_{ma}/V_{max})} \tag{2}
\]

Where \( Q \) is an equivalent queue length, \( C \) is CCTV position (In addition, \( C \) in this paper means road length or can replace by \( L \)), \( V_{max} \) is a maximum speed a vehicle can reach on an empty road.

A queue’s length can be translated into the amount of vehicles accumulated or congestion by

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K = Q / AVL \tag{3}
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Where AVL is the length of space a vehicle occupies when stopping, and can be calculated as follows.

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AVL = \left(\sum_{i=1}^{N} LVT_i + \sum_{i=1}^{N} MG_i\right)/N \tag{4}
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Thirdly, amount of vehicle between CCTV-flow and departure-flow in each minute are much different. Thus, some characteristics of freeway are applied by using macroscopic property which is methods that measures larger scale than usual. Therefore, the model expended time window size at least 15 minutes and equivalent flow can be calculated as follows. \[9\]

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F_{ma} \approx \left(\sum_{i=1}^{T} F_{CCTV} / T\right) \approx \left(\sum_{i=1}^{T} F_{departure} / T\right) \tag{8}
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Where \( F_{ma} \) is equivalent departure-flow rate at time window size \( T \), \( T \) is time window size, \( F_{CCTV} \) is amount of vehicle that pass CCTV camera in each minute, \( F_{departure} \) is amount of vehicle that departure from a road in each minute.

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Fifth, the maximum velocity’s vehicle (\( V_{max} \)) down to 90% of maximum velocity’s vehicle or called effect point (\( \alpha \)) \[4\] were a period that equivalent queue length is not longer than ability of departures rate in 1 cycle length. Thus, CCTV-flow rate can be calculated by using only CCTV-velocity as follows.
\[ F_{ma} = F_{\text{max}} \left( 1 - \frac{V_{ma} - V_{\beta}}{V_{\text{max}} - V_{\beta}} \right)^2 \]  
\[ \text{and } F_{\text{max}} \text{ can be calculated by} \]
\[ F_{\text{max}} = F_{\text{max}} \left( 1 - \frac{V_{\beta}}{V_{\text{max}}} \right)^{0.1} \]

Where \( F_{\text{max}} \) is maximum flow rate at effect point (\( \alpha \)), \( F_{\text{max}} \) is maximum departure-flow rate, \( F_{ma} \) is equivalent departure-rate at time window size \( T \), \( V_{\beta} \) is velocity at effect point (\( \alpha \)), \( V_{\text{max}} \) is a maximum speed a vehicle can reach on an empty road and \( V_{ma} \) is average velocity at time window size \( T \).

In addition, velocity at effect point between 2 periods can be calculated as follows.

\[ V_{\beta} = \alpha V_{\text{max}} \quad \text{When} \quad 0 \leq \alpha \leq 1 \]  

Where \( \alpha \) is effect point, \( V_{\beta} \) is velocity at effect point, \( V_{\text{max}} \) is maximum velocity that vehicle can reach on a empty road.

A velocity that lower than effect point (\( V_{ma} < V_{\beta} \)), this means that equivalent queue length is longer than ability of departures-rate in 1 cycle length, and then equivalent queue is accumulated, thus, CCTV-flow rate can be calculated by using only CCTV-velocity as follows.

\[ F_{ma} = F_{\text{max}} \left( 1 - \frac{V_{ma}}{V_{\text{max}}} \right)^{0.1} \]  

Where \( F_{ma} \) is equivalent departure-flow rate at time window size \( T \), \( F_{\text{max}} \) is maximum departure-flow rate, \( V_{\text{max}} \) is maximum velocity that vehicle can reach on a empty road and \( V_{ma} \) is average velocity at time window size \( T \).

Finally, all equation in this paper, (1) to (13) can be rewrite into sequence of travel time estimation model which is shown below in figure 3

IV. TRAVEL TIME ESTIMATION MODEL WITH ADAPTATION FOR SHORT-HIGHWAY

Although, traditional travel time estimation model which was proposed by Arthit Buranasing and Akara Prayote had a good experiment result. Nevertheless, model could only predict travel time on un-congested condition, but could not predict travel time on congested condition. Therefore, the model must be moderately adapted by using characteristic of data input and road structure as follow.

A. Characteristic of CCTV’s Velocity

In this model, CCTV camera which was installed at the beginning of the road is cause of low-velocity from the detector whereas vehicle has just started accelerate from previous intersection to next link of the road and cannot reach the maximum speed at the short distance (distance between intersection and CCTV camera), despite of empty road or un-congested on traffic condition.

Fig. 3 Traditional Travel Times Estimation Model. [3]

Nevertheless, from the experiment by using observer method [6, 7], the velocity from the CCTV camera which was reduced will approximately be 2.0 to 3.0 time of maximum speed. Furthermore, low-velocity must multiply less than high-velocity, whereas low-velocity is possibility of congested condition and should not increase too much. As a result, velocity proportion can be calculated as follow:

\[ V_{\mu} = \varphi \frac{V_{ma}}{V_{\text{max}}} \]  

Where \( V_{\mu} \) is a velocity proportion of vehicles, \( \varphi \) is a constant of multiplier (2.5 was suitable value for the model and was used for the experiment testing), \( V_{ma} \) is an average velocity which is computed in time window size of \( T=15 \) minutes, \( V_{\text{max}} \) is a maximum speed that a vehicle can reach on an empty road.

As a consequence, the approximately average velocity that vehicle is able to run throughout the road can be form as follow.

\[ V_f = V_{\mu} \times V_{ma} \quad \text{When} \quad V_f \leq V_{\text{max}} \]  

Where \( V_f \) is an approximately average velocity that vehicle is able to run throughout the road, \( V_{\mu} \) is a velocity proportion of vehicles, \( V_{\text{max}} \) is a maximum speed that vehicle can reach on an empty road.

However, some minor velocity’s value might more than maximum speed that a vehicle can reach on an empty road, but we can eliminate as follow:

\[ V_f = V_{\text{max}} \quad \text{When} \quad V_f > V_{\text{max}} \]
Where $V_1$ is an approximately average velocity that vehicle is able to run throughout the road, $V_{max}$ is a maximum speed that vehicle can reach on an empty road.

B. Characteristic of CCTV’s Flow

Since a vehicle has just started accelerate from previous intersection to next link of the road and cannot reach the maximum speed at the short distance and cause of low-flow rate too. However, the model can handle this problem in the same way as velocity’s characteristic were adapted, thus, flow proportion can be calculated as follow

$$F_\mu = \varphi \sqrt{\frac{F_{max}}{F_{max}}}$$

(17)

Where $F_\mu$ is a flow proportion of vehicles, $\varphi$ is a constant of multiplier (2.5 was suitable value for the model and was used for the experiment testing), $F_{max}$ is equivalent departure-flow rate which is computed in time window size of $T=15$ minutes or 27 seconds on 0.5 km and 1.0 km road length.

As a consequence, the approximately average flow that vehicle will pass the detector can be form as follow.

$$F_f = F_\mu \times F_{max} \text{ When } F_f \leq F_{max}$$

(18)

Where $F_f$ is an approximately average flow that vehicle will pass the detector, $F_\mu$ is a flow proportion of vehicles, $F_{max}$ is maximum departure-flow rate.

Also, some minor flow’s value might more than maximum flow that vehicle will pass the detector, but we can eliminate as follow.

$$F_f = F_{max} \text{ When } F_f > F_{max}$$

(19)

Where $F_f$ is an approximately average flow that vehicle will pass the detector, $F_{max}$ is maximum departure-flow rate.

V. TRAVEL TIME ESTIMATION FOR SHORT-HIGHWAY MODEL AND THE PERFORMANCE

All equation in this paper, (1) to (19) can be rewrite into the sequence of travel time estimation model for short-highway which is shown below in figure 4.

The accuracy of travel time estimation model was evaluated in 2 parts, one is launch simulator by starts from empty road and release vehicles to the road and control arrival-flow rate more than departure-flow rate until road is full (road has a maximum congestion) within first 180 minutes, this part give an average error 0.19 minutes or 11.4 seconds and 0.45 minutes or 27 seconds on 0.5 km and 1.0 km road length respectively and the other 180 minutes part is vice versa which give an average error 0.25 minutes or 15 seconds and 0.35 minutes or 21 seconds. Both experiments parts on each road length, give an average error 13.2 seconds on 0.5 km road length and an average error 24 seconds on 1.0 km road length which are shown in table I and table II, graph in each experiment are shown below the table. (Average error of both 0.5 km and 1.0 km road length is 18.6 seconds)

Time’s scale on experiment graph is an only time when queue’s length is almost equal maximum road’s congestion (y-axis) and vice versa in 2nd experiment, most of them take time about 100-140 minutes (x-axis) to reach a maximum congestion and empty the road.

Note that an average error (E) in each experiment is value of different between real travel time (minutes) and travel time estimation model in each minutes (T), and in this simulator experiment is used about 180 minutes in each experiment testing (N), if value of an error is close to 0, it will have a high accuracy, whereas the travel time estimation model can predict close to the real travel time. An average error in each experiment testing can be calculated as follows.

$$E = \frac{\sum N |Real Travel Time_T - Travel Time Estimation_t|}{N}$$

![Fig 4. Travel Times Estimation for Short-highway Model.](image)

<p>| TABLE I. SUMMARY’S ERROR OF TRAVEL TIME PREDICTION ON 0.5 KM ROAD LENGTH |
|------------------------|-----------------|-----------------|-----------------|</p>
<table>
<thead>
<tr>
<th>CL</th>
<th>GTP 25%</th>
<th>50%</th>
<th>75%</th>
</tr>
</thead>
<tbody>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>1st</td>
<td>2nd</td>
<td>1st</td>
<td>2nd</td>
</tr>
<tr>
<td>60 (Second)</td>
<td>0.24</td>
<td>0.80</td>
<td>0.17</td>
</tr>
<tr>
<td>120 (Second)</td>
<td>0.25</td>
<td>0.09</td>
<td>0.18</td>
</tr>
<tr>
<td>240 (Second)</td>
<td>0.17</td>
<td>0.16</td>
<td>0.14</td>
</tr>
<tr>
<td>Average</td>
<td>All 1st average is 0.19</td>
<td>All 2nd average is 0.25</td>
<td></td>
</tr>
</tbody>
</table>
TABLE II. SUMMARY’S ERROR OF TRAVEL TIME PREDICTION ON 1.0 KM ROAD LENGTH

<table>
<thead>
<tr>
<th>CL</th>
<th>GTP</th>
<th>25% 1st</th>
<th>50% 1st</th>
<th>75% 1st</th>
<th>25% 2nd</th>
<th>50% 2nd</th>
<th>75% 2nd</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 (Sec)</td>
<td>25%</td>
<td>0.49</td>
<td>0.53</td>
<td>0.64</td>
<td>0.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>50%</td>
<td>0.51</td>
<td>0.36</td>
<td>0.21</td>
<td>0.26</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>75%</td>
<td>0.34</td>
<td>0.28</td>
<td>0.56</td>
<td>0.21</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>1st</td>
<td>0.45</td>
<td></td>
<td></td>
<td>0.35</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td></td>
<td></td>
<td></td>
<td>0.35</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

VI. CONCLUSION AND REMARK

This paper developed the model for travel time estimation for short-highway by using only flow rate and average velocity from a single camera which is installed at the beginning of the road as input without using traffic signal data or departure-rate in the pre-timed system. In this model experiment exclude exception-event such as accident, using siren of vehicle, human cross a road and etc, vehicles flows are run normally. The result of experiment is satisfy and gives average error or different only 18.6 seconds from real travel time. However, the model is not suitable for the long-highway or the road length is not over 1.0 km, whereas velocity which is derived from CCTV camera is not affected by the congestion in the end of the road until vehicles are accumulated to the effect point, which is the point that congestion affect to the CCTV’s velocity obviously and this point is the main idea of the model.

REFERENCES