A New Measure of Travel Time Reliability

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Abstract: In this paper, standard score of travel time is proposed as a new measure of travel time reliability. ETC (Electronic Toll Collection) data is firstly used to estimate and clarify the micro relationship between travel time variance and accident/incident happenings on some popular routes on the Metropolitan Expressway Co., Ltd. at Tokyo. We find that although the common travel time reliability measures such as 95percentile travel times are more sensitive to the happenings of accidents, if compared with average travel times, the difference is not that significant. On the other hand, the standard scores of travel times have a potential of being adopted as a new measure of travel time reliability since it can better distinguishes the different travel time distributions of cases with and without accidents.

Key Words: travel time reliability, ETC data, urban expressway

1. INTRODUCTION

In this paper, we try to propose a new measure of travel time reliability, travel time standard score (TTSS), by utilizing data from Electronic Toll Collection (ETC) system.

Travel time reliability is defined as “a consistency or dependability in travel times, as measured from day to day or across different times of day” (Federal Highway Administration (FHWA), 2006). It is said to be a good measure of service of expressway networks because it focuses more on unexpected delay caused by accidents or other kinds of unexpected incidents (Chen C., et al., 2003; Maruyama et al, 2007; Mehran, 2009).

The main purpose of travelers is to be sure to arrive at their destinations on time. Therefore, compared with average travel time, travel reliability often becomes a more important concern of drivers. On the other hand, for the managing authorities of expressway road networks, the travel time reliabilities of their network reflect their ability of incident management and can give a different perspective in the evaluations of various improving works such as ITS solutions.

Travel time reliability is important and often come out with the mention of accidents. However, the explicit relationship between travel time reliability and accident happening is still absent from our literature review so far.
After the adoption of ETC system in 2001, usage of ETC is becoming more and more common among the MEX drivers. Currently more than 80% of MEX’s 1.16 million daily drivers are using ETC to pay their toll (MEX, 2008). Similar systems are rapidly widespread in the developing world as well, e.g. Taiwan, Malaysia and China. The entering and exiting records of the ETC using drivers consist of an important data sources for various researches, if with careful considerations of privacy protection.

In fact, vehicle detector data can also be used to estimate common travel time reliability measures (Maruyama et al, 2007; Mehran, 2009). However, vehicle detectors are usually poorly installed in developing countries. With even poorer maintenance, the data can hardly be used in travel time related estimations (Wang and Nakamura, 2003). Therefore the much more reliable (it must be) ETC data should have an important potentials in travel time related researches in developing countries (Wang et al, 2009).

In this research, at first ETC data from the MEX network are used to estimate some common day to day travel time reliability measures of a part of Route No.4, a major route of MEX which linking a major intercity expressway from west part of Japan to the downtown Tokyo. Then the statistic relationship between travel time reliability and accident happening is stated and the standard scores of peak hour travel times are estimated and compared. Our research is intended to describe and justify the usage of travel time reliability as a Level of Service (LOS) measure of expressway accident control.

2. STUDY ROUTE AND PERIOD

A route connecting Chuo Expressway Tokyo Exit and Gaien is selected for the research. This is a major route used by drivers from west part of Japan to enter the downtown Tokyo, as shown in Figure 1. The total length of the route is 10.27 km. This route consists of 17 sections of lengths from 210m to 1030, with an average value of 604.1m.

A one-month data set of July 2006 is chosen as the research period. In addition to ETC data, we have also data of double type vehicle detectors, and accident happening and endurance time data (5-min time step), for all of the 17 sections.

This route is selected because there are relatively more accidents happening on it with a sudden curb near the end of it. Also the traffic volume of this route is high, thus enable enough data for our research.
3. TRAVEL TIME AND TRAVEL TIME RELIABILITY MEASURES

(1) Travel Time Measures
Travel time measures include: median travel times ($mTT$) and average travel times ($aTT$).

\[ aTT = \frac{\sum_{i=1}^{N} TT_i}{N} \]  

(2) Travel Time Reliability Measures
A wide range of travel time reliability measures have been recommended by earlier researchers (Chen C., et al.; FHWA, 2006; Mehran, 2009). The following measures are used in this paper: 95th percentile travel times ($95per\ TT$), buffer time ($BT$), and average travel time deviations ($aTTD$).

- 95th percentile travel time ($95per\ TT$)
  The simplest method to measure travel time reliability by estimating the worst delays happened during the research period.

- Buffer Time ($BT$)
  Extra time that travelers have to add to the average travel times to guarantee on-time arrival 95 percent of the time,

\[ BT = 95per\ TT - aTT \]  

- Average travel time deviations ($aTTD$)
  This is a measure to show the variation of travel times, the smaller the higher travel time reliability,

\[ aTTD = \frac{\sum_{i=1}^{N} |TT_i - aTT|}{N} \]  

where $TT_i$ is the travel time of the $i^{th}$ vehicle, and $N$ is the total number of cars within the time period.

(3) Travel Time Standard Score ($TTSS_i$) of the $i^{th}$ vehicle
In this paper we propose to use Travel Time Standard Score as a measure of travel time reliability. Different from average travel times, we want to know more information about the more extreme situations, such as accident happenings and TTSS is simply a convenient measure in this case because by it we can easily find what a percentage of travelers experienced some unusual (with higher standard deviations) travel times.

Just like to compare the performance of two mathematic classes in a high school, sometimes we have more interest on the information of how many “excellent” students with outstanding standard scores in each class.

\[ TTSS_i = \frac{TT_i - aTT}{aTTD} \cdot 10 + 50 \]  

And we propose to use the percentage of TTSS above 60 as a measure of travel times in our following research.

4. MEASURE OF ACCIDENT HAPPENINGS – NAP
In this paper, we use number of accident affected time periods (NAP) as a measure of accident happenings on the research route. NAP equals the total number of 5-min time steps affected by accident aroused congestions during the research period. It represents both the frequency of accidents and their seriousness and impact ranges, thus a suitable measure. NAP is between 0 and the maximum value $60 \times 17 = 1020$ when all the 17 sections are affected by accidents through all the 60 times steps of 5 minutes within a morning peak of 5 hours.

$$NAP = \sum_{j=1}^{M} \text{Number of Affected Time Steps of Section } j$$  \hspace{1cm} (4)

where $M$ is the total number of sections on the research route, which equals to 17 for the research route of this paper.

5. ESTIMATION RESULTS AND THE ANALYSIS

Here the daily average travel times and travel time reliability measures of the study route are estimated for all the workdays within the one month study period of July, 2006, before the analysis of the relationship between travel time reliability and accident happenings. The data of July 13, 2006 is excluded because we can access data from only several evening hours during that day.

(1) Estimation results – the common measure of travel time and travel time reliability

From the following table, we can see the daily average travel times and travel time reliability measures of the morning peak hours (6:00 ~ 11:00) through the workdays of July, 2006.

Table 1: Estimation Results – Chuo Expressway to Gaien Exit, MEX (July, 2006)

<table>
<thead>
<tr>
<th>Date</th>
<th>aTT</th>
<th>mTT</th>
<th>95per TT</th>
<th>BT</th>
<th>aTTD</th>
<th>NAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jul. 3(Mon.)</td>
<td>9.3</td>
<td>7.5</td>
<td>12.8</td>
<td>3.5</td>
<td>3.0</td>
<td>0</td>
</tr>
<tr>
<td>Jul. 4(Tue)</td>
<td>16.4</td>
<td>15.1</td>
<td>28.7</td>
<td>12.3</td>
<td>5.6</td>
<td>95</td>
</tr>
<tr>
<td>Jul. 5(Wed)</td>
<td>8.2</td>
<td>7.4</td>
<td>9.2</td>
<td>1.0</td>
<td>1.7</td>
<td>0</td>
</tr>
<tr>
<td>Jul. 6(Thu)</td>
<td>14.1</td>
<td>14.1</td>
<td>18.8</td>
<td>4.7</td>
<td>3.6</td>
<td>0</td>
</tr>
<tr>
<td>Jul. 7(Fri)</td>
<td>15.9</td>
<td>15.9</td>
<td>26.6</td>
<td>10.8</td>
<td>5.0</td>
<td>62</td>
</tr>
<tr>
<td>Jul. 10(Mon)</td>
<td>10.6</td>
<td>9.1</td>
<td>14.4</td>
<td>3.8</td>
<td>3.2</td>
<td>0</td>
</tr>
<tr>
<td>Jul. 11(Tue)</td>
<td>17.2</td>
<td>17.6</td>
<td>25.6</td>
<td>8.4</td>
<td>5.6</td>
<td>0</td>
</tr>
<tr>
<td>Jul. 12(Wed)</td>
<td>18.8</td>
<td>19.2</td>
<td>36.4</td>
<td>17.6</td>
<td>6.4</td>
<td>0</td>
</tr>
<tr>
<td>Jul. 14(Fri)</td>
<td>20.0</td>
<td>21.2</td>
<td>28.0</td>
<td>8.1</td>
<td>5.1</td>
<td>17</td>
</tr>
<tr>
<td>Jul. 18(Tue)</td>
<td>16.8</td>
<td>15.8</td>
<td>27.4</td>
<td>10.6</td>
<td>2.8</td>
<td>85</td>
</tr>
<tr>
<td>Jul. 19(Wed)</td>
<td>15.3</td>
<td>15.3</td>
<td>20.9</td>
<td>5.6</td>
<td>3.5</td>
<td>0</td>
</tr>
<tr>
<td>Jul. 20(Thu)</td>
<td>15.4</td>
<td>14.2</td>
<td>31.7</td>
<td>16.3</td>
<td>5.5</td>
<td>117</td>
</tr>
<tr>
<td>Jul. 21(Fri)</td>
<td>16.0</td>
<td>16.4</td>
<td>20.3</td>
<td>4.4</td>
<td>3.5</td>
<td>0</td>
</tr>
<tr>
<td>Jul. 24(Mon)</td>
<td>16.2</td>
<td>14.4</td>
<td>39.1</td>
<td>22.9</td>
<td>5.5</td>
<td>36</td>
</tr>
<tr>
<td>Jul. 25(Tue)</td>
<td>13.6</td>
<td>14.0</td>
<td>18.0</td>
<td>4.3</td>
<td>3.6</td>
<td>0</td>
</tr>
<tr>
<td>Jul. 26(Wed)</td>
<td>19.4</td>
<td>18.9</td>
<td>32.4</td>
<td>13.0</td>
<td>6.1</td>
<td>0</td>
</tr>
<tr>
<td>Jul. 27(Thu)</td>
<td>18.7</td>
<td>18.2</td>
<td>29.7</td>
<td>11.0</td>
<td>5.5</td>
<td>0</td>
</tr>
<tr>
<td>Jul. 28(Fri)</td>
<td>19.0</td>
<td>17.9</td>
<td>33.3</td>
<td>14.3</td>
<td>5.5</td>
<td>0</td>
</tr>
<tr>
<td>Jul. 31(Mon)</td>
<td>15.7</td>
<td>16.3</td>
<td>21.1</td>
<td>5.5</td>
<td>3.3</td>
<td>0</td>
</tr>
<tr>
<td>Average</td>
<td>15.6</td>
<td>15.2</td>
<td>25.0</td>
<td>9.4</td>
<td>4.4</td>
<td>21.7</td>
</tr>
</tbody>
</table>

Correlation with NAP 0.114 0.018 0.355 0.441 0.198
Comparison of Correlations with NAP

Figure 2: Comparison of Correlations with NAP

Figure 3: Comparison of Correlations with NAP

(2) Estimation results – the travel time standard scores ($TTSS$)
By Equation (4), the $TTSS$ of all single ETC travel times are calculated. In Figure 3, we summarize the distribution of percentages of travel times above groups of $TTSS$ scores. Our results show that for days with accidents, the distribution of $TTSS$ is wider, with more extreme values. And significant differences can be found at the $TTSS$ of 60, between days with accidents and days without.

In Table 2, the percentages of each day, with accidents or without, are listed. The average score of days with accidents is 19.3% and for days without accidents 14.9%. Theoretically, for
Table 2 Summary of Percentages of TTSS above 60, day by day morning peaks

<table>
<thead>
<tr>
<th></th>
<th>Percentage of TTSS above 60</th>
<th>Deviations</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Acc.</td>
<td>19.3 3.2 12.0 17.9 19.9 10.0 10.7 7.8 11.0 17.6 24.2 18.7 19.0</td>
<td>5.9 14.7</td>
<td></td>
</tr>
<tr>
<td>With Acc.</td>
<td>21.6 15.5 16.5 22.9 16.5 22.8</td>
<td>3.3 19.3</td>
<td>18.9</td>
</tr>
</tbody>
</table>

a pure normal distribution, the percentage above TTSS 60 should be 15.9%. We can find the days with accidents show very clear and significant difference in this measure.

(3) Analysis of the relationship between travel time reliability measures and accident happenings
As shown in both Table 1 and Figure 2, obviously the measures of travel time reliability show much more significant correlations with \( NAP \), a measure of accident happenings used in this paper. Earlier authors (FHWA, 2006; Maruyama, T., et al., 2007; Mehran, 2009) all mentioned the practical fact that unlike average travel times, travel time reliabilities more dependent on the control of non-recurrent congestions, often caused by accidents and other incidents.

- Recurrent Congestions (by over demand) \( \rightarrow \) average travel time
- Non-recurrent Congestions (by accidents, etc.) \( \rightarrow \) travel time reliability

Our results give out a simple but explicit explanation of the above fact. All of the 3 travel time reliability measures, 95per TT, BT, and aTTD show much higher correlations with \( NAP \), if compared with aTT and mTT. Especially for the measure of BT, where the average travel time aTT is subtracted, the highest correlation with the accident happenings is found.

Furthermore, our research shows that we can use a new measure, percentage of TTSS above 60, as a new measure of travel time reliability. This measure can give out an explicit measure of the higher travel time deviations due to the non-recurrent congestions, and can be easily compared and understood.

6. CONCLUDING REMARKS
In the earlier works and the practical world as well, travel time reliability measures are widely used to show the effects of accident controls without explicit explanations. In this paper, ETC data are used to analyze the relationship between travel time reliability and accident happenings. We find that compared with average travel times, travel time reliability measures show much higher correlations with accident happenings, thus justify the usage of travel time reliability as an LOS measure of road network. Also we discuss and prove the possibility of using travel time standard score (TTSS) as a new measure of travel time reliability in this paper.

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