APPLES TO APPLES: MEASURING THE PERFORMANCE OF TRANSIT AND ROADWAYS EQUIVALENTLY

Reuben M. Juster
Faculty Research Assistant
Center for Advanced Transportation Technology
University of Maryland
College Park, MD 20742, United States
Tel: 301-314-0426
Fax: 301-405-5959
Email: RMJcar@umd.edu

Submitted for presentation at the 2016 TRB 95th Annual Meeting of the Transportation Research Board and for publication in the Transportation Research Record

Word Count: 4295 + (2 Tables + 9 Figures) * 250 = 7045
ABSTRACT
This paper proposes a methodology to assess transit performance using travel time and travel time reliability similarly to highway performance measurement. This allows transit and highway performance to be analyzed together as a system. Currently, each component of the transportation system usually has some kind of performance monitoring program, but each component is monitored separately from one another. This method solves some of the issues with the performance measures agencies presently adopt including the lack of consistency from agency to agency, and how they do not truly reflect the quality of service. The methodology is applied on two corridors between Northern Virginia and Washington DC. The results showed that transit tends to be more reliable and less subjected to congestion than highways on those corridors, and that proposed methodology can be used to measure transportation system performance.

Keywords: Performance Measurement, Urban Transportation Systems, Multimodal, Public Transportation, Big Data, Transit Data, Vehicle Probe Data
INTRODUCTION

Our urban areas depend on their transportation system, a system that contains roadways, bikeways, transit, railways, and ports. These modes work together to transport people and freight throughout regions. If these modes are to work together, their performance should be measured together. By using common metrics for each component of the system, the public will be better able to choose which mode(s) meets their needs and decision makers will better be able to allocate funding to make the greatest impact to the transportation system. Performance measures cover a wide variety of transportation attributes such as financing, safety, and service performance and reliability. No one performance measure will measure all those attributes for every mode. This paper proposes a methodology traditionally used for highway performance measurement for highways and transit together on the last listed attribute, service performance and reliability. This can be accomplished by using travel time percentile-based performance measures.

American public transit agencies report their own chosen performance metrics in addition to the specific performance measures agencies are required to send to the Federal Transit Administration (FTA) through the National Transit Database (NTD) (1). While existing performance measures give some insight to how well transit systems operate, performance measures often differ from agency to agency, mode to mode, and sometimes conceal performance issues experienced from a user’s perspective. Most transit agencies give a binary value (on-time or late, working or not working) to indicate whether or not there system is performing well. Using a binary value does not express the extent an issue effects the performance of the system. For example, indicating that an agency’s heavy rail system was on-time 90% of the time tells us that the system is late 10% of the time. Of that 10%, what percent of the instances resulted in delaying passengers ten minutes, thirty minutes, one hour? That cannot be answered using current methodology. With data made available from transit agencies through archived data or potentially their open data program, researchers have developed their own methodology for transit performance measures. A summary of how public agencies self-report service performance, proposed methodology, and the NTD program is covered in the “Current and Proposed Transit Practice” section.

State Departments of Transportation (DOTs) also have certain performance metrics they use for their own purposes and specific measures they are required to report to the Federal Highway Administration (FHWA). There are multiple reports that state DOTs send to the federal government such as the Highway Performance Monitoring System (HPMS) reports, but the most pertinent performance measures to this paper are the travel time index (TTI) and the planning time index (PTI) which are congestion and reliability performance measures respectively.

Similar performance measures reflecting the travel time and the variance of the travel time (reliability) are anticipated to be required for Moving Ahead for Progress in the 21st Century Act (MAP-21) (2, 3). Highway performance monitoring, especially travel time percentile-based metrics is covered in the “Current Highway Practice” section.
The proposed travel time percentile-based transit performance measures use the same methodology as highway performance measures. One of the primary advantages of using the same methodology is that transit and highway congestion and reliability can be compared using the same metrics. This is especially true if the transit route shares or is parallel to the same right of way as a highway facility such as the Dan Ryan Branch of the Chicago Transit Authority’s (CTA) Red Line (Figure 1), the Los Angeles County Metropolitan Transportation Authority’s Green Line, and the western part of the Washington Metropolitan Transit Authority’s (WMATA) Orange Line. The transit performance measure methodology is explained and elaborated in the “Proposed Methodology” section.

In “Methodology Application”, the proposed approach is applied to the transportation system between Northern Virginia and Washington DC along the I-66 and the I-95/I-395 corridors, and the Virginia Railway Express commuter rail service.
CURRENT AND PROPOSED TRANSIT PRACTICE

Most transit agencies have two sets of performance measurements: One they use for internal purposes/what they send out to the public and the performance measures they are required to send to the NTD. Below summarizes the NTD requirements, the WMATA internal performance measurements, New York’s Metropolitan Transit Authority (MTA) internal performance measurements, and transit performance measurements proposed by researchers.

National Transit Database Requirements

Transit agencies that receive funding through the FTA must submit reports to the NTD (1). There are two main report types. An urban report conducted by transit agencies located in urban areas and a rural report for transit agencies located in rural areas. The FTA allocates funding to all transit agencies based on the reports. The National Transit Database Policy Manual contains many provisions on what and how data should be included in the report. Much of the reported information is consolidated into an annual transit profile for each transit agency. The profiles include a plethora of data, some of which are operational performance measures such as operating expense per vehicle revenue mile. The performance measures reported include values from previous years. See Figure 2 for a sample of an annual transit profile. The National Transit Database can provide support for policy and decision makers, but the performance measures included are focused on financial and asset information, not operations and reliability.

FIGURE 2 Washington Metropolitan Area Transit Authority 2013 National Transit Database profile. (Source: NTD, 2013.)
Washington Metropolitan Area Transit Authority (WMATA)

WMATA generates a quarterly and annual “Vital Signs” report, a document containing many performance measures and corresponding commentary (4). In terms of operational performance, WMATA monitors on-time performance and fleet availability for heavy rail and buses using an internally developed methodology. For bus on-time performance, a bus is considered on time if it is “no more than 2 minutes early or 7 minutes late”. During heavy rail rush hour service, the on-time performance is the ratio of the number of occurrences when a train services a station within 2 minutes of the scheduled headway over the total occurrences of a train servicing a station. During non-rush heavy rail service, on-time performance is the ratio of the number of occurrences when a train services a station within 150% of the scheduled headway over the total occurrences of a train servicing a station. Fleet availability is the ratio of total bus miles over the number of failures for buses, and total railcar revenue miles over the number of failures resulting in delays greater than three minutes for heavy rail. These performance measures are specialized for transit service and could not be used for highways. They also do not weight exceptionally late service worse than slightly late service.

New York City Transit (NYCT)

New York City Transit, the agency within the Metropolitan Transportation Authority that operates subways and buses within New York City, has a performance dashboard available on its website (5). Multiple performance indicators are available for viewing. Each indicator has a definition, a monthly chart that shows how the indicator has changed over time, a target, a year to date value, the percent change from the target, and the timeliness of the underlying data. There are two relevant indicators including ‘Subway Wait Assessment’, which is the number of train headways that are at most 25% divided by all train headways, and ‘Weekday Terminal On-Time Performance’, which is the percentage of trains that start their journey at their first station within 5 minutes of the schedule and have not skipped any scheduled stations. Both of these indicators are available system wide individually for each line. Similar to WMATA, these transit performance measure are not applicable to highways and do not weight exceptionally late service worse than slightly late service.

Proposed Transit Performance Measures

In the age of big and open data, transit agencies are opening up their data to application developers for all types of purposes, but usually for vehicle arrival predictions or schedule information. Some agencies such as the Massachusetts Bay Transportation Authority (MBTA) and NYCT have vehicle position feeds available (6, 7). Transit agencies are encouraging developers to use their data and have even set up showcases and forums to expose some of the better applications and to help applications in development. The vehicle position feeds could be used to generate performance measures that are similar to highway performance measures which are based on measured travel times. The MTBA has been using their vehicle position feed to generate reports on how their heavy rail headway and travel time change throughout the day between key segments as seen in Figure 3.

Reuben M. Juster
FIGURE 3 MBTA Daily Performance Report. (Source: MBTA, 2015)

Though this report is currently used for internal purposes, it is a vast improvement to currently used binary methodology since severe delays can be differentiated from minor delays.

Some researchers were given access to archived vehicle position data. Bertini et al. (2014) used TriMet archived automatic vehicle location (AVL) bus data to analyze bus trajectories (8). In
addition to arterial network performance measures, the trajectories were used to generate specific bus performance measures including what percent of time buses spent dwelling and percent of the time buses spent at certain speed bins along their routes. This type of information can be used to identify issues within the bus route. Ma et al (2014) used six months of archived AVL data along with some supplementary datasets from Queensland, Australia’s TransLink (9). Using the bus position data, the researchers calculated the time it took buses to get between stops and modeled how different planning, operational, and environmental variables affected travel time reliability in the form of average travel time, buffer time, and coefficient of variation. Hendren et al. (2014) used internal WMATA customer SmarTrip data to generate travel time percentiles and calculate travel time variability (10). The authors argued that those type of performance measures are more customer focused than some of the vehicle focused performance measures that WMATA utilizes. They also alluded to how these percentile-based measures closely resemble highway performance measures.

CURRENT HIGHWAY PRACTICE
The highway community has many sets of performance measures to evaluate all aspects of highway operations, planning, and maintenance. Performance measures based on travel time percentiles are becoming the standard for highway corridors and networks. These performance measures utilize vehicle probe data, which is provided by third-party vendors that aggregate speed and location data from individual vehicles utilizing Global Positioning System (GPS). Probe data is available for every minute of the day, 365 days a year, for all freeways and many major arterial roadways. Since this data is available on such a large temporal and spatial scale, cumulative distribution functions (CDF) like Figure 4, can be calculated from roadway segments or corridors for a given time period.

FIGURE 4 Sample Cumulative Distribution Function with PTI Calculation.

The x-axis represents a range of travel times that were detected along a roadway segment or corridor. The corresponding percentile of the y-axis represents the percent of all the travel time
values detected that were less than or equal to that travel time value. Given a CDF, a few percentiles can be used together as performance measures. PTI, which is used as a reliability performance measure, is typically the 95th percentile of travel time over the free-flow travel time. In Figure 4, the 15th percentile is used as an estimate of free-flow travel time. The PTI is a multiplier that is used with free-flow travel time to get the amount of time one should reserve for travel to ensure they make it to their destination on time. For example, if it takes 30 minutes to get to one’s destination during free flow conditions and the PTI is 1.5 for the time of day the trip is to take place, one should leave 45 minutes (30 minutes * 1.5) before the time they need to reach their destination. Likewise, the TTI, which is used as a congestion performance measure, is typically calculated as the 50th percentile (the median) travel time over the free-flow travel time. Sometimes the mean travel time is used instead of the median travel time. The TTI is a multiplier that is used with the free-flow travel time to get the typical travel time during a specific time of day, usually peak periods.

The Federal Highway Administration (FHWA) and many state departments of transportation (DOT) such as Washington and Maryland use percentile-based performance measures. The Maryland State Highway Administration publishes annual performance reports through the Maryland Mobility Report (MMR). The MMR maps PTI and TTI for the entire state as seen in Figure 5.

![Maryland Freeway/Expressway Congestion Map](image)

**Legend**
- Uncongested (TTI < 1.15)
- Light (TTI 1.15-1.3)
- Moderate (TTI 1.3-2.0)
- Severe (TTI > 2.0)

**Notes**
- Based on Travel Time Index (TTI), the ratio of the average travel time to the free-flow travel time of the segment.
- For example, a TTI of 1.5 means that a trip that takes 10 minutes in uncongested conditions will take 15 minutes in average peak hour traffic.

**AM Peak**
- 13% of the freeway/expressway system is congested.
- 22% of the VMT on the freeway/expressway system occurs in congested conditions.
Most of the time, only one or two percentiles are used to create a performance measure. Juster, Young, & Sharifi (2014) proposed using the entire CDF as a performance measure (14). This is particularly effective when showing travel time data on the same facility during different conditions (before and after an improvement project/normal conditions vs. rush hour conditions) or two parallel facilities (highway and transit).

PROPOSED METHODOLOGY

One of the biggest issues regarding performance management of our transportation system is that each component of our transportation system is measured differently. With the proliferation of AVL data from transit systems and probe data from highway systems, it is possible to adopt system wide travel time percentile-based performance measures. This paper proposes using the TTI and PTI as the performance measures across all modes to evaluate the transportation system during a certain time period.

METHODOLOGY APPLICATION

Study Location

The study location for applying the proposed methodology is the I-95/I-395 corridor and the I-66 corridor between the distant Northern Virginia exurbs to Washington DC. Both of these corridors face significant congestion, especially inbound Washington DC in the morning peak period and outbound from Washington DC during the evening peak period.

The Virginia Railway Express (VRE) system provides commuter rail service towards Washington DC during the morning and away from Washington DC during the evening with limited train service in the opposite direction for the purposes of deadheading. VRE has two routes: The Manassas Line which begins at the Broad Run Station where it parallels I-66 and provides access to job centers in Alexandria, Crystal City, and downtown Washington DC. The Fredericksburg Line, which begins in Fredericksburg (Spotsylvania in September 2015), parallels I-95/I-395 and joins the Manassas Line at Alexandria. See Figure 6 for an overview of the study location.
Study Data

The transit data was provided directly from VRE. It contained two years’ worth of data for both routes from July 1st, 2013 to June 30th, 2015. The database consisted of 68,304 records of when a train was delayed reaching a station. The travel time for each train for each day on each segment along the service route is the difference in arrival times for a station and the preceding station. If there are no delay records, the travel time is considered to be the scheduled travel time. If a train incurred delay in reaching a station, the recorded delay was added to the scheduled travel time. The resulting travel times were aggregated forming travel time percentiles which allow for PTI and TTI calculations. The freeflow travel time was considered to be the scheduled travel time.

The highway data was obtained through INRIX and the I-95 Corridor Coalition’s Vehicle Probe Project (VPP). Using the University of Maryland Center for Advanced Transportation Technology (CATT) Lab’s VPP Suite Massive Data Downloader, the average travel time for every freeway segment of the study area for the same time period as the VRE data in one minute increments was downloaded. The data was processed using almost the same methodology as the annual Maryland Mobility Report (13). One of the few changes from the Mobility Report methodology was to include a wider time period to capture the VRE service period. Each record
from the downloaded VPP data included the average travel time for a one minute period on a Traffic Message Channel (TMC) segment. The TMC segmentation system was developed to deliver real-time traffic and weather information through the radio and has since been adopted by navigation systems and outsourced travel time data providers (15). The TMC segments the VPP uses consists of segments that go between interchanges/intersection and those that are in interchanges/intersections.

Study Results

The TTI (Figure 7) and PTI (Figure 8) are mapped separately for the morning (5:00 AM to 9:00 AM) and evening (3:00 PM to 8:00 PM) peak periods.

FIGURE 7 Travel Time Index for the morning (left) and evening (right) peak periods.
FIGURE 8 Planning Time Index for the morning (left) and evening (right) peak periods.

A visual inspection of the maps shows that VRE service was more reliable and less congested than freeway travel. Table 1 shows the results weighted by the length of segments.

**TABLE 1 Average Results of Study Area Weighted by Segment Length**

<table>
<thead>
<tr>
<th>Performance Measure (Time Period)</th>
<th>VRE Service</th>
<th>Freeway Corridor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Manassas</td>
<td>Fredericksburg</td>
</tr>
<tr>
<td>TTI (AM)</td>
<td>1.06</td>
<td>1.05</td>
</tr>
<tr>
<td>TTI (PM)</td>
<td>1.06</td>
<td>1.05</td>
</tr>
<tr>
<td>PTI (AM)</td>
<td>1.38</td>
<td>1.15</td>
</tr>
<tr>
<td>PTI (PM)</td>
<td>1.38</td>
<td>1.15</td>
</tr>
</tbody>
</table>

The weighted averages of the performance measures supports what is seen on the maps. Those who commute on these corridors may think the freeway performance should be even worse. This was due to extending the peak period timeframes earlier and later to include the VRE service time, which tend to have a wider timeframe than the peak periods. A comparison of freeway performance measures using data from only the traditional peak periods and data from the entire VRE service time can be seen below in Table 2.
It is important to note that while the transit data and highway data used the same methodology to generate the performance measures, they are inherently different in nature. Each VPP data point represents the average speed of any probe vehicle detected on a TMC segment for the one minute period being reported. Each train record is how late a single train arrived at a station. Since VRE only has thirty trains per day that service up to eleven stations, there are many more data points for the VPP data, allowing for more variation. Since VRE service is scheduled, it is not as subjected to slow downs as freeways are, also limiting the variation. Figure 9 below show a comparison of VRE and freeway CDFs. The VRE travel times are from the Quantico station to the Rippon station. The freeway travel times are AM peak period records (5-9 AM) on I-95 North from VA-619 to Dale Blvd. which roughly parallels the VRE service between Quantico and Rippon.

While I-95 is faster for most percentiles, VRE has much greater consistency across all percentiles. It can be expected that VRE has more favorable travel times closer to Washington DC and may be a focus of a future study.
CONCLUSIONS AND NEXT STEPS

This paper proposes and demonstrates a methodology for viewing the transportation system using the same performance measures for all modes. Travel time percentile-based performance measures can be meaningful to most modes of transportation and if data is available, it is possible to generate performance measures on a continual basis. Agencies can adjust the specifics of the performance measures to suit agency policies and goals. The biggest obstacle to using this methodology is the lack of archived transit travel time data and the compartmentalization of transportation systems.

Vehicle probe data such as the data provided by VPP has allowed the highway community to efficiently monitor their roadways, generate performance measures on freeways with great accuracy and consistency, and disseminate accurate and timely information to the public all without significant expense to the agency. While many transit agencies provide predicted arrival time feeds, there are limitations in archiving these feeds and the feeds are predicted times, not actual times. Many larger transit agencies have archived travel time/vehicle location data feeds, which they use for internal performance monitoring purposes, but the data is not integrated into an analysis of the transportation system.

The transportation community has historically been compartmentalized by modes. If the community wants a truly successful transportation system that meets the needs of all who use it, the entire system’s performance should be monitored using the same metrics all in one place, instead of separate reports/chapters using different metrics for each part of the system. The method demonstrated allows highway travel to be directly compared to transit travel using metrics critical to the user. The same methodology could be used to assess multi-modal trips, creating a comprehensive view of the system regardless of the modes used. MAP-21 will require states and MPOs to generate congestion performance measures and hold them accountable for meeting congestion targets. This paper’s methodology would allow jurisdictions to add transit into the calculation of congestion possibly leading to lower congestion levels and giving jurisdictions more of an incentive to maintain their transit systems. This possibility highlights the methodology’s potential to force decision makers to look at transit as part of the transportation system instead of a separate entity.

This paper only touches the surface of the types of analysis that can be performed on a system using the same metrics. While this paper focuses on showing performance measures on each segment, the author proposes calculating path performance. For this paper’s study location that could include the travel time and travel time reliability on a journey from Fredericksburg to Washington DC via I-95, carpool, commuter bus, or VRE. If this type of analysis was performed on a wide range of origins and destination in a region, an origin destination matrices with different performance measures could be generated. In addition, since VRE is a highly scheduled service without a consistent headway, it was not possible to incorporate headway into the performance measures calculations. If performance measures were generated for a transit service with stable headways, it would be beneficial to calculate the performance measures on the transit service’s headway to assess wait time.
Acknowledgements
This paper would not be possible without Sonali Soneji of the Virginia Railway Express who supplied the train data, the Virginia and Washington DC departments of transportation who participate in the Vehicle Probe Project, and Kaveh Farokhi Sadabadi for helping with the analysis of the VPP data.

REFERENCES

