Travel Time Estimation for Highway in Pre-Timed Systems

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Abstract—Only a single CCTV camera is installed in any position on a road. This causes difficulties to the automated estimation of travel time. 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 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; Highway; Traffic Signal

1. Introduction

Travel time is one of the most important measures for evaluating the performance of traffic network system and also important to traveler for decisions on travel choices and avoid unnecessary delay, however, the majority of works on travel time estimation are on freeway, where no traffic light is involved in the system. Highway, on the other hand, is more complicated as traffic light cycles play an important role and many factors are hidden in system and affect to travel time [1].

So far, works on highway travel time estimation have been conducted with different techniques and different constraints of input data. For example, Yeon and Ko [2] used queuing theory and shockwave analysis which were separately used to estimate travel time on a highway and compared with field-measured travel time which was collected from three CCTV cameras along the highway. The two techniques performed well on un-congested traffic condition, but not so good on congested traffic condition. Li [3] used kinematics wave theory combined with queuing theory to estimate travel time. In this work, flow rates (both arrival and departure) were controlled quite static and could not estimate on congested condition. Li and McDonald [4] used Speed-Time profiles of driving patterns to estimate travel time. This work suggested that traffic congestion significantly affected to the travel time, but traffic congestion must be separated into un-congested and congested condition to estimate travel time. Recently, Liu and Ma 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.) [5]

Hence, so far to the best of our knowledge, travel time estimation on highway requires at least two type of raw data, one is the data from CCTV camera and the other is traffic signal data or departure-flow rate, but in this paper, we attempt to estimate travel time on highway by using only flow rate and average velocity in each minute from a single camera which is installed in any position on road without using traffic signal data or departure-flow rate on the pre-timed system [6]. This paper is organized into the following sections: Section
II queue length estimation and simulation setting. Equivalent queue and travel time model in section III. CCTV-flow and departure-flow model in section IV. CCTV-flow and its position in section V. A CCTV-flow and CCTV-velocity model in section VI. A travel time estimation model and performance in section VII and a conclusion and remark is drawn in section VIII.

2. Queue Length Estimation and Simulation Setting

Travel time estimation model in this paper, we used equivalent queue length estimation model and used all simulation setting which were proposed by Buranasing and Prayote [7]. We will briefly introduce as follows.

2.1 Equivalent Queue Length Estimation Model

The equivalent queue length can be estimated in sequence as follows.

\[ V_{ma} = \sum_{i=1}^{T} \frac{V_{CCTV,i}}{T} \]  

(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.

\[ Q = C \sqrt{1 - \frac{V_{ma}}{V_{max}}} \]  

(2)

Where \( Q \) is an equivalent queue length, \( C \) is CCTV position, \( V_{max} \) 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 density by

\[ K = \frac{Q}{AVL} \]  

(3)

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

\[ AVL = \frac{\sum_{i=1}^{N} LVT_i + \sum_{i=1}^{N} MG_i}{N} \]  

(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.

However, \( K \) is set to 0, when no vehicle passes and \( V \) is zero [7]. In addition, maximum density on a road can be calculated as follows.

\[ K_{max} = \frac{RL}{AVL} \]  

(5)

Where \( K_{max} \) is maximum density, \( R \) is road length, \( L \) is number of lane.

2.2 Simulation Software and Setting for Experiment

We used Quadstone Paramics Simulation software [7] (figure 1) for experiment testing and used all simulation setting which was derived from Buranasing and Prayote. [8] (Quadstone Paramics Simulation Software which was also used in theirs proposes.) In theirs proposes, they defined as follows; a road length 1 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, 240 seconds and using green time per red time 20%, 40%, 60%, 80 % in each cycle length experiment. (For instance, green time 20% of 120 seconds cycle length, means green time 24 seconds and red time 96 seconds.) Yellow time was included in green time. In simulation, collection data was derived from a single CCTV camera which was installed at position 0.5 km. of the road (on the middle of the road) and detected flow rate and average velocity in each minute (figure 2) 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-rate until road was full (road had a maximum density) 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.

![Traffic Simulations on Quadstone Paramics.](image)

Figure 1. Traffic Simulations on Quadstone Paramics.

### 2010-07-21
09:09:02;1216606146;NCCTVDoor4;ToSukhumvit;39.33 km/h;20 cars/min
09:09:02;1216606146;NCCTVDoor4;ToRamaIV;76.22 km/h;7 cars/min
09:10:02;1216606206;NCCTVDoor4;ToSukhumvit;25.54 km/h;32 cars/min
09:10:02;1216606206;NCCTVDoor4;ToRamaIV;91.12 km/h;12 cars/min

![Sample’s data from CCTV camera.](image)

Figure 2. Sample’s data from CCTV camera.

### 3. Equivalent Queue and Travel Time Model

Although changing type of traffic light control, duration of traffic light cycle, even fluctuation of arrival-flow and etc. Those factors are effect to travel time. However, those factors are also effect to equivalent queue length, for instance, if arrival rate is stable, traffic control duration of red time longer than green time, thus vehicle will have high accumulated in the queue. On the contrary, if duration of green time longer than red time, thus vehicle will have low accumulated in queue and so forth. In addition, equivalent queue length is also effect to travel time, whereas in normally, if queue is long, travel time is high, but if queue is short, travel time is low.

Furthermore, in pre-timed system, departure-flow is fixed departure pattern by traffic light control. Thus, the last vehicle on road always has a maximum travel time whenever that road has a maximum density. As a consequence, travel time estimation can be calculated as follows.

\[
T = T_{\text{max}} \left( \frac{K}{K_{\text{max}}} \right)
\]

Where \( T \) is travel time, \( T_{\text{max}} \) is maximum travel time on road, \( K \) is density, \( K_{\text{max}} \) is maximum density

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

\[
T = \frac{R}{V_{\text{max}}}
\]

Where \( R \) is road length, \( V_{\text{max}} \) is a maximum speed a vehicle can reach on an empty road.
Using Pearson’s correlation coefficient for evaluated correlation and relationship between 2 parameters, equivalent queue and travel time. It gives a linear correlation with average value 0.82 in all experiment and each experiment value is shown in table I.

### TABLE I. SUMMARY’S PEARSON CORRELATION OF EQUIVALENT QUEUE AND TRAVEL TIME.

<table>
<thead>
<tr>
<th>GTP CL</th>
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<th>60%</th>
<th>80%</th>
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<tbody>
<tr>
<td>1st</td>
<td>2nd</td>
<td>1st</td>
<td>2nd</td>
<td>1st</td>
</tr>
<tr>
<td>60 (Second)</td>
<td>0.95</td>
<td>0.96</td>
<td>0.97</td>
<td>0.92</td>
</tr>
<tr>
<td>120 (Second)</td>
<td>0.96</td>
<td>0.93</td>
<td>0.93</td>
<td>0.90</td>
</tr>
<tr>
<td>240 (Second)</td>
<td>0.91</td>
<td>0.90</td>
<td>0.60</td>
<td>0.56</td>
</tr>
<tr>
<td>Average</td>
<td>All 1st average is 0.85</td>
<td>All 2nd average is 0.79</td>
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</tbody>
</table>

In the table, CL is cycle length and GTP is green time proportion. Note that 1st part is the experiment that starts from empty queue to queue is full in 180 minutes and 2nd part is the experiment that starts from queue is full to empty queue in 180 minutes.

### 4. CCTV-Flow and Departure-Flow Model

Amount of vehicle that pass CCTV Camera depends on arrival-flow rate, but amount of vehicle that departure from road is organized by traffic signal control. Hence, amount of vehicle between CCTV-flow and departure-flow in each minutes are much different, whereas in red time period, no vehicles departs, but vehicles can still passes CCTV camera in this period. Nevertheless, in this work, the traffic signal data or truly departure-flow doesn’t exist for the input data. Thus, some characteristics of freeway are applied in this work by using macroscopic property which is methods that measures larger scale than usual. Therefore, in this work we expended time window size at least 15 minutes. [9] (Time mean speed measurement was recommended by HCM 1985 that requires at least 15 minutes.) As a result, CCTV-flow and departure-flow can be formed as follows.

\[
F_{ma} = \frac{\sum_{i=1}^{T} F_{CCTV_i}}{T} = \frac{\sum_{i=1}^{T} F_{departure_i}}{T}
\]

(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 depart from a road in each minute.

Using Pearson’s correlation coefficient for evaluated correlation and relationship between 2 parameters, CCTV-flow and departure-flow, it gives a linear correlation with average value 0.96 in all experiment and each experiment is shown in table II. Thus, this means that CCTV-flow and departure-flow are nearly similar in time window size \( T \) (more than 15 minutes). Also, an average different value between them are nearly similar too, an average different in all experiment is 0.76 veh/min and each experiment value is shown in table III.

### TABLE II. SUMMARY’S PEARSON CORRELATION OF CCTV-FLOW AND DEPARTURE-FLOW

<table>
<thead>
<tr>
<th>GTP CL</th>
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</thead>
<tbody>
<tr>
<td>1st</td>
<td>2nd</td>
<td>1st</td>
<td>2nd</td>
<td>1st</td>
</tr>
<tr>
<td>60 (Second)</td>
<td>0.94</td>
<td>0.93</td>
<td>0.97</td>
<td>0.96</td>
</tr>
<tr>
<td>120 (Second)</td>
<td>0.95</td>
<td>0.95</td>
<td>0.96</td>
<td>0.97</td>
</tr>
<tr>
<td>240 (Second)</td>
<td>0.93</td>
<td>0.95</td>
<td>0.96</td>
<td>0.96</td>
</tr>
<tr>
<td>Average</td>
<td>All 1st average is 0.96</td>
<td>All 2nd average is 0.97</td>
<td></td>
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</tbody>
</table>

### TABLE III. SUMMARY’S ERROR OF CCTV-FLOW AND DEPARTURE-FLOW IN TIME WINDOW SIZE \( T=15 \) MINUTES

<table>
<thead>
<tr>
<th>GTP CL</th>
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<th>60%</th>
<th>80%</th>
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</thead>
<tbody>
<tr>
<td>1st</td>
<td>2nd</td>
<td>1st</td>
<td>2nd</td>
<td>1st</td>
</tr>
<tr>
<td>60</td>
<td>0.66</td>
<td>0.73</td>
<td>0.80</td>
<td>0.51</td>
</tr>
</tbody>
</table>
5. CCTV-Flow and Its Position

Whenever equivalent queue length is not longer than CCTV position, amount of vehicle that pass CCTV camera will depends on arrival-flow rate, but if equivalent queue length is longer than CCTV position, amount of vehicle that pass CCTV camera will depends on departure-flow rate ($F_{ma}$), whereas traffic light controller in pre-timed system has a fixed duration cycle length, so vehicle will departures from the road in some fixed pattern and we will always know this pattern whenever equivalent queue length is longer than CCTV camera in any position. In this period, we will also know maximum departures-flow rate ($F_{max}$), since vehicles that pass CCTV in this period will pass in as same pattern as departure-flow rate. Therefore, maximum travel time on any road in pre-timed system can be calculated as follows.

$$T_{max} = \frac{K_{max}}{F_{max}}$$  \hspace{1cm} (9)$$

where $T_{max}$ is maximum travel time, $K_{max}$ is maximum density on a road and $F_{max}$ is maximum departure-flow rate, which is stated in a following section.

6. CCTV-Flow and CCTV-Velocity Model

In simulation, data from CCTV camera has only two parameters for input in this work to develop a model, one is the CCTV-flow and the other is an average CCTV-velocity, these parameters were applied by using observer method [9], and were revealed that the maximum velocity’s vehicle ($V_{max}$) down to 90% of maximum velocity’s vehicle (In this paper called effect point ($\alpha$)) 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.

$$F_{ma} = F_{max} \left(1 - \frac{V_{ma} - V_\beta}{V_{max} - V_\beta}\right)^2$$  \hspace{1cm} (10)$$

And $F_{max}$ can be calculated by

$$F_{max} = F_{max} \left(1 - \frac{V_\beta}{V_{max}}\right)^{0.1}$$  \hspace{1cm} (11)$$

Where $F_{max}$ is maximum flow rate at effect point ($\alpha$), $F_{max}$ is maximum departure-flow rate, $F_{ma}$ is equivalent departure-rate at time window size $T$, $V_\beta$ is velocity at effect point ($\alpha$), $V_{max}$ 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.

$$V_\beta = \alpha V_{max} \text{ When } 0 \leq \alpha \leq 1$$  \hspace{1cm} (12)$$

Where $\alpha$ is effect point, $V_\beta$ is velocity at effect point, $V_{max}$ 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.

$$F_{ma} = F_{max} \left(1 - \frac{V_{ma}}{V_{max}}\right)^{0.1}$$  \hspace{1cm} (13)$$

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

![Table](https://via.placeholder.com/150)

<table>
<thead>
<tr>
<th>(Second)</th>
<th>120</th>
<th>0.74</th>
<th>0.77</th>
<th>1.09</th>
<th>0.81</th>
<th>1.08</th>
<th>0.65</th>
<th>0.63</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Second)</td>
<td>240</td>
<td>0.84</td>
<td>0.94</td>
<td>1.01</td>
<td>0.90</td>
<td>1.48</td>
<td>1.05</td>
<td>1.03</td>
</tr>
<tr>
<td>Average</td>
<td>All 1st average is 0.79</td>
<td>All 2nd is average 0.74</td>
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</tbody>
</table>
From the experiment, by take CCTV-velocity at time window size $T=15\ (V_{ma})$, applied into equation above for estimation CCTV-flow ($F_{ma}$) and compare with real CCTV-flow, the result is shown in table IV by give an average error 3.27 veh/min in all experiment. ($F_{max}$ in each experiment is fixed in some suitable value by using observer method.)

### TABLE IV. SUMMARY’S ERROR OF CCTV-FLOW PREDICTION

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<thead>
<tr>
<th>GTP CL</th>
<th>20%</th>
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<th>1st</th>
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<th>2nd</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 (Second)</td>
<td>0.99</td>
<td>0.67</td>
<td>2.86</td>
<td>2.28</td>
<td>4.46</td>
<td>5.59</td>
<td>10.17</td>
<td>5.16</td>
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</tr>
<tr>
<td>120 (Second)</td>
<td>1.32</td>
<td>0.40</td>
<td>2.37</td>
<td>1.83</td>
<td>3.88</td>
<td>4.91</td>
<td>5.52</td>
<td>9.83</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>240 (Second)</td>
<td>1.04</td>
<td>1.56</td>
<td>2.44</td>
<td>1.88</td>
<td>2.30</td>
<td>1.42</td>
<td>3.05</td>
<td>2.64</td>
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<tr>
<td>Average</td>
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</table>

#### 7. Travel Time Estimation Model and Performance

All equation in this paper, (1) to (13) can be rewrite into sequence which is shown below in figure 3.

Accuracy of travel time estimation model is also 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-rate until road is full (road has a maximum density) within first 180 minutes, this part give an average error 0.47 minutes or 28.2 seconds and the other 180 minutes part is vice versa which give an average error 0.41 minutes or 24.6 seconds. Both experiments parts give an average error 0.44 minutes or 26.4 seconds which is shown in table V and graph in each experiment is shown below the table. (Time’s scale on experiment graph is an only time when queue’s length is equal CCTV position and vice versa in 2nd experiment, most of them take time about 100 minutes to reach a long queue.)

Note that an average error (E) in each experiment is value of different between real travel time and travel time estimation model in each minutes, and in this simulator experiment is used about 100 minutes in each
experiment testing (N) to reach a long queue, 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.

\[ E = \sum_{T=1}^{N} (\text{Real Travel Time}_T - \text{Travel Time Estimation}_T) \]

### TABLE V. SUMMARY’S ERROR OF TRAVEL TIME PREDICTION

<table>
<thead>
<tr>
<th>CL (Second)</th>
<th>GTP</th>
<th>20%</th>
<th>40%</th>
<th>60%</th>
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<tr>
<td></td>
<td></td>
<td>0.81</td>
<td>0.56</td>
<td>0.43</td>
<td>0.35</td>
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<td>120</td>
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<td></td>
<td>0.95</td>
<td>0.59</td>
<td>0.42</td>
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<td>240</td>
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<tr>
<td></td>
<td></td>
<td>0.88</td>
<td>0.65</td>
<td>0.21</td>
<td>0.31</td>
</tr>
<tr>
<td>Average</td>
<td>All 1st average is 0.47</td>
<td>All 2nd average is 0.41</td>
<td></td>
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</tbody>
</table>

8. Conclusion and Remark

This paper studies the effect of primary factors to travel times and is used to develop the model for travel time by using only flow rate and average velocity from a single camera which is installed in any position on road as input without using traffic signal data on 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 26.4 seconds from real travel time. However, the model cannot be estimated in case queue length is longer than CCTV position, but if there are some methods that can handle with a long queue, those methods can apply with this travel time estimation model by replace in queue length estimation method (K) which is stated in Section II.

Figure 4. Graph of travel time prediction compare with real travel time (All of 1st experiment).
9. References


