EXAMINING TRAVEL TIME RELIABILITY ON HAN-SHIN EXPRESSWAY NETWORK

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Abstract: Increased economic activities and improvements in quality of life have resulted in a corresponding increase in human and material traffic across existing transport networks. Hence, there is a need for examining the reliability of these networks. The main objective of this study is to examine travel time reliability of various sections in the Han-Shin expressway network Osaka and Kobe area. Performed travel time reliability evaluation of each route considered in this study. To do this, various existing travel time reliability indices are considered and are examined. The advantage of travel time reliability is that, it can be used in policy assessment as a new evaluation technique and also may be used as travel time related information to the system users. Further in this study, conventional congestion measures presently using a measuring performance of Han-shin expressway network are compared with travel time reliability measures. Results reveal that reliability measures are more capable of measuring the variability in congestion level.

Key Words: Travel Time Reliability, Urban Expressway, Travel Time Distribution

1. INTRODUCTION

Increased economic activities and improvements in quality of life have resulted in a corresponding increase in human and material traffic across existing transport networks. Hence, there is a need for examining the reliability of these networks. The term reliability is defined in system engineering as probability of a device performing its purpose adequately for the period of time intended under the operating conditions encountered. (Billinton and Ronald 1992). In road network reliability it is defined as the network which can guarantee an acceptable level of service for road traffic even if the function of some links are physically
damaged or large amount of travel demand is occasionally generated (Asakura and Kashiwadani, 1991). Since 1991, travel time reliability has attracted many researchers in the area of transport network reliability because of its importance as compared with other network reliability measures such as connectivity reliability, capacity reliability etc.

Travel Time Reliability can be mainly defined in two ways based on literature available. Initially, Asakura and Kashiwadani (1991) defined travel time reliability as probability that a trip between a given Origin to Destination pair can be made successfully within a given time interval and a specified level of service. Main performance indicators considered were specified travel time and specified network service. Since then various mathematical models have been developed to measure the travel time reliability of the transportation system. All these models are robust and having systematic procedure to perform the travel time reliability. Recently, Federal Highway Administration (FHWA) defined travel time reliability as consistency or dependability in travel time, as measured from day to day and or across different times of the day (FHWA Report 2006, Margiotta 2002). Travel Time distribution is the base for development of various performance indicators belong this category. This approach is relatively simple and useful to both transport users as well as professionals. The advantage of travel time reliability is that, it can be used in policy assessment as a new evaluation technique and also may be used as new travel time related information to the users (Asakura Y 2006).

The main objective of this study is to examine travel time reliability of various sections in the Han-shin expressway network in Japan. Also quantitative performance evaluation of each section considered in this study and performance among them are examined. For performing this, empirical travel time reliability analytical approach is considered. The motivation for considering this approach is that relatively new and easily understood by the non-technical community. Further in this study, the relationship between the conventional congestion measures presently used for measuring performance of sections in the Han-shin expressway is investigated with reliability measures. Results reveal that reliability measures are capable of measuring the variability in congestion level.

2. REVIEW ON TRAVEL TIME RELIABILITY AND APPLICATIONS

Since 1991, various researchers are constantly contributing their great innovative ideas to measure the travel time reliability. Based on existing literature, travel time reliability measurements can be classified into empirical/practical based measurements and mathematical/theoretical based measurements. Empirical based measurements are mainly framed from travel time distribution. All these measurements are useful to both transport system planer as well as user. The added advantage is that these measures are easily understood by the non technical users. ( FHWA Report 2006, Lomax T et.al 2003 and Margiotta 2002). Mathematical based measurements are robust and having systematic approach, conventional User Equilibrium (UE) principle is the base for all the models developed under this category. ( Bell ,1999, Chen et. al 2003, Lee S et al 2000, Chan and Lam WHK 2005). All the existing studies on travel time reliability can be differentiated based on above classification and presented at Figure 1. This study attempts to discuss empirical based travel time reliability measurements. Subsequent paragraphs discuss some of the performance indicators belong to this category.
Federal Highway Administration (FHWA), US Department of transportation in association with Texas Transportation Institute and Cambridge System Inc has been studied on Travel time reliability measurements and they have recommended the following measurements to quantify the travel time reliability (FHWA Report 2006 and 2004)

(i) Statistical range measures: These measures are often recognized as theorized measures. In these measures standard deviation (the amount of variation) statistical parameter can be used to present an estimate of range. Travel time window and percent variation method comes under this category. Travel time window, can be expressed as the standard deviation of travel time can be combined with average travel time.

\[
\text{Travel Time Window} = \text{Average Travel Time} \pm \text{Standard Deviation}
\]

Percent of variation, is the ratio of standard deviation to the average travel time. This is a form of the statistical measure of coefficient variation.

\[
\text{Percent Variation} = \frac{\text{Standard deviation}}{\text{Average travel time}} \times 100\%
\]

(ii) 95th or other Percentile Travel Time: Simplest measure of travel time reliability is 95th or other percentile travel times for specific travel routes or trips, which indicates how bad delay will be on the heaviest travel days. 95th % travel time indicates that 19 out of 20 working days travel is in time to work. This measure is ideally suited for traveler information.

(iii) Buffer Index: It represents the extra time (buffer) to ensure on-time arrival for most trips. This extra time is added to account for any unexpected delay. The buffer index is expressed as a percentage.

\[
\text{Buffer Index (BI)}(\%) = \frac{95\text{th percentile travel time} - \text{Average travel time}}{\text{Average travel time}}
\]

(iv) Planning Time Index (PTI): This index represents how much total time a travel should allow ensuring on time arrival. While the BI shows additional travel time that is necessary,
the planning time index shows the total travel time that is necessary (Figure 2). PTI differs from the BI as it includes typical delay as well as unexpected delay.

\[
\text{Planning Time Index (PTI)} = \frac{\text{95th percentile travel time}}{\text{Free - flow travel time}}
\]

Statistical range measures are difficult to communicate users. On the other hand, 95th% travel time, Buffer Index (BI) and Planning Time Index (PTI) are comparatively useful to communicate users. Out of BI and PTI, PTI is especially more useful in view of comparing travel time index (ratio of average travel time to free flow travel time, utilizing for measuring of average congestion) on similar scales. (FHWA Report 2006, Mark Hallenbeck, 2006)

![Figure 2 Ideal travel time distribution and reliability measures](image)

Primarily these measures are implemented to various road networks in US. In particular FHWA has conducted National Traffic Monitoring Programme. Under this programme FHWA tracks reliability measures such as BI and PTI in more than 30 cities and this information communicates to key decision makers as a monthly dashboard report. In another study they measured travel time reliability in freight significant corridors. This BI is further used by commercial vehicle operators to estimate buffer time to ensure 95% confidence that driver would arrive on time. Similarly, Washington State Department of Transportation (WSDOT) conducted study on Travel Information and Performance Measures. For this study WSDOT used archived freeway operational data to develop reliability measures in terms of 95% of travel time. This is communicated to Puget Sound area. Also they are maintaining a web page, from this web page commuter can get the reliability information such as 95% travel time for selected route and respective direction.

Van Lint et. al (2004) studied travel time reliability on freeways for Netherlands road network. They suggested reliability measure such as skewness of the distribution and relative width of travel time distribution based on 10th, 50th and 90th % of travel time distribution. Further they conclude that median and percentile values are more robust statistics than mean and variance for quantifying the travel time reliability.
3. DATA COLLECTION AND TRAVEL TIME ESTIMATION

Data used in this study were collected from four selected routes in Han-Shin Expressway road network. Han-Shin expressway extends 233.8 Km in the Osaka and Kobe area of Japan and about one million vehicles travel the expressway every day. The physical characteristics of selected sections are discussed at Table 1.

<table>
<thead>
<tr>
<th>Route Number</th>
<th>Name</th>
<th>Route Details</th>
<th>Length(km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Ikeda Line, North Bound</td>
<td>Toyonaka kita to Merging point of circular line</td>
<td>12.0</td>
</tr>
<tr>
<td>12</td>
<td>Moriguchi Line, North Bound</td>
<td>Moriguchi to Merging point of circular line</td>
<td>10.8</td>
</tr>
<tr>
<td>13</td>
<td>Higashiosaka Line, North Bound</td>
<td>Mizubashiri to Merging point of circular line</td>
<td>11.1</td>
</tr>
<tr>
<td>15</td>
<td>Sakai Line, North Bound</td>
<td>Saki to Merging point of circular line</td>
<td>11.7</td>
</tr>
</tbody>
</table>

Continuous operational data of entire year (from 1st April 2005 to 31st March 2006) were used in this study for calculating the travel time. Travel time on each link was estimated by using time slice method for all days in the selected year. Yoshimura and Suga (2004) conducted study on validation of travel time information on the Han-Shin Expressway. In that study they made correlation analysis between travel times of Automatic Vehicle Identified (AVI) data and time slice method. They found that time slice method follows travel time fluctuation without delay. The following features were considered during estimation of travel time.

- Link travel time for every 5 minutes was calculated using the spot speed observed by traffic detector located at every 500 meters on each section.
- The minimum speed, 3km/h, assumed for route travel time calculation, as the same criteria used for the traffic control system of Han-Shin Expressway network.
- If spot speed data were not available due to technical failure of the traffic detector, the value of the previous time interval was considered.
- Route travel time was estimated by using time slice method (Yoshimura and Suga 2004) and for one hour period these travel times were averaged.

Peak hour travel time in the morning and evening were plotted for the above routes throughout the year to know the behavior of travel time during these peak hours. This was presented at Figure 3 and the following observations were identified.

- Travel time in morning peak is stable for Ikeda line (Route No.11). It becomes unstable during afternoon peak.
- Moriguchi line (Route No.12) shows higher fluctuation in morning peak than Ikeda line.
- Higashiosaka line and Sakai line shows higher travel times during morning peak.
- Seasonal fluctuation of travel times particularly observed in the afternoon peak period. Travel times were increasing from month of July to December, after that slightly decreasing in the month of January. Further travel time is increasing in the coming fiscal year.
A) Route No.11 Ikeda Line (morning peak 8:00-9:00 a.m., evening peak 17:00-18:00)

B) Route No.12 Moriguchi Line (morning peak 10:00-11:00 a.m., evening peak 14:00-15:00)

C) Route No.13 Higashiosaka Line (morning peak 10:00-11:00 a.m., evening peak 17:00-18:00)

D) Route No.15 Sakai Line (morning peak 8:00-9:00 a.m., evening peak 17:00-18:00)

Figure 3 Peak hour travel time pattern on various routes in Han-shin expressway

4. EVALUATION OF TRAVEL TIME RELIABILITY MEASUREMENTS

In this section detailed travel time reliability analysis was carried in detail for routes considered in Han-Shin expressway network. Initially, various relative travel time statistical parameters were calculated. After that a detailed comparative evaluation among selected routes was done by using the suggested travel time reliability measure and finally this study area is compared with US Seattle study area through common performance indicators. All these are explained in detail in the following subsequent sections.
4.1 Calculation of Travel Time Statistics
Travel Time statistical parameters such as minimum, maximum, mean, and median travel times for each route are plotted (Figure 4). All this statistical information needful to know about variability in travel time and also further will be required to calculate various travel time reliability indices which are estimated in the subsequent section. The observations from these parameters are briefly discussed as follows.

- The average minimum travel time in Ikeda line (Route No.11) is about 8.2 min, in remaining routes this is about 7.3 min. This means that the free flow travel time in all the routes is approximately same.
- Two clear peaks of travel time (morning peak and evening peak) were observed in Ikeda line and Sakai line (Route No. 15). In both the routes afternoon peak hour travel time is more than the morning peak hour travel time. Where as in Moriguchi (Route No.12) and Higashiosaka line (Route No.13) only one peak (morning peak hour) of travel time is clearly observed. And also these peak hour travel times are higher than the previous two routes.
- The relative difference between morning peak to evening peak is about 35min in Ikeda line. This value is almost 4 times higher than the relative peak hour travel time difference of Sakai line.
- The gradients to reach morning peak in Ikeda line and Sakai line is looking similar pattern. Similarly gradients to reach morning peak in Moriguchi line and Higashi Osaka line following similar pattern.
- Median travel time profile follows the mean travel time profile in all the routes.
- Average travel time profile follows the same trend of maximum profile but the profiles are smoother than maximum profile. In Moriguchi line occurrence of peak hour average travel time is shifted one hour earlier as compared to occurrence of peak hour maximum travel time.
- The relative difference between average peak hour travel time in Ikeda line is substantially less, is 5 min. Where as this difference in maximum profile is about 35min. This indicates that average travel time fails to explain most travels experience during the bad days they suffered with the unexpected delay. Therefore there is a need to investigate the travel time reliability measurements.

Statistic Range measures: Average travel time and standard deviation (the amount of variation) helpful to estimate statistical range measures such as travel time window and percent of variation explained at eqn.1 and 2. Figure 5 explains relational parameters Standard Deviation (SD) and Coefficient of Variation (CV) of travel time for each section. The following observations were identified

- Ikeda line having smaller SD value during morning peak and observed higher value during evening peak period than the all other routes.
- CV becomes larger after morning peak and before evening peak in all the corridors. Ikeda line become lower CV variation during morning and evening peak hours(0.23-0.29) than the other corridors( value varies approximately 0.4 to 0.5)
- SD and CV is useful parameters than the average travel time, but difficult to communicate to users. These parameters are helpful to the planers in internal analysis.
4.2 Comparative Evaluation of Travel Time Reliability Measure

In this section, performance of selected routes are compared by considering the suggested travel time reliability measures such as 95th percentile travel time and Buffer Time Index. The method for calculation of these indices is explained in section 2.

i) 95th % Travel Time:  The 95th % travel time reliability for all the routes are presented in Figure
6. From this it can be identified that 95th % travel time of Moriguchi line and Higashiosaka line shows higher travel time values than Ikeda line and Sakai line during morning peak hours. During evening peak hour Ikeda line having higher value of 95th % travel time reliability. This indicates that in the morning hours Ikeda line and Sakai line is more reliable than the other routes. In the evening peak hour, Ikeda line is most unreliable than the other routes. The occurrence of peak hour time is same as compared to maximum profile, but in the case of Moriguchi line the peak hour time is shifted to next hour. The 95th percentile travel time depends on the length of the route. Further the mean 95th percentile travel time of each route was estimated by considering the length of the route. Results are also emphasized that the mean 95th % travel per km for of Moriguchi line(40/10.8=3.70) and Higashiosaka line(37/11.1=3.33) shows higher values than Ikeda line(35/12=2.90) and Sakai line(33/11.7=2.82).

![Figure 6 95th percentile travel time comparison among various routes](image)

**iii) Buffer time and Buffer Index:** Buffer time and buffer time index was calculated for each section this is explained at Figure 9. BTI values become relatively smaller during the peak hours for all four routes. Particularly in Ikeda line this difference is substantial. BT and BTI are having some similarities in profile shape with SD and CV. Among the four routes Ikeda line having low buffer time is about 8min, this is almost half of the buffer time of the remaining routes during the morning peak hour. Even though for higher values of average travel time observed in Ikeda line, this route becomes more reliable than the other three routes during this period. When considers BTI during morning time Sakai Line and evening time Higashiosaka line having higher Buffer index values.

![Figure 7 Comparison of buffer time and buffer time index among various routes](image)
All these reliability measure including average travel time of each section imposed on travel time distribution, this was presented at Figure 10. From observing the travel time distribution, it can be identified that Ikeda line having less width in travel time distribution and also this was not skewed from mean. This indicates that this route is more reliable than the other routes if it is evaluated by the fluctuation around the average value. Even though the higher mean travel time in Ikeda line needs less Buffer time. There is similar pattern distribution in Moriguchi line and Higashiosaka line. But the Sakai line distribution completely different shape than the other three routes and also the buffer time and the average travel is almost same in this section.

A) Route No. 11 Ikeda line
B) Route No. 12 Moriguchi line
C) Route No. 13 Higashiosaka Line  D) Route No. 15 Sakai line

Figure 8 Travel time distribution and cumulative distribution imposed with corresponding reliability measure of various routes

iv) Occurrence Probability of Doubled and tripled Travel Time
To know the behavior of occurrence probability of double and triple travel time, the normal travel time has increased two times and three times. Normal travel time considered as the travel time at 60Km/h speed. The occurrence probability of the double travel time during peak hours for Sakai line that is less than 20% and remaining lines this is more than 50%. Similarly the occurrence probability of tripled travel time for Ikeda line is more than 20% in afternoon peak as compared to 10% during morning peak.
4.3 Comparison with US Seattle Study

Figure 10 explains travel time reliability as measured by BTI for routes considered in Han-shin expressway, Osaka Kobe area and Seattle road network, Seattle US. For comparison present study with Seattle study, travel time reliability index such as Buffer time index was considered. From the figure it can be identified that more percentage time should be budgeted for traveling on Han-shin expressway. If the average travel time is similar for all the routes, it can be quantified that trip reliability on Hanshin expressway is approximately two times as low as the Seattle road network.

5. RELATIONSHIP BETWEEN RELIABILITY AND CONGESTION MEASURES

In Han-Shin expressway, congestion section is defined as the section having with 30km/h
speed and congestion index is the accumulated distance and time of that congestion section (Fig.11). At present this approach is practically using to measure the performance of any section on Han-shin expressway. In this study an investigation is carried out to find the relationship between the travel time reliability measurements and congestion level measurements. This investigation further will be very much useful to both system users and planners to understand about the performance of the section. In this study, congestion level is compared with 95th % travel time and buffer time index (BTI). The severity order of congestion represented by the congestion index may not be always consistent with that of the average travel time, 95th percentile travel time and BTI. This is mainly because the congestion measure depends on average travel time of the routes where as travel time reliability indexes such as 95% travel time and BTI considers the travel time distribution. This further indicates that travel time reliability measures are capable of measuring the variability in congestion level. Figure 11 explains the relationship between congestion index and reliability measure among the various routes in this study

<table>
<thead>
<tr>
<th>Route Name</th>
<th>Quantity Of Traffic Jam (km/time)</th>
<th>Route Name</th>
<th>Average Travel Time (minutes)</th>
<th>Route Name</th>
<th>95% Travel Time (minutes)</th>
<th>Route Name</th>
<th>BTI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Osaka Line</td>
<td>11,474</td>
<td>Osaka Line</td>
<td>26.7</td>
<td>Hokkaido Line</td>
<td>29.5</td>
<td>Osaka Line</td>
<td>0.840</td>
</tr>
<tr>
<td>Hokkaido Line</td>
<td>9,880</td>
<td>Mongolian Line</td>
<td>24.2</td>
<td>Osaka Line</td>
<td>33.2</td>
<td>Hokkaido Line</td>
<td>0.634</td>
</tr>
<tr>
<td>Mongolian Line</td>
<td>6,330</td>
<td>Sapporo Line</td>
<td>22.8</td>
<td>Hokkaido Line</td>
<td>26.5</td>
<td>Sapporo Line</td>
<td>0.605</td>
</tr>
<tr>
<td>Sapporo Line</td>
<td>5,901</td>
<td>Sapporo Line</td>
<td>18.9</td>
<td>Hokkaido Line</td>
<td>33.1</td>
<td>Sapporo Line</td>
<td>0.377</td>
</tr>
</tbody>
</table>

![Figure 11: Relationship between congestion measures and travel time reliability measures among various routes](image)

Figure 11 Relationship between congestion measures and travel time reliability measures among various routes

in this study past three years (2003 to 2005) trends of congestion index and for the same time travel time reliability index trends have studied. Figure 12 represents the behavior of congestion index and reliability indices of past 3 years. It was observed that congestion index increased 10% during the year 2003 to 2005. Average travel time follows the similar pattern but the ratio varies a little amount. Reliability measures such as 95% travel time, buffer time and buffer time index is improved from year 2003 to 2005. Particularly higher improvement in 95% travel time reliability during the evening hours. Buffer time is reduced by 4 min during the peak hours.
6. CONCLUSIONS AND SIGNIFICANT FINDINGS

The following significant conclusions are drawn from this study:

- Travel time in morning peak is stable for Ikeda line (Route No.11). It becomes unstable during afternoon peak. Moriguchi line (Route No.12) shows higher fluctuation in morning peak than Ikeda line.
- Morning and evening peak travel time can be clearly observed in Ikeda line and Sakai line. In both the routes evening peak travel time is more than morning peak travel time.
- Seasonal fluctuation of travel times particularly observed in the afternoon peak period. Travel times were increasing from month of July to December, after that slightly decreasing in the month of January. Further travel time is increasing in the coming fiscal year.
- The relative difference between morning peak to evening peak is about 35 minutes in Ikeda line. This value is almost 4 times higher than the relative peak hour travel time difference of Sakai line (Route No. 15).
- CV value becomes larger after morning peak and before evening peak in all the corridors. Ikeda line become lower CV variation during morning and evening peak hours(0.23-0.29) than the other routes (varies approximately 0.4 to 0.5)
- Based on 95th Percentile travel time can be conclude that, in the morning hours Ikeda line and Sakai line is more reliable than the other routes. In the evening peak hour Ikeda line is most unreliable than the other routes.
- BTI values become relatively smaller during the peak hours for all four routes. Particularly in Ikeda line this difference is substantial. BT and BTI are having some similarities in profile shape with SD and CV.
- Among the four routes Ikeda line having low buffer time is about 8 min, this is almost half value as compared with other routes during the morning peak hour.
- From travel time distribution it was identified that Ikeda line having less width in
distribution and also not skewed from mean, this indicates that this route is more reliable than the other routes.

- The highest average travel time is that of Ikeda line, even though this route becomes more reliable than the other routes during morning peak period. (by considering 95th % travel time and Buffer Index and CV values)
- The occurrence probability of double travel time during peak hours for Sakai line observed that is less than 20% and remaining lines this is 50% and more.
- Congestion measure compared with reliability measures, the severity order of congestion represented by the congestion index may not be always consistent with reliability measurements such as 95% travel time and Buffer Time index. This indicates that travel time reliability measures are capable of measuring variability in congestion.
- Based on past trend observation the congestion index increased to 10% where as reliability is improved from year 2003 to 2005. Particularly higher improvement in 95% travel time reliability during the evening hours.
- BTI reliability index used as a tool for comparing performance of present study area to US Seattle study for selected routs. The results are emphasized that travel time reliability in Osaka is less than the Seattle.

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