Highway Performance Measures for a Multimodal Corridor

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ABSTRACT

Highway performance measures for a multimodal corridor are developed and implemented in the Portland, Oregon Interstate 5 test bed. With the implementation of ITS, extensive disaggregate freeway data sets are now available and can be used as the basis for transportation performance measures. These measures are increasingly available to state and regional transportation agencies implementing performance-based systems planning. The benefits of nationally used performance measures are reviewed, and thirteen were selected for application to the corridor study test bed, using archived loop detector data collected in January 2002. The results are presented visually and described quantitatively. DOTs already collecting or archiving large amounts of ITS data can automate the data conversion process and have data available for these performance measures for use in making future planning and policy decisions.

BACKGROUND

Transportation agencies have relied on manual counts and limited data for monitoring system performance. The Oregon Department of Transportation (ODOT) and the City of Portland have implemented intelligent transportation systems (ITS) sensors, including loop detectors and video surveillance along freeways and arterials making it possible for TriMet, the regional transit provider, ODOT and other agencies to consider real-time traffic conditions when making operational decisions. This project continues this successful collaboration by leveraging traffic surveillance data (from video and loop detection) along a freeway/arterial corridor to generate performance indicators that can communicate with and “inform” the freeway traffic management centers (TMCs) and the TriMet bus dispatch system (BDS).

For public transportation, manually collected data include on-time performance, run times, and passenger activity. These data are costly to collect, inadequate for real time operations management and traveler information systems, and insufficient for transit planning. The implementation of advanced public transportation system (APTS) technologies including automated vehicle location (AVL), driven by global positioning systems (GPS), makes possible the continuous monitoring of each bus/train.

The increase in data availability and interest in performance measurement based on these data requires development of data visualization techniques that provide quick visual inspection of these measures. Data visualization is a logical extension of advances in data collection, archiving, and analysis.

The objective of this project reported here is to establish a test bed for evaluating and testing innovative uses of APTS data in a multimodal corridor. Using archived and real-time transit and traffic flow information, this project is showcasing the benefits of advanced transportation information technologies to improve transit operations, as well as short and long term planning. Methods are being developed to warehouse, integrate and validate relevant transportation- and traffic-related data from diverse sensors and sources in the Interstate 5 Corridor. The corridor includes a freeway, two parallel arterials (Barbur Blvd. south of downtown and Interstate Ave. to the north) local and express bus routes and planned light rail transit (LRT) lines.

PERFORMANCE MEASURES

Performance measures provide systematic targets for improving the efficiency and equity of person and freight movement over time. ITS deployments make it possible to transform vast amounts of data into information needed for adjusting operating strategies, evaluating system performance, and making decisions about future transportation investments \((1,8,9,10,11)\). Thus, new systems-oriented performance measures can be used to communicate the dynamics of system performance and to assess the opportunities for improving traveler safety and mobility, system efficiency, economic productivity, and reducing energy consumption and pollution.

This project is a part of a larger study on APTS in multimodal corridors using advanced technologies to improve transportation planning, analysis and evaluation. Along with a parallel study for transit, this study identifies measures using data from highway sensors, and from TriMet’s AVL-equipped “smart” buses, meeting the multimodal objective of the APTS study. Eventually these two performance measure data sets will be fused. In the next sections, performance measures selected from a literature review are applied to the test bed corridor in Portland.

LITERATURE REVIEW

Most transportation performance measures focus on freeways, making it difficult to construct comprehensive system wide measures since little data are available on arterials \((5)\). When arterial data are available, they are usually limited both spatially and temporally. For example, it is difficult to evaluate incident impacts and the delay resulting from vehicle diversion from a freeway to an arterial because there is usually very little arterial monitoring equipment.
Performance measures are usually linked to specified goals and objectives for one mode, but some have multimodal applications. The performance measure typology applicable to a multimodal planning process includes (6):

- **Efficiency**: Measures such as volume to capacity ratio, delay, level of service (LOS), and travel time express facility use of the system capacity from the supply perspective.
- **Effectiveness**: Indicators reflecting user perceptions, including mobility, reliability, and accessibility.
- **Externality**: Measures associated with pollution, emissions, accidents reflect the system supply perspective.

A new era of multimodal federal, state and regional transportation planning includes frameworks for application of performance measures (1, 4, 5, 6, 7, 8, 9, 10, 11). Highway performance is also tracked at a nationwide level (9, 10, 14), and statewide ITS data can be used to report important statistics (6, 7, 9, 10). To help promote the use of performance measures a national Performance Measures Library (6) offers a concise look-up guide for typical measures used, as shown in Table 1 (an expanded version can be found online at: http://www.gcu.pdx.edu/modules/hwyper_table1.htm).

Recently, performance measures were synthesized from 35 nationwide DOTs and Metropolitan Planning Organizations (MPOs) for monitoring and operations management of highway systems (15). Based on an evaluation of best practices, several key measures were recommended to serve as foundations for other commonly reported measures:

1. **Quantity of travel**
   - (i) Person-miles traveled
   - (ii) VMT

2. **Quality of travel** Average speed weighed by PMT
   - (i) Average travel time
   - (ii) Travel time reliability
   - (iii) Average delay
   - (iv) LOS

3. **Utilization of the system**
   - (i) Percent of system at LOS X
   - (ii) Density
   - (iii) Percentage of travel congested
   - (iv) V/C ratio
   - (v) Percent of miles operating in desired speed range
   - (vi) Vehicle occupancy
   - (vii) Lane-mile-hours at LOS E or F

4. **Safety**
   - (i) Crash severity
   - (ii) Crash type
   - (iii) Incidents induced delay
   - (iv) Evacuation clearance time

In Oregon, the transportation system performance is monitored as part of its congestion management system (CMS) (16). Congestion indicators used in Oregon include per capita VMT, V/C ratio, and auto occupancy. ODOT is in the process of adding several other mobility and safety indicators recommended by NCHRP (6) into their systems performance reporting (11).

**CORRIDOR PERFORMANCE ANALYSIS**

Interstate 5 is the major north-south transportation corridor through Oregon and is the most significant segment of ODOT’s Advanced Transportation Management System (ATMS). A 22-mile (35.2 km) corridor was selected for analysis between Jantzen Beach and Stafford Road, as shown in Figure 1. This corridor includes inductive loop detectors (in 2- and 3-lane cross-sections) at 25 northbound and 15 southbound locations. These detectors support the region’s comprehensive ramp metering program.

**Data Description**

The freeway analysis used archived loop detector data collected on five days in January 2002. The raw data included vehicle counts, occupancy and average speed for each lane and on-ramp, recorded over 20-second intervals. Data were screened for outliers and errors. The raw data included errors due to misreporting of time intervals during...
which no vehicles were counted (reported as -999 rather than zero), as well as malfunctioning of southbound Stations 1, 10, and the ramp at southbound Station 9 and northbound Station 20 during all five days of analysis. Figure 2 summarizes loop detector status information for five days of data. Southbound Station 9 and northbound Station 4 reported no data between 14:25 and 16:56 and 0:00 to 16:16 respectively on two separate days, and is thus listed as a partial malfunction

**Average Daily Traffic (ADT)**

Figure 3(a) shows the mean study corridor ADT calculated over the five study days for both freeway directions, and the ADT reported by ODOT from tube counts at the same locations. Figure 3(b) shows the difference between the ADT measured using the two data sources. As shown, the ADT calculated from the detector data varies somewhat from that measured by ODOT. Using the archived detector data to estimate the corridor ADT over many days would be more reliable than the 48-hour road-tube counts used to derive annual ADT volumes. Since the detectors can transmit data all day, every day, ADT calculated from this source can provide more accurate temporal statistics using data already being collected.

**Travel Time (Method 1)**

Travel time is a principal measure of transportation system performance used by traffic engineers, planners, and analysts and can be easily understood by the public (18). The total corridor travel time (referred to as Method 1) was calculated by summing the estimated travel time for each freeway segment represented by each detector. The midpoints between each pair of detectors were used to delineate the segments and travel times were estimated for each day studied. For example, Figure 4 shows travel time versus time for January 24 for both north- and southbound directions. Figure 4 also illustrates the cumulative travel time and free-flow travel time throughout the day. As the cumulative line deviates from the cumulative free-flow travel time the travel time increases can be clearly observed. At 7:05:00 the travel time increased from 23 min. to 28 min. Similarly, at 19:42 the travel time decreased from 49 min. to 24 min. The free-flow travel time on this day was 24 min.

**Travel Time (Method 2)**

A second travel time estimation method was also examined. The previous estimation used the sum of the estimated travel time across each segment for every 20-second interval. The location-time method (Method 2) considers the movement of a hypothetical reference vehicle as it moved through the corridor. It was assumed that traffic conditions would change as vehicles moved through the corridor. The difference in travel time between the two methods was found to be negligible.

**Average Speed**

Average speed, the analogue of travel time, is another principal parameter that describes the state of a given traffic stream. Decreased vehicle speed reflects the reduction in mobility people experience during congestion. The duration of congestion can also be determined by observing the periods during which reduced speeds are experienced. For this study, the 20-sec speed data were plotted versus time using the right-hand axis as shown in Figure 5. In order to magnify the speed reductions, oblique cumulative plots were constructed where the difference between the cumulative speed curve and a line \( \frac{d}{dt} = v_0 t' \) was plotted on the left-hand axis. The rescaling rate \( v_0 \) was chosen arbitrarily to maximize visual resolution and \( t' \) was the elapsed time from the beginning of the curve. Further details describing the use of oblique plots are available in (19). Figure 5(a) clearly depicts the times at which notable speed changes occurred.

**Vehicle Miles Traveled (VMT)**

VMT is an aggregate indicator of traffic volume. Even though VMT is not a direct measure of congestion, it is useful for monitoring trends over time. In this study, the corridor VMT was calculated using segment counts from mainline and on-ramp detectors. The VMT for each 20-second period for which loop data was available is a product of the segment length and the number of vehicles counted by the detector in that interval. It was assumed that once the vehicles were on the freeway, they would travel the length of the entire downstream segment. The corridor VMT was summed over 24 hours for each day and further converted to a VMT measured for each successive 1-mile segment (to account for variations in loop detector spacing).

Figure 6 shows a box plot of the VMT measured for each one mile segment over the five study days. The box plot captures the minima and maxima for each dataset (limited to five days in this example) as well as the median and the boundaries of the first and third quartiles. As shown, the VMT varies somewhat throughout the corridor.
Vehicle Hours Traveled (VHT)

VHT is a measure that reflects mobility and quality of travel at the system or facility level. Its advantage over VMT is that VHT also includes the amount of delay that occurs, better representing the impacts of congestion. VHT for the corridor is shown in Figure 6. To calculate VHT, freeway and ramp counts were multiplied by the travel time (location-time method). The average VHT for five days was calculated and normalized to facilitate comparison. ODOT can base their VHT calculations upon data collected over many days, thus accounting for seasonal and day-of-week variations in traffic flow.

Vehicle Miles Traveled by Congestion Level

Congestion level and LOS can be determined from detector occupancy data. Occupancy is the fraction of time that vehicles are present over the loop during each measurement interval. Higher occupancy reflects longer vehicle travel times across the detectors, indicating congested conditions. Figure 7 shows VMT classified by LOS. This figure highlights how traffic quality of service changes along the corridor.

Volume to Capacity Ratio (V/C)

The V/C ratio measures a facility’s capacity utilization by the current or projected traffic (14). A link-based measure, the V/C ratio reflects mobility and quality of travel and is widely used due to the availability of volume and capacity values for transportation links. Capacity can be defined as the maximum sustainable throughput for a facility. For this study the capacity of the freeway was assumed to be 2000 veh/hr/lane. The mean V/C ratio for five days for the southbound direction is shown as a surface plot in Figure 8. Since certain sections along I-5 change from 3 lanes to 2, the V/C ratio was adjusted accordingly. As seen in the figure, stations operating at LOS above “D” in the southbound direction included Stations 3 (Columbia Blvd.) and 8 (Going St.) in the morning peak period and Station 13 (Upper Boones Ferry Rd.) during the evening peak period. A LOS greater than “D” indicates that operations are taking place at near capacity and flow breakdowns can occur. Sites at this level should be candidates for remedial measures. The V/C measure should be based on many days’ data, in order to consider variations across days of the week, seasons and multiple years.

Delay

One of the costs of congestion is delay, defined as the excess time required to traverse a section of roadway compared to the free flow travel time. For this study, delay was calculated for the freeway mainline volumes excluding on-ramps for all five study days. The estimation of freeway delay was based on the difference between actual travel time and the free-flow travel time on the freeway segments. Delay was calculated by segment of the study corridor for all 5 days using the following equation:

\[
\text{Delay (veh-hours)} = \frac{\text{Distance (VMT)}}{\text{Average Speed (mph)}} - \frac{\text{Distance (VMT)}}{\text{Freeflow Speed (mph)}}
\]

Total delay (veh-hr.) for each station was defined as the sum of all delay at that station throughout the day. Figure 9 shows the average delay due to congestion for the southbound direction. For locations that indicate higher delays, as an example, a DOT can focus its incident response efforts to reduce further delays. Finally, Figure 10 shows average delay per station for all 5 days. From this plot one can see several spikes of delay that occur at key bottlenecks along the corridor.

Person Miles Traveled (PMT)

Person miles traveled is an aggregate quantity of travel used to identify mobility performance. Person-miles are usually computed by the summation of the products of Average Annual Daily Traffic (AADT) multiplied by the length of the roadway segment and the average vehicle occupancy depending on the traffic composition. The PMT was calculated by multiplying the VMT by the average vehicle occupancy. The traffic composition, comprised of the percentages of passenger cars, buses and trucks, was obtained by vehicle count at a random location on I-5 using traffic surveillance video available at the Portland State University ITS Laboratory. Vehicle occupancies were estimated to be: 1.4 for passenger cars; 25 for buses; and 1.1 for trucks (18); these values were applied to generate the total PMT for this corridor.

Q-Ratio

The Q-ratio, equal to the total VMT divided by total VHT, is a measure of the quality of travel (10). This measure is a proxy for the average travel speed in the sense that larger Q-ratios indicate higher speeds and better quality of travel. Figure 11 shows a box plot of the Q-ratio, also calculated per one mile segment along the corridor. As seen
in, the figure, average Q-ratio for southbound I-5 remained in the range of 45 mph (72.5 km/h) to 55 mph (88.6 km/h) on all days of analysis.

**Mobility Index (MI)**

The mobility index measures the person flow in the transportation system and is calculated by multiplying average speed by the average vehicle occupancy, or the PMT divided by VMT. The mobility index provides a multimodal cross-comparison since it is independent of vehicle type (19). The index is applicable at the route, segment, corridor, regional or statewide levels in that higher values indicate better performance. Figure 12 shows the mobility index for northbound and southbound I-5 by station. It was observed that northbound I-5, Station 1 (Stafford) and Station 15 (Macadam) and southbound I-5, Stations 11 (Hood River Ave.), 13 (Upper Boons Ferry) and 14 (Lower Boons Ferry) showed better passenger movements as compared to other locations.

**Corridor Analysis**

The previous discussion has focused on means for reporting corridor performance based on freeway surveillance data. The next phase of the project will fuse bus AVL data with that from the freeway in order to leverage greater levels of information for corridor management and information systems. As one example, Figure 13 shows travel time measurements for a sub-section of the northbound I-5 corridor (between Hwy 217 and I-405). As shown, travel time reported by the loop detectors is plotted at every 20-sec observation for one 24-hour period. Clearly there is variability in travel times reported as expected from the high resolution data. The TriMet BDS also recorded bus travel times for 23 express buses that traveled along the freeway on the same day. As shown, the bus corridor travel times range between 5 and 12 minutes during the day. In the future, the fusion of these data sources will assist both ODOT and TriMet in making operational decisions and in providing real time traveler information.

**CONCLUSIONS**

This project established a test bed for evaluating and testing innovative uses of ITS data in a multimodal corridor in Portland, Oregon. Techniques were tested using loop sensor data in order to improve traffic operations and maximize person-throughput, and ultimately enhance customer satisfaction in the corridor. This project is a part of ongoing research at Portland State University that will ultimately fuse highway performance data with arterial and transit operations data along a section of I-5 and Barbur Boulevard. The overall project will serve to highlight the benefits of APTS in multimodal corridors.

This study, as part of the APTS project, represents a first step towards integrating ITS data into an assessment of highway system performance. Operational efficiency of I-5, an important interstate that passes through the heart of Oregon, was examined. Several performance measures were selected based on a literature review and evaluated using loop detector data from I-5. Most DOTs that collect this data do not use it for generating statistics relevant for policy analysis. Most of the ITS data from freeways is used for traveler information and then discarded. With access to large data sets, DOTs can automate the process of converting it into useful performance measures for use in making future planning and policy decisions without additional data collection costs.

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A complete version of Table 1 can be found online at: http://www.gcu.pdx.edu/modules/hwyper_table1.htm
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