ANALYSIS OF RELIABILITY OF A BUS TRANSIT SYSTEM USING RIDER EXPERIENCE

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Word Count: Text (3,131+ Figures/Tables 8× 250) = 5,131 total words

Submitted for publication and presentation at the
89th Annual Transportation Research Board Meeting
January 10-14, 2010
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Transportation Research Board 89\(^{th}\) Annual Meeting
January 10-14, 2010

ABSTRACT
Along with transit fares, travel time is a very important factor in attracting riders. Uniformity in travel times including the waiting time at origin or transfer points also play an important role in the user’s choice to opt for transit service rather than other modes of transportation. Riders expect to have a certain amount of consistency in transit travel routines. However, inconsistent travel times discourage users with low tolerance for time variability. Therefore, measuring the reliability or dependability of transit travel times is of vital importance to evaluate an existing transit system to both the user and the transportation planners. This study analyzes transit user data for the Las Vegas Citizen Area Transit (CAT) service in evaluating reliability measures. This paper describes five different methods of evaluation – reliability based on normalized standard deviation, analysis of variance, confidence intervals, reliability based on non-failures and information theory based approach.

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INTRODUCTION
Transit travel times are influenced by many factors such as traffic conditions, weather and passenger loads. The passenger experiences uncertainty in time spent waiting for the bus and the actual travel. If transfer points are required to reach the user’s destination, this adds to the above-mentioned uncertainty (1). Reliability indicates the certainty or dependability in using any transportation system. Evaluating the reliability of travel times using the transit system can enable effective trip planning for the passenger and help transit planning officials in management of the system by understanding travel time reliability. Many transportation officials and researchers have employed statistical analyses to define reliability as a measure. This paper describes analyses based on information theory, failure analysis, confidence intervals in addition to other traditional methods.

LITERATURE REVIEW
Reliability is a measure of system performance. It has been used extensively in analyzing various aspects of transportation and traffic engineering. For public transit systems, reliability is extremely important from the standpoint of improving ridership quality and hence increasing ridership. Historically, bus transit systems have failed to attract riders of choice. One of the key factors is its lack of reliability (2, 3, 4). A transit user customer satisfaction survey conducted by Calgary Transit Authority showed that people value reliability and convenience over ride comfort (5). In another study, comparing the user perceptions concerning headways of bus operations to reliability, the results showed that public appreciated a reliable service to more frequent arrivals (6). Transit agencies recognize the significance of transit travel time reliability on attractiveness of transit services to existing and prospective riders (7).

Over the past few years, several researchers have attempted to quantify reliability of transit systems. Casello et al (4) used automatic vehicle location data to estimate the reliability of transit service in Waterloo. This study showed that by increasing reliability of the transit system, the system user costs decreased significantly. Fan and Machemehl (8) investigated the effects of bus headway and schedule reliability index on passenger waiting times using a six-month period data in Austin, Texas. This paper also discusses the benefits of having coordinated bus arrivals compared to random arrivals. In another study to investigate transit service reliability, results showed that bus delays did not propagate to the following time points (9). A study in Seol, South Korea showed that traditional Transit Capacity and Quality of Service Manual (TCQSM) method to evaluate reliability of passenger comfort and level of service were not consistent with passengers’ satisfaction on bus service (10). Van Oort and van Nes (11) discussed the dilemma in the choice between reliability of service and length of service line of bus transit service. Although long lines connect places far apart, saving transfers, issues related to schedule adherence is considered as a serious issue. The study researchers addressed this issue by providing some innovative alternatives. Muller and Furth (12) showed issues of reliability of bus transit services associated with transfer points on low frequency routes. The authors use mathematical models to identify ways to prevent unnecessary delays. In Portland, Oregon, the local transit provider developed several statistical analyses on the automatic vehicle location data to evaluate transit system performance (13).

In summary, most of the documents consider reliability of service as the most important factor in evaluating performance of a transit system. By improving reliability of transit system, it is expected to attract more riders.
OBJECTIVE

Literature review shows that reliability of bus transit systems is extremely important from both operators’ and users’ perspectives. In several cases, as expected, reliability indices were ranked higher than other performance indices, including headways. Although several documents discuss reliability from transit operator’s perspective, reliability from user’s point of view has not been explored in detail. The objective of this paper is to develop models to analyze reliability of a bus transit system using rider experience.

METHODOLOGY

When riders use a transit system, they face several additional constraints compared to a motorist. Figure 1 shows flow diagram of a transit ride with one transfer point. It starts at the time they leave origin until they reach their final destination. Compared to a motorist, who has to deal with only one uncertainty (travel time), a transit rider is faced with several different uncertainties. Miller and Furth (11) illustrated that a transit rider considers transit time as the time he/she leave origin until he/she reaches the final destination, including walk time. Each of these constraints has its own reliability issues. Table 1 lists each of them for a transit ride with one transfer point. When addressing the reliability of a transit rider, it is extremely important to consider each of these separately for analyses. These reliabilities could be broadly classified into rider reliability, rider-transit reliability, transit reliability, travel time reliability, and transfer reliability. Traditionally, these various factors were factored into the travel time for transit system. However, since each of them possess different kinds of properties; they need to be analyzed separately for better understanding of the system and for more accurate estimation of reliability. Walking does not have a direct relationship to the reliability of transit operation. However, it plays a key role in attracting passengers. It also shows the value that the rider gives to reliability. On the flipside, reliability might indicate whether the riders face any issues during their walking/biking phase. If they are due to maintenance of the facility or security issues, they need to be addressed properly in order to attract more riders. Therefore, reliability of each of these components is important in determining reliability of the transit system. It is important to note that for every additional transfer point, uncertainty of the system increases by a factor.

Once the reliability issues are identified, the next step is to develop analysis tools for estimating reliability. That is explained in the following section.

ANALYSIS METHODOLOGY

“Reliability” is a measure of the repeatability or dependability of the system. For a set of values (travel times, speeds), reliability would indicate if these measures provide comparable values. In general, repeatability of travel time and speed could be framed in terms of time-of-day, day of the week, etc. Thus, travel time reliability is determined by conducting analysis on data measured for a certain segment. The analysis in this paper aimed at providing a reliability measure for the cumulative rider-transit reliability and also the rider reliability in particular. One of the two datasets was based on the cumulative effective speeds for the transit system and the other was based on the rider’s effective speeds. In this study five different approaches are used in obtaining various reliability measures as described below.
Reliability based on Normalized Standard Deviation

For a given sample dataset of effective travel speeds, the statistical mean can be computed using Equation 1. In order to study the changes in travel time with respect to the mean, it is essential to compute standard deviation using Equation 2. Normalization can be performed by using Equation 3 using the average computed. In this paper, the standard deviation was normalized with the effective average speed computed with the posted transit values. A lower standard deviation would indicate that the values are closer to the mean and therefore more reliability. Given a dataset \((s_1, s_2, \ldots, s_N)\), we denote the mean by

\[
\bar{x} = \frac{\sum_{i=1}^{N} s_i}{N} \tag{1}
\]

\[
\sigma = \sqrt{\frac{\sum_{i=0}^{N} (s_i - \bar{x})^2}{N}} \tag{2}
\]

\[
\sigma_N = \frac{\sigma}{\bar{x}} \tag{3}
\]

Where,

\(s_i\): Effective speed on a certain transit route

\(\bar{x}\): Average effective speed for the given data

\(N\): Sample size

\(\sigma\): Standard deviation of effective speeds for the given dataset

\(\sigma_N\): Normalized standard deviation

Analysis of Variance (ANOVA)

The variance in rider walk time averages for different users were compared for hypothesis testing. The Null hypothesis is defined by the desired \(\alpha\) value representing the variation between the various users. If the variation parameter \(P\) calculated using ANOVA technique is less than ‘\(\alpha\)’ value, then null hypothesis \((H_0)\) is accepted indicating that the variation in mean falls within the desired regions. Otherwise the alternate hypothesis \((H_a)\) is accepted.

Travel Time Mean Estimation based on Confidence Intervals

Average of measured travel times of the sample data \(\bar{x}\) may or may not reflect an accurate measure of the actual population mean \(\mu\) (absolutely every effective speed that existed). The actual effective speed mean can be estimated using t distribution (since actual population variance is unknown) with a certain confidence interval as shown in Equation 4.

\[
\bar{x} = \bar{x} \pm \frac{\bar{x} - \mu}{\sigma / \sqrt{N}} \tag{4}
\]

For 95% Confidence Intervals, \(\alpha = 0.05\).
Percentile \( \left( \bar{x} - \frac{t_{\alpha/2}}{\sqrt{N}} \right) < \mu < \left( \bar{x} + \frac{t_{\alpha/2}}{\sqrt{N}} \right) = 0.95, \)

Where,
- \( \bar{x} \): Average effective speed for the given data
- \( t_{\alpha/2} \): Value from t table for degree of freedom \( N-1 \)

**Reliability as a Measure of Non-Failures**

Reliability can be perceived as the probability of success of a certain route. This method provides the probability of success or failure defined by Equation 5. Success, in terms of effective speeds, can be defined as whether the travel speeds are above or below a desired level.

\[
R_i = \frac{s_T}{N}
\]

(5)

Where,
- \( N \): Sample size
- \( s_T \): Total number of successes, where \( s_l < s_d \)

**Information Theory based Approach**

In information theory, the information content, \( H(n) \), contained in a certain message is given by Equation.

\[
H(n) = \sum_{i=1}^{N} P_i \log_2 P_i
\]

(6)

\[
P_i = \frac{N_i}{N}
\]

(7)

\[
N = \sum_{i=1}^{N} N_i
\]

(8)

Where,
- \( H(n) \): Information Content
- \( N \): Total number of various effective speeds
- \( N_i \): Frequency of speeds that lie within a specific interval.

**CASE STUDY: LAS VEGAS BUS TRANSIT USER DATA**

Regional Transportation Commission (RTC) of Southern Nevada has been operating bus transit system in the Las Vegas area since 1992 (14). RTC offers FOUR different bus systems, Citizen Area Transit (CAT), Deuce, Metropolitan Area Express (MAX), AND Para-transit services for various routes. The entire RTC bus transit system serves 36 routes with over 350 vehicles. Ridership for the system is over 190,000 per weekday.
Data Assimilation
Travel time data was collected from the Citizen Area Transit (CAT) system users. These analyses are based on three different riders’ travel data. Each of these users had one transfer point (all different from each other). Figure 2 shows route map for each of the riders. Data collected during the study includes starting time from the origin, transit stop waiting time, travel time, transfer point waiting time, travel time for second leg, and arrival time at destination. Data over a period of 2 months were collected. Weekday travel information from home to work and work to home were summarized and were used for analyses illustrated in the previous section. For demonstration purposes, only two reliability categories, that of rider reliability and that of system reliability, are analyzed here. As indicated before, reliability of each of the reliability categories are important and they need to be analyzed in detail too. These other reliability categories could be analyzed using similar methodologies.

RESULTS
The following section summarizes the results obtained for the reliability analyses for rider and the system based on the various methods discussed.

Reliability Based on Normalized Standard Deviation
Table 2 shows the results of reliability analysis based on normalized standard deviation. This table shows that for both system and rider, normalized standard deviation values are 0.30 and 0.33 respectively, which are relatively low values. This means that speeds of both system and rider are consistent, showing higher reliability.

Analysis of Variance (ANOVA)
ANOVA was performed only on rider data. Due to lack of data, it was not performed on system data.

Null Hypothesis is $H_0 : \mu_1 = \mu_2$

Alternate Hypothesis is $H_A : \mu_1 \neq \mu_2$

It was tested for $\alpha = 0.05$ for 95% confidence level. Table 3 shows calculation for this method. The value of $P (1.03E-08)$ from the table is less than $\alpha$ value (0.05). Therefore, $R_{obs} > R_{crit}$ the null hypothesis is rejected indicating that there is significant change in mean speeds.

Travel Time Mean Estimation based on Confidence Intervals
Table 4 shows the summary of estimation of the $95^{th}$ percentile confidence intervals for the system and for riders. The value of $\mu$ is 8.33 for the system and 2.44 for riders (obtained from Table 2). Since the values of $\mu$ for both system and riders are in between the calculated upper limits and lower limits respectively, the system can be defined as reliable.

Reliability as a Measure of Non-Failures
Table 5 shows the summary of estimation of reliability as a measure of non-failures for both system and for riders. Results indicate that when a threshold of 10.0 mph is considered as the speed of the system, its reliability is 0.39 and increases to 0.95 when the threshold is decreased to 5.0 mph. For riders, average pedestrian walking speed is used as first threshold. MUTCD (15)
provides average walking speed as 2.7 mph. When this value is used, the reliability shows a
value of 0.33. When the threshold is lowered to 1.0 mph, in the case of elders, the reliability is
0.93.

**Information Theory based Approach**
Table 6 summarizes information theory-based reliability analysis for the system and for riders.
Result for system shows the value of reliability \( R \) for the system as 0.37, which indicates the
system is not very reliable. However, it is very consistent with the reliability value of the rider
(0.35).

**CONCLUSIONS**
The objective of this paper was to develop a methodology to evaluate reliability of transit
systems. This paper discusses five different methods to estimate reliability- normalized standard
deviation, analysis of variance, confidence intervals, reliability based on non-failures and
information theory based approach.

Using bus transit user data from Las Vegas metropolitan area, reliability values of the
system and rider are estimated for each of the methods introduced. The results show that in the
case of traditional statistical analyses, the results for both rider and system data have values
that do not deviate very much from the mean. The low standard deviation indicates fairly reliable
data. Analysis of variance performed for the rider effective speed data shows that the changes in
mean are significantly different across various users. The computation of reliability based on
non-failures gives an indication of the sensitivity of data related to changes in threshold.
Typically, lower thresholds had more reliability. The choice of the threshold value is therefore
very important and is dependent upon the decision of the transportation officials. Using the
information theory approach, reliability is defined as the reciprocal of the information content in
the dataset. This method also indicated low reliability for both rider and the system in the
intervals considered for effective speeds.

In this paper, the authors only analyzed the system and rider reliabilities. As discussed in
this paper, each of the other reliability categories is equally important. Therefore, similar analysis
is recommended for these categories as well.

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FIGURE 1 Flow Diagram of a Transit Rider’s Trip (with one transfer).
FIGURE 2 Transit Map of Riders
### TABLE 1 Reliability Issues for Transit Riders (with one transfer)

<table>
<thead>
<tr>
<th>Start Event</th>
<th>End Event</th>
<th>Action</th>
<th>Time Associated</th>
<th>Reliability Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Start from Origin</td>
<td>Reach Transit Stop</td>
<td>Walk/Bike</td>
<td>Walk/Bike Time</td>
<td>Rider Reliability</td>
</tr>
<tr>
<td>Reach Transit Stop</td>
<td>Board Transit 1</td>
<td>Wait at Transit Stop</td>
<td>Transit Arrival Time</td>
<td>Rider - Transit Reliability</td>
</tr>
<tr>
<td>Board Transit 1</td>
<td>Transit 1 Starts</td>
<td>Wait Inside Transit</td>
<td>Transit Departure Time</td>
<td>Transit Reliability</td>
</tr>
<tr>
<td>Transit 1 Starts</td>
<td>Transit 1 Reaches Transfer Point</td>
<td>Transit Ride</td>
<td>Travel Time</td>
<td>Travel Time Reliability</td>
</tr>
<tr>
<td>Transit Reaches Transfer Point</td>
<td>Boarding Location of Transit 2</td>
<td>Offboard/Walk/Bike</td>
<td>Transfer Access Time</td>
<td>Transfer Reliability</td>
</tr>
<tr>
<td>Boarding Location of Transit 2</td>
<td>Board Transit 2</td>
<td>Wait at Transfer Point</td>
<td>Transfer Wait Time</td>
<td>Transfer Reliability</td>
</tr>
<tr>
<td>Board Transit 2</td>
<td>Transit 2 Starts</td>
<td>Wait Inside Transit</td>
<td>Transit Arrival Time</td>
<td>Transit Reliability</td>
</tr>
<tr>
<td>Transit 2 Starts</td>
<td>Transit 2 Reaches Final Stop</td>
<td>Transit Ride</td>
<td>Travel Time</td>
<td>Travel Time Reliability</td>
</tr>
<tr>
<td>Reach Transit Final Stop</td>
<td>Reach Destination</td>
<td>Offboard/Walk/Bike</td>
<td>Walk/Bike Time</td>
<td>Rider Reliability</td>
</tr>
</tbody>
</table>

**Total Travel Time**

| Walk/Bike, Wait, Transit Ride | Walk/Bike, Wait Time, Travel Time | System Reliability |

**Transit Travel Time**

| Wait, Transit Ride | Wait Time, Travel Time | Transit System Reliability |
TABLE 2: Result of normalized standard deviation method

<table>
<thead>
<tr>
<th>Parameters</th>
<th>System</th>
<th>Rider</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean, µ (mph)</td>
<td>8.33</td>
<td>2.44</td>
</tr>
<tr>
<td>Variance</td>
<td>5.68</td>
<td>0.83</td>
</tr>
<tr>
<td>SD</td>
<td>2.38</td>
<td>0.91</td>
</tr>
<tr>
<td>Normalized SD</td>
<td>0.30</td>
<td>0.33</td>
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</table>
TABEL 3: Calculation for ANOVA

<table>
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<tr>
<th>Parameters</th>
<th>Rider</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_{abs}$</td>
<td>13.43</td>
</tr>
<tr>
<td>$P$</td>
<td>1.03E-08</td>
</tr>
<tr>
<td>$F_{crit}$</td>
<td>2.47</td>
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</tbody>
</table>
TABLE 4: Calculation Time Mean Estimation based on Confidence Interval

<table>
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<tr>
<th>Parameters</th>
<th>System</th>
<th>Rider</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper limit of μ</td>
<td>8.76</td>
<td>2.62</td>
</tr>
<tr>
<td>μ</td>
<td>8.33</td>
<td>2.62</td>
</tr>
<tr>
<td>Lower limit of μ</td>
<td>7.89</td>
<td>2.26</td>
</tr>
<tr>
<td>95&lt;sup&gt;th&lt;/sup&gt; percentile</td>
<td>5.27</td>
<td>0.98</td>
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</table>
TABLE 5: Summary of Failure Analysis

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<thead>
<tr>
<th></th>
<th>System</th>
<th>Rider</th>
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<tr>
<td>Min</td>
<td>1.35</td>
<td>Min</td>
</tr>
<tr>
<td>Max</td>
<td>12.36</td>
<td>Max</td>
</tr>
<tr>
<td>Range</td>
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<td>Range</td>
</tr>
</tbody>
</table>

**Threshold = 10 mph**

<table>
<thead>
<tr>
<th></th>
<th>Success</th>
<th>Failure</th>
<th>$R_{System}$</th>
<th>$R_{Rider}$</th>
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</thead>
<tbody>
<tr>
<td>Success</td>
<td>30</td>
<td>46</td>
<td>0.39</td>
<td>0.33</td>
</tr>
<tr>
<td>Failure</td>
<td>72</td>
<td>4</td>
<td>0.95</td>
<td>0.93</td>
</tr>
</tbody>
</table>

**Threshold = 2.727 mph**

<table>
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<th>$R_{System}$</th>
<th>$R_{Rider}$</th>
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</thead>
<tbody>
<tr>
<td>Success</td>
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<td>67</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Failure</td>
<td>93</td>
<td>7</td>
<td></td>
<td></td>
</tr>
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</table>

**Threshold = 5 mph**

<table>
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<th>Success</th>
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<th>$R_{Rider}$</th>
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<tbody>
<tr>
<td>Success</td>
<td>72</td>
<td>4</td>
<td>0.95</td>
<td>0.93</td>
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<tr>
<td>Failure</td>
<td>93</td>
<td>7</td>
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</table>

**Threshold = 1 mph**

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<th>$R_{Rider}$</th>
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</thead>
<tbody>
<tr>
<td>Success</td>
<td>93</td>
<td>7</td>
<td></td>
<td></td>
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<tr>
<td>Failure</td>
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<td>7</td>
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## TABLE 6: Summary of Information Theory based Approach

<table>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.37</td>
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<table>
<thead>
<tr>
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