ODOT Operations Performance Measures

Final Report

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Technical Advisory Committee:

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Mr. Ed Fischer	ODOT Traffic Management Section
Mr. Jeff Graham	FHWA
Mr. Galen McGill	ODOT Traffic Management Section
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Mr. Bud Reiff	Lane Council of Governments
Mr. David Ringeisen	ODOT Transportation Data Section
Mr. Dick Walker	Metro

Others providing assistance at ODOT:

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Mr. Dan Kaplan	ODOT Transportation Inventory and Mapping Unit
Mr. Stacy Shetler	ODOT Traffic Management Section
Mr. Steve Reed	ODOT Traffic Engineering Section

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EXECUTIVE SUMMARY

Introduction and Project Objectives

This report describes the results of the analysis, findings and recommendations for the ODOT operations performance measurement project. The research was performed by the Texas Transportation Institute with substantial assistance of the Technical Advisory Committee (TAC).

The project has three primary objectives:

1. Identify a small set of mobility performance measures that can serve the needs of operations performance measures.
2. Develop, test and document methods for implementing these measures at a system and corridor level so that ODOT staff is able to fully implement the measures statewide.
3. Make recommendations for future improvements to data gathering and measures estimation to improve the measures' accuracy, geographic precision, and sensitivity to operations programs.

Performance Measures

The TAC agreed upon six key performance measures that are described in detail in this report. The measures are:

1. Travel Time Index (TTI)
2. Travel delay
3. Buffer Index (BI)
4. Volume-to-capacity ratio (V/C)
5. Travel time and
6. Speed

Methodology

The methodology is described in the report, and visually in Figure 1. It includes obtaining a free-flow speed and peak-period speed estimate from ramp meter (ITS) data when such data are available and reliable. In the absence of ramp meter data, an estimate of the free-flow speed and peak-period speed can be obtained from the Highway Economic Requirements System—State Version (HERS-ST) using Highway Performance Monitoring System (HPMS) data. Delay estimates from HERS-ST can be used as an estimate of the "baseline" delay to which delay reduction factors are applied to give "benefit" for operational treatments.

The operational treatments include surveillance cameras, ramp metering, freeway service (incident) patrols, and signal progression. The delay reduction factors are the same as those used in the TTI Urban Mobility Study, and they are applied to either the recurring and/or incident delay. Peak-period speed can be estimated with and without the operational treatments, and the subsequent performance measures can be obtained.

Test Corridors

The methodology was tested on four corridors: an urban transportation system (I-5 and Barbur Boulevard in Portland), an urban limited access/expressway corridor (Bend Parkway in Bend), an urban signalized arterial corridor (Powell Boulevard in Portland), and a rural corridor (Salmon River Highway from Lincoln City to Valley Junction). Table 5 of the report contains the characteristics of each of the test corridors, including available data.

Recommendations, Next Steps, and Summary of Lessons Learned from Methodology Application

The methodology provides a framework for estimating operations performance measures given operational treatments. The methodology was used to identify the impact of existing operational treatments, and it should be noted that it can be applied to perform "what-if" scenarios given the implementation of future operational treatments.

Several items were identified for improvement of the methodology and the results. These include issues related to data quality as well as additional sensitivity testing that can be performed to improve the methodology. Finally, the report includes a summary of enhancements to HERS-ST that will improve the methodology. Some of these enhancements are already planned for the next version of HERS-ST. The text below summarizes key elements of data improvement areas to enhance the methodology, further analysis to improve the methodology, and statewide applications and next steps.

Data Improvement Areas to Enhance Methodology

HPMS-like Data inputs: In some cases, suspiciously high ADT/lane values were found along I-5 and Powell Boulevard. This indicates either an incorrect traffic volume, number of lanes, or both. There is a need to review the dataset for these values. There is also concern that some of the section lengths are incorrect because they are very short. Finally, there is a need to review K and D factors for accuracy—particularly there is an interest in estimating weekend and weekday factors separately for rural corridors.

Automatic Traffic Recorders (ATRs): Oregon is unique in obtaining speed data from ATRs. This study was assisted by obtaining ATR data in two places along the Bend Parkway and at one location along the Salmon River Highway. ODOT expressed interest in identifying additional ATR locations, ensuring they are calibrated, and identifying whether speed data can be obtained. It was noted that ODOT is doing an upgrade of ATR stations and some of the new stations can measure speed. The speed data can be used to calibrate or validate the estimates produced in this study.

Weigh-in-Motion (WIM) Stations: ODOT is working with the Motor Carrier Division to get their WIM data. This would also provide a source of data for calibrating or validating the estimates from this study.

Incident Data: Incident data for each of the study corridors were obtained and reviewed for analysis. The primary and secondary route designated in the Advanced Traffic Management System (ATMS) incident data often had numerous ways of identifying a given road. Review of the data dictionary for the ATMS (Portland-area) incident management data indicates that the confirm time, primary milepost, secondary milepost, number of lanes affected, and estimated end time are not required data elements. Requiring these elements, as well as standardizing road names, would help ensure the most important incident data elements are included. Though the data are less extensive, the incident data in the CAD database include these data elements as time received, dispatch time, arrival time, and clear time as well as including the location of the incident by milepost.

Ramp Meter (ITS) Data: There is a need to better understand what constitutes a -999 speed and volume value. It is not clear to what extent this may be caused by equipment malfunction, incomplete 20-second polling data within the 15-minute period, or as a result of zero counts. It is also not clear how the data are being aggregated from the 20-second polling cycle to the 15-minute period level. Investigation of the 15-minute average speeds by station across the year had limited variability and indicated the need for calibration in some places. It is also possible that a communication overload may result in controllers not being polled every 20 seconds and, therefore, an error is reported. There is also a need to include meta-data (data about the data) along with each 15-minute data element to allow the analyst to understand the quality of the data being used.

Other data sources: Numerous other data sources could be inventoried for use in estimating statewide performance. There is a need to inventory where the different types of sensors (WIM, ATR, ITS, traffic signals) are located.

Further Analysis to Improve Methodology

Weekend and Weekday Factors and HPMS Data: It would be useful to obtain weekend and weekday factors for unique analysis by these days, particularly along rural locations where there may be substantial differences. This was briefly investigated for the Salmon River Highway, and the D factor was found to be different for the weekend and weekday analysis. Sensitivity analysis in HERS-ST is necessary to investigate these differences further.

Factors and Local Conditions: There is a need to obtain additional travel time and speed data to calibrate the model and the spreadsheet. It is possible that local knowledge and/or studies of specific corridors may suggest higher or lower delay reduction factors for different operational treatments. There may also be local knowledge of percent green time for signalized corridors in specific areas also.

Data Quality Control: There is a need for work to improve the quality of data sources such as the ramp metering (ITS data) and the incident data.

Longer Sections in HERS-ST: There is a need to investigate the affect of longer sections of road on the output statistics. This would be a sensitivity analysis to identify how lengths of double or triple the current sections affect the delay values. This would be particularly useful for the affect of different influence areas for signalized intersections.

Statewide Application and Next Steps

Keeping a Consistent Speed in the Statewide Application: Any statewide performance measure analysis should keep a consistent source of speed data (and subsequently computed performance measures) because this value will change over time, and it is important to understand the extent that this measure(s) is changing due to the measurement versus due to operational improvements. For example, if HERS-ST is the source for the measures, then the "HERS-ST Speed" should be kept from year-to-year as a data element. When supplemental speed information is available, they can be kept in the database next to the HERS-ST speed. There may even be speeds from more than one other source if different studies or local knowledge might be available. Other speed sources might include the real-time ITS data, floating car studies, ATR, etc. This would provide the opportunity to see trends not only in operational performance from year to year, but to also see how these speed values may differ by data source. This would allow for the calibration of the HERS-ST values with any other data sources that might be present.

Possible "Beta" Version Before Final Distribution: During meetings with the TAC, the concern was expressed that unreliable data may be indicating that there is an operational problem (rather than an actual problem really existing). To ultimately get a statewide methodology in place, identifying and fixing data issues such as those identified in this report are an inevitable part of the start-up process. It might be possible that the statewide implementation of the estimation procedures could be performed over a year or two or three and the results could be identified as "beta" or "prototype" to allow a review of the process over years and to allow for calibration of the results across years, and at different geographic locations, based on local knowledge or studies before the final "roll-out." This may alleviate some of the concerns about unreliable data indicating problems that are not present.

Future Operations Performance Measures Committee Activities: It is imperative to continue the momentum of the operations performance measures TAC that was created by this effort. The TAC, or a sub-set of the TAC, should be identified to continue this work. The group would follow up on the data improvement issues and further analysis items to improve the methodology. After identifying the new committee, one of the first tasks would be to update the data for the test corridors described here and redo the analysis in HERS-ST and re-compute the performance measures to identify changes.

1.0 INTRODUCTION

This report describes the results of the analysis, findings and recommendations for the ODOT operations performance measurement project. This report includes the following sections:

- Project objectives;
- Definition of performance measures;
- Specifications for measure calculation;
- Oregon test corridors
- Individual test corridor methodology findings
- Investigation and findings of ramp metering (real-time) speed and volume data
- Discussion of V/C in HERS-ST
- Summary of lessons learned with methodology application
- References
- Additional bibliography
- Appendix A: Matrix of performance measure characteristics
- Appendix B: ODOT available data sources
- Appendix C: Performance measure descriptions
- Appendix D: ITS data summary and quality control in the mobility monitoring program
- Appendix E: Portland 2002 regional mobility and reliability data
- Appendix F: HERS-ST procedure for recurring and incident delay for freeway and signalized arterials
- Appendix G: Description of spreadsheet calculations
- Appendix H: Description of HERS-ST and operations performance measures (OPM) analysis

Spreadsheets were created for illustration of the methodology for performance measure calculation. This report often refers to these spreadsheets and their contents. There is one spreadsheet which is entitled "ODOT Operations Performance Measures" and there are six separate worksheets in the spreadsheet defined as follows:

Bend_Parkway(Hwy4):	contains calculations for Bend Parkway.
Powell_Blvd(Hwy26):	contains calculations for Powell Boulevard.
I-5_Barbur(Hwy91):	contains calculations for the I-5 and Barbur Boulevard system analysis.
Salmon_River(Hwy39):	contains calculations for Salmon River Highway (ORE 18).
FFS with ITS data:	contains yearly average speed by time period and station from real-time data.
I-5 ITS and HERS-ST comparison:	contains the analysis of real-time and HERS-ST estimates along I-5.

2.0 PROJECT OBJECTIVES

This project has three primary objectives:

1. Identify a small set of mobility performance measures that can serve the needs of operations performance measures.
2. Develop, test and document methods for implementing these measures at a system and corridor level so that ODOT staff is able to fully implement the measures and methods on a statewide level.
3. Make recommendations for future improvements to data gathering and measures estimation to improve the measures' accuracy, geographic precision, and sensitivity to operations programs.

3.0 DEFINITION OF PERFORMANCE MEASURES

The Technical Advisory Committee agreed upon six key performance measures that are described in this report. The measures are

- Travel Time Index (TTI)
- Travel delay
- Buffer Index (BI)
- Volume-to-capacity ratio (V/C)
- Travel time and
- Speed

A matrix summarizing the characteristics of these measures is shown in Appendix A. It should be noted that at the Technical Advisory Committee meeting on February 5, 2004, the group suggested adding travel time and speed to the measures used in the study. Travel time will be added as it shows the effect of land use and transportation service improvements. Average speed will also be added because it is easy for audiences to understand. The measures of travel time and speed will be readily available due to the computation of the other four performance measures.

A spreadsheet of an ODOT catalog of data is provided in Appendix B for reference. Many of the data elements used in the performance measures, and in the methodology described in this report, come from Highway Performance Monitoring System (HPMS)-like data elements. The ODOT Transportation Planning Analysis Unit (TPAU) has these data elements available in either the congestion management system (CMS) database and/or the Integrated Transportation Information System (ITIS). When ITS data are available, speed and performance measure computations may be measured directly from the available data. Detailed descriptions of the performance measures are provided in Appendix C.

It is important to note that the guiding principles used in this study consider the needs and uses for the performance information first, identifies the appropriate measures next and then attempts to identify methods for calculating, estimating or measuring the performance measures. The project described in this report focuses on the measure and data steps that can be accomplished in the future. The results of the study are intended to form one element of a comprehensive travel evaluation program that includes travel model and system monitoring information.

System performance and user experiences are both important components of this program, as is the effect of the entire range of programs being pursued to improve transportation from added capacity and improved operations to demand management and land use planning elements.

4.0 SPECIFICATIONS FOR MEASURE CALCULATION

This section briefly describes the procedures for estimating each of the performance measures. Figure 1 illustrates a process that can be used to estimate the performance measures for roadway sections. The results of roadway section analyses can be weighted together by VMT for corridor, region or system estimates (e.g., see Equation 1 for TTI in Appendix C). The steps of the flowchart are described in the sections that follow.

Step 1. Identify Roadway Section for Analysis

The identification of the roadway section for analysis is the first step. The methodology that follows is applicable to urban freeways, rural highways, and signalized arterial segments. The results of the roadway section analysis can be weighted together by VMT for corridor, regional or system estimates. Because the ITS data and Integrated Transportation Information System (ITIS) data may have different section identifiers, this step may include identifying a section label variable that is consistent across both data sources when ITS data are available.

Step 2. Identify Whether ITS Data Are Available

Archived ITS data provide the ability to directly measure free-flow speed and operating speed for the roadway section of interest. Therefore, when real-time ITS data are available, they are preferred for the direct measurement of these speeds. If ITS data are not available, an estimation procedure is necessary.

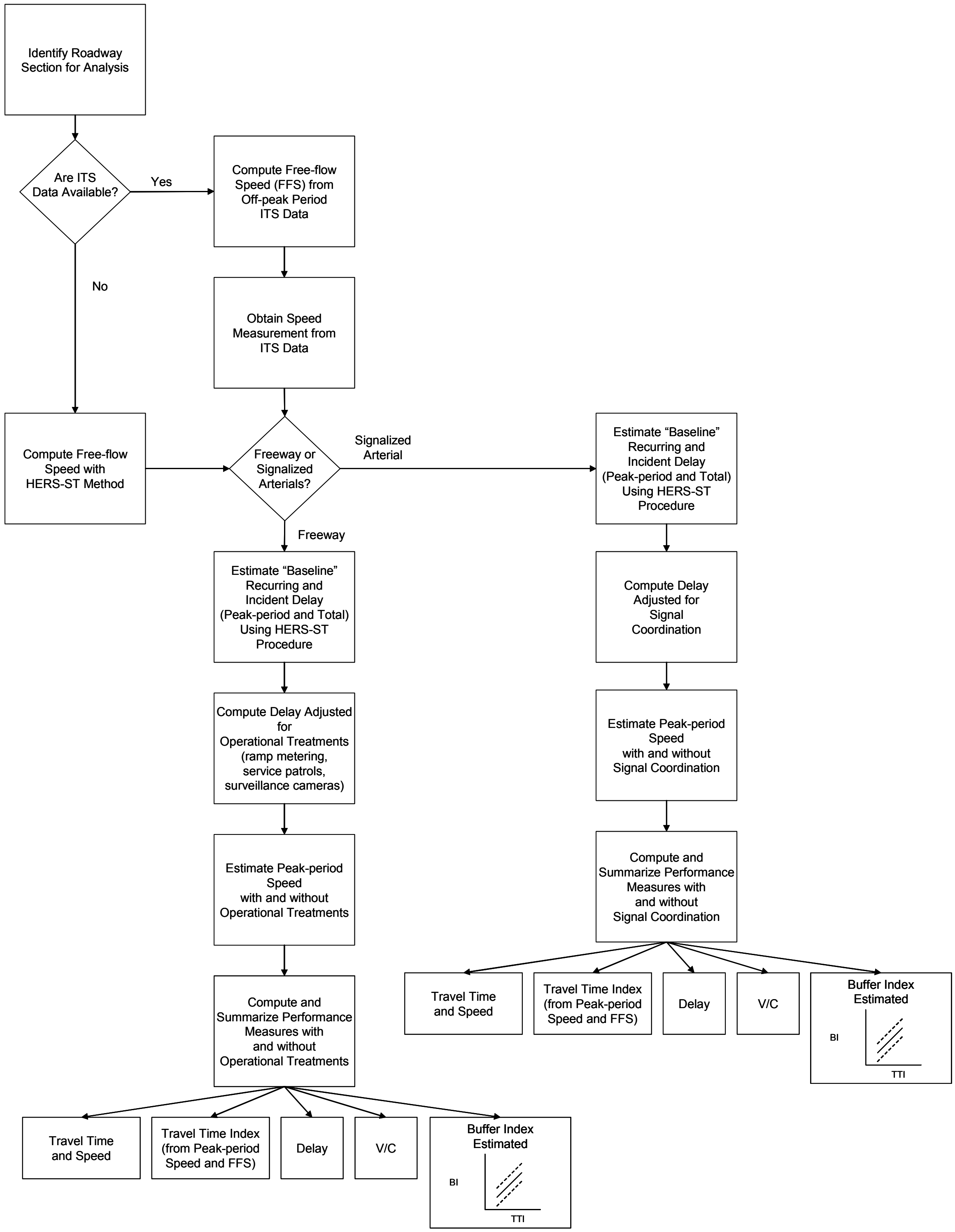
Step 3. Compute Free-flow Speed

As indicated in Step 2, free-flow speed (FFS) can be either measured with ITS data or estimated from the speed limit or with Highway Economic Requirements System, State Version (HERS-ST) using HPMS or HPMS-like data from ITIS. It is also possible to assume a FFS (e.g., 50 mph or 60 mph) for a given facility type. This allows for the flexibility to use a speed that is more of a target or acceptable value.

3.1 Free-flow Speed Estimation with ITS Data

The 2002 ITS data for the Portland area have been processed according to the procedure and quality control rules implemented in the Mobility Monitoring Program (MMP) by the Texas Transportation Institute and Cambridge Systematics. Appendix D is the reproduced Chapter 3 from the 2002 MMP report (*1*). Appendix D describes the data, including the quality control processes and how lane-by-lane data are aggregated to the section level. Appendix E shows the summarized ITS data from Portland in 2002. Free-flow speed can be measured from the speed along the section of the roadway during the off-peak period with the ITS data.

Figure 1. Methodology to Estimate Operational Performance Measures for ODOT



3.2 Free-flow Speed Estimation with HERS-ST Method

When ITS data are not available, the HERS-ST method can be used to estimate the free-flow speed. The Technical Report (section 4.1) under "documents" of the HERS-ST Internet site describes the estimation procedure for free-flow speed in more detail (see http://www.fhwa.dot.gov/infrastructure/asstmgmt/hersdoc.htm).

The free-flow speed from HERS-ST is a function of the maximum allowable speed on a curve (VCURVE), the maximum allowable ride-severity speed (VROUGH), and the maximum speed resulting from speed limits (VSPLIM). VCURVE is a function of the radius of curvature and superelevation. Pavement roughness is considered in the VROUGH computation, and it is a function of present serviceability rating (PSR) values. VSPLIM is computed by adding a factor to the posted speed. The free-flow speed can be estimated with this process with readily-available section data used by the ODOT Transportation Planning Analysis Unit (TPAU). TPAU has developed a program in R-code that computes the free-flow speed using a subset of the HPMS data and follows the HERS-ST procedure. Consideration of vehicle class (truck percentages) is included.

Step 4. Pursue Different Analysis Path for Freeways or Signalized Arterials

The subsequent delay equations in the methodology have been developed for freeways or signalized arterials.

Step 5. Estimate Delay with and without Incidents Using HERS-ST Procedure

Appendix F provides a procedure for estimating recurring and incident-related delay in HERS-ST. The relationships used in the Urban Mobility Study for speed estimation are based upon these HERS-ST equations. More information can be found in the report *Sketch Methods for Estimating Incident-Related Impacts* (http://plan2op.fhwa.dot.gov/toolbox/toolbox.htm) (*2*).

5.1 Estimating Recurring and Incident Delay on Freeways

The procedure in Appendix F illustrates the input variables, intermediate and output variables, and the steps of the procedure. As shown by the index K ("counter" variable), there are three period/direction combinations that are analyzed. These are 1) peak period, peak direction, 2) peak period, counter-peak direction, and 3) the off-peak period. The variables used in the analysis include HPMS-like inputs such as AADT, number of through lanes, D-factor, and shoulder widths (left and right). It should be noted that the analysis does not appear to use the left shoulder in the analysis, and it is unclear why this is an input item. The variables in capital letters shown in the parenthesis below refer to the variables explained in more detail in Appendix F. It should be noted that the peak period is defined as a certain percentage of travel for a given AADT/C ratio (see Table F-2 of Appendix F).

Capacity is a necessary input for the procedure shown in Appendix F. The two-way capacity is necessary to compute the AADT/C ratio (ACR). Note that the ACR is the ratio of the AADT to hourly capacity. The peak capacity for the peak direction (one-way) (PKCAP) and capacity during the peak period in the counter-peak direction (one-way) (CPCAP) is also necessary. TPAU has developed a spreadsheet program in Visual Basic (VBA) that uses a subset of the HPMS data, rewritten from the HERS-ST FORTRAN code, to compute segment roadway capacities based upon the 1997 *Highway Capacity Manual (HCM)*. These capacity estimates are identical to the estimates that HERS-ST computes, the only difference is that TPAU's version is a "standalone" analysis that only calculates capacity using a subset of the original data used by HERS-ST. Either process can be used in the delay equations.

The procedure in Appendix F can be used to estimate the total delay for the three periods of 1) peak period, peak direction, 2) peak period, counter-peak direction, and 3) the off-peak period. The recurring delay equations are a function of the V/C ratio, free-flow speed, AADT/C (where "C" is the hourly capacity) ratio, and bottlenecks per mile factor. The incident delay equations are a function of the number of lanes on the freeway, V/C ratio, AADT/C ratio, and factors for incident rate, incident duration, and shoulder width (Shoulder factors [SHFAC] are shown in Table F-1 of Appendix F).

5.2 Estimating Recurring and Incident Delay *on Signalized Arterials*

The procedure in Appendix F illustrates the input variables, intermediate and output variables, and the steps of the procedure for signalized arterials also. Analyses are again for the three periods of 1) peak period, peak direction, 2) peak period, counter-peak direction, and 3) the off-peak period. As before, the variables used in the procedure are HPMS-like including the number of lanes, AADT, and D-factor.

The number of lanes in the peak period, counter-peak direction and capacities are required in the signalized arterial procedure. TPAU has developed a spreadsheet program to compute segment roadway capacities based upon the 1997 *Highway Capacity Manual* used in HERS-ST that can be applied to this methodology.

Tables F-6 to F-8 of Appendix F can be used to estimate the recurring delay for the peak-period, peak direction, peak period, counter-peak direction, and the off-peak direction. Table F-9 of Appendix F can be used to determine an estimate of incident delay.

Step 6. Estimate Peak-Period Speed with and without Operational Treatments

6.1 Estimating Peak-Period Speed *on Freeways*

Where ITS data are available, operating speed can be directly measured along the roadway section of interest from the MMP data.

When ITS data are not available, the peak-period speed on freeways is computed as a function of the free-flow speed and the peak-period delay along the roadway segment of interest. Step 5 produces both recurring and incident delay. Prior to estimating the peak speed including operational treatments, "credit" is given to those segments of roadway that have incident management (service patrols and/or surveillance cameras) or ramp metering present. A percent reduction in delay is applied to both the recurring and incident delay for ramp metering based on a combination of HERS-ST analysis and examination of archived data. A similar delay reduction credit can be used to adjust the incident delay for the presence of service patrols and/or surveillance cameras. This is the same methodology that was used in the 2003 Urban Mobility Report (*3*).

Table 1 shows the delay reduction factors used for ramp metering benefits in delay reduction. These delay reduction factors were computed based upon the ITS Deployment Analysis System (IDAS), HERS-ST methods and HPMS data. These percent delay reduction factors apply to both recurring and incident delay. The congestion level in Table 1 refers to the different congestion ranges identified in the UMS methodology by ADT/lane. The congested ranges are:

- Below 15,000 ADT/lane (uncongested)
- 15,000 to 17,500 ADT/lane (moderate)
- 17,501 to 20,000 ADT/lane (heavy)
- 20,001 to 25,000 ADT/lane (severe)
- Over 25,000 ADT/lane (extreme)

Table 1. Ramp Metering Benefits in Percent Delay Reduction (HPMS and Deployment Tracking) (Adapted from Reference *3*)

Ramp Meter Strategy	Congestion Level				
	Uncongested	Moderate[1]	Heavy[1]	Severe[1]	Extreme[1]
No ramp meters	0	0	0	0	0
Isolated , pre-timed, centrally controlled or traffic responsive (recurring/incident)	0	peak=0 off-peak=0	peak=5.6 off-pk=0	peak=11.0 off-peak=7.3	peak=12.4 off-peak=11.6

[1] Derived from an equation relating speed to delay reduction for each congestion level. Delay reduction applied to recurring and incident delay estimates.
Source: HERS-ST Operations Preprocessor, Minnesota Ramp Metering Study, and TTI Analysis

Tables 2 and 3 show the percent reduction in incident delay that would result from freeway service patrols and surveillance cameras, respectively.

Table 2. Incident Delay Percent Reduction Benefits of Freeway Service Patrols (HPMS and Deployment Tracking) (Adapted from Reference *3*)

System Coverage	Patrol Cycle (miles each vehicle covers)	Congestion Level				
		Uncongested	Moderate	Heavy	Severe	Extreme
No patrols		0	0	0	0	0
If 100% of the system is covered	More than 10 miles Less than 10 miles	0 0	18 25	21 28	24 31	28 35

Source: HERS-ST and TTI Analysis

Table 3. Incident Delay Percent Reduction Benefits of Surveillance Cameras (HPMS and Deployment Tracking) (Adapted from Reference *3*)

System Coverage	Congestion Level				
	Uncongested	**Moderate**	**Heavy**	**Severe**	**Extreme**
No cameras	0	0	0	0	0
Coverage amount					
25%	0	2.5	3.0	3.5	3.5
50%	0	2.5	3.0	3.5	4.0
75%	0	3.0	3.5	4.0	4.5
100%	0	3.0	3.5	4.0	5.0

Source: HERS-ST and TTI Analysis

After the incident delay has been computed with and without the operational treatments present, the peak-period speed can be computed with the free-flow speed and the delay estimate. This will then provide a peak-period speed with and without the operational treatments. For section-level analysis, the roadway segment either will or will not have ramp metering, freeway service patrols, or surveillance cameras. The free-flow speed and peak-period speed can then be used to subsequently estimate the performance measures of interest.

6.2 Estimating Peak-Period Speed on Signalized Arterials

A similar procedure is performed to estimate the peak speed on signalized arterials. Prior to estimating the peak speed with operational treatments, "credit" is given to those segments of roadway that have signal coordination. A percent reduction is provided as per Table 4. The ADT/lane levels for principal arterial streets are:

- Below 5,500 ADT/lane (uncongested)
- 5,501 to 7,000 ADT/lane (moderate)
- 7,001 to 8,500 ADT/lane (heavy)
- 8,501 to 10,000 ADT/lane (severe)
- Over 10,000 ADT/lane (extreme).

After the incident delay has been computed with and without signal coordination benefits, the peak-period speed can be computed with the free-flow speed and the peak-period delay estimate. Sensitivity analysis can be performed to identify the affect on peak-period speed given different levels of signal coordination benefits. The free-flow speed and peak-period speed can then be used to subsequently estimate the performance measures.

Table 4. Signal Coordination Benefits in Percent Delay Reduction (Adapted from Reference *3*)

Signal Strategy	Signal Density (signals per mile)	Congestion Level				
		Uncongested	Moderate	Heavy	Severe	Extreme
No coordination	- -	0	0	0	0	0
Traffic Actuated	Less than 3 per mile	0	0.5	0.5	0.5	0.3
	3 to 6 per mile	0	2.2	2.1	1.9	1.5
	More than 6 per mile	0	2.1	2.1	1.5	1.1
Progressive (centralized or real-time)	Less than 3 per mile	0	1.0	1.0	0.9	0.7
	3 to 6 per mile	0	5.0	4.8	4.5	3.6
	More than 6 per mile	0	6.1	6.0	4.6	3.1

Source: HERS-ST and TTI Analysis

Step 7. Compute and Summarize Performance Measures

In this step, the performance measures are computed and summarized for the roadway segment of interest (freeway or signalized arterial).

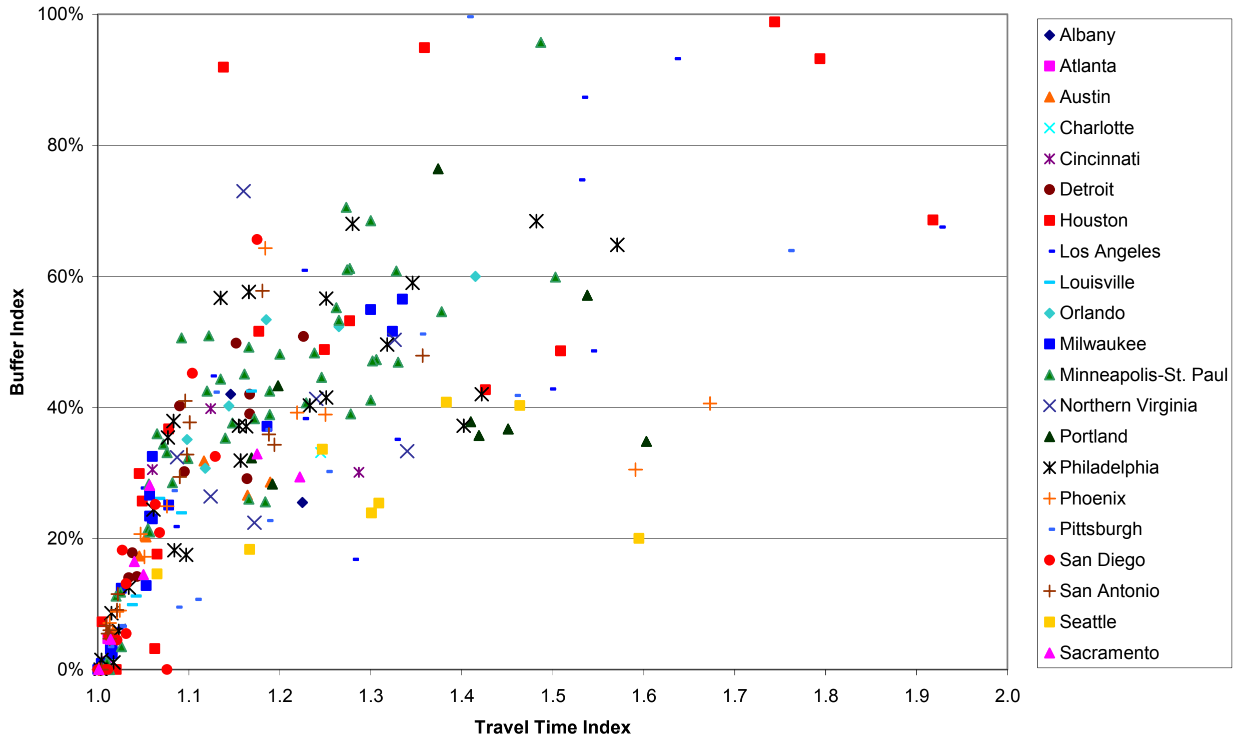
7.1 Computing and Summarizing Performance Measures on Freeways

The TTI can be computed as the travel rate (minutes per mile) in the peak period (using the peak-period speed estimate), divided by the travel rate (minutes per mile) in the off-peak period (i.e., with the FFS). TTI can be computed with the peak-period speed with and without the operational treatments to provide an estimate of the change in travel conditions due to these operational treatments. If desired, a similar calculation can be performed with the 24-hour travel rate to estimate average daily conditions.

Delay and V/C are two of the other performance measures that will be computed as a part of the procedure. They have been computed as inputs to the delay equations, so they can simply be carried forward to this step. Section 8.0 discusses V/C calculation in more detail based on test corridor experiences.

The Texas Transportation Institute (TTI) has been investigating the relationship between the Travel Time Index and Buffer Index where real-time ITS data available based on data from numerous cities in the 2002 Mobility Monitoring Program (MMP) Report. Reliability was investigated based on the number of lanes on the facility in a given direction. The segments were organized based on the number of lanes. Initially, the segments were grouped together in the following categories: 2-lanes-or-less, 3-lanes, 4-lanes, and 5-lanes or more in a given direction. The resulting graphs showed a substantial amount of data for the 3-lanes and 4-lanes segments, but there were not many data points in the 2-lanes-or-less and 5-lanes-or-more groups. In order to have more data points upon which to develop relationships, the 2-lanes-or-less and 3-lane segments were combined and the 4-lanes segment and the 5-lanes-or-more segments were combined. This resulted in two categories of roadways: 3-lanes or less and 4-lanes or more. Figure 2 illustrates a scatter-plot of the available data by city for the 3-lanes-or-less condition.

Figure 2. Urban Areas with Freeway Sections Having 3 or Less Lanes



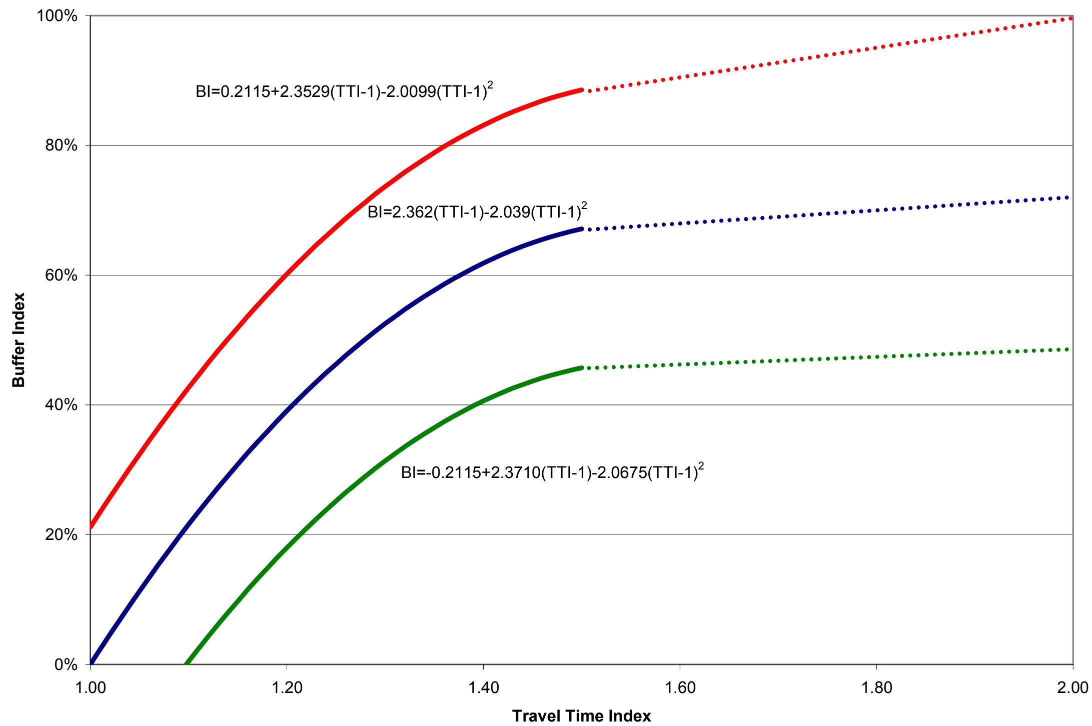
A second-order polynomial best-fit line and corresponding prediction intervals were calculated for 3-lanes or less and 4-lanes or more. Figure 3 shows the graphic for 3-lanes or fewer. The prediction intervals that are shown are at the 85% confidence level. The equations for the best-fit line and upper and lower prediction intervals are shown on the plot. These equations are valid for a Travel Time Index of up to 1.50. Beyond that level, there was not enough data to generate an equation to predict Buffer Index with any level of confidence. For TTI values greater than 1.50, it is suggested that the values generated for a TTI of 1.50 should be used, and it should be noted that the uncertainty with the prediction at that level of congestion.

Finally, the above process for estimating the performance measures is generally for a specific roadway section. For a corridor or system analysis, a weighted average of the segment performance measures can be computed using VMT as the weighting factor.

7.2 Computing and Summarizing Performance Measures on Signalized Arterials

TTI will be computed based upon the peak-period speed computed in Step 6 divided by the free-flow speed computed from the HERS-ST procedure. Delay and V/C ratio have already been computed earlier in the procedure. Researchers at TTI continue to investigate the relationship between TTI and BI on signalized arterials. There are far fewer locations with real-time data on arterial facilities than freeway locations. The research team has identified some data in Houston as well as some potential data in Colorado, Michigan and Minneapolis that might be used to develop future relationships.

Figure 3. Travel Time Index and Buffer Index Relationship on Freeways with 3 or Less Lanes



5.0 OREGON TEST CORRIDORS

The methodology for performance measure development was tested on four corridors: an urban transportation system, an urban limited access/expressway corridor, an urban signalized arterial corridor, and a rural corridor. It is important to note that the primary intent of testing the methodology on the four corridors is to identify the necessary data elements, applicable factors, and to demonstrate the process as opposed to focusing on getting the "correct answer" for the performance measures on a given corridor. Therefore, improvements to data elements and measure estimation from the test corridors are the primary results (per project objective #3 in Section 2.0).

Table 5 summarizes the characteristics of the corridors selected for testing the methodology as well as the available data for each location. It identifies the case study corridor locations, project limits and the primary available data that was used for the project. The corridors in the Portland area have incident data available through the Advanced Traffic Management System (ATMS) while the other corridors have incident data summarized in the computer-aided dispatch (CAD) system. Where available, speed data sources for comparison to the HERS-ST model estimates are shown in Table 5. These include the ramp metering speed and volume data along I-5 and automatic traffic recorder (ATR) speed data along the Bend Parkway and the Salmon River Highway. Straight-line charts and video logs were obtained for all of the corridors to assist in locating cross-streets, geometry, ramp location and other specific features along the corridors.

Archived weather data are also available from the weather station at milepoint 72 along US 26, which is approximately 2 miles west of the I-5 corridor. Crash data were obtained for all the corridors.

Table 5. Characteristics of Oregon Test Corridors

Corridor Type	Location	Limits (length)	Primary Available Data
Urban Transportation System	I-5 (Portland)	MP 293.11 to 299.77 (6.7 miles)	• ATMS incident information • Nearby weather station • Straight-line charts and video log • Speed and volume (ramp meter data from mainline and ramps) • Crash data • HERS-ST/HPMS-like data inputs
	Barbur Boulevard (99W) (Portland)	MP 1.33 to 7.81 (6.5 miles)	• ATMS incident information • Straight-line charts and video log • Crash data • HERS-ST/HPMS-like data inputs
Urban Limited Access/ Expressway Corridor	Bend Parkway (US97) (Bend)	MP 133.86 to 141.26 (7.4 miles)	• CAD incident information • Speed and volume (2 ATR stations) • Straight-line charts and video log • Crash data • HERS-ST/HPMS-like data inputs
Urban Signalized Arterial	Powell Boulevard (US26) (Portland)	MP 0.75 to 2.95 (2.2 miles)	• ATMS incident information • Straight-line charts and video log • Crash data • HERS-ST/HPMS-like data inputs
Rural Corridor	Salmon River Highway (ORE 18) (Lincoln City to Valley Junction)	MP -0.41 to MP 24.07 (24.5 miles)	• CAD incident information • Speed and volume (ATR station) • Straight-line charts and video log • Crash data • HERS-ST/HPMS-like data inputs

6.0 INDIVIDUAL TEST CORRIDOR METHODOLOGY FINDINGS

Table 6 summarizes key characteristics and performance measure values for each of the corridors, including the I-5/Barbur Boulevard System based upon the methodology. A spreadsheet ("ODOT Operations Performance Measures.xls") accompanies this report and includes the detailed segment analysis of the HERS-ST input, output and performance measure computation. Column headings and a further description of the spreadsheet are contained in Appendix G. The discussion below describes the findings of the methodology applied to each test corridor. The discussion includes procedural findings as well as quantification of the performance measures for each corridor.

It is important to note that Table 6 begins with **reported roadway inventory information that in some cases appears suspect for some segments along the test corridors.** For example, freeway ADT/lane values are seldom over 25,000 and very rarely found over 30,000 in the United States; however ADT/lane values along I-5 were found up to 33,000. Similarly, along signalized arterials, the most congested range used in the TTI Urban Mobility Study is over 10,000 ADT/land and traffic volumes over approximately 15,000 ADT/lane are considered suspicious. ADT/lane values over 10,000 were found along the signalized arterial Powell Boulevard. These data considerations are discussed in further detail in a later section of this report. They are mentioned at this point **only to clarify that the performance measures were calculated and the methodology was developed using these roadway inventory data inputs. The data values would require further screening and investigation prior to statewide implementation of such a methodology.** These values do not negate the validity of the methodology approach, but rather point to the importance of data quality and review prior to application.

The initial intent was to perform the HERS-ST analysis with two years of data (2001 and 2002). However, because HERS-ST is driven by HPMS-like data that may not change substantially from year-to-year or may simply differ by the factor used for AADT estimation, the HERS-ST analysis was performed for 2002 only. It would be beneficial to run HERS-ST across years to further identify the effect that year-to-year changes in traffic parameters (AADT, K-factor, D-factor, etc.) might have on the operational performance measures computed as part of this methodology test. The ramp meter data (ITS data) were available along I-5 for both 2001 and 2002, and they were investigated over both years.

Appendix H provides further description of data integration and the HERS-ST process used for this study.

A listing of the HERS-ST input data are discussed in Appendix G. These data elements predominantly include a section ID, beginning and ending mileposts for the segment, and HPMS-like data elements. These HPMS-like data elements include, but are not limited to, variables that identify:

- functional class
- rural/urban designation
- facility type
- AADT
- number of lanes
- lane width
- pavement quality
- K-factor
- D-factor
- peak number of lanes
- number of signals
- number of stops
- percent green
- posted speed
- horizontal curvature (extent of curves)
- vertical curvature (extent of curves)

Table 6. Reported Roadway Inventory and Subsequent Performance Measure Calculation

Roadway Inventory/ Performance Measure	Corridor / System					
	I-5		Barbur Blvd		I-5/Barbur System	
Roadway Inventory						
Length (miles)	6.7		6.5		–	
Signal density (signals per mile)	–		4.2		–	
Number of HERS-ST segments	23		96		119	
AADT/lane range	11,700-32,700		3,100-14,700		–	
Posted Speed	50-55		35-45		–	
Operational treatments present (benefits included in total delay)	•Incident patrols •CCTV cameras •Ramp metering		•Actuated sig.		•Incident patrols •CCTV cameras •Ramp metering •Actuated sig.	
Additional Calculations and HERS-ST Output						
Free-flow speed (FFS) range (mph)	56-61		41-46		–	
Annual VMT (1000s)	293,800		60,750		354,600	
Number of travelers[1] (1000s)	27,640		9,400		37,000	
AADT/C (weighted average by VMT)	10		10		10	
V/C (peak period) (weighted avg. by VMT)	0.82		0.47		0.76	
Travel Time Performance Measures	Operational Treatments[2]					
	Without	With	Without	With	Without	With
TTI (weighted average by VMT) Ratio of FFS to peak-period speed	1.82	1.50	1.32	1.32	1.74	1.47
BI (computed with TTI from peak-period speed)						
Lower prediction interval	46%	46%	–	–	–	–
Middle prediction interval	67%	67%	–	–	–	–
Upper prediction interval	89%	89%	–	–	–	–
Speed (mph) Peak-period speed (weighted average by VMT)	12-64 (36)	40	11-48 (37)	37	(36)	39
Average trip travel time (min) Peak-period speed	11	10	11	11	11	10
Travel time (passenger-hours in 1000s)	4,150		1,560		5,700	
Base HERS-ST Delay						
Incident delay (hours in 1000s)	1,600		18		1,618	
Total delay (hours in 1000s)	2,200		442		2,642	
Total delay (hours/1000 VMT)	7.5		7.3		7.5	
Total delay (hours/1000 travelers)	80		47		74.4	
Treatment(s) total delay reduction						
Hours in 1000s	668		6		674	
Hours/1000 VMT	2.3		0.1		1.9	
Hours/1000 travelers	24		0.6		20.1	
Total Delay (includes operational treatments)						
Hours in 1000s	1,540		436		1,976	
Hours/1000 VMT	5.2		7.2		5.6	
Hours/1000 travelers	56		46.4		54.3	

[1]Average vehicle occupancy assumed at 1.25.
[2]"With" operational treatments include those currently in the field.

Table 6. Reported Roadway Inventory and Subsequent Performance Measure Calculation (cont.)

Roadway Inventory/ Performance Measure	Corridor / System					
	Bend Parkway		Powell Blvd		Salmon River Highway	
Roadway Inventory						
Length (miles)	7.4		2.2		24.5	
Signal density (signals per mile)	1.1		3.2		–	
Number of HERS-ST segments	60		21		109	
AADT/lane range	4,200-9,200		9,360-25,600		2,500-9,650	
Posted Speed	45		35-40		25-55	
Operational treatments present (benefits included in total delay)	• Actuated signals (select locations)		• Actuated signals		• Incident patrols	
Additional Calculations and HERS-ST Output						
Free-flow speed (FFS) range (mph)	51		41-46		26-61	
Annual VMT (1000s)	77,900		38,500		99,700	
Number of travelers[1] (1000s)	13,400		21,970		5,100	
AADT/C (weighted average by VMT)	8		33		5	
V/C (peak period) (weighted avg. by VMT)	0.44		1.20		0.50	
Travel Time Performance Measures	Operational Treatments[2]					
	Without	With	Without	With	Without	With
TTI (weighted average by VMT) Ratio of FFS to peak-period speed	1.13	1.13	1.88	1.80	1.16	1.16
BI (computed with TTI from peak-period speed)						
Lower prediction interval	–	–	–	–	–	–
Middle prediction interval	–	–	–	–	–	–
Upper prediction interval	–	–	–	–	–	–
Speed (mph) Peak-period speed (weighted average by VMT)	15-48 (46)	46	1-36 (22)	22	24-58 (50)	50
Average trip travel time (min) Peak-period speed	9	9	6	6	29	29
Travel time (passenger-hours in 1000s)	2,000		1,830		2,470	
Base HERS-ST Delay						
Incident delay (hours in 1000s)	8		78		5	
Total delay (hours in 1000s)	180		1,250		185	
Total delay (hours/1000 VMT)	2.3		32.4		1.9	
Total delay (hours/1000 travelers)	13.4		56.8		36.2	
Treatment(s) total delay reduction						
Hours in 1000s	2		21		2	
Hours/1000 VMT	0.02		0.5		0.02	
Hours/1000 travelers	0.1		0.9		0.5	
Total Delay (includes operational treatments)						
Hours in 1000s	178		1,230		183	
Hours/1000 VMT	2.3		31.9		1.9	
Hours/1000 travelers	13.3		55.9		35.7	

[1]Average vehicle occupancy assumed at 1.25.
[2]"With" operational treatments include those currently in the field.

From these data input, HERS-ST was run to obtain several fundamental performance estimates. HERS-ST was developed by FHWA to obtain performance estimates over large systems (e.g., statewide roadway system). As a result, HERS-ST does not provide delay or speed outputs for individual segments along a particular corridor. Therefore, HERS-ST was run for each segment of each study corridor to obtain the desirable HERS-ST output for each segment. The "Number of HERS-ST segments" row of Table 6 indicates the number of segments, and subsequent runs, that were batched for each study corridor. Code was then written to get the results of the HERS-ST sectional output and add them to the rows of segment data used as input into HERS-ST (see discussion in Appendix H).

The primary HERS-ST output of interest include peak-period speed, counter-peak period speed, off-peak speed, capacities for these three time periods, average effective speed (a 24-hour speed estimate), V/C, vehicle-miles of travel, zero-volume delay, incident delay, "other" delay (due to congestion), and total delay. All of the delay estimates are daily delay rather than peak-period delay. From this HERS-ST output, the performance measures were developed for this project. The HERS-ST input data, HERS-ST output data, and subsequent performance measures calculations are all in one spreadsheet location for each corridor analysis.

6.1 Urban Transportation System (I-5 and Barbur Boulevard; Portland)

The first page of Table 6 presents performance measure calculations for I-5, Barbur Boulevard, and for both roadways considered together to illustrate the methodology applied to a system. The discussion below highlights the key findings for the urban transportation system using the HERS-ST methodology.

The first column of data in Table 6 is for I-5. Free-flow speed (FFS) ranges from 56 to 61 mph. As described in the methodology section of this report, FFS is estimated internally by HERS-ST as a function of maximum allowable speed on a curve, the maximum allowable ride-severity speed, and the maximum speed resulting from speed limits. The FFS considers truck percentages as well. The ODOT Transportation Planning Analysis Unit (TPAU) has created R-code that computes the FFS based on the HERS-ST methodology. Unfortunately, HERS-ST does not output FFS as a data element so this external calculation of FFS is necessary. HERS-ST then computes an estimate of delay due to signals, incidents, congestion and a sum as the total delay. HERS-ST uses the delay estimate and the FFS to estimate the "average effective speed," which is a representative 24-hour speed. HERS-ST also outputs a peak-period speed. The peak-period speed is also presented in Table 6 along with the associated Travel Time Index. HERS-ST does not directly output peak-period delay. Section 7.2 discusses the difficulty experienced in trying to obtain FFS from the ITS data.

It should be noted that in a few segments, the FFS was computed as lower than the peak-period speed. This only occurred for a few segments along I-5. This occurred along 3 southbound sections. They are section ID #001102049325, 001102049952, and 001102049953. This indicates either an error in the R-code or perhaps an error in the HERS-ST software that does not check for this possibility. A FFS less than the peak-period speed results in a Travel Time Index less than 1.00. For this analysis, in these cases the TTI was set to 1.00.

As indicated earlier in Section 6.0, there were also some unusually high ADT/lane values along I-5. These values were as high as 32,700. This indicates an error in either the traffic volume number of lanes, or both.

The Buffer Index is presented as a percent. The discussion in Section 4.0, Step 7, presented the relationship developed for the BI given a TTI for a directional segment of freeway with three lanes or less. Equally important, that section also describes the limited data available for developing the TTI and BI relationship and appropriate use of the graphic. The Texas Transportation Institute (TTI) continues to investigate relationships for signalized facilities, but there are only limited data available at this time.

Table 6 indicates the operational treatments that are present along I-5 (incident patrols, CCTV cameras, ramp metering) and Barbur Boulevard (actuated signals). HERS-ST produces an estimate of incident and total delay. The HERS-ST model is not sensitive to delay reductions due to these operational treatments because the HERS-ST estimates are based upon segment-by-segment travel demand and capacity computations. Therefore, the delay obtained from HERS-ST is treated as a "base" delay (see Figure 1) to which reduction factors can be applied to give benefit for the operational treatments that are present. The benefits used in the Urban Mobility Study for operational treatments were previously shown in Table 1 (ramp metering), Table 2 (freeway service patrols), Table 3 (surveillance cameras), and Table 4 (signal coordination).

The spreadsheet illustrating these calculations shows that the percent delay reduction associated with freeway service patrols (column CZ), surveillance cameras (column DB), ramp metering (column DD), and signal progression (column DF) for the "I-5_Barbur(Hwy91)" worksheet. The percentage of delay reduction is based upon the traffic level (AADT/lane) as shown in Tables 1 through 4. Freeway service patrols and surveillance cameras reduce incident delay, while ramp metering and signal coordination are applied to both recurring and incident delay (total delay). Referring to Table 2, freeway service patrol credit was given along I-5 assuming vehicles cover more than 10 miles each. Surveillance camera delay reduction (Table 3) was allocated assuming 100% system coverage with cameras. Table 6 presents the base HERS-ST delay (both incident and total delay). The incident and total delay are shown in annual hours. Total delay is also shown in hours per 1000 VMT and hours per 1000 travelers. The total delay reduction due to the operational treatments is shown in hours, hours per 1000 VMT and hours per 1000 travelers. The last row of the table shows the total delay after the delay reduction percentages are applied to the base HERS-ST delays.

HERS-ST estimates a large amount of incident delay along I-5 (approximately 73 percent of the total delay). The simulation (QSIM) upon which HERS-ST is based uses an incident rate of approximately 9 incidents per MVMT. The literature on incident characteristics for arterial facilities is scarce. HERS-ST uses the freeway incident distributions to apply to signalized arterials. Assumptions are applied to the freeway incident distributions for application to arterials. The following describes some of these key assumptions from Appendix E of *Sketch Methods for Estimating Incident-Related Impacts* (http://plan2op.fhwa.dot.gov/pdfs/Pdf2/finalrept.pdf) (*2*). The report describes "If the incident is an accident, then it is assumed that 11 percent of the accidents occur within 50 feet of the signal. This percentage is based on Tennessee data on suburban arterials. Although this number might seem low, the data (10,000 accidents) showed that a larger share of accidents occurred at non-signalized intersections along the sections. If the accident does not occur within 50 feet of the signal or the incident is not an accident, then it is assigned a distance from the signal assuming a uniform distribution along the remaining section length. Here, section length is based on the signal density to account for interaction among signals."

The report further describes that an adjustment factor is used to adjust capacity downstream of incidents based on NETSIM experiments. The result is a 57 percent drop in capacity for incidents that occur at the signalized intersection (11 percent of incidents) down to 8 percent when the incidents occur at a distance of greater than or equal to 50 feet from the signalized intersection (89 percent of incidents). Queues do not form at midblock locations nor does the queue spill back to upstream signals. These assumptions are noted in light of the fact that not all signalized corridors may operate in this fashion. The Barbur Boulevard incident delay is estimated by HERS-ST as only 4 percent of the total delay. Referring to Table 4, signal coordination benefit was given along Barbur Boulevard with a signal density between 3 to 6 signals per mile (see cell X147) for traffic actuated signals.

Table 6 also includes the TTI, BI, speed and travel time performance measures after considering the delay reduction due to the operational treatments. For the I-5 corridor, an estimate of the peak delay in hours per 1000 VMT is estimated in cell CY37 of the spreadsheet with the estimate of the FFS and the weighted corridor peak speed. Assuming the delay reduction in the peak period is at least the same rate as found for the full 24-hour periods (2.3 hours per 1000 VMT), the total delay in the peak is computed as 8.5 hours per 1000 VMT in the peak periods. With this delay estimate, and an estimate of the FFS, the peak speed and 24-hour speed are estimated to include the operational improvements. These values, as well as the associated TTI, BI and travel time after the operational treatments are shown for I-5 in Table 6. Similar computations are not included for Barbur because there is only a 0.1 hour/1000 VMT reduction in delay due to the operational improvements and this is not substantial enough to show a change in the measures during the peak period. The measures are averaged together for I-5 and Barbur Boulevard by VMT to provide estimates for the system after the operational treatments are considered. For example, the peak-period speed increases from 36 mph to 39 mph as a result of the operational treatments. The peak-period speed increases from 36 mph to 40 mph along I-5 due to the operational treatments.

An investigation of the spreadsheet calculations shows that delay is often focused around the signalized intersection locations (see bold rows in the spreadsheet for Barbur Boulevard). The total delay in hours per 1,000 vehicle-miles of travel is typically less than 1 for segments when signals are not present (column BR). However, when signals are present on the segment of interest, the total delay seems to "jump" to over 15 hours per 1,000 vehicle-miles of travel. It can be as high as 67 hours per 1,000 vehicle-miles of travel. This is a result of doing a segment-by-segment analysis. For the entire corridor, however, these segment "spikes" in delay are weighted to provide more intuitive corridor results. This suggests that the HERS-ST model is likely more adequate for corridor analysis and estimates rather than for particular segments. This is particularly true for signalized segments.

The measures for the I-5/Barbur Boulevard are weighted together by VMT. In the final weighted analysis, the total delay reduction along the corridor results in approximately 2 hours of delay reduction per 1000 VMT or approximately 20 hours of total delay reduction per 1000 travelers (assuming an average vehicle occupancy of 1.25). The total delay adjusted for the presence of operational treatments is 5.6 hours per 1000 VMT and 54 hours per 1000 travelers.

The I-5 corridor also contained real-time ITS data that are used for ramp metering. Section 7.0 of this report discusses the use of the volume and speed ITS data and compares the total delay results from HERS-ST with results obtained from the ramp metering data.

6.2 Urban Limited Access/Expressway Corridor (Bend Parkway; Bend)

The second page of Table 6 summarizes the reported roadway inventory and subsequent performance measure calculation for Bend Parkway, Powell Boulevard, and Salmon River Highway. Bend Parkway provided a unique opportunity to investigate the application of delay reduction due to operational treatments. Consideration was given to providing some delay reduction due to freeway service patrols along the Bend Parkway. However, the maximum AADT/lane along the Bend Parkway is around 9,000 and benefits for service patrols are not realized until AADT/lane values are over 15,000 ADT/lane (for the freeway environment as shown in Table 2). Delay reduction benefit for signal coordination is provided in the spreadsheet workbook “Bend_Parkway(Hwy4)” for actuated signals along portions of the beginning and end of the Parkway where signal density is approximately 3. Rows 5, 9-13, and 57-58 of the spreadsheet are highlighted in purple and represent segments over which the actuated signal delay reduction are assumed to apply. This demonstrates the ability to introduce location-specific operational treatments along a corridor with the methodology. Column CZ shows the actual percentage of benefit given for each location given the signal density for traffic actuation shown in Table 4. The signal density is less than 3 from mileposts 139.46 to 140.87 and the signal density is more than 3 from mileposts 134.08 to 134.82. The total delay reduction due to actuated signals along the corridor is relatively small at 1,900 annual hours. The delay reduction was too small to indicate a change in the 24-hour or peak-period speed; therefore, the non-delay performance measures remain unchanged due to the presence of the operational treatments.

There are two ATR stations along the Bend Parkway that provide speed and volume information. ATR 09-007 is located at MP 135.95 (S. of Empire Boulevard) and ATR 09-009 is located at MP 137.36 (S. of Revere Exit). The worksheet for Bend Parkway shows two green rows where the ATRs are located. The AADTs for these rows (in column I) are from the ATR for 2002. The detectors were not collecting speed in 2002. For this study, 51 days of volume and speed data were collected at these ATR locations to compare to the HERS-ST estimates. Speed and volume were collected from February 24, 2004 to April 14, 2004. Table 7 shows the ATR and HERS-ST speed and volume estimates along Bend Parkway. The average speed and ADT for ATR 09-007 from these days were 54 mph and 40,800, respectively. The average speed and ADT for ATR 09-009 were 51 mph and 38,000, respectively. The 2002 ADTs at these locations were 36,700 (ATR 09-007) and 34,800 (ATR 09-009) and HERS-ST estimated a 24-hour speed of 48 mph for both of these locations. Although these estimates are fairly similar, it appears that HERS-ST is under-estimating 24-hour speeds if a speed estimate of 48 mph is being produced for ADTs in the range of 35,000 to 37,000 because speeds of up to 54 mph were observed at an ADT of

40,800. Of course this assumes the ATR data are calibrated and all other geometric conditions are coded into HERS-ST as they appear in the field and there are no changes between 2002 and 2004.

Table 7. ATR and HERS-ST Speed and ADT Estimates along Bend Parkway

ART Number	Milepoint	Estimated 2004 Speed[1]	Estimated 2004 ADT[1]	HERS-ST 2002 24-hour Speed	HERS-ST 2002 ADT
09-007	135.95	54	40,800	48	36,700
09-009	137.36	51	38,000	48	34,800

[1]2004 based on 51 days of data.

Closer inspection of both ATR stations indicated that there was very low variability in traffic speeds from hour-to-hour. The speed data by speed bin did seem to indicate that there were speed data being collected for all the bins. It is possible that the traffic along this corridor has low variability. ODOT personnel in the Transportation Data Section could likely identify if the data may be suspect. It would be useful to measure the speeds and volumes over a small time period adjacent to the ATRs with road tubes or a similar technology as a calibration check. Most DOTs do not obtain speed data from their ATRs, and this is a relatively easy and beneficial way to obtain year-round speed estimates at select locations along this corridor.

6.3 Urban Signalized Arterial (Powell Boulevard; Portland)

The second page of Table 6 summarizes the calculation of the performance measures along Powell Boulevard. This was the shortest study corridor (2.2 miles) and the signal density along the corridor was approximately 3 signals per mile. Delay reduction benefit along this corridor was given for actuated signals in a similar manner as performed for Barbur Boulevard. Column CZ of the "Powell_Blvd(Hwy26)" worksheet shows the percent reduction given on each segment for the AADT/lane (column CG). The percent reduction is either 1.5 or 1.9 per Table 4. This results in a total of nearly 21,000 hours of delay reduction due to actuated signals (0.5 hour per 1,000 VMT). This is slightly more benefit than credited along Barbur Boulevard. As with the Bend Parkway corridor, the delay reduction was too small to indicate a change in the 24-hour or peak-period speed; therefore, the performance measures remain unchanged due to the presence of the operational treatments.

The AADT/lane values along Powell Boulevard appear suspiciously high. These high travel demands are the cause for the increased delay and subsequently higher delay reduction on Powell Boulevard than along Barbur Boulevard. The highest level of congestion on arterial facilities is greater than 10,000 ADT/lane according to the UMS methodology. The ADT/lane for the segments along Powell where signals are present is at or near this level. The ADT/lane values are as high as 25,000 ADT/lane for some of the unsignalized segments. These very high values would indicate either an incorrect number of lanes or an AADT volume that is too high. If the ADT/lane values were reduced, the results for the delay reduction would be lower. The speeds would also be higher along the corridor if the travel demand were reduced. Though the input roadway data were reviewed for accuracy, it appears that the Powell Boulevard location might require further review, particularly for the ADT/lane locations over 25,000. This demonstrates the usefulness of the AADT/lane measure as an estimate of the reliability of the roadway segment inventory data.

It should also be noted that it is possible that for delay on signalized arterials (Powell, Barbur, and along the segments on Bend Parkway where there are signals), HERS-ST is over-estimating the delay due to incidents along signalized arterials because the freeway incident distribution is used and diversion on arterials is more likely than in a freeway environment.

Unfortunately, speed data were not available for comparison with the HERS-ST model outputs. It would be useful to obtain such speed estimates as a method to compare and calibrate the HERS-ST speed estimates.

6.4 Rural Corridor (Salmon River Highway; Lincoln City to Valley Junction)

Salmon River Highway is the longest corridor at nearly 25 miles. The results of the Salmon River Highway analysis are located on the second page of Table 6. Rural incident response is performed along this rural corridor through roving patrols that provide motorist assistance. The delay reduction factors provided in Table 2 are for roving freeway service patrols so they are not directly applicable to the rural two-lane highway environment. Recent research by Dr. Bertini at Portland State University has identified the benefits of the ODOT Region 2 incident response program (*4*). As part of this work, a relationship between the duration of the incident and the subsequent delay in vehicle-hours was developed for the Salmon River Highway (ORE 18). The report also notes that the pre-incident response program duration was 2.07 hours and the post-incident response program incident duration was 1.42 hours. Computing the estimated vehicle-hours for these two duration values provides a 47 percent delay reduction due to the rural incident response program along ORE 18. Therefore, the delay reduction factor applied to incident delay along this facility was 47 percent. These computations, and subsequent delay reduction in hours per segment, are shown in columns CZ to DC in the "Salmon_River(Hwy39)" worksheet. This results in an annual delay reduction of 2,400 hours as shown in Table 6. The delay reduction was too small to indicate a change in the 24-hour or peak-period speed; therefore, the performance measures remain unchanged due to the presence of the operational treatments.

HERS-ST initially estimated only 5,200 hours of base incident delay for ORE 18. HERS-ST uses a queuing analysis methodology for estimating incident impacts. It would appear that the relatively low travel levels are adequately handled during the incident conditions; therefore, relatively low values of incident delay are realized on each segment. The 24-hour average speed is 50 mph and the facility is posted at 45 to 55 mph; therefore, these values would indicate that the corridor is relatively uncongested.

There is one ATR along the Salmon River Highway at milepoint 23.76. The location of this ATR is shown in the spreadsheet with the row highlighted in green. Fourteen days of speed data were obtained from the speed detector from April 7, 2004 to April 21, 2004 for this study. The speed averaged 47 mph from the ATR, which compares well to the 50 mph corridor 24-hour speed estimated from HERS-ST. The ATR ADT was 18,800 for the two weeks of data, while the 2002 AADT used in HERS-ST was 19,300 and the segment 24-hour period speed was 41 mph. As with the Bend Parkway ATR data, there was very little variability in the ATR speeds by hour and across days. It would be beneficial to ensure the ATRs are calibrated. As stated previously, the ATR could be a valuable source of speed data for use in the future methodology application.

Because ORE 18 is a rural corridor that is substantially traveled during weekends/holidays, an attempt was made to investigate performance measure changes within HERS-ST during average conditions versus weekend/holiday traffic. TTI and ODOT personnel investigated this further along this rural corridor. HERS-ST has been initially run to obtain "average" conditions because the AADT, K-factor, and D-factor used were theoretically based on all days. The idea was to re-run HERS-ST with conditions that might be more representative to weekend/holiday travel and then compare those results to the initial HERS-ST run. The highest hours of traffic along this corridor were during weekend/holidays. Though the K-factors were similar to those that were used in the initial HERS-ST analysis, a D-factor of approximately 62 might be more representative of the weekend/holiday traffic rather than the value of approximately 50 that was used for the initial HERS-ST run.

HERS-ST was re-run with K-factors of 9 and 11 and a range of D-factors from 50 to 65. The total delay results did not differ when the K-factor was changed (for a given D-factor), but there was variability in the results when the D-factor was altered and the K-factor was kept constant. It appears that the D-factor is the controlling factor along this corridor in the HERS-ST analysis. It appears that an increased D-factor might make sense along this corridor because the weekend splits are probably more dramatic than the weekdays. This corridor is also relatively uncongested so it makes some sense that the K-factor might have less influence. It would appear that the D-factor has more influence than the K-factor on the results of this section, and it appears that altering the D-factor might be a method to estimate weekend/holiday travel conditions on rural corridors of this sort in the methodology. Further analysis of the K-factor and D-factor over larger ranges would be necessary for a more thorough sensitivity analysis.

7.0 INVESTIGATION AND FINDINGS OF RAMP METERING (REAL-TIME) SPEED AND VOLUME DATA

Real-time data are available along the I-5 test corridor in Portland along the test corridor. This provided the opportunity to compare the results from the real-time ramp metering data to the estimates from HERS-ST modeling. This section describes the real-time data quality control and results of this comparison.

7.1 Data Quality Summary

Table 8 and Table 9 show summary quality control statistics for the 2001 and 2002 real-time detector and station data, respectively. In 2001 and 2002, there were seven stations of loop data in the northbound direction. In 2001, there were only two stations of loop data in the southbound direction and in 2002 there were two stations added for a total of four. Eight entrance ramp detectors were present in the northbound direction and two entrance ramp detectors were present in the southbound direction in both 2001 and 2002.

Table 8. Percent of Data Removed for 2001 ITS Data by Detector/Station in the I-5 Test Corridor

Station	Detector	Milepost	Detector Title	Cross Street	Freeway or Entrance Ramp	Volume Percent Removed	Speed Percent Removed	Occupancy Percent Removed
1008	1089	293.18	I5N293.18-ML1	Haines St NB	Freeway	35%	49%	35%
	1090	293.18	I5N293.18-ML2	Haines St NB	Freeway	34%	48%	34%
	1091	293.18	I5N293.18-ML3	Haines St NB	Freeway	34%	49%	34%
1009	1097	293.74	I5N293.74-ML1	Pacific Hwy W NB	Freeway	86%	86%	86%
	1098	293.74	I5N293.74-ML2	Pacific Hwy W NB	Freeway	8%	8%	7%
	1099	293.74	I5N293.74-ML3	Pacific Hwy W NB	Freeway	7%	7%	7%
1010	1105	295.18	I5N295.18-ML1	Capital Hwy NB	Freeway	28%	28%	27%
	1106	295.18	I5N295.18-ML2	Capital Hwy NB	Freeway	5%	5%	5%
	1107	295.18	I5N295.18-ML3	Capital Hwy NB	Freeway	7%	7%	7%
1011	1113	296.26	I5N296.26-ML1	Spring Garden St NB	Freeway	11%	12%	11%
	1114	296.26	I5N296.26-ML2	Spring Garden St NB	Freeway	11%	11%	11%
	1115	296.26	I5N296.26-ML3	Spring Garden St NB	Freeway	11%	11%	11%
1012	1121	296.6	I5N296.60-ML1	Multnomah Blvd NB	Freeway	14%	17%	14%
	1122	296.6	I5N296.60-ML2	Multnomah Blvd NB	Freeway	14%	14%	14%
	1123	296.6	I5N296.60-ML3	Multnomah Blvd NB	Freeway	14%	14%	14%
1013	1129	297.33	I5N297.33-ML1	Terwilliger Blvd NB	Freeway	7%	7%	7%
	1130	297.33	I5N297.33-ML2	Terwilliger Blvd NB	Freeway	7%	7%	7%
	1131	297.33	I5N297.33-ML3	Terwilliger Blvd NB	Freeway	8%	8%	8%
1015	1145	299.7	I5N299.70-ML1	Macadam Ave NB	Freeway	3%	3%	3%
	1146	299.7	I5N299.70-ML2	Macadam Ave NB	Freeway	3%	3%	3%
1105	1770	293.36	I5S293.36-ML1	ORE 99W SB	Freeway	100%	100%	100%
	1771	293.36	I5S293.36-ML2	ORE 99W SB	Freeway	100%	100%	100%
	1772	293.36	I5S293.36-ML3	ORE 99W SB	Freeway	100%	100%	100%
1036	1306	299.25	I5S299.25-ML1	Hood Ave SB	Freeway	4%	4%	4%
	1307	299.25	I5S299.25-ML2	Hood Ave SB	Freeway	4%	4%	4%
	1308	299.25	I5S299.25-ML3	Hood Ave SB	Freeway	4%	4%	4%
5008	1094	293.18	I5N293.18-ENTD1	Haines St NB	Ramp	37%	N/A	N/A
5009	1102	293.74	I5N293.74-ENTD1	Pacific Hwy W NB	Ramp	65%	N/A	N/A
5010	1110	295.18	I5N295.18-ENTD1	Capital Hwy NB	Ramp	9%	N/A	N/A
5011	1118	296.26	I5N296.26-ENTD1	Spring Garden St NB	Ramp	12%	N/A	N/A
5012	1126	296.6	I5N296.60-ENTD1	Multnomah Blvd NB	Ramp	14%	N/A	N/A
5013	1134	297.33	I5N297.33-ENTD1	Terwilliger Blvd NB	Ramp	9%	N/A	N/A
5014	1142	297.33	I5N297.33-ENTD1	Bertha NB	Ramp	9%	N/A	N/A
5015	1149	299.7	I5N299.70-ENTD1	Macadam Ave NB	Ramp	4%	N/A	N/A
5036	1311	299.25	I5S299.25-ENTD1	Hood Ave SB	Ramp	5%	N/A	N/A
5105	1775	293.36	I5S293.36-ENTD1	ORE 99W SB	Ramp	100%	N/A	N/A

Note: Shaded areas indicate entrance ramp stations where only volume data are collected.

Table 9. Percent of Data Removed for 2002 ITS Data by Detector/Station in the I-5 Test Corridor

Station	Detector	Milepost	Cross Street	Detector Title	Freeway or Entrance Ramp	Volume Percent Removed	Speed Percent Removed	Occupancy Percent Removed
1008	1089	293.18	Haines St NB	I5N293.18-ML1	Freeway	10%	10%	10%
	1090	293.18	Haines St NB	I5N293.18-ML2	Freeway	9%	9%	9%
	1091	293.18	Haines St NB	I5N293.18-ML3	Freeway	9%	9%	9%
1009	1097	293.74	Pacific Hwy W NB	I5N293.74-ML1	Freeway	52%	54%	40%
	1098	293.74	Pacific Hwy W NB	I5N293.74-ML2	Freeway	9%	9%	9%
	1099	293.74	Pacific Hwy W NB	I5N293.74-ML3	Freeway	29%	29%	28%
1010	1105	295.18	Capital Hwy NB	I5N295.18-ML1	Freeway	31%	38%	30%
	1106	295.18	Capital Hwy NB	I5N295.18-ML2	Freeway	17%	17%	17%
	1107	295.18	Capital Hwy NB	I5N295.18-ML3	Freeway	17%	17%	17%
1011	1113	296.26	Spring Garden St NB	I5N296.26-ML1	Freeway	20%	21%	20%
	1114	296.26	Spring Garden St NB	I5N296.26-ML2	Freeway	20%	20%	20%
	1115	296.26	Spring Garden St NB	I5N296.26-ML3	Freeway	21%	21%	21%
1012	1121	296.6	Multnomah Blvd NB	I5N296.60-ML1	Freeway	11%	16%	11%
	1122	296.6	Multnomah Blvd NB	I5N296.60-ML2	Freeway	11%	11%	11%
	1123	296.6	Multnomah Blvd NB	I5N296.60-ML3	Freeway	12%	13%	12%
1013	1129	297.33	Terwilliger Blvd NB	I5N297.33-ML1	Freeway	10%	10%	10%
	1130	297.33	Terwilliger Blvd NB	I5N297.33-ML2	Freeway	10%	10%	10%
	1131	297.33	Terwilliger Blvd NB	I5N297.33-ML3	Freeway	16%	17%	16%
1015	1145	299.7	Macadam Ave NB	I5N299.70-ML1	Freeway	21%	21%	21%
	1146	299.7	Macadam Ave NB	I5N299.70-ML2	Freeway	21%	21%	21%
1105	1770	293.36	ORE 99W SB	I5S293.36-ML1	Freeway	26%	29%	26%
	1771	293.36	ORE 99W SB	I5S293.36-ML2	Freeway	26%	26%	26%
	1772	293.36	ORE 99W SB	I5S293.36-ML3	Freeway	26%	26%	26%
1107	1777	295.18	Capital Hwy SB	I5S295.18-ML1	Freeway	71%	72%	71%
	1778	295.18	Capital Hwy SB	I5S295.18-ML2	Freeway	71%	71%	71%
	1779	295.18	Capital Hwy SB	I5S295.18-ML3	Freeway	71%	71%	71%
1108	1780	296.26	Spring Garden St SB	I5S296.26-ML1	Freeway	71%	74%	71%
	1781	296.26	Spring Garden St SB	I5S296.26-ML2	Freeway	71%	71%	71%
	1782	296.26	Spring Garden St SB	I5S296.26-ML3	Freeway	71%	71%	71%
1036	1306	299.25	Hood Ave SB	I5S299.25-ML1	Freeway	24%	24%	24%
	1307	299.25	Hood Ave SB	I5S299.25-ML2	Freeway	24%	24%	24%
	1308	299.25	Hood Ave SB	I5S299.25-ML3	Freeway	24%	24%	24%
5008	1094	293.18	I5N293.18-ENTD1	Haines St NB	Ramp	13%	N/A	N/A
5009	1102	293.74	I5N293.74-ENTD1	Pacific Hwy W NB	Ramp	69%	N/A	N/A
5010	1110	295.18	I5N295.18-ENTD1	Capital Hwy NB	Ramp	17%	N/A	N/A
5011	1118	296.26	I5N296.26-ENTD1	Spring Garden St NB	Ramp	21%	N/A	N/A
5012	1126	296.6	I5N296.60-ENTD1	Multnomah Blvd NB	Ramp	12%	N/A	N/A
5013	1134	297.33	I5N297.33-ENTD1	Terwilliger Blvd NB	Ramp	11%	N/A	N/A
5014	1142	297.33	I5N297.33-ENTD1	Bertha NB	Ramp	10%	N/A	N/A
5015	1149	299.7	I5N299.70-ENTD1	Macadam Ave NB	Ramp	21%	N/A	N/A
5036	1311	299.25	I5S299.25-ENTD1	Hood Ave SB	Ramp	24%	N/A	N/A
5105	1775	293.36	I5S293.36-ENTD1	ORE 99W SB	Ramp	27%	N/A	N/A

Note: Shaded areas indicate entrance ramp stations where only volume data are collected.

The researchers received 15-minute aggregated data by detector (lane). The 15-minute data provide volume, speed and occupancy information for the mainline of the freeway and just volume for the entrance ramps. Because the ramps do not provide speed data and also because HERS-ST was run for just the mainline in this project, the entrance ramp volume data were not included in the analysis. The quality control procedures established in the Mobility Monitoring Program (MMP) project (see Appendix C) were applied to the mainline data. According to the system documentation, a value of -999 is reported for volume and speed when the 15-minute period is malfunctioning. Dr. Robert Bertini indicated in recent e-mail correspondence that the loop detectors report a negative error code (-1 or -999) when there is a zero count. He also indicated that the system may be counting large trucks as two vehicles. This would result in a system-wide over-counting, and his research team is evaluating this situation further. TTI found that the -999 values were present throughout all times of the day, and there did not appear to be a pattern in their location. If this is due to zero volume, it is suspicious that these values can occur during peak periods. Because it is not known if/when the -999 values indicated a malfunction, negative values were assumed incorrect, and these data were removed from the dataset.

Table 8 and Table 9 include the percent of volume, speed and occupancy data removed by station/detector. The majority of the removed data is due to the negative values and a much smaller percent of data removal is due to other quality control performed in MMP for suspicious combinations of speed, volume and occupancy. Research continues at Portland State University to investigate this issue. In addition, two sets of station data were available northbound at milepost 297.33. They were named Terwilliger and Bertha and the Terwilliger data were used. It appeared that the data were the same; however, Bertha was missing a small amount of data so the Terwilliger station was used at this location.

Table 8 illustrates that all data were removed from station 1105, indicating that only one station of data were available in the southbound direction. Table 9 (2002) indicates an improvement in the amount of data removed at this station. In addition, two additional stations of data were added to the southbound direction. In the analyses presented in this report, the 2002 values are used to compare to HERS-ST because HERS-ST was run for only the 2002 data. While 2002 data used for illustration purposes, similar computations have been performed for 2001, and they are available to those interested.

7.2 Obtaining Free-flow Speed from Real-time Data

The methodology presented previously described how free-flow speed could be measured directly from real-time detectors when such data are available. Therefore, the free-flow speed by station (averaged lane-by-lane data) was investigated by time of day to obtain an estimate of free-flow speed. The analysis of free-flow speed was quite revealing. The accompanying spreadsheet includes a workbook entitled “FFS from ITS data,” which shows the average speed (for the 2002 year) for each 15-minute period of the year and each station. Typical peak periods (6:00 to 9:00 a.m. and 4:00 to 7:00 p.m.) are highlighted in yellow on the spreadsheet. Intuitively, following any given station from left-to-right (time period to time period), there is generally a decrease in speeds as these peak-periods are compared to the off-peak time periods, albeit by only a few miles per hour in some cases. One station actually has relatively higher speeds in the peak (station 1105) and another has relatively unchanged speeds in the peak (station 1107) compared to the off-peak periods.

It is also not clear how data are aggregated in the field from the initial polling rate (typically 20-seconds, 30-seconds or 1-minutes) to the 15-minute data that was received for analysis. For example, weighting speed by the number of vehicles in each polling cycle within the 15-minute period is necessary to get an accurate speed estimate. Factoring up volumes for missing cycles within the 15-minute period would provide a better estimate of 15-minute volumes. Again, it is not clear if these control procedures are in place (or to what extent). Observation of the early morning speeds indicates substantial variability across stations. In some cases, this variability is striking. For example, station 1012 reports speeds in the upper 30s and lower 40s in the off-peak periods and the speeds are not substantially different during the peak periods. This suggests the possibility of a calibration error in the station. Similar trends in the other stations suggest a similar possibility that would need to be more closely analyzed. Based upon the variability in the free-flow speeds across stations, and the fact that station 1012 has a very low FFS, the research team used the posted speed (column A) as a reference of FFS for the real-time data.

7.3 Analyses of Ramp Metering Data and Calculation of Performance Measures

After identifying that the posted speed would be used as the reference speed for the performance measures, the 15-minute ITS data were analyzed in SAS with the standard methods used in MMP. The data at a given station along the mainline are assumed to be applicable to half the distance to the next station. The process is as follows (see Appendix C for more detail):

1. Summarize data at the detector level across lanes. Average speed is weighted by volume and volumes are factored up according to missing data across lanes.
2. With daily 15-minute station-level data from step #1, VMT, travel time and delay are computed as well as the TTI. A "floor" value of TTI=1.00 is set if the TTI is less than 1.00. Analysis is performed for five periods are identified as:
   - 12:00 a.m. to 6:00 a.m. (early morning),
   - 6:00 a.m. to 9:00 a.m. (morning peak),
   - 9:00 a.m. to 4:00 p.m. (mid-day),
   - 4:00 p.m. to 7:00 p.m. (afternoon peak), and
   - 7:00 p.m. to 12:00 a.m. (late evening).

   Average speed is weighted by volume at the daily period level for the station. Volume is summed up at the daily period level and then factored up for missing 15-minute data in a period. Average TTI is computed by weighted VMT at the daily period level.
3. With daily time period station-level data from step #2, compute the average speed weighted by volume at the yearly period level. The volume is summed up to the yearly period level and factored up for missing days for a period. Average TTI weighted by factored VMT at the yearly period level. Add up factored VMT and factored delay at the yearly period level.
4. With yearly time period station-level data from step #3, average speed is weighted by volume at the station level. The volume is summed up at the station level and factored up for missing periods for a station. Average TTI is weighted by factored VMT at the station level. Add up factored VMT and factored delay at the yearly station level.

5. Section estimates of performance measures are obtained by weighting station-level values by VMT.

To compare the HERS-ST estimates and ITS data measurements, it was necessary to create station lengths that were equivalent in length between the two data sources. HERS-ST used multiple segments and the ITS data have station lengths that did not match. The HERS-ST measures were re-computed for the stations that match with the ITS data. This is done in rows 78 and higher in the "I-5 ITS and HERS-ST comparison" workbook. It was also necessary to re-compute all the performance measures in HERS-ST relative to a free-flow speed equal to the posted speed because the posted speed was used in the ITS data. This is done in columns CE and higher from rows 1 to 73 in the attached spreadsheet. Ensuring the analysis was presenting an "apples-to-apples" comparison between HERS-ST and the ITS data was not a trivial task. This is explained in more detail in the spreadsheet itself and also Appendix G.

Table 10 presents a summary of the performance measures and corridor characteristics from HERS-ST and the ITS data. Total VMT and AADT/lane values are shown first in the table and they differ by approximately 17 percent along the corridor. The Travel Time Index values are presented by station and then averaged for each direction and for the entire corridor.

Disaggregate (by station) performance measure values are shown in the attached spreadsheet for all measures, but only the TTI values are shown here for illustration. Relatively speaking, the results are similar across different measures. Generally, it is noticeable that there is less congestion in the ITS data measures compared to the HERS-ST measures. There are lower travel (AADT/lane, VMT) and increased speeds. This is partly expected because of the source of the data in each case. The modeled data in HERS-ST is estimating the conditions while ITS data are actually measuring what is in the field (assuming the loops are providing reliable information). During incident conditions, for example, vehicles leave the freeway and use alternate routes. This not only results in fewer vehicles being counted by the monitoring systems, it also means the delay that those vehicles experience is not counted (*5*). It is also possible that the HERS-ST estimates are over-estimating delay and congestion. It is also possible that it could be some combination of both of these affects.

7.3.1 Comparison of Delay Between HERS-ST and ITS Data Methods

Estimates of the hours of delay from HERS-ST and the ITS data were then investigated and compared. HERS-ST outputs an estimate of the annual total delay and incident delay (based on an entire day) for the free-flow speed. HERS-ST does not directly output peak-period delay. It does output an estimate of the peak-period speed. It was thought that with the total (peak-period) delay could be estimated with the peak-period speed estimate and the posted speed; however, the delay values from this analysis did not make sense compared to the total delay values. Because of the internal computation of the speed from segment data it is hypothesized that the delay estimate cannot be averaged for the corridor in this manner. The computations of this method are shown in the attached spreadsheet and discussed further in Appendix G. In addition, the HERS-ST estimates were computed based on FFS rather than the posted speed. The ITS delay was computed based on the posted speed. Therefore, even larger differences in delay between ITS data and HERS-ST might be expected because the FFS were generally slightly higher than the posted speeds. It would be ideal if HERS-ST could output the incident and total delay for the peak-period directly.

Table 10. Summary of Performance Measures and Corridor Characteristics for HERS-ST and Real-time Data[1]

Performance Measure/ Corridor or Characteristics	HERS-ST 24-hour	Real-time Data 24-hour	Absolute Difference	HERS-ST Peak-period	Real-time Data Peak-period	Absolute Difference
VMT (1000s)						
Southbound	147,150	121,450	17%	–	42,600	–
Northbound	146,700	121,360	17%	–	44,300	–
Corridor	293,840	242,800	17%	–	86,900	–
AADT/Lane						
Southbound	20,500	16,800	18%	–	–	–
Northbound	20,000	17,300	13%	–	–	–
Corridor	20,000	17,100	16%	–	–	–
TTI (by station)						
1105 (SB)	1.05	1.03	0.02	1.09	1.06	0.03
1107 (SB)	1.14	1.01	0.13	1.28	1.01	0.27
1108 (SB)	1.13	1.01	0.12	1.26	1.02	0.24
1036 (SB)	1.65	1.10	0.55	1.97	1.23	0.74
Southbound	1.34	1.04	0.30	1.45	1.08	0.37
1008 (NB)	1.01	1.01	0.00	1.00	1.02	0.02
1009 (NB)	1.07	1.08	0.01	1.13	1.13	0.00
1010 (NB)	1.12	1.17	0.05	1.24	1.31	0.07
1011 (NB)	1.14	1.06	0.08	1.27	1.14	0.13
1012 (NB)	1.16	1.24	0.08	1.32	1.29	0.03
1013 (NB)	1.20	1.12	0.08	1.39	1.24	0.15
1015 (NB)	1.64	1.19	0.45	1.91	1.38	0.53
Northbound	1.36	1.14	0.22	1.44	1.25	0.19
Corridor	1.35	1.09	0.26	1.45	1.17	0.28
BI						
Southbound	56%	7%	49%	65%	9%	56%
Northbound	59%	19%	40%	65%	25%	40%
Corridor	58%	13%	45%	65%	17%	48%
Speed (mph)						
Southbound	44	59	14	40	57	17
Northbound	42	51	9	38	48	10
Corridor	43	55	12	39	53	14
Travel Time (min)						
Southbound	9	7	2	10	7	3
Northbound	10	8	2	11	8	3
Corridor	9	7	2	10	8	2
Travel Time[2] (passenger-hours in 1000s)	3,310	2,130	36%	–	–	–
V/C						
Southbound	–	–	–	0.83	0.69	–
Northbound	–	–	–	0.82	0.68	–
Corridor	–	–	–	0.82	0.69	–

[1]Results for performance measures above include adjustments for operational treatments except for HERS-ST V/C.
[2]Average vehicle occupancy assumed at 1.25.
Real-time data analysis is performed compared to posted speed, not free-flow speed, due to relatively low free-flow speeds in the real-time data. HERS-ST is compared to FFS.
Stations and sections were adjusted in HERS-ST to “match” the length of real-time data loop locations.

The total delay values presented in Table 11 are from HERS-ST and the ITS data. They show a very large delay difference of 270 percent. As indicated previously, it appears that some of the delay is being missed in the ITS data. This could be caused by diversion to side-streets during incident conditions or it may be due to calibration problems in the ITS data. It is also possible that the HERS-ST estimates are over-estimating delay.

Table 11. Summary of Hours (in 1000s) of Annual Delay as the Sum of Daily Delay for HERS-ST and Real-time Data

Delay	**HERS-ST 24-hour**[1]	**Real-time Data 24-hour**		**Percent Difference**	
Total Delay		MMP Methods		MMP Methods	
Southbound	742	88		750%	
Northbound	801	335		140%	
Corridor	1,540	423		270%	
Incident Delay		TRAC method[2]	ATMS data[2]	TRAC method[2]	ATMS data[2]
Southbound	492	26	3	1,800%	>2,000%
Northbound	526	137	18	300%	>2,000%
Corridor	1,020	163	21	500%	>2,000%
Recurring Delay		TRAC method[2]	ATMS data[2]	TRAC method[2]	ATMS data[2]
Southbound	250	21	21	1,100%	1,100%
Northbound	275	249	135	10%	100%
Corridor	525	270	156	100%	250%

[1] HERS-ST values are based on free-flow speed while real-time data delay is computed relative to posted speed.
[2]Incident delay estimated with two methods—1) TRAC method that designates incident delay when occupancy values are five-or-more percentage points above the median occupancy and 2) ATMS data method that uses actual reported incident data records.

7.3.2 Estimating Incident Delay

The MMP procedure computes an estimate of total delay with the ITS data, but not incident delay specifically. Two methods of estimating incident delay from ITS data have been investigated here. One method developed by researchers at the Washington Transportation Research Center (*6*) uses a purely statistical method for defining what are “normal” (recurring) and “unusual” (non-recurring) conditions. When measured lane occupancies (percentage of the time that a vehicle is detected) are five-or-more percentage points above the median occupancy for a given location and time, delay is assigned as nonrecurring; otherwise it is assigned as recurring. Note that only two categories are possible—incident and recurring—and a more disaggregated look at the causes is not possible with this type of approach.

Generally, lane occupancies near 20 to 30 percent are typical of the beginning of congested conditions, with values above 50 percent indicating significant constrained operations and slow speeds. This process analyzes the amount of delay in the regions where lane occupancies are higher than the median conditions (plus the 5 percentage point factor). The concept is that these conditions are consistent with unusual conditions and that the irregular nature of the conditions is more likely to be caused by an event that could be influenced by a strong operations program. This approach is called the “TRAC” approach in the analysis here.

Cambridge Systematics and TTI have developed another methodology to analyze the sources of delay on a detailed basis (every time period on every segment). Any delay that is evident through the archived traffic data is then assigned to recurring, incident, or weather categories depending on whether the incident or weather events are present at a particular location and time. Each direction of the freeway is analyzed separately. Time/space regions of possible incident influence were created for each incident based upon the incident duration and the number of lanes blocked. Incident time and location were identified from the ATMS incident log along I-5 for the mileposts in the study. The weather station on US 26 was used to identify the length of weather incidents and "flag" those times and locations. The local date and time as well as the surface condition were used from the archived weather data.

The process then identifies delay sources in the following manner:

- Delay is based on the posted speed.
- If no incident or weather flags are present, all delay is assigned as "recurring." If either one or both incident and weather flags are present AND the observed speed is 10 percent higher than the median speed (by location, weekday/weekend, time) all delay is also assigned as "recurring." This assumes that if a weather or incident event exists, but speeds are not "less than normal," the events have no appreciable effect.
- Assign incident delay or weather delay based on flags. If observed speeds are less than the above threshold, then the delay above that associated with the median speed is assumed to be weather-related or incident-related.
- If both incident flags and weather flags are set, split the delay 50-50.

After this process is done, rubbernecking in the opposite direction is accounted for. The process of identifying "regions of possible influence" for the opposite direction is performed.

The results of the "TRAC" and "ATMS" methods are also shown in Table 11 for the incident delay computation compared to the HERS-ST estimate of incident delay. As with the total delay estimates, the method found that the incident delay is computed lower in these methods than is produced in the HERS-ST methodology. Another possible reason for the relatively low "TRAC" method is that it might be that the median occupancy factor for the Portland area should be lower than the 5 percent used. This factor could change by geographic area. The "ATMS" method could also be low for a number of reasons. The primary factor is that there are many more incidents than are recorded. The incident logs are completed by busy ATMS operators. Their primary focus is on maintaining travel conditions to the best level possible.

The researchers investigated the ATMS incident data for I-5, but some records could have been lost if secondary cross route or milepost information was incorrect. Incident rates along I-5 were approximately 3 to 9 per million vehicle miles of travel which may be off by a factor of 10 or more compared to incident rate studies from other large areas.

Parsing the data to the incidents of interest was a difficult task. For example, the primary route designation for I-5 had over 25 different identifying methods (e.g., "I-5," "I5", "i5", etc.). According to the data dictionary on incident recording, key elements are not required in the coding of the incident. These include the milepost of the primary route and secondary route, number of affected lanes, and actual start and actual end. As mentioned previously, another reason for the lower than expected delay is that vehicles avoid an incident on the freeway either by going to another corridor, parallel streets or traveling at some other time.

Table 12 shows the summarized results of the TRAC method showing the percentage of non-recurring and recurring delay. Table 13 illustrates the percent of recurring delay and percent of delay attributed to incidents, rubbernecking and weather conditions.

Table 12. Results of TRAC Method of Computing Delay Estimates with ITS Data (2002 Hours in 1000s)

Corridor Section	Total Delay	Non-recurring Delay	Recurring Delay	Percent Non-recurring	Percent Recurring
Southbound	47	26	21	55%	45%
Northbound	386	137	249	35%	65%
Corridor	433	163	270	38%	62%

Table 13. Results of Delay Estimates with ITS Data and ATMS Incident Data (2002 Hours in 1000s)

Corridor Section	Total Delay	Recurring Delay	Non-recurring Delay			Percent Recurring	Non-recurring Delay		
			Incident	Rubbernecking	Weather		Percent Incident	Percent Rubbernecking	Percent Weather
Southbound	37	21	3	3	10	56%	9%	8%	26%
Northbound	263	135	18	14	96	51%	7%	5%	37%
Corridor	300	156	21	17	106	52%	7%	6%	35%

8.0 DISCUSSION OF V/C IN HERS-ST

HERS-ST estimates peak-period V/C as a function of the K-factor, AADT, and internally-computed capacity. These peak-period values for V/C are shown in Table 6 and Table 10. The values for V/C in this report have not been reduced for the influence of the operational treatments. Most estimation methods, including the Urban Mobility Study, use a delay reduction factor rather than an estimation of capacity improvement due to the operational treatments. Estimates of capacity improvements due to operational improvements could be estimated through micro-simulation. TTI proposes an approach that would incorporate these delay reduction values to estimate the changes in the V/C. This approach would back-calculate V/C out of the HERS-ST equations given the delay estimate after the operational affects have been considered. The following sections identify the location of the equations that would be used in this process.

Table F-4 (Appendix F) presents the equations for travel rate without incidents (recurring delay) for free-flow (non-signalized) facilities. The equations are for the off-peak and peak periods, for ranges of V/C and AADT/C, with independent variables of free-flow speed, AADT/C, bottlenecks per mile (given default values are used in HERS-ST), and three-hour peak-period V/C. Table F-5 (Appendix F) presents the equations for incident delay for peak and off-peak periods for a given number of directional lanes, for ranges of V/C and AADT/C, with independent variables of AADT/C, shoulder factors (given in Table F-1), and three-hour peak-period V/C values. The sum of the recurring delay (Table F-4) and incident delay (Table F-5) gives the estimate of total delay. It is this total delay that is output by HERS-ST for the 24-hour period (not broken out by peak period and off-peak period).

Table F-8 (Appendix F) presents the equations for travel rate without incidents (recurring delay) for signalized arterials. The equations are for the off-peak and peak periods, for ranges of V/C and AADT/C, with independent variables of free-flow speed, zero-volume delay, bottlenecks per mile (given default values are used in HERS-ST), and three-hour peak-period V/C. Table F-9 (Appendix F) presents the equations for incident delay given similar inputs as for recurring delay. The sum of the recurring delay (Table F-4) and incident delay (Table F-5) gives the estimate of total delay. It is this total delay that is output by HERS-ST for the 24-hour period (not broken out by peak period and off-peak period).

For both free-flow (non-signalized) facilities and signalized arterials, if the off-peak period and peak period incident and total delay were provided as output from HERS-ST, then the delay reduction factors could be applied to these values. Given this new delay with the operational treatments considered, these equations could be computed iteratively to compute the V/C that reflects the change in delay. If HERS-ST eventually included operational treatment affects such as ramp metering, HERS-ST could also presumably include the re-calculated V/C as well.

The travel-time based performance measures of speed, travel time, TTI, BI and delay capture the operational treatment affects in a more intuitive fashion than V/C because they are related to travel time and are more understandable and meaningful to the traveling public. It is more difficult for motorists to understand how a reduced V/C affects their trip. Over the years, the HCM has also evolved toward speed and density measures for level-of-service (LOS) computations rather than V/C.

9.0 RECOMMENDATIONS, NEXT STEPS AND SUMMARY OF LESSONS LEARNED FROM METHODOLOGY APPLICATION

In general, the methodology presented here provides a framework for estimating operations performance measures given operational treatments. It should be noted that the test corridors investigated with the methodology included the affects of the existing operational treatments. The methodology could also be used to estimate the affect of future operational treatments. There are some improvements to both the methodology and data elements that can be made to improve the estimation of the performance measures, and these items are discussed below. Finally, section 9.4 describes additional considerations for statewide implementation as well as next steps.

9.1 HERS-ST "Wish List" to Improve HERS-ST ODOT Performance Measure Methodology Efficiency

There are several elements of the methodology that could be improved as improvements are made to HERS-ST by FHWA. Several suggested additions to the HERS-ST would facilitate the methodology for ODOT. These include:

9.1.1 Output Peak-period and Off-peak Period Delay and VMT, Not Just Total Daily Delay

This would allow the methodology to go directly from the peak-period delay estimates to delay reductions based on the operational treatments because it is not possible to back-calculate the peak-period delay because of the confounded internal computations HERS-ST uses to compute delay and FFS (particularly on signalized arterials). For the test corridors performed here, the delay reduction was only substantial along the I-5 corridor. The incident delay should also be provided for the peak-period and off-peak period as well. Having the delay output by incident and total and by peak-period and off-peak (or given the total) would allow for estimating V/C changes with operational treatments as well. Having the peak-period and off-peak period VMT would also allow for weighting performance measure estimates for the corridor.

The next version of HERS-ST (available in late 2004) will output delay by period (peak-period and off-peak period). This will allow for more accurate direct estimates of peak-period delay rather than getting estimates total daily delay (as performed in the attached spreadsheet).

9.1.2 Output Delay at the Section Level

Delay, and all of the associated performance measures are output for the system, not for the individual sections, of a given HERS-ST run. This requires the analyst to batch the HERS-ST for each section and then get the output of interest rather than just running one run for all of the sections.

The ability to get output at the section level will be possible in the next version of HERS-ST (available in late 2004).

9.1.3 Output Free-flow Speed

If FFS were output directly from HERS-ST, there would be no need to back-calculate it through R-code and the exact value being used in HERS-ST would be known by roadway segment.

9.1.4 Incorporate Operational Treatment Effects into HERS-ST

The developers of HERS have developed some relationships for delay that incorporated effects of incident severity and duration of incidents. This early work also incorporated some IDAS effects of these treatments. It may be possible that some of these effects could be eventually incorporated directly into HERS-ST. Presumably the operational measures such as peak-speed, 24-hour speed (average effective speed), delay (incident and recurring, peak period and off-peak period), and V/C could also be output before and after the consideration of the operational treatments.

9.1.5 Ability to Incorporate Local Crash Rate and Incident Rate Information Directly into HERS-ST

HERS-ST develops crash rates and incident rates from previous studies. ODOT has some crash data and incident information available that could potentially provide an estimate of the incident delay estimates if this actual data could be input directly into HERS-ST. It may currently be possible to input some crash rate information directly into HERS-ST for some of the incident delay computations.

9.2 Data Improvement Areas to Enhance Methodology

An estimation technique and/or any simulation tool is certainly sensitive to the quality of the data being input into the model. This section makes some observations of the data elements that were used in this project and how the data collection and data elements might be improved in some cases.

9.2.1 HPMS-like Data Inputs

The HERS-ST analysis is controlled by the level of quality in the HPMS data inputs. These include segment traffic parameters such as AADT, number of lanes, K-factors, D-factors, etc. One relatively quick check of the data is investigating the AADT/lane values. The typical ranges for different congestion levels for arterials and freeways were provided earlier in this report. Very high (or low) values of AADT/lane can provide an indication that there may be suspect traffic volume or number of lanes information. There were incidents of these very high segment AADT/lane values along the Powell Boulevard and I-5 corridors.

Another example of changes made to the HERS-ST input is the percent green time on signalized arterials. The percent green time had a default value of 65 percent for signalized links. This value was thought to be relatively high, and a value of 45 percent was selected based upon an FDOT LOS study as well as professional judgment (*7*). The percent green time has a direct affect on the capacity of the facility and subsequent performance measures. It would be valuable to investigate this factor further and identify percent green time values from signal timing information as this value would change by corridor.

Another key input from the HPMS data is the section length. In some cases, a section length of 0.01 mile (approximately 50 feet) was found (particularly on I-5). Statistics are computed in HERS-ST on a section-by-section basis; therefore, it is imperative that section lengths be accurate as well. There is a need to review the HPMS (and/or ITIS) database to fix these presumably-incorrect short sections.

9.2.2 Automatic Traffic Recorders

Speed and volume data were obtained along two ATR stations on the Bend Parkway and one ATR station along the Salmon River Highway (ORE 18). Most state DOTs do not get speed data from their ATRs. This is valuable information to obtain since the equipment is already in the field. There was low variability in the ATR speeds in both locations across hours of the day. It appeared that there were speeds being collected in the range of speed bins as well as traffic volumes. However, the low variability in the ATR speeds seems suspicious. For example, along Salmon River Highway the speeds were the same on weekends as weekdays and during the peak and off-peak hours. Similar trends were also found along Bend Parkway across hours. It may be that there really is low variability in speeds at these locations and ODOT personnel more familiar with the data and/or the corridor might be more knowledgeable. Alternatively, it could be that there is a need to calibrate the ATR stations.

9.2.3 Crash Data and Incident Data

Crash data for each corridor were provided to the research team. The crash data were summarized by number and rate of total crashes as well as crash types. This information is located in columns BG to BN for each corridor spreadsheet. The crash data were in Excel spreadsheet form with columns of data elements as coded from the police reports. All necessary data elements were present for determining total numbers of crashes as well as severity.

The incident data were obtained from two sources. The computer-aided dispatch (CAD) data were used for the corridors outside of Portland. The ATMS incident logs were used for the corridors within the Portland area. The ATMS incident logs were also used for estimating recurring and incident delay with the real-time data. Several improvements could be made to the ATMS incident log information. The primary route designated in the incident data often had numerous different ways of identifying a given road. Standard name identifiers for the roadways would make the database easier for sorting the incident logs by site. The secondary route was also given in text and was highly variable. The milepost for the secondary route was rarely included. Including the secondary route milepost would assist in identifying exactly where the incident was located especially when a secondary roadway may intersect a primary roadway at more than one location (i.e., I-5 and Barbur Boulevard). The difference between the "confirm time" and the "estimated end time" was used to estimate the incident duration. Recent work by Dr. Bertini indicates that the estimated end time may actually be later in time than the actual end time of the incident because operators continue to get a pop-up reminder to put in the estimated end time if the incident is still in the system (*8*). Review of the data dictionary for the ATMS incident management data indicates that the confirm time, primary milepost, secondary milepost, number of lanes affected, and estimated end time are not required data elements. Requiring these data elements would help ensure the most important incident data elements are included. Though the data are less extensive, the incident data in the CAD database include these data elements as time received, dispatch time, arrival time, and clear time. The location of the incident by milepost is also provided.

The incident logs (whether from CAD or ATMS) were summarized for each corridor and the number of incidents as well as the incident rate per million VMT were computed. These values are shown in the right-most columns of the spreadsheet for each corridor. It is clear that some of the incidents are missing simply because the crash rates computed with the crash data are often much higher than the incident rates and the incident rates theoretically include all types of incidents (including crashes).

9.2.4 Archived Weather Data

As shown in Table 5 there is an archived weather station at milepoint 72 along US 26, which is approximately 2 miles west of the I-5 corridor. This station was used to estimate the hours of delay due to weather along the I-5 corridor with the real-time data. The date, time, and surface condition from this weather station were used in the analysis. The weather station provided columns for many other data elements and many of them were not reporting for the data investigated. Though this did not affect the analysis, it was not clear why there were so many data elements reporting "No Data" (e.g., precipitation accumulation, numerous surface characteristics, sub-surface temperature, water level, etc.).

9.2.5 Real-time Ramp Metering Data (ITS Data)

The real-time data were analyzed for both 2001 and 2002 for this study along the I-5 corridor. During the quality control process, it was observed that -999 values were reported for speed and volume for some stations for some time periods. This condition appeared over any/all time periods across a day, and it did not appear isolated to the data either temporally or spatially. According to the literature describing the system, negative values are supposed to indicate a malfunction. Recent e-mail correspondence with Dr. Robert Bertini indicates that the negative values also appear when there is no volume counted. Though the cause of the negative values is not clear, it appeared that having -999 values occurring at all times throughout the day is curious because it would be very odd for their to be periods of zero volume during peak conditions. Therefore, the -999 values were removed from the dataset. Tables 8 and 9 showed the amount of removed data (either negative or from quality control checks) for both 2001 and 2002, respectively. There is a need to understand what is meant by the negative values and when they occur. Research is underway by Dr. Bertini to further investigate this issue.

Another concern was the limited variability in the 15-minute average speeds for each station as an average of the year. These summaries were investigated to get an estimate of the free-flow speed during off-peak periods. There appeared to be limited variability across a given day. This is shown in an accompanying spreadsheet workbook. This could suggest the need for calibration of the loop detectors if they are not picking up expected changes in the peak periods. Also, some stations were reporting very low speeds (approximately 37 to 43 mph) for an entire day. This also suggests the need for calibration of the detectors.

It is also unclear how the data are summarized when they are aggregated from the local controller unit at the polling cycle (typically 20-seconds, 30-seconds or 1-minute) to the 15-minute aggregation level on which the analysis was performed. If the volume data are not factored up for missing polling cycles within the 15-minute period, traffic volumes would be low. Similarly, if speeds are not weighted for the number of vehicles in each polling cycle, speeds could be incorrect. It is also unclear what can occur at the polling cycle level that would constitute a negative value for the 15-minute reporting of the data (i.e., does one missing polling cycle in a 15-minute period cause a negative value to be reported?).

It would also be useful if meta-data (data about the data) could be included for each 15-minute aggregation of the ramp meter (ITS) data. Such data provides insight into the reliability of the data given the aggregation that was necessary to get to the 15-minute level, and the amount of data that were available. The Texas Transportation Institute can provide research in the area of meta-data needs and standard methods, as needed.

The entrance ramp real-time loop detectors only provide traffic volume at this time. The entrance ramp data were not included in the performance measure analysis for this project beyond the quality control analysis. Speed data on the entrance ramps would also be useful. More importantly it is better to consider what is desirable to measure on the ramps for performance measurement. Queuing is the unique feature on ramps that is impossible to identify with just volume data. Queuing analysis would provide a better estimate of the delay on the ramps. If it were possible to place the ramp detector far enough upstream on the ramp such that it is before the queue, and it can identify the true demand at the ramp location, a volume estimate at that one location would be useful. It could be associated with a free-flow speed for the ramp and delay estimates could be computed. The metering rate would also be useful to know the processing rate of vehicles at the ramp. If the detector is under the traffic queue, there is no way to know when and how the demand is being managed at that location.

Another difficulty on ramps are geometric constraints on speed along the ramp including cloverleafs. This is another reason that the detector would need to be placed upstream of the queue to ensure the effects of the geometric constraints, and not the traffic queue, are being measured by the detector.

9.2.6 Other Potential Data Sources

During the June 17th TAC meeting, it was noted that ODOT was working with the Motor Carrier Division to get their weigh-in-motion (WIM) data. This would also provide a source of data for calibrating or validating the estimates from this study.

There was further discussion about what other data sources would be useful and where they may be located. This would include an inventory of different types of sensors (WIM, ATR, ITS, and traffic signals).

9.3 Further Analysis of Interest for Fine-tuning the Methodology

There are other issues that should be further investigated that could enhance the methodology when applied to roadways in Oregon.

9.3.1 Adjusting Traffic Factors in HERS-ST Input for Weekend/Holiday Conditions

Discussion was provided in Section 6.4 (Salmon River Highway corridor) about the possibility of editing the travel demand factors (AADT, K-factor, D-factor) to be more sensitive to weekends/holiday travel. A quick analysis of this corridor was performed that initially indicates that the D-factor might be different enough for the weekends/holiday conditions that this change could be made on routes with high weekend/holiday travel. Sensitivity analysis in HERS-ST on this topic would require more analysis, but it appears as a promising approach. There was discussion at the June 17th TAC meeting about obtaining factors for weekend and weekday factors, particularly along other rural locations where there may be substantial differences.

It was further suggested at the meeting that there was a need to review K and D factors in the ITIS database for both urban and rural conditions. The possibility of using an urban model was indicated as a possible way to initially obtain K and D factors.

9.3.2 Further Investigation of Free-flow Speed R-code

Unfortunately, HERS-ST does not output FFS directly. R-code has been written by TPAU to compute the FFS for the case study corridors studied here. In some places along I-5 the FFS was found to be less than the 24-hour speed. This rarely occurred, but it either suggests an internal computation error within HERS-ST or the need to review the R-code being used for this computation.

9.3.3 Factors with Local Conditions

The methodology primarily uses delay reduction factors for operational treatments developed from early HERS pre-processors and IDAS databases. These relationships represent the average conditions from the literature from these operational treatments. It is very possible that local knowledge and/or studies of specific corridors may suggest higher or lower delay reduction factors for different operational treatments. For example, local signal progression studies may provide insight that actuated signals provide more benefit than that provided here. It is also possible, and very likely, that different corridors would have different delay reduction factors if there is some local knowledge or study that has been done. As another example, delay reduction due to rural incident patrols were applied along the Salmon River Highway test corridor based on research by Dr. Bertini (*4*).

This study also assumed an average vehicle occupancy of 1.25 based on national averages. This was used to estimate the delay values per 1000 travelers. Local studies or insight could also be introduced to supplement these average conditions with more accurate data based on available studies.

Another area where local knowledge may supplement these results is incident rates for signalized and non-signalized corridors. It would be useful to be able to input this directly into HERS-ST though that is not possible at the moment and HERS-ST uses a modified freeway incident distribution for signalized arterials.

9.3.4 Sensitivity Analysis of HERS-ST

For this study, only the 2002 HERS-ST data were analyzed. It would be useful to do similar analysis of the output measures from HERS-ST to understand the sensitivity of HERS-ST to the traffic parameters that are likely to change from year-to-year. Typically, these would include the travel parameters such as AADT, K-factor, and the D-factor. This might include the number of signals or the percent green time on signalized corridors. A test section could be batched through HERS-ST that includes ranges of these variables, while keeping all other variables the same. This could be done for different facility types as well to see how much this varies by facility type. From the results of the corridor analysis, it is hypothesized that there would be more sensitivity along signalized corridors.

Another sensitivity analysis of interest would be investigating the affects of longer sections of road on the HERS-ST output statistics. This would include an analysis of the affects of lengths double or triple the current sections would have on delay values. This would be particularly useful for the affect of different influence areas for signalized intersections.

9.4 Statewide Application and Next Steps

9.4.1 Keeping a Consistent Speed in the Statewide Application

Any statewide performance measure analysis should keep a consistent source of speed data (and subsequently computed performance measures) because this value will change over time, and it is important to understand the extent that this measure(s) is changing due to the measurement versus due to operational improvements. For example, if HERS-ST is the source for the measures, then the "HERS-ST Speed" should be kept from year-to-year as a data element. When supplemental speed information is available, they can be kept in the database next to the HERS-ST speed. There may even be speeds from more than one other source if different studies or local knowledge might be available. Other speed sources might include the real-time ITS data, floating car studies, ATR, etc. This would provide the opportunity to see trends not only in operational performance from year to year, but to also see how these speed values may differ by data source. This would allow for the calibration of the HERS-ST values with any other data sources that might be present.

9.4.2 Possible "Beta" Version Before Final Distribution

There were some concerns expressed at the Technical Advisory Committee meeting on June 17, 2004 that unreliable data may be indicating that there is an operational problem (rather than an actual problem really existing). To ultimately get a statewide methodology in place, identifying and fixing data issues such as those identified in this report are an inevitable part of the start-up process. It might be possible that the statewide implementation of the estimation procedures could be performed over a year or two or three and the results could be identified as "beta" or "prototype" to allow a review of the process over years and to allow for calibration of the results across years, and at different geographic locations, based on local knowledge or studies before the final "roll-out." This may alleviate some of the concerns about unreliable data indicating problems that are not present.

9.4.3 Future Operations Performance Measures Committee Activities

During the Technical Advisory Committee meeting on June 17, 2004, there was discussion pertaining to the importance of continuing the operations performance measures TAC momentum. There was discussion about identifying the committee, or a sub-set of the committee, to continue this work. The group would follow up on the data improvement issues (section 9.2) and further analysis items (section 9.3) to improve the methodology. After identifying the new committee, one of the first tasks would be to update the data for the test corridors described here and redo the analysis in HERS-ST and re-compute the performance measures to identify changes.

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APPENDIX A

Matrix of Performance Measure Characteristics

ODOT Operation Performance Measures						
Matrix of Measure Characteristics, see "ODOT measures framework text, 12-8-2003.doc" for more information						
Measure	Description	Attributes and Related Points	Dimensions	Misc Elements that may be Considered	Data Elements	
					Corridor	*System/Area*
Travel Time Index (TTI)	Estimates additional time needed to make a trip during a typical peak travel period in comparison to traveling at free-flow speeds.	It affects the traveler. Estimated effects reflect conditions of the physical infrastructure and operations programs. Addresses transportation policy towards more effective use of the existing transportation system.	Percentage of additional travel time in the peak relative to free-flow conditions.	Weather conditions, incident management programs, ramp metering, coordinated traffic signal systems, HOV facilities, or public transportation.	For each section of the corridor: ADT, D factor, K factor, number of lanes, speed, facility type, and an estimate of free-flow speed. Identification of whether operational treatments and/or public transportation facilities are present.	Same as corridor level for all corridors in the system/area. If estimation is necessary (no ITS data) then the following can be used: ADT, peak-period directional split, facility type, number of lanes and free-flow speed.[1]
Travel Delay	Estimates the hours of extra time spent traveling as a result of congestion.	Travel delay has many of the same attributes as the travel time index. Travel delay may be more applicable in areas that target dense development patterns. Travel delay is sensitive to the total amount of travel and, therefore, is sensitive to the effects of different land use patterns. The measure might be difficult to use in a corridor or sub-area. As with all the measures listed here, it can be used to prioritize the relative need of different areas on the system relative to one another.	Total extra travel time in hours. At the corridor level, it might be hours per mile. At the system/area level, it might be total hours, hours per person or per 1,000 travelers.	See above.	See above.[1]	See above.
Buffer Index (BI)	Estimates the additional time that a traveler needs to budget during peak-period travel to be assured of arriving on time with a 95 percent confidence. Buffer Index is a measure of travel reliability, which is becoming an increasingly important policy issue because of concerns about the effects of congestion on economic development given the importance of just-in-time delivery to manufacturing processes.	The measure is sensitive to operations programs (ramp metering, incident management), and it can be applied to a system/area or corridor level analysis. Similar to the TTI, it measures the effects of congestion on the traveler. It has the potential for addressing the effects of travel demand management and transit on dedicated right-of-way.	Percentage of additional time a traveler needs to budget that is a function of the average travel rate and the 95th percentile travel rate as measured with ITS data.	See above.	See above.[1]	See above.
V/C	Estimates the ratio between the existing volume and capacity for a section of roadway.	V/C has been recognized in the 1999 Oregon Highway Plan as a mobility standard by highway classification and area type. Methodologies for calculating V/C are well established. V/C does not directly measure how the individual traveler is affected by congestion. It estimates the relationship between the physical infrastructure (supply) and traffic volume (demand). It can be calculated to include operations programs. It is hard to communicate to the public because of limited meaning to the traveler.	Dimensionless ratio of the volume to capacity. Can also be expressed as a volume percentage above/below capacity.	See above.	See above.[1] Capacity estimate as well.	See above. Capacity estimate as well.
Travel Time	Time it takes for a vehicle to traverse a given distance. Can be measured in person-hours for estimating area-wide impacts.	It is sensitive to operational treatments. Travel time for a given trip is understandable to the traveler.	Minutes, hours, or person-hours.	See above.	Length, speed, volume, and occupancy.	Length, speed, volume, and occupancy.
Speed	The rate of travel over a given distance.	It is sensitive to operational treatments. Speed for a given trip is understandable to the traveler.	Miles per hour.	See above.	Speed.	Speed.

[1]Corridors/areas with operational treatments and/or where public transportation facilities are present can also be used.

Potential ODOT Data Sources	Estimation Procedures		Location	
	Corridor	System/Area	Urban	Rural
ADTs, K and D factors: ATRs, 48-hour counts, ATMS; Facility type, number of lanes: State Highway Inventory and Classification; Speed: 48-hour counts, ATMS, WIM; Weather conditions; Corridor/area identification of operational treatments, transit ridership: ODOT staff	ITS data are used to measure speed and traffic volumes for the peak periods along the sections of the corridor. VMT can be used to weight across sections. Corridors with and without operational treatments or public transportation can be compared to estimate the benefit of these treatments.	A process similar to the corridor analysis is used. VMT is used to weight all corridors together that make up the system or area.	Ideally, TTI will be measured using ITS data in urban areas (especially Portland).	Rural roadways will generally be at free-flow (TTI=1.0) unless there is an incident or slow-moving vehicle. Therefore, incident management programs are anticipated to have the most operational benefit in rural areas. Delay reduction due to incident management for rural conditions will be investigated (see travel delay measure below). As the need arises and rural areas become instrumented, TTI can be measured directly from ITS data.[2]
See above.	See above for the use of ITS data for corridor analysis. Depending upon the extent and accuracy of available data, relationships could be developed that investigate the impact of independent variables such as crash rates, presence of incident management programs, presence of ramp metering, rural/urban, roadway type, terrain, and others on travel delay.	See above. Depending upon the extent and accuracy of available data, tables similar to those presented as Table 6 and Table 7 of the 1999 Oregon Highway Plan could be developed to summarize average travel delay changes by the conditions of interest (e.g., rural/urban, with or without operational improvements, inside/outside growth boundary).	Ideally, Travel delay will be measured using ITS data in urban areas (especially Portland).	Rural roadways will generally be at free-flow (no travel delay) unless there is an incident or slow-moving vehicle. Therefore, incident programs are anticipated to have the most operational benefit in rural areas. Delay reduction due to incident management for rural conditions will be investigated. One starting point will be delay reduction rates for rural incident response programs in Region 2 based on work performed by Robert Bertini and Galen McGill. As the need arises and rural areas become instrumented, travel delay can be estimated directly from ITS data, which will provide a clearer picture of incident management impacts in the rural areas.[2]
See above.	Research is underway to better understand the relationship between TTI and Buffer Index for various cities and corridors where ITS data are available. Relationships between TTI and Buffer Index are also being investigated when incident management and/or ramp metering are present and not present. As an equation, this might be expressed as: Buffer Index = (x)(TTI) - (y)(Incident Management Coverage) - (z)(Ramp metering Coverage) ± Incident Rate ± Crash Rate. Where data exists, this relationship could be investigated throughout facilities in Oregon. Comparison could also be made to such a relationship that is developed based upon archived data sources in the Portland area. Investigating the relationship in areas with/without archived data will likely provide insight into how the measure can be estimated with more confidence with detailed archived data when it is available.	A process similar to corridor analysis would be used. VMT or PMT would be used to weight all corridors together that make up the system or area.	Ideally, Buffer Index will be measured using ITS data in urban areas (especially Portland).	Rural roadways will generally be at free-flow (Buffer Index=0) unless there is an incident or slow-moving vehicle. Therefore, incident management programs are anticipated to have the most operational benefit in rural areas. Buffer Index reduction due to incident management will be investigated (discussed under "estimation procedure"). As the need arises and rural areas become instrumented, Buffer Index can be measured directly from ITS data.[2]
See above. Capacity from the State Highway Inventory and Classification log.	Depending upon the extent and accuracy of available data, relationships could be developed that investigate the effect of independent variables such as crash rates, presence of incident management programs, presence of ramp metering, rural/urban, roadway type, terrain, and others on V/C.	Depending upon the extent and accuracy of available data, tables similar to those presented as Table 6 and Table 7 of the 1999 Oregon Highway Plan could be developed to summarize average V/C changes by the conditions of interest (e.g., rural/urban, with or without operational improvements, inside/outside growth boundary).	Ideally, V/C will be measured using ITS data in urban areas (especially Portland).	Rural roadways will generally be at free-flow and below capacity (V/C<1.0) unless there is an incident (lane closure) or slow-moving vehicle. Therefore, incident management programs are anticipated to have the most operational benefit in rural areas. V/C reduction due to incident management will be investigated (discussed under "estimation procedure"). As the need arises and rural areas become instrumented, V/C can be estimated directly from ITS volume data and updated capacity estimates.[2]
See above.	ITS data are used to measure speed and traffic volumes for the peak periods along the sections of the corridor. VMT can be used to weight across sections. Corridors with and without operational treatments or public transportation can be compared to estimate the benefit of these treatments. When ITS data are not available or unreliable, a HERS-ST estimation procedure can be used.	A process similar to the corridor analysis is used. VMT is used to weight all corridors together that make up the system or area. When ITS data are not available or unreliable, a HERS-ST estimation procedure can be used.	Ideally, TTI will be measured using ITS data in urban areas (especially Portland). When ITS data are not available or unreliable, a HERS-ST estimation procedure can be used.	Rural roadways will generally be at free-flow unless there is an incident or slow-moving vehicle. Therefore, incident management programs are anticipated to have the most operational benefit in rural areas. Delay reduction due to incident management for rural conditions will be investigated (see travel delay measure below). As the need arises and rural areas become instrumented, TTI can be measured directly from ITS data.[2]
See above.	ITS data are used to measure speed and traffic volumes for the peak periods along the sections of the corridor. VMT can be used to weight across sections. Corridors with and without operational treatments or public transportation can be compared to estimate the benefit of these treatments. When ITS data are not available or unreliable, a HERS-ST estimation procedure can be used.	A process similar to the corridor analysis is used. VMT is used to weight all corridors together that make up the system or area. When ITS data are not available or unreliable, a HERS-ST estimation procedure can be used.	Ideally, TTI will be measured using ITS data in urban areas (especially Portland). When ITS data are not available or unreliable, a HERS-ST estimation procedure can be used.	Rural roadways will generally be at free-flow unless there is an incident or slow-moving vehicle. Therefore, incident management programs are anticipated to have the most operational benefit in rural areas. Delay reduction due to incident management for rural conditions will be investigated (see travel delay measure below). As the need arises and rural areas become instrumented, TTI can be measured directly from ITS data.[2]

[2]Special events and/or the tourist season may also impact rural roadway operations. The impacts on freight operations could also be investigated in the rural areas along primary freight corridors during select time periods.

APPENDIX B

Spreadsheet of ODOT Data Sources

DATA	TYPE OF DATA	DATA SOURCE	PURPOSE OF THE DATA	OWNER	CONTACT
Continuous Volumes	Hourly volume by direction by lane by hour	Permanent collection Stations (ATR's). There are ~140 stations across the state ~10 traffic signals are set up as ATR's	Part of Traffic Count Program Used to create Seasonal Factors to factor short term counts Used to project system wide changes Used to supplement directional data in the HPMS Database Monthly reports created from data Summaries Published in the Traffic Volume Tables	Traffic Monitoring	Tim Thex
Continuous Speed and Length	vehicle speed and lengths are binned into hourly groups	Permanent collection Stations (ATR's). There are ~10 stations across the state that collect this data	Data provided to Traffic Management for reporting purposes	Traffic Monitoring	Tim Thex
Short term counts	48 hour, axle only counts	Road tubes collect a 48 hour axle hit total at locations throughout the state at a three year interval	Data is converted to Average Annual Daily Traffic. Data is published in the Traffic Volume Tables. Volumes used to calculate VMT and growth factors. Volumes used to calculate crash rates.	Traffic Monitoring	Tim Thex
Short term classification Counts	Hourly volumes of 13 types of vehicles for 24 hour duration	People visually collect data on handwritten sheets. Counts are located throughout the state at a three year interval. Project counts are done as requested.	Data supplements the HPMS Database Used to create Axle correction factors for short-term counts	Traffic Monitoring	Tim Thex
Continuous Volumes and average speed. Occupancy	Volume by lane reported in 15 minute, hourly, and daily intervals. Average speed and occupancy per interval is also reported.	ATMS Ramp Meters Includes mainline and ramps	Data used for tuning metering times Data used to estimate travel time Data used for other Traffic Engineering calculations	REG 1	Jack Marchant
ODOT Incident Management (Portland) ODOT Device Management (Portland	Text box for details about incidents such as stalls, closures, and crashes. Details may include time of incident, dispatch time, incident clear time.	ATMS	Incident Data secondary in purpose to the record keeping system for managing devices such as cameras, vms, and ramp meters.	REG 1	Richard Santana

Safety Management System	number identifying a safety problem	Crash data: Number and severity Volume data: AADT	Data used for identifying system safety needs	Traffic Management	Chris Monsere
Vehicle weight, class, axle spacing, and speed	individual records per vehicle and lane	24 Weigh in Motion sites using load cell technology	Data used for Federal Reporting. Data used for preclearance program	Motor Carrier	Walt Collier
Dispatch records: ODOT(non Portland) starting 1995 and OSP(state wide) starting 1990	every call assigned a #, location, call type, county, date, time dispatched, time arrived, time cleared and other information.	Computer Aided Dispatch Database	Automated way to record and archive dispatch information. Various reports	OSP	Richard Peek
Crashed on the State System Fatalities on entire system	Crash Rates for State System segments. Fatality statistics	DMV crash reports, OSP reports	Crash Rates used as an input for the Safety Management System Federal Reporting	CARS Unit	Mark Wills
State Highway Inventory and Classification	Inventory of roadway features by mile point that includes: number of lanes, lane widths, functional class, type of pavement, intersecting roads, and other features of interest.	Physical inventory, survey data, construction plans, etc.	Data used as a record of existing hwy features. Various reports are generated from this information	RICS Unit	Heather King
Weather Data	Depending on site: Temperature, Dew point, Precipitation, Relative humidity, Visibility, Average wind speed, Wind gusts, Wind direction	RWIS	Information posted to Trip Check Web Site.	IS Unit	John Lingerfelt
HTCRS	Traveler information, road closures, road restrictions, construction, incidents, Truck information, weather warnings, etc.	Information called into ODOT Dispatch and District offices.	Information posted to Trip Check Web Site, road condition phone line	ITS Unit	Larry McKinley

APPENDIX C
Definition and Discussion of Performance Measures

Travel Time Index (TTI)

Travel Time Index is a comparison between the travel conditions in the peak period to free-flow conditions. The measure can be averaged for freeways and arterial streets using the amount of travel on each portion of the network. An average corridor value can be developed using the number of persons using each facility type (or modes) to calculate the weighted average of the conditions on adjacent facilities. The corridor values can be computed for hourly conditions and weighted by the number of travelers to estimate peak-period or daily index values.

The travel time index in Equation 1 compares measured travel rates to free-flow conditions for any combination of freeways and arterial streets. Index values can be related to the general public as an indicator of the length of extra time spent in the transportation system during a trip. Vehicle travel or person travel (measured in miles traveled on each part of the system) can be used as the weighting factor. Equation 1 illustrates a relatively simple version of the calculation using vehicle-miles of travel (VMT), but person miles could also be used, as could a value of time calculation that incorporates person and freight travel.

$$\text{Travel Time Index} = \frac{\left(\dfrac{\text{Freeway Travel Rate}}{\text{Freeway Free-flow Rate}} \times \text{Freeway Peak Period VMT}\right) + \left(\dfrac{\text{Principal Arterial Street Travel Rate}}{\text{Principal Arterial Street Free-flow Rate}} \times \text{Principal Arterial Street Peak Period VMT}\right)}{\left(\text{Freeway Peak Period VMT} + \text{Principal Arterial Street Peak Period VMT}\right)} \qquad (1)$$

When measured from ITS speed and volume data or when estimated from models, the TTI uses the units of travel rate due to the ease of mathematical calculation from section speeds. The value in Equation 1 indicates the ratio of peak travel time to free-flow travel time. The peak-period value is calculated as a weighted average for all travel (vehicle-miles of travel) in the time period of interest. In addition to speed and volume, other necessary data elements for calculation with ITS data include an indication of whether the roadway is a freeway or arterial (facility type), and the number of lanes in each direction along the segment. Travel time measured directly from probe vehicles or from toll tag reader (also known as automated vehicle identification) is preferable to speed data derived from point data collection sources. Current deployments of toll tag reader systems are limited however to only a few cities.

Average effective speed can be estimated when ITS data are not available. "Average effective speed" is the term used for an estimate of the operating speed as approximated by the Highway Economic Requirements System—State Version (HERS-ST) (http://www.fhwa.dot.gov/infrastructure/asstmgmt/hersindex.htm). HERS-ST has been developed for and supported by FHWA. The HERS-ST methodology first estimates the free-flow speed (FFS) and then delay (recurring and nonrecurring) for either the freeway or signalized arterial segment. The average effective speed is then computed from the FFS and delay estimates. This average effective speed can be used to estimate TTI.

Travel Delay

Travel delay estimates the hours of extra time spent traveling as a result of congestion. It has the same attributes as the Travel Time Index because both measures are calculated in the same way. Travel delay, however, may be more applicable in areas that target dense development patterns because it includes the distance traveled. The most basic form of travel delay is shown in Equation 2 as the difference between the actual and free-flow period travel times. When measured with ITS data, the actual travel time for a specific corridor can be calculated from the speed data. To obtain a system-level calculation, several corridors (freeway and arterial) can be summed to get the total delay in hours. Using a delay measure of hours per mile of road, hours per 1,000 miles traveled or hours per 1,000 travelers might be more meaningful to agencies at the corridor level, but the public may not understand these measures as it is difficult to relate to key decisions or travel experience. At the system/area level, annual hours of delay per person or per traveler might be readily understood and useful for agency evaluation purposes as well. It may also be desirable to calculate delay relative to some acceptable or target speed or travel time. This might allow the recognition of the inevitable nature of some congestion, while providing a way to target severe congestion problems.

$$\begin{matrix}\text{Delay}\\ \text{(hours)}\end{matrix} = \left[\begin{matrix}\text{Actual}\\ \text{Travel Time}\\ (\text{minutes})\end{matrix} - \begin{matrix}\text{Acceptable}\\ \text{Travel Time}\\ (\text{minutes})\end{matrix}\right]\left[\frac{1\text{ hour}}{60\text{ minutes}}\right] \qquad (2)$$

Incident delay can also be computed with both the freeway and signalized arterial procedures described in this report as output from HERS-ST. This will allow for estimation of the impacts of operational treatments such as ramp metering and incident management (service patrols and surveillance cameras).

Buffer Index

The Buffer Index expresses the amount of extra “buffer” time needed to be on-time for 95 percent of the trips (e.g., late for work on one day per month). It is a measure of trip reliability. Indexing the measure provides a time and distance neutral measure, but the actual minute values could be used by an individual traveler for a particular trip length. With ITS data, the index is calculated for each road or transit route segment and a weighted average is calculated using vehicle-miles or more desirably person-miles of travel as the weighting factor (Equations 3 and 4).

For each section of roadway or transit route…

$$\text{Buffer Index} = \left[\frac{\begin{matrix}\text{95th Percentile Travel Rate} \\ \text{(in minutes per mile)}\end{matrix} - \begin{matrix}\text{Average Travel Rate} \\ \text{(in minutes per mile)}\end{matrix}}{\begin{matrix}\text{Average Travel Rate} \\ \text{(in minutes per mile)}\end{matrix}} \times 100\% \right] \tag{3}$$

$$\begin{matrix}\text{Weighted Average} \\ \text{of Buffer Index for} \\ \text{Several Sections}\end{matrix} = \frac{\left(VMT_{\text{section 1}} \times BI_{\text{section 1}}\right) + \left(VMT_{\text{section 2}} \times BI_{\text{section 2}}\right) + \ldots}{VMT_{\text{section 1}} + VMT_{\text{section 2}} + \ldots} \tag{4}$$

The calculations basically consist of calculating the average and 95th percentile travel time for each section of roadway for each combination of days and time periods. The Buffer Index values of each road section can be calculated and then combined to calculate the Buffer Index for a corridor or area. Vehicle-miles (or person-miles) of travel would be used to weight each section Buffer Index value (Equation 4).

The Texas Transportation Institute continues to investigate relationships to estimate the Buffer Index using a set of factors that might include both physical characteristics, operational treatments, demand management policies and performance estimates from either the ITS data available or estimating procedures. Based upon ITS data available from cities in the Mobility Monitoring Program (MMP), relationships have been developed to predict BI from TTI for freeway corridors with 3 lanes or less or greater than 3 lanes in a given direction.

Volume-to-Capacity Ratio

The volume-to-capacity ratio (V/C) measures the relative levels of volume and capacity for a section of roadway. V/C has been recognized in the 1999 Oregon Highway Plan as a mobility standard by highway classification and type. V/C does not directly measure how the individual traveler is affected by congestion, and it can be difficult to communicate to the general public for this reason. It estimates the relationship between the physical infrastructure (supply) and traffic volume (demand). A capacity estimate is also necessary to determine the V/C ratio. ODOT has developed a spreadsheet analysis using *Highway Capacity Manual* methods to compute capacity. Capacity is also an output of the HERS-ST procedure.

Travel Time and Speed

At the Technical Advisory Committee meeting on February 5, 2004, the group suggested adding travel time and speed to the measures used in the study. Travel time will be added as it shows the effect of land use and transportation service improvements. Average speed will also be added because it is easy for audiences to understand. The measures of travel time and speed will be readily available due to the computation of the other four performance measures.

APPENDIX D

ITS Data Summary and Quality Control in the Mobility Monitoring Program

(excerpted from Monitoring Urban Roadways in 2002: Examining Reliability and Mobility with Archived Data, Chapter 3 – The Data, Reference *1*)

This chapter summarizes aspects of the archived freeway operations data that were used in the mobility and reliability analyses described in this report. The chapter is organized as follows:

- **Participating cities and their archived data**—this section presents information on the cities that participated by submitting archived data, including the type of sensor technology used to collect the data, the level of detail of the archived data, and the data elements that were submitted.
- **Overview of data processing**—this section provides an overview of the data processing steps used to prepare the data for analysis, including pre-processing, data quality checking, and aggregation to a common data standard, and finally the mobility and reliability analysis.
- **Data quality checking**—this section describes the data quality checks used in preparing the archived data for analysis.
- **Mobility and reliability measure calculations**—this section introduces some of the steps that led to calculating the mobility and reliability statistics.

PARTICIPATING CITIES AND THEIR ARCHIVED DATA

Representatives of a total of 23 cities participated in the Mobility Monitoring Program by submitting archived freeway traffic data from 2002 (Exhibit 3-1). Participants who submitted data were initially given basic guidelines about the type of traffic data needed and the preferred formats, with some variation being acceptable on a city-by-city basis. In the process of gathering archived traffic data from 23 cities and dealing with various data formats and organization, the project team developed written documentation on preferred data formats. These preferred data formats (Exhibit 3-2) were developed to clarify exactly what data was needed, as well as to "standardize" the archived data (with some minor variation) being submitted to the Program. Some of the preferred data formats and organization arose from how the data were to be processed in the SAS application software. Other details of organization were included because they were already present and consistent in the majority of cities submitting archived data. Note that the preferred data formats reference data elements contained in national ITS standards like the ITE/AASHTO Traffic Management Data Dictionary.

In future years, the project team will encourage use of these preferred data formats to reduce our pre-processing burden and standardize our initial data processing software for all cities. Because participation and data submission is strictly voluntary, however, we are in a position to accept the data format and organization that is most convenient for cities to provide.

Exhibit 3-1. Participating Cities and Agencies for 2002 Archived Data

Participating City (Years of data in MMP)	Contact Agency
Albany, NY (2 years)	New York State DOT
Atlanta, GA (3 years)	Georgia DOT
Austin, TX (2 years)	Texas DOT
Charlotte, NC (2 years)	North Carolina DOT
Cincinnati, OH/KY (3 years)	TRW, Inc./ARTIMIS/Kentucky Trans. Cabinet
Detroit, MI (3 years)	Michigan DOT
Hampton Roads, VA (3 years)	Univ. of Virginia/VTRC/VDOT
Houston, TX (3 years)	Texas DOT/TTI
Los Angeles, CA (3 years)	UC-Berkeley/Caltrans
Louisville, KY (2 years)	Kentucky Transportation Cabinet
Milwaukee, WI (2 years)	Wisconsin DOT
Minneapolis-St. Paul, MN (3 years)	Minnesota DOT and UM-Duluth
Northern Virginia (1 year)	Univ. of Virginia/VTRC/VDOT
Orlando, FL (2 years)	Florida DOT
Philadelphia, PA (2 years)	Mobility Technologies, Inc.
Phoenix, AZ (3 years)	Arizona DOT
Pittsburgh, PA (2 years)	Mobility Technologies, Inc.
Portland, OR (2 years)	Oregon DOT
Sacramento, CA (1 year)	UC-Berkeley/Caltrans
Salt Lake City, UT (1 year)	Utah DOT
San Antonio, TX (3 years)	Texas DOT
San Diego, CA (2 years)	Caltrans
Seattle, WA (3 years)	Washington State DOT/Washington State Transportation Center (TRAC)

Exhibit 3-2. Preferred Archived Data Formats for Mobility Monitoring Program (Page 1 of 2)

PREFERRED DATA FORMATS FOR FHWA'S MOBILITY MONITORING PROGRAM

The following sections summarize the preferred formats for submitting data to FHWA's Mobility Monitoring Program. While other formats are acceptable, the following formats are encouraged for unambiguous and efficient data exchange. The required data submissions should include 2 principal datasets: 1) actual traffic data records; and 2) traffic sensor location information. Many of the data elements have already been defined by national ITS standards (e.g., Traffic Management Data Dictionary, TMDD) and are indicated as such.

<u>File Formats</u>

- The traffic data records should be submitted in delimited ASCII-text files. Acceptable delimiting characters include commas, tabs, or spaces.
- Empty/blank fields or "null" values should be indicated by providing a blank space in the respective field. Metadata should document particular error codes (e.g., "-1" or "255") and meaning if these error codes are contained in the dataset.
- A separate text file should be submitted for each day for each city, with data from all sensor locations being included in a single daily file. The file should be named to include a location or agency code and a date stamp (YYYYMMDD format). For example, "msp_20020101.txt" contains data for Jan. 1, 2002 for Minneapolis-St. Paul, Minnesota.
- The text files should be compressed for transmission using industry standard PC (*.zip) or Unix (*.z or *.gz) compression software.
- The traffic monitoring data should be submitted by DVD, CD, or FTP.

<u>Data Elements</u>

- The data should be aggregated to 5-minute time periods for each travel lane. Even 5-minute time periods should be used (e.g., 12:00 am, 12:05 am, 12:10 am, etc.)
- Each row of the text file should contain the following data elements:
  1. **Time** (HH:MM with 24-hour clock) and date (MM/DD/YYYY) stamp. Documentation should indicate whether this is a start or ending time;
  2. **Detector identifier** (DETECTOR_Identifier_identifier in TMDD);
  3. **Vehicle traffic volume count** (DETECTOR_VehicleCount_quantity);
  4. **Average lane occupancy**, if available (DETECTOR_Occupancy_percent); and
  5. **Average speed or travel time** (LINK_SpeedAverage_rate or LINK_TravelTime_quantity).
- If the data have been aggregated from a shorter time period (e.g., 20 seconds or 1 minute), each 5-minute record should indicate how many sub-records were used in the summary statistic calculation. This "completeness" value is reported as the percentage of the total possible records that are included in the summary statistic.

Exhibit 3-2. Preferred Archived Data Formats for Mobility Monitoring Program (Page 2 of 2)

Sensor Location Information

- Location information should be provided for each unique traffic sensor. The location information can be provided in delimited text files, spreadsheets, or databases.
- The location information should include the following for each traffic sensor that reports data at any time during the year:
  1. Detector identifier (same as used in the traffic data records, DETECTOR_Identifier_identifier);
  2. Lane designation or code (DETECTOR_LaneNumber_code);
  3. Number of directional through travel lanes at that location (LINK_LaneCount_quantity);
  4. Roadway name and/or designation (LINK_RoadDesignator_number);
  5. Roadway direction (DETECTOR_Direction_code);
  6. Roadway facility type, such as mainlane, HOV, entrance ramp, etc. (LINK_Type_code);
  7. A linear distance reference such as roadway milepost (in miles or kilometers);
  8. Sensor activation date which indicates when the sensor began providing valid data; and
  9. Sensor de-activation date which indicates when the sensor stopped providing valid data. If the sensor is still active, this field could be blank or contain null values.

Additional Documentation

Additional documentation on the ITS data archives is encouraged. This documentation could include information on the following aspects:

- Data collection technology and source;
- Data quality control checks and summary results;
- Data transformation or estimation processes (e.g., equations used to estimate speeds from single loops); and
- Other information that would help analysts better interpret the quality and content of the ITS data archives.

The mobility and reliability analyses in the Mobility Monitoring Program are built around estimated travel times for freeway routes. As Exhibit 3-3 indicates, however, nearly all of the participating cities have traffic management centers that collect speeds and volumes at specific points along the freeway route. For 22 cities (all except Houston), the data were collected at point locations using a variety of traffic sensor technologies including single and double inductance loops, microwave radar, passive acoustic, and video image processing. For Houston, link travel times are collected via their automatic vehicle identification (AVI) system, and these link travel times are supplemented with volume trend data from a limited number of double inductance loops. In many cities, multiple sensor technologies were used to collect the traffic speed and volume data. All of these technologies use a small, fixed zone of detection, and the traffic speed and volume measurements are taken as vehicles pass through this zone. The last section in this chapter describes how these point speeds and volumes are transformed to travel time estimates for mobility and reliability performance measures.

Exhibit 3-3 also indicates the level of detail at which the archived data is submitted to the Mobility Monitoring Program. The time aggregation level varies widely, from 20 seconds in San Antonio to 15 minutes in several areas. In some cases, the data are collected in smaller time intervals (e.g., 20 seconds to 2 minutes) but aggregated to larger time intervals for storage purposes. Nearly all of the archived data are provided on a lane-by-lane basis.

The extent of freeway monitoring coverage is also presented in Exhibit 3-3, and ranges from 9 percent in Louisville, Kentucky to 100 percent in Milwaukee, Wisconsin and Salt Lake City, Utah. The average coverage is 40 percent, or slightly more than one-third of all freeway lane-miles in these urban areas. Note that the participating cities were not chosen based on their monitoring coverage, but on their ability to provide archived data. In many cities, this freeway monitoring coverage includes the most congested freeways as well as lightly congested freeway routes. In several cities, the monitoring coverage does not include very congested routes for a variety of reasons (e.g., reconstruction, upcoming deployment, etc.).

Exhibit 3-3. Summary of Archived Data Characteristics for 2002

Participating City	Freeway System Monitored, %	Traffic Sensor Technology	Data Level of Detail Time	Data Level of Detail Space
Albany, NY	10% (10 of 104 mi.)	Single and double loop detectors	15 minutes	by lane
Atlanta, GA	18% (73 of 300 mi.)	Video imaging and microwave radar	15 minutes	by lane
Austin, TX	22% (23 of 105 mi.)	Double loop detectors	1 minute	by lane
Charlotte, NC	12% (13 of 92 mi.)	Microwave radar	30 seconds	by lane
Cincinnati, OH/KY	27% (47 of 176 mi.)	Double loop detectors, video imaging, microwave radar	15 minute	by direction
Detroit, MI	39% (110 of 282 mi.)	Single and double loop detectors	1 minute	by lane
Hampton Roads, VA	11% (19 of 181 mi.)	Double loop detectors	2 minutes	by lane
Houston, TX	61% (298 of 368 mi.)	Probe vehicle (AVI), limited double loop detectors	Anonymous individual probe vehicle travel times by link. Loop data are 20 seconds by lane.	
Los Angeles, CA	86% (579 of 676 mi.)	Single loop detectors	5 minutes	by lane
Louisville, KY	9% (12 of 137 mi.)	Microwave radar, loop detectors, video imaging	15 minutes	by direction
Milwaukee, WI	100% (111+ of 111 mi.)	Loop detectors, microwave radar	5 minutes	by lane
Minneapolis-St. Paul, MN	60% (190 of 317 mi.)	Single loop detectors	30 seconds	by lane
Northern Virginia	46% (59 mi of 127 mi.)	Loop detectors	1 minute	by lane
Orlando, FL	20% (32 of 157 mi.)	Double loop detectors	1 minute	by lane
Philadelphia, PA	37% (128 of 347 mi.)	Microwave radar, passive acoustic detectors	1 minute	by lane
Phoenix, AZ	30% (53 of 179 mi.)	Double loop detectors, passive acoustic detectors	5 minutes	by lane
Pittsburgh, PA	27% (78 of 284 mi.)	Microwave radar, passive acoustic sensors	1 minute	by lane
Portland, OR	39% (54 of 137 mi.)	Double loop detectors	15 minutes	by lane
Sacramento, CA	54% (57 of 105 mi)	Loop detectors	5 minutes	by lane
Salt Lake City, UT	100% (80+ mi of 80 mi.)	Double loops, microloops, acoustic detectors	60 minutes	by direction
San Antonio, TX	36 % (77 of 211 mi.)	Double loop detectors, acoustic detectors	20 seconds	by lane
San Diego, CA	66 % (163 of 248 mi.)	Loop detectors	30 seconds	by lane
Seattle, WA	41 % (116 of 241 mi.)	Mostly single loop detectors	5 minute	by lane

Real-time traffic data collection and archiving processes have been developed independently in most of the cities and the details of these processes vary among the cities. As a general rule, TMCs at least have the capability to archive data from their surveillance systems. In a few cases, this capability is not used because of priorities elsewhere in the TMC, but it is clear that TMC software is being constructed with archiving as a function. However, the state of the practice in TMC archiving is still fairly primitive. The most common practice is to transfer the data to a storage device where they reside in simple file formats without an active information management system. Quality control is rarely performed at this level and access to the data is provided on a case-by-case basis without the benefit of a query or reporting structure – data are simply provided in whatever file formats are used to store them.

- Data are collected by traffic sensors and accumulated in roadside controllers. These field measurements are collected for each individual lane of traffic. At 20-second to 2-minute intervals, the roadside controllers transmit the data to a central location, typically a TMC.
- Some cities perform quality control on field-collected data, but this checking is simple and based on minimum and maximum range value thresholds.
- Cities that use single inductance loop detectors as sensors can measure only volumes and lane occupancies directly. In these cases, speed estimation algorithms are used to compute speeds from volumes and lane occupancies. These speed estimation algorithms vary among cities.
- Internal processes at the TMC aggregate the traffic data to specified time intervals for archival purposes. These time intervals vary from 20 seconds (no aggregation) to 15 minutes. In some cases, the data are also aggregated across all lanes in a given direction at a sensor location.
- The aggregated data are then stored in text files or databases unique to each TMC. CDs are routinely created at the TMCs to offload some of the storage burden and to satisfy outside requests for the data.

Calibration and maintenance of field equipment and communications are nearly universal problems. The main impediment is lack of resources to devote to these tasks; TMC budgets are limited and must be used to address a multitude of issues. Calibration—at least to very tight tolerances—is not seen as a priority, given that operators focus on a broad range of operating conditions rather than precise volume and speed measurements. Or in some cases traffic managers may be willing to accept a certain level of data quality to satisfy only their current operations applications. This philosophy may be changing as a result of more stringent data requirements for traveler information purposes (e.g., travel time messages on variable message signs). However, we found the current data resolution used by TMCs to be quite coarse for supporting their traditional operations activities, such as incident detection and ramp meter control.

Maintenance is a problem (due primarily to funding limitations) even when loops are known to be producing erroneous or no data. The problem is exacerbated where loops are used because most agencies are reluctant to shut down traffic on heavily traveled freeways just for loop repair.

This is not to say that faulty loops are never repaired, but maintenance is often postponed to coincide with other roadway activities, which helps spread the cost burden as well.

Field checking of sensors is done periodically but no standardized procedures are used across all cities. If a detector is producing values that are clearly out of range, inspection and maintenance are usually performed. However, calibration to a known standard is rarely, if ever, performed. This means that more subtle errors may go undetected. Bearing in mind that TMCs typically do not require highly accurate data for most of their operations, this approach is reasonable and practical. Work zones exacerbate these problems and often contractors unknowingly sever communication lines or pave over inductance loops.

OVERVIEW OF DATA PROCESSING

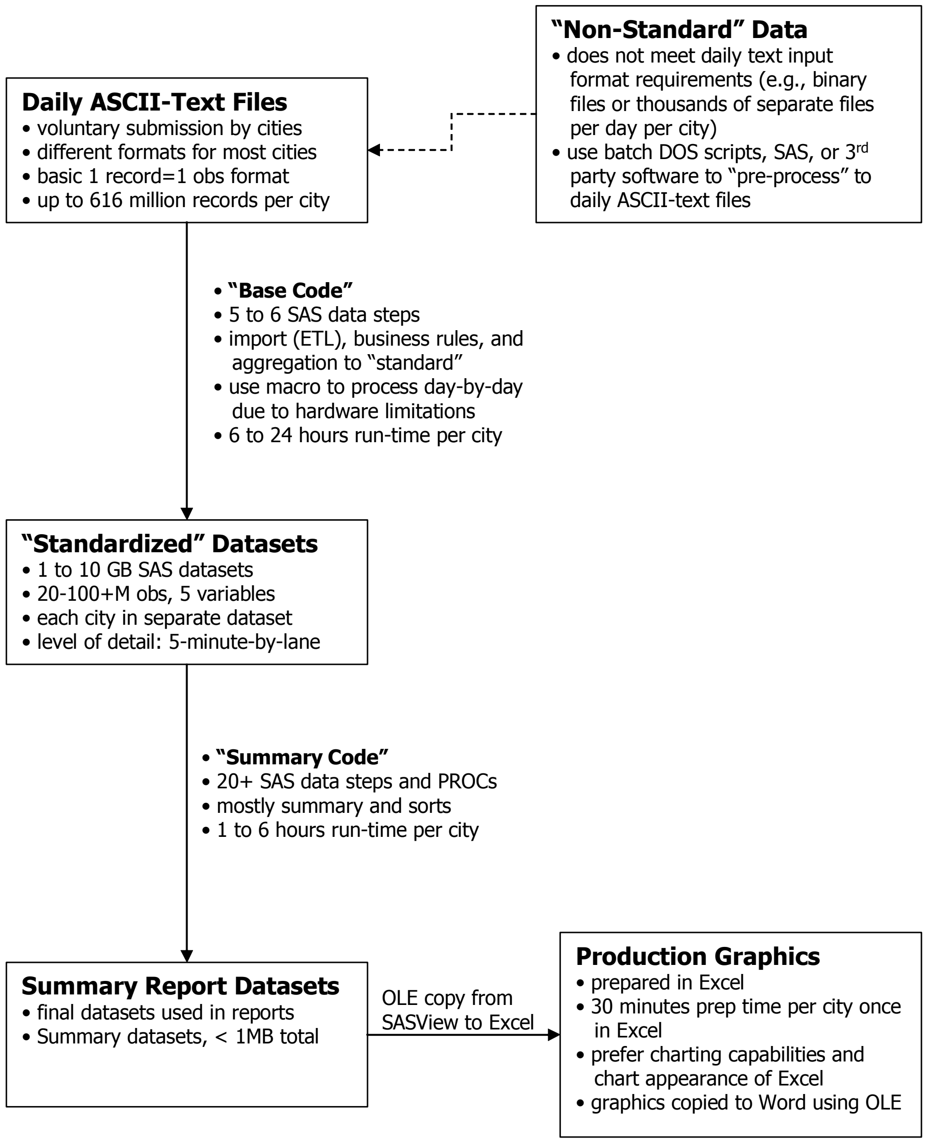
This section presents a brief overview of the data processing steps used to transform the archived data into mobility and reliability statistics. The relatively mundane topic of data processing is included here because of its departure from traditional traffic data monitoring practices. In analyzing the archived freeway data from the 23 participating cities, the project team processed over 7 billion data records, with a total computer processing time best measured in days.

Exhibit 3-4 shows an overview of the basic data processing steps used to prepare and analyze the archived data. Perhaps the greatest challenge in the data processing was "standardizing" the archived datasets from 23 different cities, or essentially 23 different legacy systems. In many cases, the lack of adequate metadata (i.e., descriptive information about the archived data) complicated the process of properly interpreting and analyzing the archived data. For example, each city's dataset may use different data error codes to indicate various hardware or software failures. Or similar data error codes could be used by several cities to mean different types of data errors. In other cases, various flaws, nuances, or characteristics in the archived data may be known by the data collector but undocumented, and potentially go undetected by the project team unless careful study was initiated. **The experience of the project team indicates that dealing with legacy system data is much more manageable when metadata is used to describe the origin, lineage, characteristics, and subtle nuances of the archived data.**

The data processing for the Mobility Monitoring Program is primarily accomplished using SAS software on a Microsoft Windows platform for 2 reasons: 1) the project team's previous software programming experience with SAS; and 2) ability and flexibility of SAS to handle a wide range of complex computations on very large datasets. Many other relational database management systems (RDBMS) could also be used to accomplish the same data processing tasks as was performed in SAS.

The data processing flows shown in Exhibit 3-4 have been optimized for the use of SAS in generating annual mobility and reliability reports. Some of the data processing steps, however, may be similar for other data archiving and analysis activities. For example, the first step that includes the "base code" is known as extraction, transformation and loading (ETL) in the data warehouse industry and is a common function for most data warehouse projects. The project team has attempted to standardize the software code as much as possible for ease and automation of data processing. However, the software code is custom-tailored (mostly in the "base code") to meet the different formats and organization of submitted archived data.

Exhibit 3-4. Overview of Data Processing within Mobility Monitoring Program



The data processing as shown in Exhibit 3-4 would ideally start with daily ASCII-text files that meet the preferred data formats indicated in Exhibit 3-2. However, many cities submit data in a form that requires pre-processing (e.g., binary file formats or thousands of separate files per city per day). Pre-processing this “non-standard” data requires extra steps and time at the beginning to prepare the archived data to be processed using the “base code.”

Once the submitted archived data meets basic formatting and organization requirements, it is processed using the “base code.” This software code: 1) imports the data to SAS; 2) performs data quality checking; 3) aggregates detailed data to a common standard (currently 5-minute lane-by-lane); and 4) generates summary statistics on the data quality checking and processing steps. Some of these steps, such as the data quality checks, have been standardized for all cities. Other steps are unique to each city based on the aggregation level and other data characteristics. This step involves the longest amount of processing time, sometimes taking up to 24 hours for the largest cities with the most detailed data (e.g., 20-seconds, lane-by-lane).

The “standardized” datasets are produced as a result of the “base code.” The data elements and table structure of these datasets are very similar with a few exceptions (e.g., some cities are 5-minute lane-by-lane, others may be 15-minute or by direction). Thus the “summary code,” which contains the mobility and reliability measure calculations described in Chapter 4, has largely been standardized for all cities. The “standardized” datasets are analogous to the database tables that would be kept on-line in an RDBMS environment.

The “summary code” performs all mobility and reliability measure calculations, and produces relatively small datasets (less than 1 megabyte total) that are then used to produce the charts and tables shown throughout this report and the city report appendices. Microsoft Excel was selected for the ease of producing report-ready graphics.

In summary, the data processing steps and software code used to analyze the archived data has developed in this way as a result of: 1) previous project team experience; and 2) the specific application of creating annual mobility and reliability reports. Different approaches are very likely given different implementation scenarios and development teams. Several of the data processing steps conducted in the Mobility Monitoring Program may be relevant to other data archiving or data warehouse activities. In particular, the “base code” contains data quality checking procedures and other steps that are most likely required in other data warehouse efforts. The “summary code” contains mobility and reliability measure calculations that are described in Chapter 4 and may be useful to others developing performance measure programs.

DATA QUALITY CHECKING

The topic of data quality is included here because of its overall importance in checking and evaluating the validity of archived data. Readers should note that the project team has not been able to systematically assess data accuracy. This means that the traffic speeds and volumes in the archived data could be systematically higher or lower (e.g., ± 10 to 20 percent) than true speeds and still be within the range of possible data values that pass quality control.

Exhibit 3-5 presents the data quality checks that were used in processing the 2002 archived data. The data quality checks have been developed from these sources:

- Current practices in other TMCs or data archiving systems;
- Suggested practices recommended in the literature; and
- Practices found to be necessary from project team analysis of the archived data.

These data quality checks can be characterized as basic validity checks and should detect major problems with data errors. More subtle erroneous or suspect data could potentially go undetected with these basic rules. The project team is reviewing the use of more sophisticated data quality checking, and we will continue to balance the sophistication of the data quality checking with the amount of available data processing time. The data quality checks shown in Exhibit 3-5 will likely evolve and further develop as the project team accumulates more experience with the archived data. More sophisticated quality checks could include tests like these:

- Rapid fluctuations in values across successive time periods;
- Detectors in adjacent lanes at the same location reporting significantly different values or trends;
- Detectors in adjacent upstream or downstream locations reporting significantly different values or trends;
- Detectors from multiple locations reporting the same values (indicative of a system problem);
- Reported values that are significantly different from the location's history for similar days of the calendar.

The results of the quality control checks are shown in Exhibit 3-6. This table reports the percent of the original dataset that passed the quality control checks. The table presents traffic volume and speed data quality separately, as some of the validity checks could have rejected one of the data values but not the other. Also note that Exhibit 3-6 only evaluates the validity of the data that was archived and submitted. This table does not reflect data that are missing and were never reported because of various hardware or software failures.

Exhibit 3-7 summarizes information on data completeness or availability, another dimension of data quality. The data completeness measures the number of actual data values to the number of total possible values that one could expect (given the number of sensors and a polling rate). For example, if the data are reported by 5-minute time interval, 288 data values or records per day per detector are to be expected (i.e., 1,440 minutes per day divided by 5-minute periods equals 288 records). Exhibit 3-7 reports data completeness at three critical processing steps:

1. Original dataset as submitted by participating cities;
2. Dataset after quality control removes values failing the validity checks; and
3. Analysis dataset (after quality control and any imputation) that is used for mobility and reliability performance measure calculations

Exhibit 3-5. 2002 Data Validity Checks in Mobility Monitoring Program

Quality Control Test and Description	Sample Code with Threshold Values	Action
CONTROLLER ERROR CODES • Special numeric codes that indicate that controller or system software has detected an error or a function has been disabled.	If VOLUME={code} or OCC={code} or SPEED={code} where {code} typically equals "-1" or "255"	• Set values with error codes to missing/null, assign missing value flag/code.
NO VEHICLES PRESENT • Speed values of zero when no vehicles present • Indicates that no vehicles passed the detection zone during the detection time period.	If SPEED=0 and VOLUME=0 (and OCC=0)	• Set SPEED to missing/null, assign missing value code • No vehicles passed the detection zone during the time period.
CONSISTENCY OF ELAPSED TIME BETWEEN RECORDS • Polling period length may drift or controllers may accumulate data if polling cycle is missed. • Data collection server may not have stable or fixed communication time with field controllers.	Elapsed time between consecutive records exceeds a predefined limit or is not consistent	• Action varies. If polling period length is inconsistent, volume-based QC rules should use a volume flow rate, not absolute counts.
DUPLICATE RECORDS • Caused by errors in data archiving logic or software process.	Detector and date/time stamp combination are identical.	• Remove/delete duplicate records.
QC1-QC3: Logical consistency tests • Typically used for date, time and location. • Caused by various types of failures.	If DATE={valid date value} (QC1) If TIME={valid time value} (QC2) If DET_ID={valid detector location value} (QC3)	• Write to off-line database and/or remove records with invalid date, time or location values.
QC4: Maximum volume • Traffic flow theory suggests a maximum traffic capacity.	If VOLUME > 17 (20 sec.) If VOLUME > 25 (30 sec.) If VOLUME > 250 (5 min.) If VPHPL > 3000 (any time period length)	• Assign QC flag to VOLUME, write failed record to off-line database, set VOLUME to missing/null.
QC5: Maximum occupancy • Empirical evidence suggests that all data values at high occupancy levels are suspect. • Caused by detectors that may be "stuck on."	If OCC > 95% (20 to 30 sec.) If OCC > 80% (1 to 5 min.)	• Assign QC flag to VOLUME, OCCUPANCY and SPEED; write failed record to off-line database; set VOLUME, OCCUPANCY and SPEED to missing/null
QC6: Minimum speed • Empirical evidence suggests that actual speed values at low speed levels are inaccurate.	If SPEED < 5 mph	• Assign QC flag to SPEED, write failed record to off-line database, set SPEED value to missing/null
QC7: Maximum speed • Empirical evidence suggests that actual speed values at high speed levels are suspect.	If SPEED > 100 mph (20 to 30 sec.) If SPEED > 80 mph (1 to 5 min.)	• Assign QC flag to SPEED, write failed record to off-line database, set SPEED value to missing/null

Exhibit 3-5. 2002 Data Validity Checks in Mobility Monitoring Program (Continued)

Quality Control Test and Description	Sample Code with Threshold Values	Action
MAXIMUM REDUCTION IN SPEED • Empirical evidence suggests that speed reductions greater than some maximum value are suspect. • Used only for AVI probe vehicle data that reports space mean speeds.	If $SPEED_{n+1} < (0.45 \times SPEED_n)$	• Assign QC flag to SPEED, write failed record to off-line database, set SPEED value to missing/null
QC8: Multi-variate consistency • Zero speed values when volume (and occupancy) are non-zero • Speed trap not functioning properly	If SPEED = 0 and VOLUME > 0 (and OCC > 0)	• Assign QC flag to SPEED, write failed record to off-line database, set SPEED value to missing/null
QC9: Multi-variate consistency • Zero volume values when speed is non-zero. • Unknown cause.	If VOLUME = 0 and SPEED > 0	• Assign QC flag to VOLUME, write failed record to off-line database, set VOLUME to missing/null
QC10: Multi-variate consistency • Zero speed and volume values when occupancy is non-zero. • Unknown cause.	If SPEED = 0 and VOLUME = 0 and OCC > 0	• Assign QC flag to VOLUME, OCCUPANCY and SPEED; write failed record to off-line database; set VOLUME, OCCUPANCY and SPEED to missing/null
QC11: Truncated occupancy values of zero • Caused when software truncates or rounds to integer value • Calculate maximum possible volume (MAXVOL) for an occupancy value of "1":	If OCC = 0 and VOLUME > MAXVOL where MAXVOL=(2.932*ELAPTIME*SPEED)/600	• Assign QC flag to VOLUME, OCCUPANCY and SPEED; write failed record to off-line database; set VOLUME, OCCUPANCY and SPEED to missing/null
QC12: Maximum estimated density • Caused by improbable combinations of volume and speed. • Traffic flow theory suggests that vehicle density rarely exceeds 220 vehicles per lane per mile.	IF ((VOLUME*(3600/NOM_POLL))/SPEED) > 220 where NOM_POLL is the nominal polling cycle length in seconds.	• Assign QC flag to VOLUME, OCCUPANCY and SPEED; write failed record to off-line database; set VOLUME, OCCUPANCY and SPEED to missing/null
QC13: Consecutive identical volume-occupancy-speed values • Research and statistical probability indicates that consecutive runs of identical data values are suspect. • Typically caused by hardware failures.	No more than 8 consecutive identical volume-occupancy-speed values. That is, the volume AND occupancy AND speed values have more than 8 consecutive identical values, respectively.	• Assign QC flag to VOLUME, OCCUPANCY and SPEED; write failed record to off-line database; set VOLUME, OCCUPANCY and SPEED to missing/null

Exhibit 3-6. Summary of Archived Data Passing Validity Checks

City	% of data passing checks	
	Volume	Speed
Albany, NY	76%	75%
Atlanta, GA	97%	94%
Austin, TX	76%	44%
Charlotte, NC	100%	100%
Cincinnati, OH/KY	59%	63%
Detroit, MI	69%	69%
Hampton Roads, VA	65%	31%
Houston, TX	N/A	97%
Los Angeles, CA	100%	97%
Louisville, KY	85%	95%
Milwaukee, WI	100%	83%
Minneapolis-St. Paul, MN	100%	89%
Northern Virginia	88%	71%
Orlando, FL	49%	55%
Philadelphia, PA	100%	99%
Phoenix, AZ	70%	66%
Pittsburgh, PA	100%	99%
Portland, OR	77%	76%
Sacramento, CA	99%	92%
Salt Lake City, UT	90%	60%
San Antonio, TX	95%	80%
San Diego, CA	97%	94%
Seattle, WA	98%	100%

Exhibit 3-7. Summary of Archived Data Completeness at Different Processing Steps

City	% complete - original data		% complete - after QC		% complete- analysis data	
	Volume	Speed	Volume	Speed	Volume	Speed
Albany, NY	74%	74%	50%	49%	50%	49%
Atlanta, GA	46%	46%	43%	40%	43%	40%
Austin, TX	96%	96%	78%	53%	80%	61%
Charlotte, NC	20%	20%	26%	30%	26%	30%
Cincinnati, OH/KY	51%	51%	10%	14%	10%	14%
Detroit, MI	77%	77%	46%	46%	43%	43%
Hampton Roads, VA	23%	23%	12%	7%	11%	6%
Houston, TX	N/A	N/A	N/A	93%	N/A	52%
Los Angeles, CA	57%	57%	57%	55%	57%	55%
Louisville, KY	88%	88%	73%	83%	73%	83%
Milwaukee, WI	79%	79%	79%	65%	79%	65%
Minneapolis-St. Paul, MN	99%	90%	99%	85%	95%	85%
Northern Virginia	23%	23%	21%	17%	22%	16%
Orlando, FL	82%	82%	31%	37%	31%	37%
Philadelphia, PA	95%	94%	95%	93%	95%	93%
Phoenix, AZ	83%	83%	56%	53%	56%	53%
Pittsburgh, PA	95%	89%	94%	87%	94%	87%
Portland, OR	80%	80%	57%	56%	57%	56%
Sacramento, CA	51%	51%	50%	47%	50%	47%
Salt Lake City, UT	33%	33%	30%	19%	30%	19%
San Antonio, TX	49%	49%	47%	40%	53%	50%
San Diego, CA	94%	85%	88%	82%	92%	88%
Seattle, WA	55%	55%	53%	55%	53%	55%

MOBILITY AND RELIABILITY MEASURE CALCULATIONS

With the exception of Houston, which reported travel times collected with their AVI system, archived data from the participating cities consisted of traffic speeds and volumes collected at various points along the freeway routes. Because the mobility and reliability performance measures are based on travel time, the project team estimated freeway route travel times from the spot speeds. Exhibit 3-8 illustrates the process whereby lane-by-lane volumes and speeds are used as the basis for estimating freeway route travel times and vehicle-miles of travel (VMT). The steps are as follows:

1. If data are reported by lane, the lane-by-lane data are combined into a "station" (e.g., all lanes in a direction). Traffic volumes are summed across all lanes, and traffic speeds are a weighted average, with weighting based on respective traffic volumes.
2. Link properties were estimated from "station" data by assuming that each detector had a zone of influence equal to half the distance to the detectors immediately upstream and downstream from it. The measured speeds were then assumed to be constant within each zone of influence, and travel times were calculated using the equivalent link lengths. VMT were also computed in this way using traffic volume.
3. Freeway links were then grouped with other similar adjacent link into analysis sections, which were typically 5 to 10 miles in length. The beginning and end points of analysis sections were typically selected to coincide with major highway interchanges or other locations where traffic conditions were expected to change because of traffic or roadway characteristics.

Travel times for these analysis sections then served as the basis for all subsequent mobility and reliability measure calculations. The specifics of these performance measure calculations are contained in Chapter 4. Readers should note that equations using travel time refer to the analysis section travel times as described above.

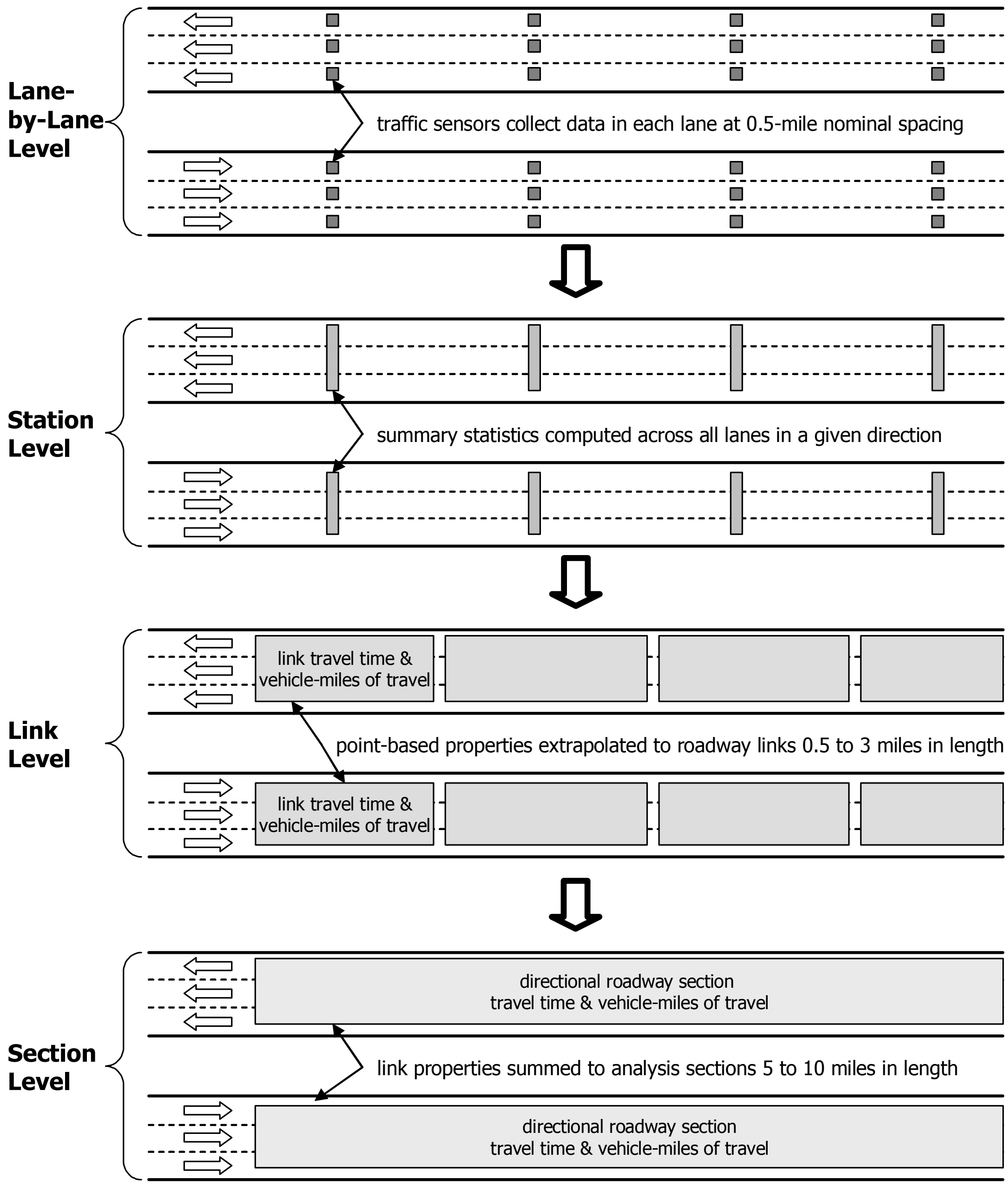
Several other aspects and definitions used in preparing the archived data for analysis were:

- Holidays were excluded from analysis. Future analyses may consider holidays separately or as part of weekends, but holidays were felt to be atypical of normal travel patterns.

- Consistent time periods for all cities were defined for analysis. These were:
  - 12:00 am to 6:00 am – early morning
  - 6:00 am to 9:00 am – morning peak
  - 9:00 am to 4:00 pm – mid-day
  - 4:00 pm to 7:00 pm – afternoon peak
  - 7:00 pm to 12:00 am – late evening

- Only mainline freeway detectors were included. Some cities reported ramp data, but these were dropped to maintain consistency across the cities.

Exhibit 3-8. Estimating Route Travel Times and VMT from Spot Speeds and Volumes



Incident Data and Other Event Data

Archiving of incident data is becoming more prevalent at TMCs. However, the nature of the data collected and the structure of the storage formats are extremely diverse. This is a larger problem than for traffic data, where the basic measurements are fairly well known and understood. By comparison, even the definition of an "incident" is subject to interpretation. The resulting inconsistency in reporting formats for incidents limits, or at least complicates, analysis opportunities.

APPENDIX E

Portland, Oregon 2002 Regional Mobility and Reliability Data

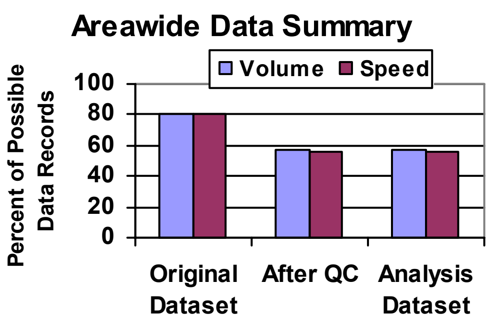
A Supplement to:
Monitoring Urban Roadways in 2002: Using Archived Operations Data for Reliability and Mobility Measurement by Texas Transportation Institute and Cambridge Systematics, Inc., December 2003.

<u>Portland, OR Findings</u>

- The peak periods constitute half of daily delay, but midday delay at 34%, is the highest of the five periods.
- Evening congestion levels are higher than morning levels.
- Weekday delay climbs from Monday to Friday, with weekend delay being equal to one weekday.
- Evening congestion affects travel conditions for longer than morning.

<u>Portland, OR Data Source</u>

- Approximately 54 miles of the more than 137-mile freeway system is included in the archived data system. The Oregon Department of Transportation provided the data.
- Data were collected using mostly double inductance loop detectors. Direct speed estimates are obtained and the data reported by lane at 1-minute intervals.



Original dataset—Percent of the total possible volume and speed data obtained from roadway sensors and archived.

After QC (Quality Control)—Percent of the total possible data that remain after removing data that failed data quality checks.

Analysis dataset—Percent of the total possible data that are available for mobility and reliability analysis purposes. Data failing the quality checks have been removed and some data have been imputed (or estimated).

*Note: All data in the analysis dataset are either 5-minute or 15-minute summaries for each or all lanes on a roadway link.

Note: Statistics reported in this Appendix are based on the best information that could be obtained. The percentage of records in the dataset varies for each corridor.

Mobility and Reliability Measures

Travel Time Index—A ratio of peak travel time to free-flow travel time. A TTI of 1.3 indicates a 20-minute off-peak trip would take 26 minutes in the peak.

Planning Time Index—Based on the idea that travelers making important peak period trips will arrive on time for 19 trips out of 20 (i.e., late for only 1 work day per month). Planning Time Index is the travel time expressed in a ratio similar to Travel Time Index.

Buffer Index—The difference between Travel Time Index and Planning Time Index expressed as a percentage. The amount of extra time above the average peak period travel time.

VMT Below 60 mph (or 50 mph)—The percentage of vehicle-miles of travel that occur during the time period at speeds below the threshold.

Days below 60 mph—Percentage of the locations and days during a year with an average speed below 60 mph.

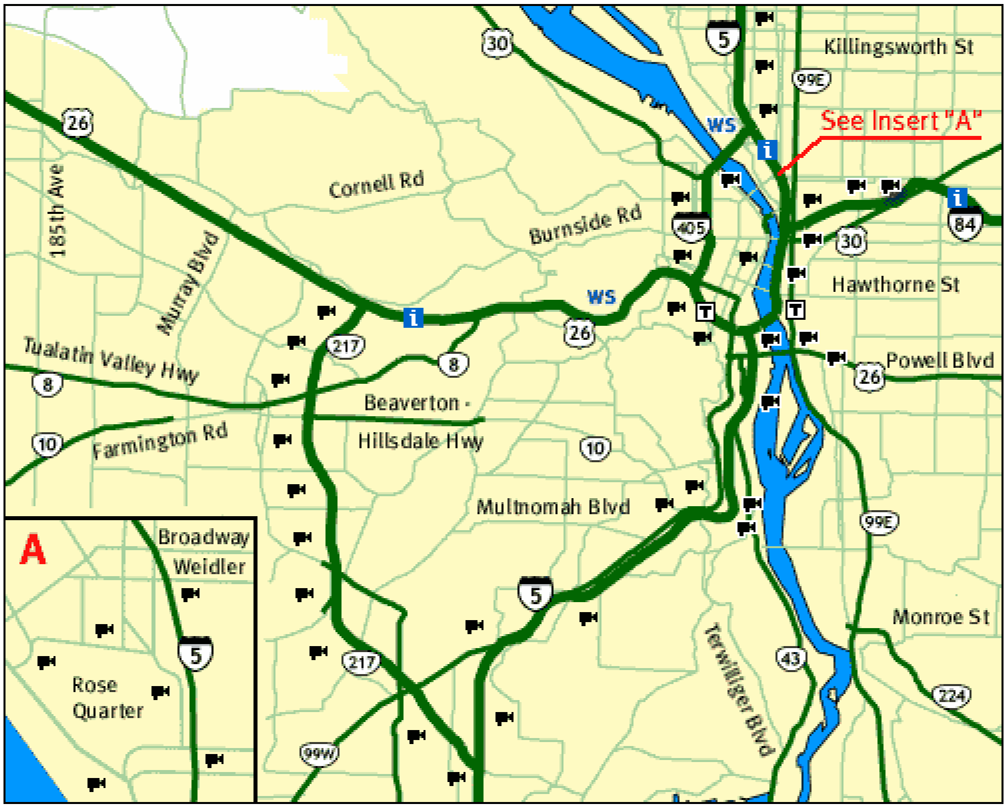


Exhibit PDX-1. Instrumented Freeway Routes in the Portland Region
(Source: Oregon Department of Transportation)

Exhibit PDX-2. Instrumented Freeway Coverage in the Portland Region

Coverage Measures	Instrumented Freeway Routes	Total Freeway System[1]	Percent Coverage
2000			
Lane-Miles	N/A[2]	N/A[2]	N/A[2]
Vehicle-Miles of Travel (million)	N/A[2]	N/A[2]	N/A[2]
2001			
Lane-Miles	210	700	30%
Vehicle-Miles of Travel (million)	2,010	4,625	43%
2002			
Lane-Miles	295	715	41%
Vehicle-Miles of Travel (million)	6,465	4,710	100+%

[1]Source is FHWA's Highway Performance Monitoring System and the Texas Transportation Institute's Urban Mobility Study (http://mobility/tamu.edu/ums).

[2]Did not participate in 2000.

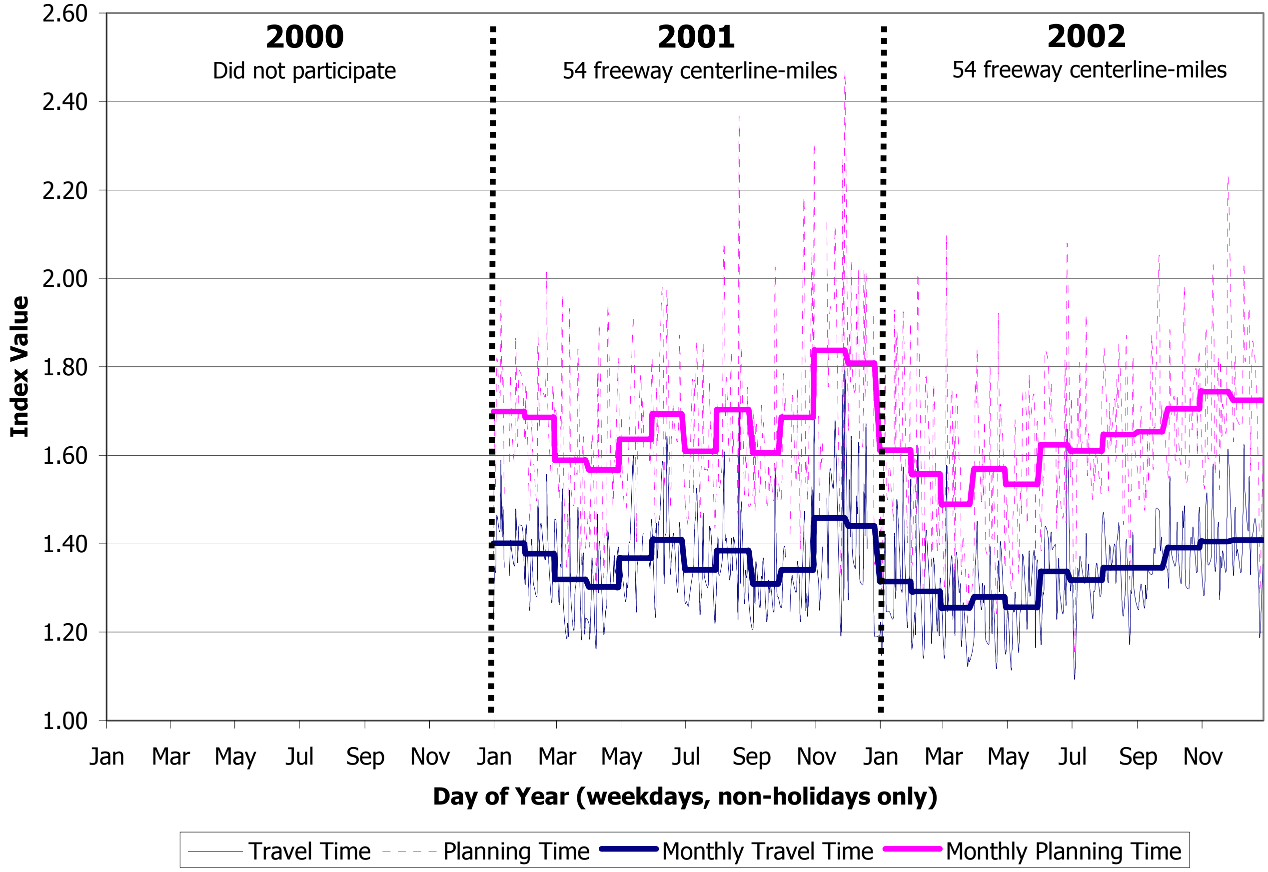
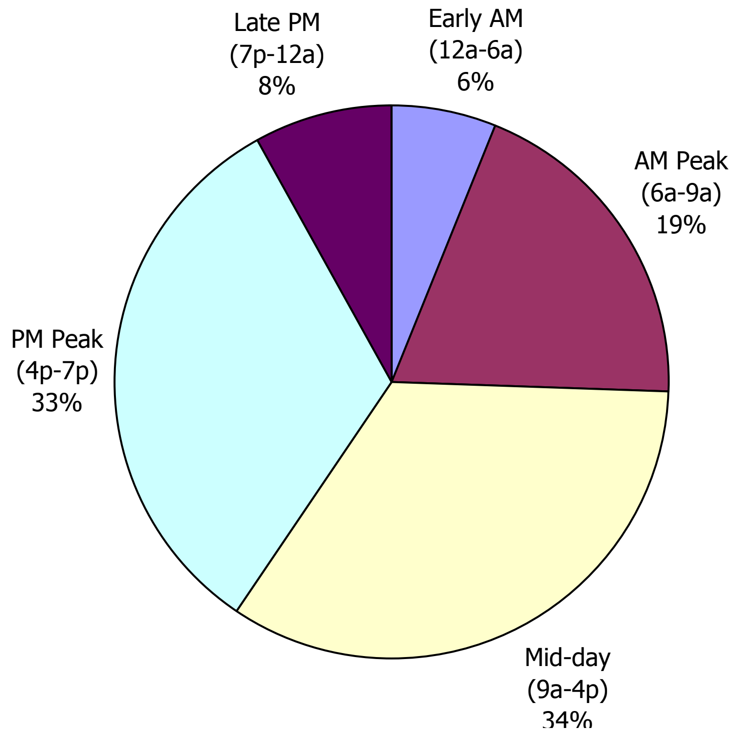


Exhibit PDX-3. Mobility and Reliability Trends, 2000 to 2002

- Congestion and reliability appear to improve through the first few months of 2002 just as in 2001.
- There are several significant congestion and unreliability days in 2002 but fewer than 2001.
- The general economic slow down may have contributed to somewhat lower congestion levels in 2002, but congestion levels steadily increased from June.

Delay, Mobility and Reliability by Time of Day



- Morning peak delay is less than midday—although it is concentrated in fewer hours.
- Midday delay is as large as evening peak.
- The Planning Time values indicate travelers should plan for a 60 to 110 percent travel time penalty in the peak periods.

Exhibit PDX-4. Share of Delay by Time Period of an Average Weekday

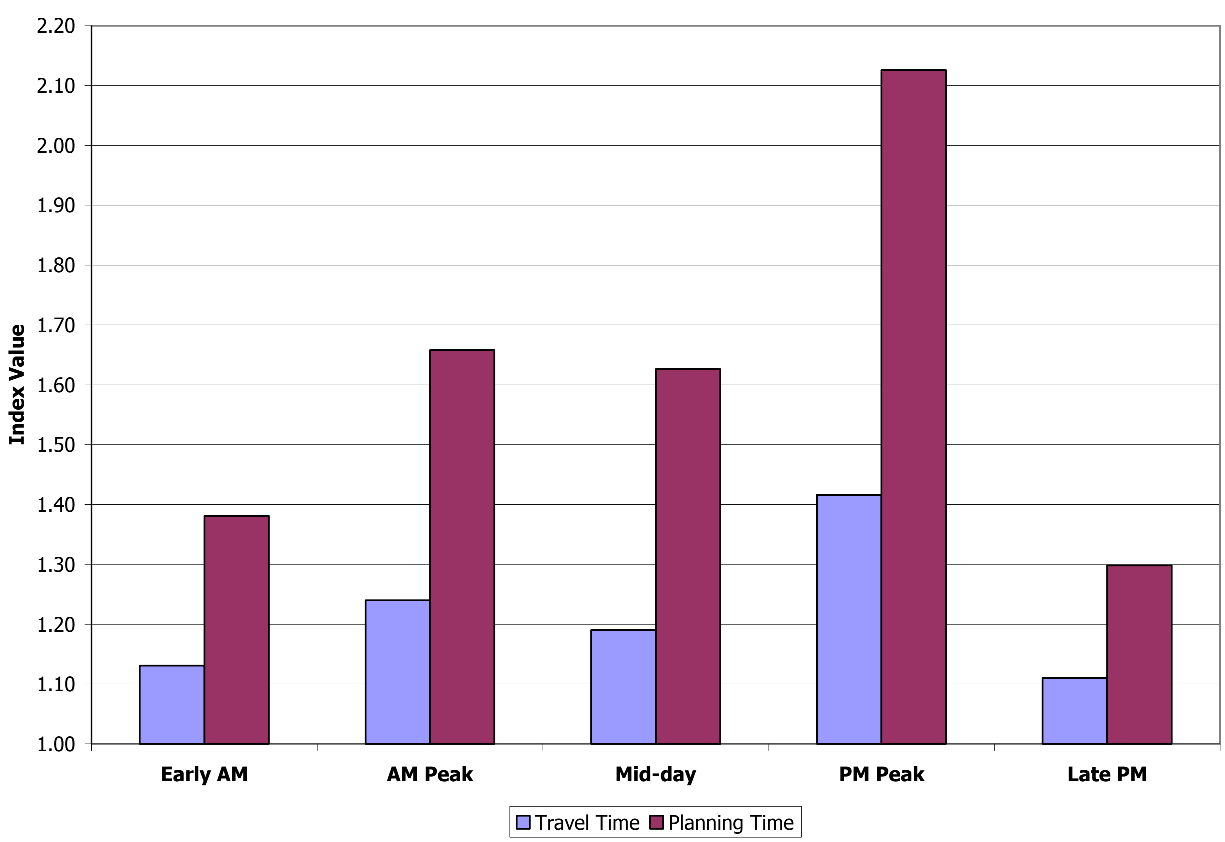
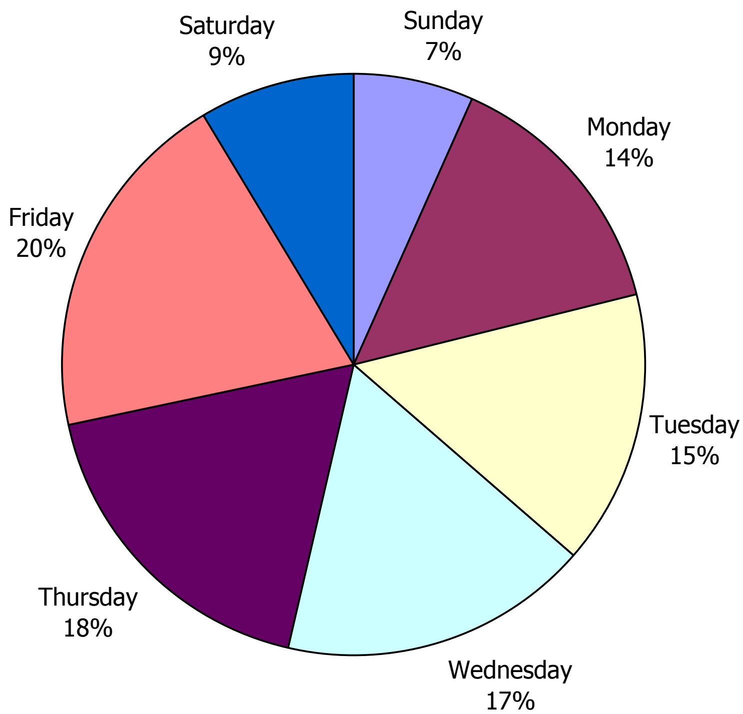


Exhibit PDX-5. Mobility and Reliability by Time Period of an Average Weekday

Delay, Mobility and Reliability by Day of Week



- Weekend delay is equal to one weekday.
- Weekday delay increases from Monday to Friday.
- Unreliability peaks on Fridays.
- The weekday Planning Time appears to vary more than average travel time.
- Weekend Planning Time is greater than the average weekday time.

Exhibit PDX-6. Share of Delay by Day of Week

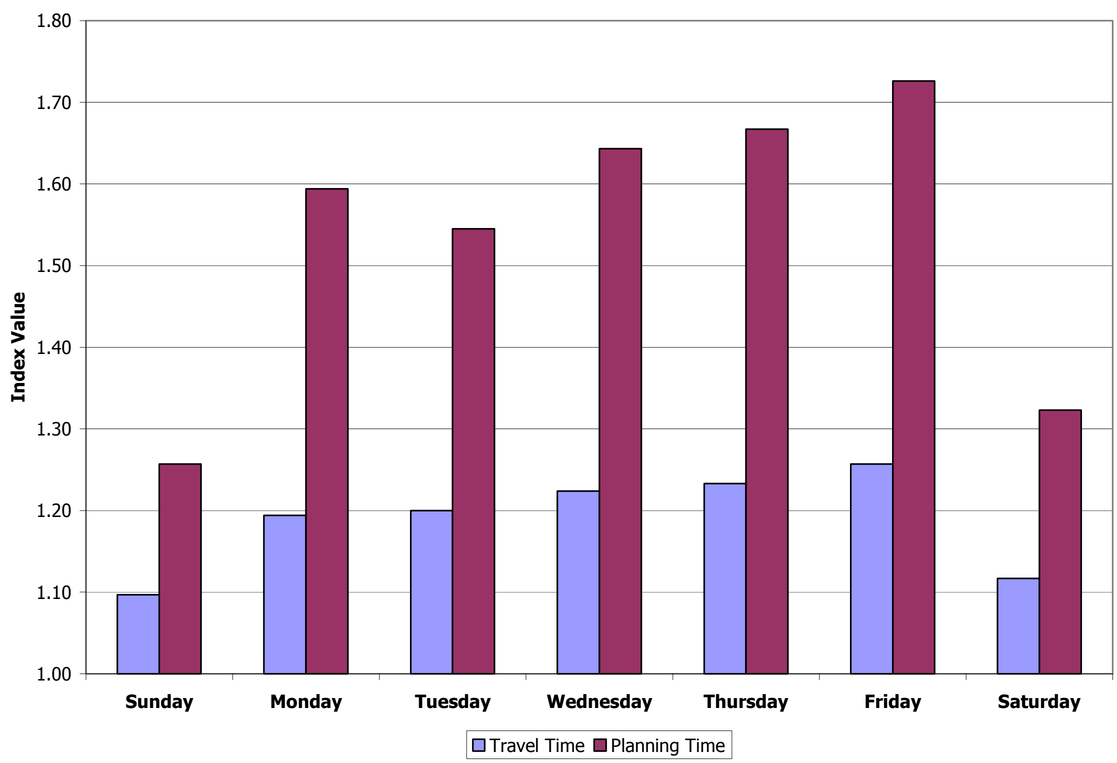


Exhibit PDX-7. Average Daily Mobility and Reliability by Day of Week

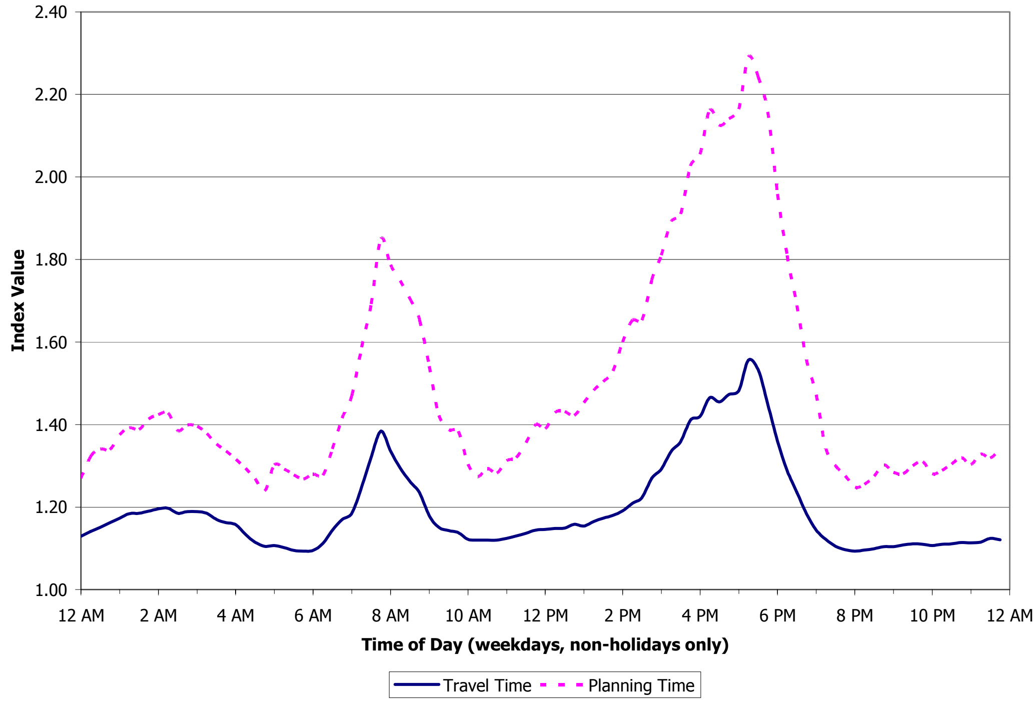


Exhibit PDX-8. Mobility and Reliability by Time of an Average Weekday

- Congestion and unreliability are generally higher in the evening peak.
- Unreliability begins to increase after 2:00 p.m.
- Congestion and unreliability are low during the early morning and late evening. Congestion is low in the early morning, but the Planning Time is relatively high (as high as average travel time in the morning peak).
- Congestion increased during the fall, with several “spikes” and few days as low as the average values from January to May.

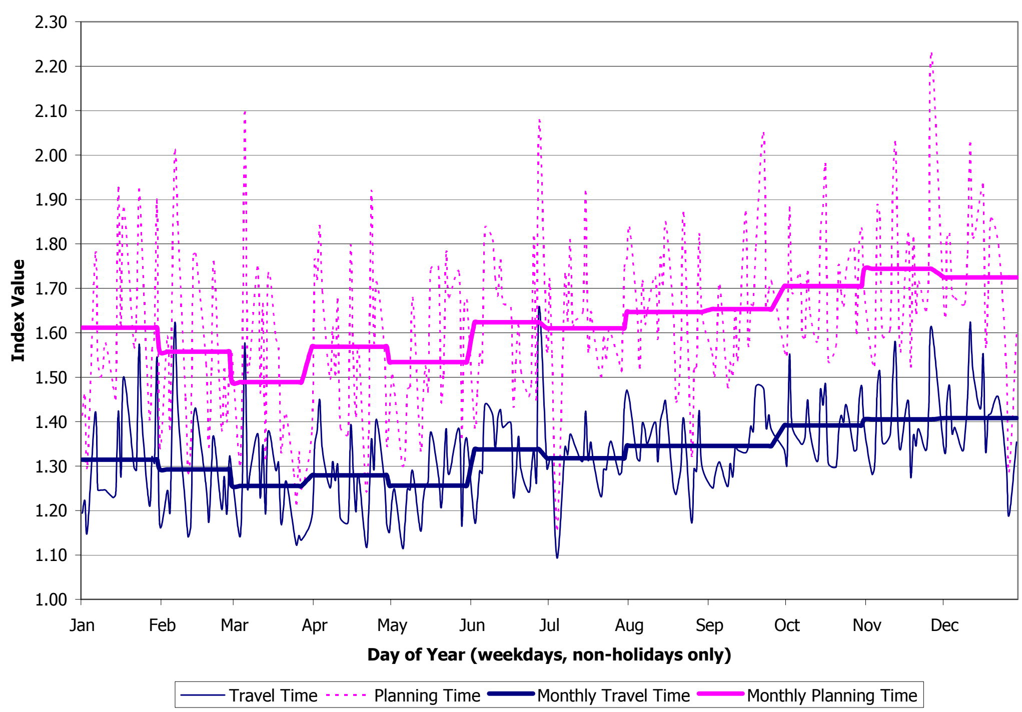


Exhibit PDX-9. Mobility and Reliability by Weekday of the Year

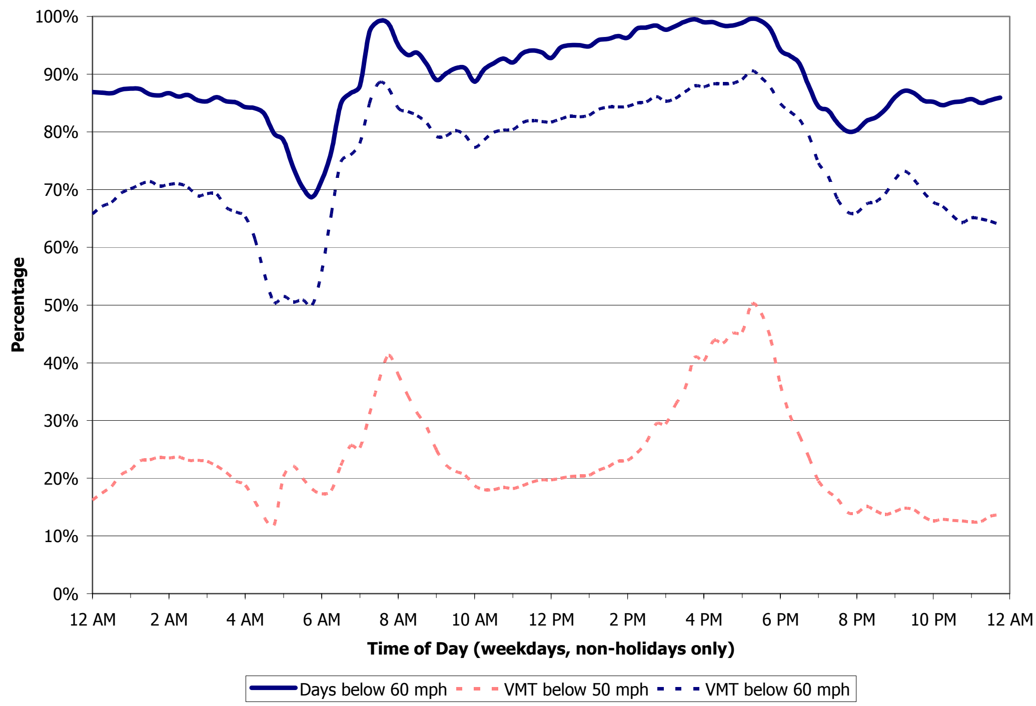


Exhibit PDX-10. Average Weekday Speed Variations

- The amount of travel under 50 mph in the evening is about 10 percent higher than in the morning, a pattern different than the 60 mph line.
- While relatively little vehicle-miles of travel (VMT) is below 40 mph, that speed range accounts for approximately 60 percent of delay.

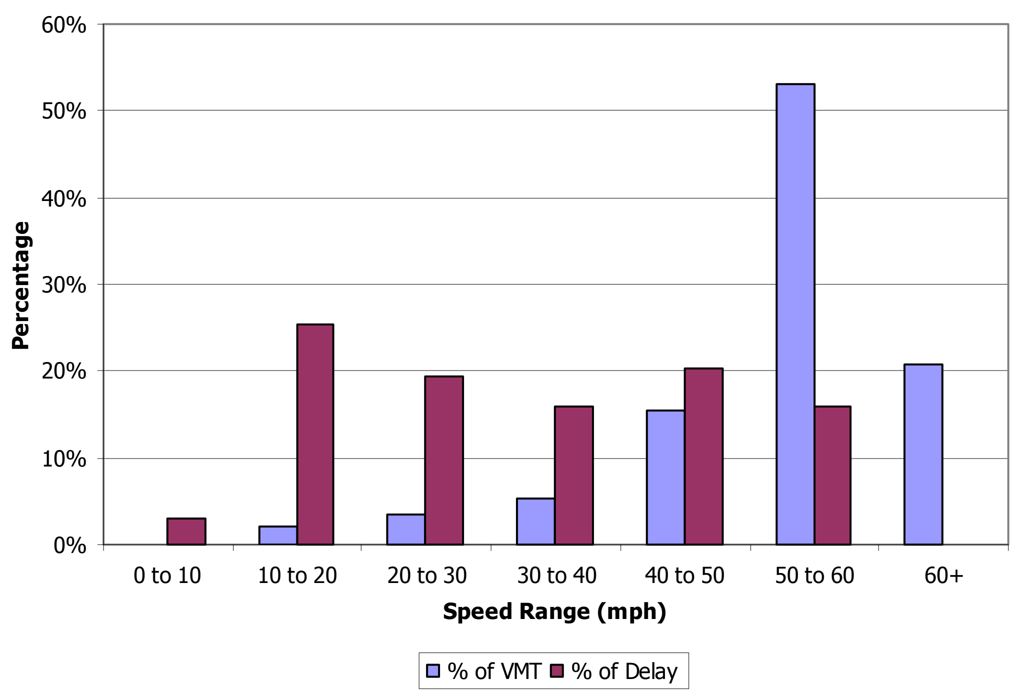


Exhibit PDX-11. Percent of VMT and Delay in Different Speed Ranges

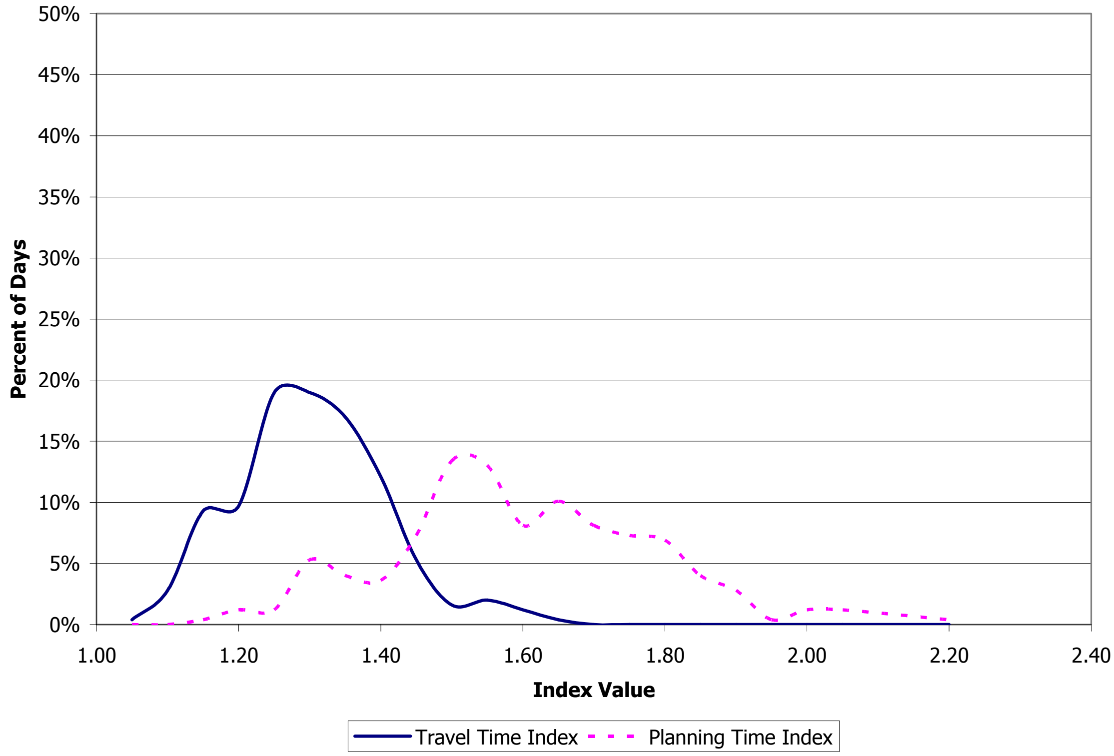


Exhibit PDX-12. Distribution of Travel Time and Planning Time Indices

- ♦ A traveler has an equal chance (10 percent) of encountering a weekday with a 15 percent time penalty and a 40 percent travel time penalty (TTI=1.40).
- ♦ The Planning Time distribution shows a broad range of conditions that must be planned for.
- ♦ The averages for almost all days require less than 50 percent extra travel time, but there are many days when the Planning Time exceeds that value.

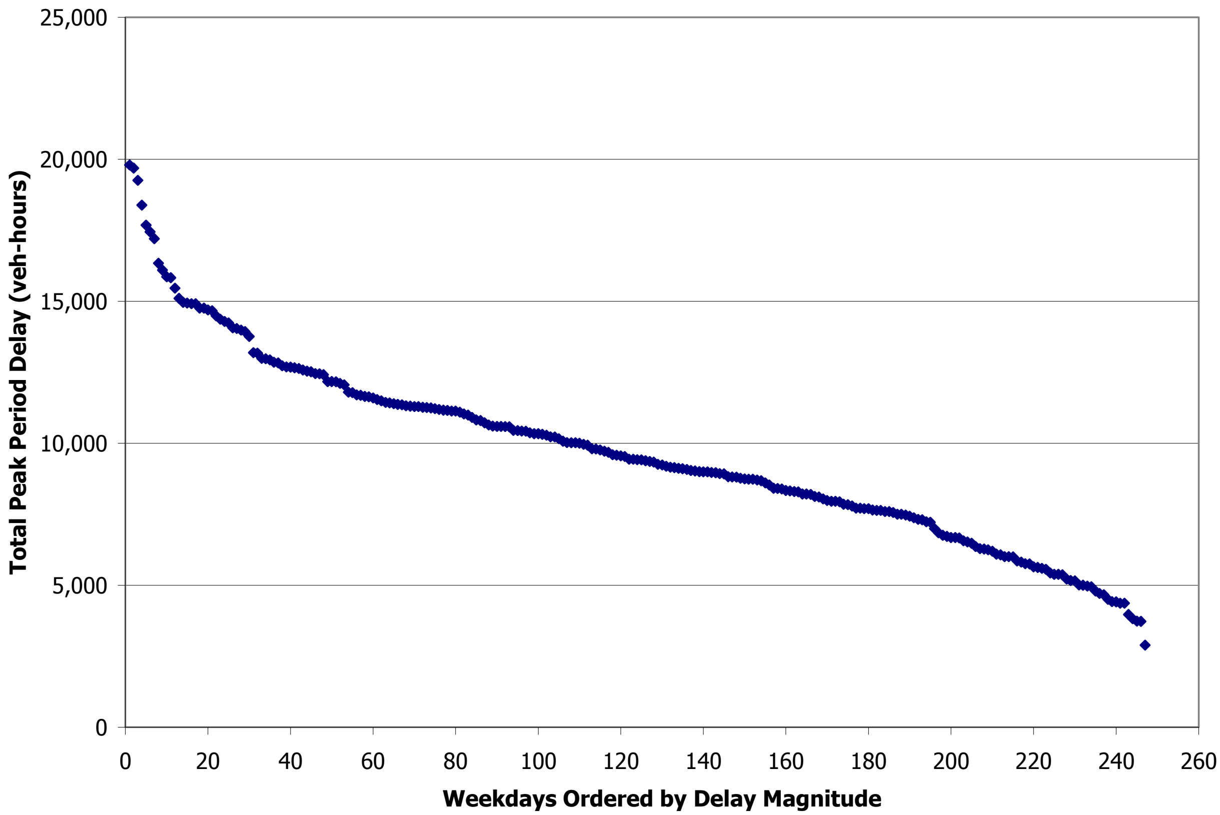
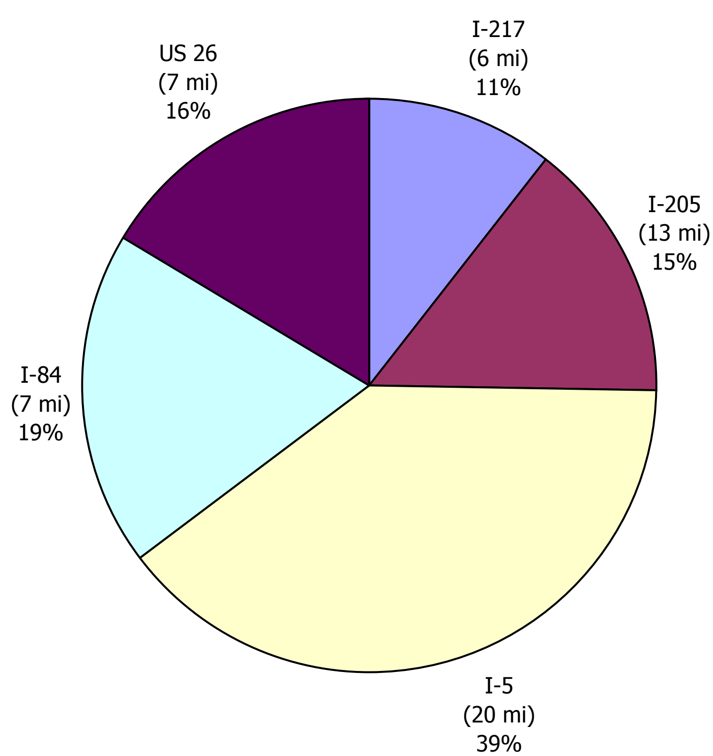


Exhibit PDX-13. Total Delay for Weekdays of the Year



- The pattern of daily delay shows delay declining sharply for the 10 most congested days, and a moderate decline for most other days.
- I-84, with about 13 percent of the mileage, has 19 percent of the delay.

Exhibit PDX-14. Share of Delay by Roadway

Exhibit PDX-15. Mobility and Reliability by Section and Time Period

Section	Length (mi)	Travel Time Index				Buffer Index			
		Morning (6a-9a)	Midday (9a-4p)	Evening (4p-7p)	Average peak period	Morning (6a-9a)	Midday (9a-4p)	Evening (4p-7p)	Average peak period
I-217 NB: 72nd Ave. to Walker Road	5.95	1.13	1.10	1.25	1.19	24%	13%	32%	28%
I-217 SB: Walker Road to 72nd Ave.	6.01	1.12	1.09	1.26	1.20	42%	27%	44%	43%
I-205 NB: ORE 99E to Division	10.33	1.12	1.12	1.27	1.20	40%	38%	51%	46%
I-205 SB: Airportway to ORE43	16.27	1.11	1.07	1.22	1.17	27%	17%	37%	32%
I-5 NB: Stafford Road to Jantzen Beach	21.81	1.21	1.24	1.60	1.41	23%	41%	51%	38%
I-5 SB: Jantzen Beach to Nyberg Road	18.5	1.36	1.30	1.47	1.42	23%	42%	48%	36%
I-84 EB: 39th Street to Morrison/I-84	2.5	1.04	1.30	2.05	1.60	5%	73%	59%	35%
I-84 WB: 33rd Street to 207th Street	12.3	1.60	1.30	1.28	1.45	44%	38%	28%	37%
US 26 EB: Helvetia Road to Skyline Road	10.1	1.29	1.23	1.46	1.37	69%	57%	84%	76%
US 26 WB: Skyline Road to Murray Street	4.06	1.25	1.19	1.82	1.54	29%	39%	84%	57%
Average for all Sections		**1.24**	**1.19**	**1.42**	**1.33**	**33%**	**36%**	**49%**	**41%**

- Several freeway sections have a significant directional congestion difference during the peak periods. In most cases, that difference also exists for peak reliability levels.
- At least eight freeway sections have midday congestion levels near or above morning peak congestion. Six of the 10 sections also have similar or greater reliability problems in the midday than in the morning peak.

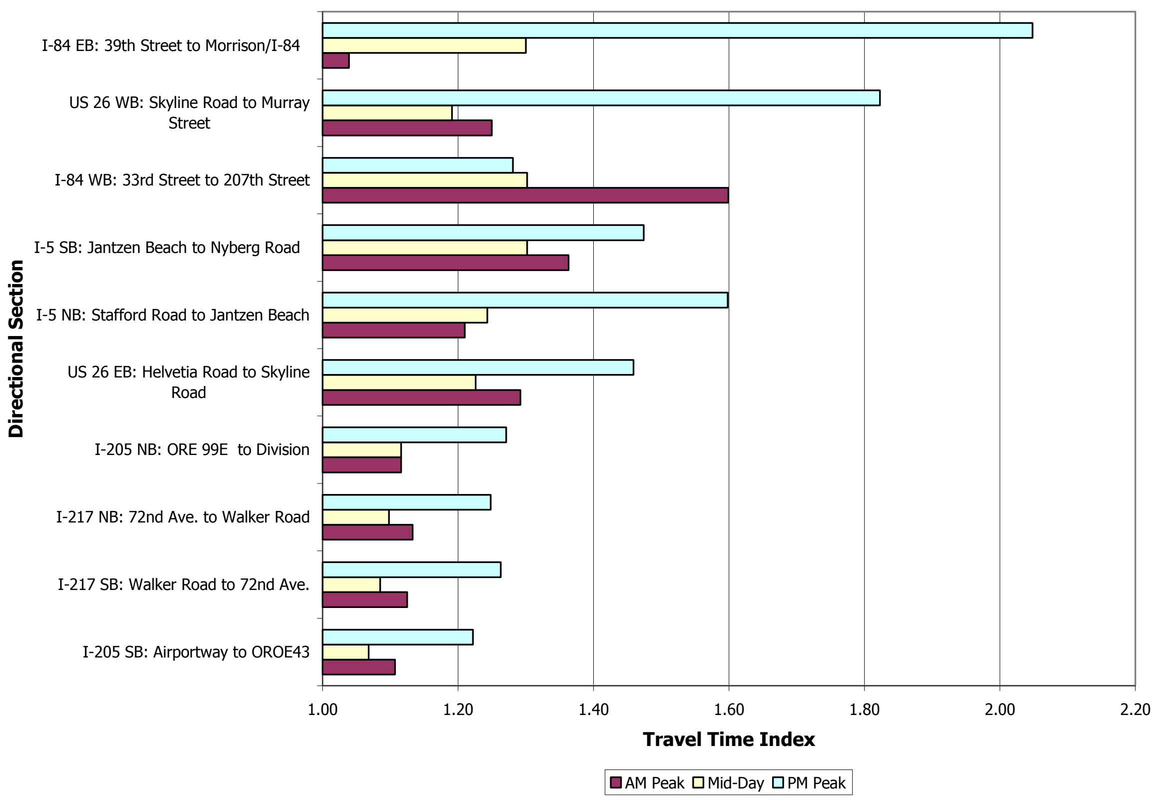


Exhibit PDX-16. Mobility by Section for Daily Time Periods

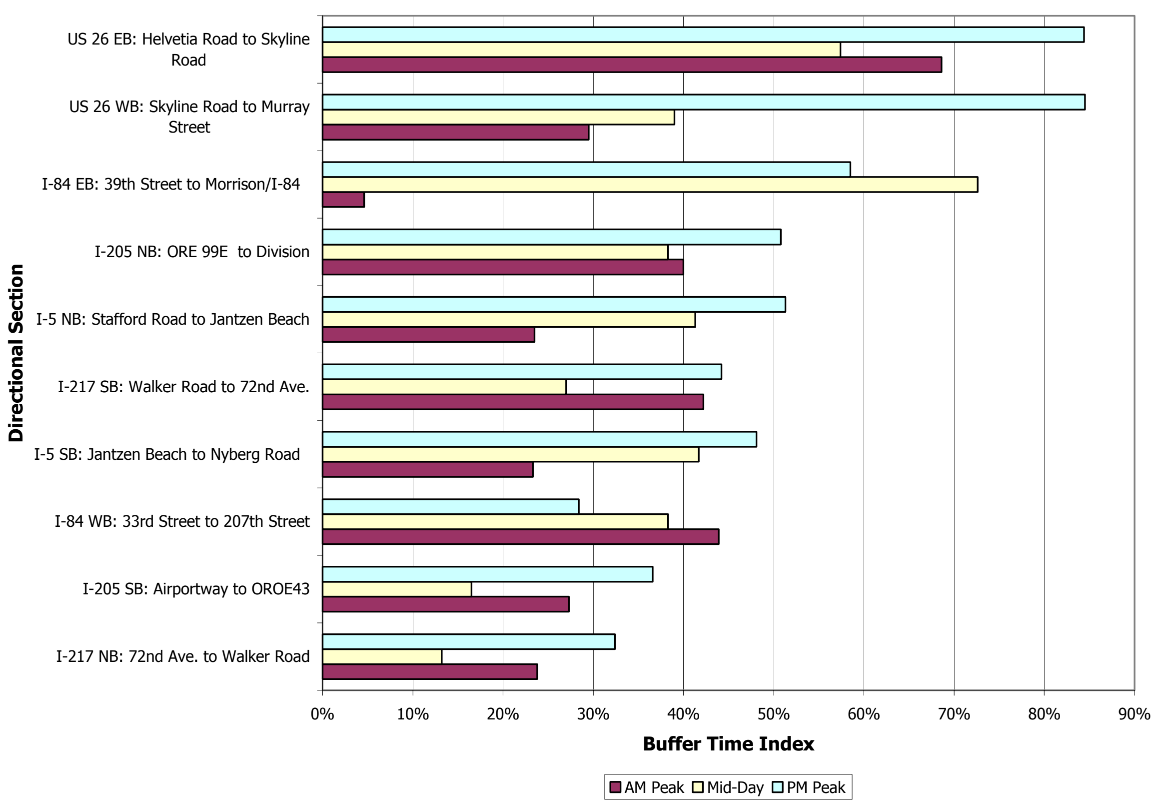


Exhibit PDX-17. Reliability by Section for Daily Time Periods

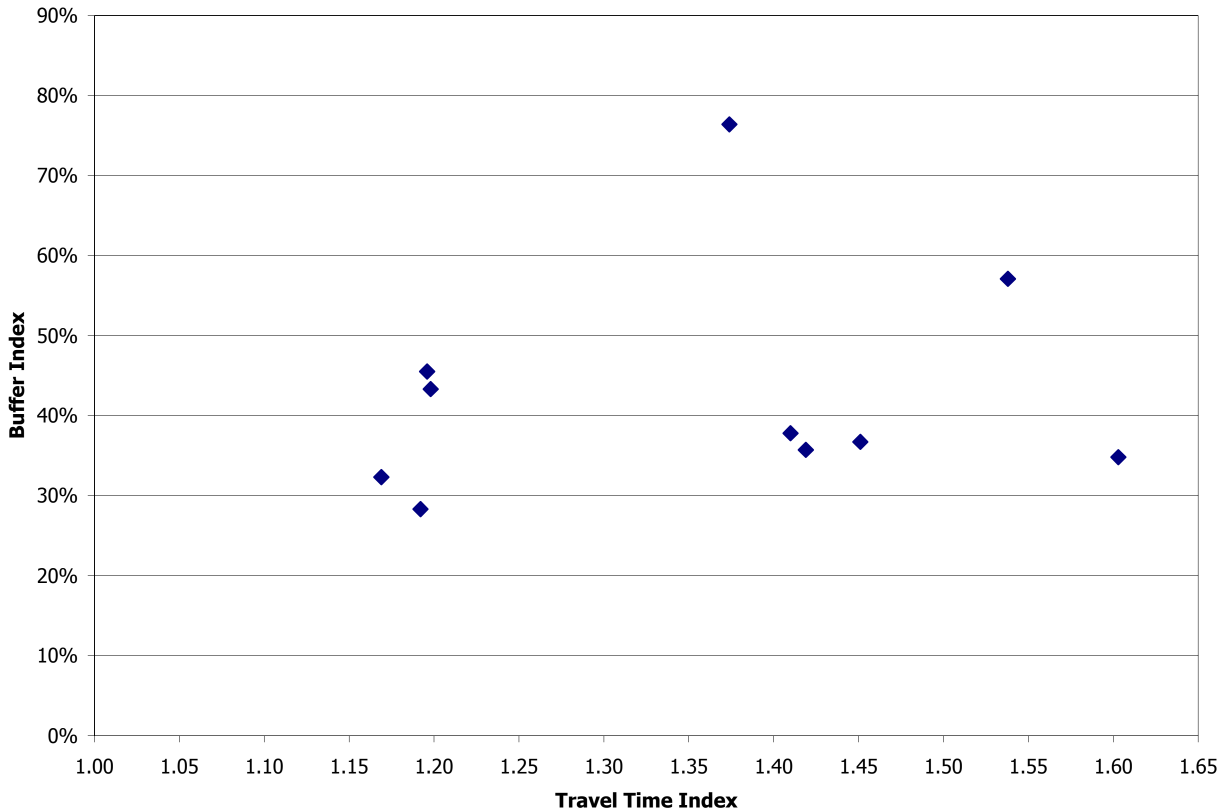


Exhibit PDX-18. Relationship Between Average Peak Period Mobility
and Reliability by Section

- Unreliability is about the same for all congestion levels.
- The two higher unreliability levels are on US 26.

2002 AVERAGE WEEKDAY SPEEDS (mph)

I-5 SB: Jantzen Beach to Nyberg Road
Portland, Oregon

Note: The speed graph indicates the changes in traffic speed during the average day and can illustrate bottleneck locations and times. Exhibit PDX-19 is shown as an example of type of display that can be created.

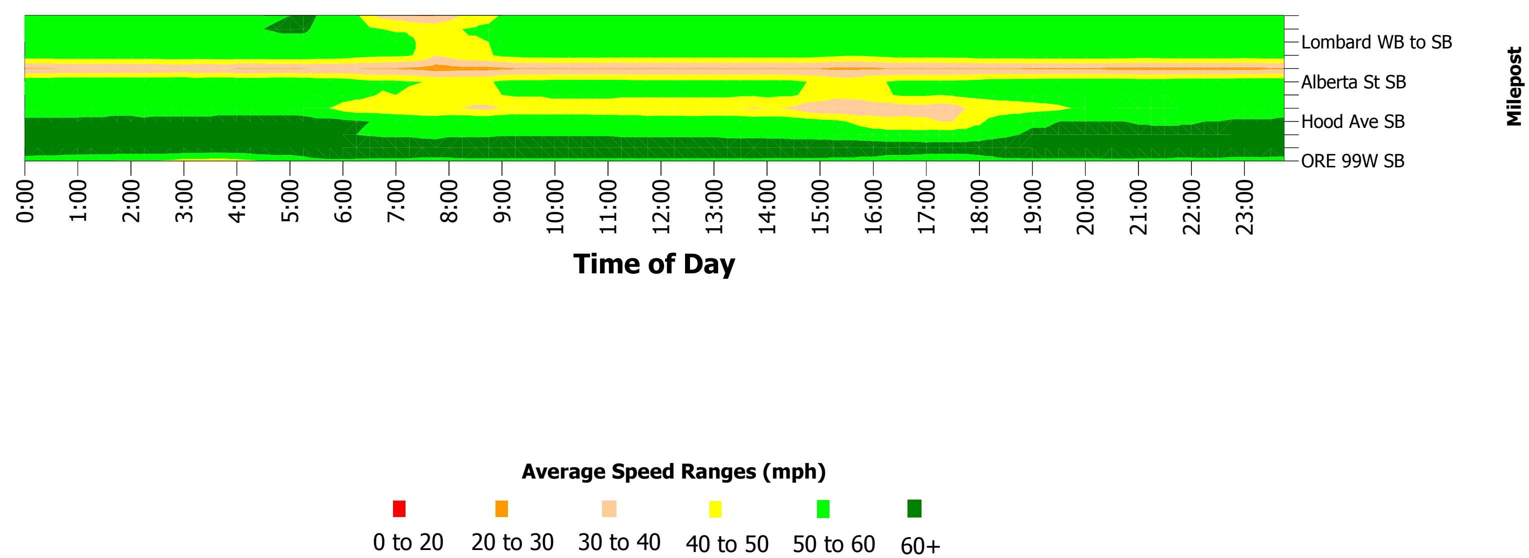


Exhibit PDX-19. Example Speed Contour for I-5 SB

- Speeds are generally slow on the section of I-5 south of Alberta Street, but there appears to be a bottleneck between Hood and Alberta.

Exhibit PDX-20. Top Ten List—Most Congested Periods

Rank	Directional Section	Date	Day of Week	Time Period	Travel Time Index
1	I-217 NB: 72nd Ave. to Walker Road	February 25, 2002	Monday	Early AM	4.24
2	I-84 WB: 33rd Street to 207th Street	December 9, 2002	Monday	AM Peak	4.08
3	I-84 EB: 39th Street to Morrison/I-84	June 28, 2002	Friday	PM Peak	3.90
4	I-217 NB: 72nd Ave. to Walker Road	October 7, 2002	Monday	Early AM	3.70
5	US 26 WB: Skyline Road to Murray Street	June 10, 2002	Monday	PM Peak	3.69
6	I-84 EB: 39th Street to Morrison/I-84	December 12, 2002	Thursday	PM Peak	3.66
7	I-217 NB: 72nd Ave. to Walker Road	October 8, 2002	Tuesday	Early AM	3.61
8	I-217 NB: 72nd Ave. to Walker Road	August 7, 2002	Wednesday	Early AM	3.59
9	I-84 EB: 39th Street to Morrison/I-84	December 13, 2002	Friday	PM Peak	3.54
10	I-217 NB: 72nd Ave. to Walker Road	August 6, 2002	Tuesday	Early AM	3.53
	Average of Top 10				**3.75**

Exhibit PDX-21. Top Ten List—Least Reliable Periods

Rank	Directional Section	Date	Day of Week	Time Period	Buffer Index
1	I-84 WB: 33rd Street to 207th Street	June 26, 2002	Wednesday	AM Peak	304%
2	I-84 WB: 33rd Street to 207th Street	September 16, 2002	Monday	AM Peak	274%
3	I-84 WB: 33rd Street to 207th Street	April 24, 2002	Wednesday	AM Peak	274%
4	I-84 WB: 33rd Street to 207th Street	March 26, 2002	Tuesday	Mid-day	247%
5	I-84 WB: 33rd Street to 207th Street	August 29, 2002	Thursday	Mid-day	243%
6	I-84 WB: 33rd Street to 207th Street	March 18, 2002	Monday	AM Peak	243%
7	I-84 WB: 33rd Street to 207th Street	July 2, 2002	Tuesday	AM Peak	236%
8	I-84 WB: 33rd Street to 207th Street	October 16, 2002	Wednesday	AM Peak	232%
9	I-84 WB: 33rd Street to 207th Street	November 20, 2002	Wednesday	AM Peak	227%
10	I-84 WB: 33rd Street to 207th Street	July 10, 2002	Wednesday	AM Peak	214%
	Average of Top 10				**249%**

- Five of the top 10 most congested peaks are in the early morning.
- Most of the least reliable periods are morning peaks, and all 10 are on one section of I-84 westbound.
- Consecutive days in August, October and December are on the most congested list.

APPENDIX F

HERS-ST Procedure for Recurring and Incident Delay for Freeway and Signalized Arterials
(excerpted from HERS-ST v2.0 Technical Report, 2002, see http://www.fhwa.dot.gov/infrastructure/asstmgmt/hersdoc.htm)

Appendix F: Delay Estimation for Sections with Traffic Signals and for Free-Flow Sections with Two or More Lanes per Direction

The second section of this appendix presents the procedure used for estimating incident delay and other congestion delay for free-flow sections with two or more lanes per direction. The third section presents the procedure used for estimating zero-volume delay, incident delay, and other congestion delay for sections with traffic signals.[1] The first section presents definitions of all variables used by the two procedures.

F.1 Definitions

The following definitions are used in the equations below.

F.1.1 Input Variables

ACR	=	ratio of AADT to two-way capacity during the off-peak period
BPM	=	bottlenecks per mile (set to 0.083 for multi-lane free-flow sections and 0.5 for sections with traffic signals)
CPCAP	=	capacity during peak periods in the counter-peak direction (one way)
CPLANES	=	through lanes in peak period, counter-peak direction
DFAC	=	directional ("D") factor
FFS	=	free-flow speed (mph)
NSIG	=	number of signalized intersections per mile (average)
OP2WCAP	=	two-way capacity during off-peak period
PKCAP	=	capacity during peak period in peak direction (one way)
PLANES	=	through lanes in peak period, peak direction

F.1.2 Intermediate and Output Variables

Index K, K = 1, 2, or 3

1	=	peak period, peak direction
2	=	peak period, counter-peak direction
3	=	off-peak period

1. Both procedures were developed in Cambridge Systematics, Inc., *2000 Revisions to HERS*, prepared for the U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., August 2002. The procedures are based on relationships developed in Cambridge Systematics, Inc., Harry Cohen, and Science Applications International Corp., *Sketch Methods for Estimating Incident-Related Impacts*, prepared for the U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., December 1998, Section 2.3.

DINC(K)	=	incident-related delay (hours per million vehicle-miles) in period/direction K (K = 1, 2, 3)
NITR(K)	=	travel rate (hours per vehicle-mile) without incidents in period/direction K (K = 1, 2, 3)
SHFAC	=	shoulder factor (based on left and right shoulder widths, see Table F-1)
TRAVF(K)	=	fraction of annual travel in period/direction K (K = 1, 2, 3)
VCRPP(K)	=	peak-period volume/capacity ratio – average hourly volume in the indicated direction during a three-hour peak period divided by capacity (K = 1 for peak direction, 2 for counter-peak direction)
ZVDSIG	=	zero-volume delay due to traffic signals (hours per vehicle-mile)

Table F-1. Shoulder Factors (SHFAC)

Number of Lanes per Direction	Number of Six Foot (or wider) Shoulders in Each Direction		
	0	1	2
2	5.22	3.04	1.00
3	4.77	2.83	1.00
4 or more	4.45	2.68	1.00

F.2 Free-Flow Sections with Two or More Lanes per Direction

F.2.1 Fractions of Travel for Free-Flow Sections.

The equations for fraction of travel for free-flow sections with two or more lanes per direction are defined in Table F-2.

Table F-2. Fractions of Travel by Peak/Off-peak Phase for Free-Flow Sections

Peak/Off-Peak	Condition	Fraction of Travel
Off-Peak Period	ACR ≤ 7	$TRAVF(3) = 0.6970$
	ACR > 7 and ACR ≤ 9	$TRAVF(3) = 0.6970 - 0.00085(ACR - 7) + 0.00212(ACR - 7)^{1.39} \times e^{-0.00798(ACR - 7)}$
	ACR > 9 and ACR ≤ 12	$TRAVF(3) = 0.6953 - 0.00187(ACR - 9) - 0.00212(ACR - 7)^{1.39} \times e^{-0.00798(ACR - 7)}$
	ACR > 12	$TRAVF(3) = 0.6897 - 0.00408(ACR - 12) - 0.00212(ACR - 7)^{1.39} \times e^{-0.00798(ACR - 7)}$

Table F-2. Fractions of Travel by Peak/Off-peak Phase for Free-Flow Sections

Peak/Off-Peak	Condition	Fraction of Travel
Peak Period	Peak Direction	$TRAVF(1) = DFAC \times (1 - TRAVF(3))$
	Counter-peak Direction	$TRAVF(2) = (1 - DFAC) \times (1 - TRAVF(3))$

F.2.2 Volume-to-Capacity Ratios for Peak Period on Free-Flow Sections.

The equations for volume-to-capacity for free-flow sections with two or more lanes per direction are defined in Table F-3.

Table F-3. Volume-to-Capacity Ratios for Peak Periods for Free-Flow Sections

Direction	Volume-to-Capacity Ratio
Peak Direction	$VCRPP(1) = 0.243 \times ACR \times TRAVF(1) \times OP2WCAP/PKCAP$
Counter-peak Direction	$VCRPP(2) = 0.243 \times ACR \times TRAVF(2) \times OP2WCAP/PKCAP$

F.2.3 Travel Rate Without Incidents for Free-Flow Sections.

The equations for travel rate for free-flow sections with two or more lanes per direction are defined in Table F-4

Table F-4. Travel Rate Without Incidents for Free-Flow Sections

Peak/Off-Peak	Condition	Travel Rate (hours per vehicle-mile)
Off-Peak Period	ACR ≤ 7	$NITR(3) = (1/FFS) \times (1 + 9.19\times10^{-11} \times ACR^{7.71})$
	ACR > 7 and ACR ≤ 11	$NITR(3) = (1/FFS) \times (1 + 9.19\times10^{-11} \times ACR^{7.71}) + 0.00000133 \times BPM \times (ACR - 7)^{6.97} \times e^{-0.356 \times (ACR - 7)}$
	ACR > 11	$NITR(3) = (1/FFS) \times (1.0367294 - 0.0169 \times ACR + 0.00177 \times ACR^2 - 0.0000407 \times ACR^3) + 0.00000133 \times BPM \times (ACR - 7)^{6.97} \times e^{-0.356 \times (ACR - 7)}$
Peak Period	VCRPP(K) ≤ 0.5995	$NITR(K) = (1/FFS) \times (1 + 0.388 \times VCRPP(K)^{7.27})$
	VCRPP(K) > 0.5995	$NITR(K) = (1/FFS) \times (1.4060195 - 1.84 \times VCRPP(K) + 2.54 \times VCRPP(K)^2 - 0.958 \times VCRPP(K)^3) + 1.69 \times BPM \times (VCRPP(K) - 0.5995)^{2.54} \times e^{1.94 \times (VCRPP(K) - 5.995)}$

F.2.4 Incident Delay for Free-Flow Sections.

The equations for incident delay[2] for free-flow sections with two or more lanes per direction are defined in Table F-5.

Table F-5. Incident Delay for Free-Flow Sections

Peak/Off-Peak	Number of Lanes per Direction	Condition	Incident Delay (hours per vehicle-mile)
Off-Peak Period	2	ACR ≤ 11	$DINC(3) = 4.05 \times ACR^{-0.251} \times e^{(0.603 \times ACR)} \times SHFAC$
		ACR > 11	$DINC(3) = 3.55826 \times 10^{-11} \times ACR^{17.1} \times e^{-0.865 \times ACR} \times SHFAC$
	3	ACR ≤ 11	$DINC(3) = 0.789 \times ACR^{-0.834} \times e^{0.854 \times ACR} \times SHFAC$
		ACR > 11	$DINC(3) = 3.5131342 \times 10^{-11} \times ACR^{16.9} \times e^{-0.847 \times ACR} \times SHFAC$
	4 or more	ACR ≤ 11	$DINC(3) = 0.153 \times ACR^{-0.881} \times e^{1.01 \times ACR} \times SHFAC$
		ACR > 11	$DINC(3) = 3.2672 \times 10^{-11} \times ACR^{16.8} \times e^{-0.82 \times ACR} \times SHFAC$
Peak Period	2	VCRPP(K) ≤ 0.5995	$DINC(K) = 4.6 \times VCRPP(K)^{-0.247} \times e^{9.2 \times VCRPP(K)} \times SHFAC$
		VCRPP(K) > 0.5995	$DINC(K) = 29173.1 \times VCRPP(K)^{5.16} \times e^{-0.789 \times VCRPP(K)} \times SHFAC$
	3	VCRPP(K) ≤ 0.5995	$DINC(K) = 0.011 \times VCRPP(K)^{-2.3} \times e^{16.9 \times VCRPP(K)} \times SHFAC$
		VCRPP(K) > 0.5995	$DINC(K) = 560567 \times VCRPP(K)^{7.99} \times e^{-3.92 \times VCRPP(K)} \times SHFAC$
	4 or more	VCRPP(K) ≤ 0.5995	$DINC(K) = 0.00035 \times VCRPP(K)^{3.19} \times e^{21.8 \times VCRPP(K)} \times SHFAC$
		VCRPP(K) > 0.5995	$DINC(K) = 5841010 \times VCRPP(K)^{10.1} \times e^{-6.12 \times VCRPP(K)} \times SHFAC$

2. These equations produce values of DINC in hours per vehicle-mile for consistency with the corresponding equations for sections with traffic signals (in Section I.3). The equations in the HERS code for multi-lane free-flow sections (but not those for sections with traffic signals) actually produce values in hours per million vehicle-miles that are subsequently converted to hours per thousand vehicle-miles and hours per vehicle-mile as needed.

F.3 Signalized Arterials

F.3.1 Fractions of Travel for Signalized Arterials.

The equations for fraction of travel for signalized arterials are defined in Table F-6.

Table F-6. Fraction of Travel for Signalized Arterials

Peak/Off-Peak	Condition	Fraction of Travel
Off-Peak	ACR ≤ 7	$TRAVF(3) = 0.7106$
	ACR > 7 and ACR ≤ 9	$TRAVF(3) = 0.7106 - 0.00160\ (ACR-7) + 0.00240\ (ACR-7)^{1.48}\ e^{-0.0431(ACR-7)}$
	ACR > 9 and ACR ≤ 12	$TRAVF(3) = 0.7074 - 0.00227\ (ACR-9) + 0.00240\ (ACR-7)^{1.48}\ e^{-0.0431(ACR-7)}$
	ACR > 12	$TRAVF(3) = 0.7006 + 0.00373\ (ACR-12) + 0.00240\ (ACR-7)^{1.48}\ e^{-0.0431(ACR-7)}$
Peak	Peak Direction	$TRAVF(1) = DFAC * (1 - TRAVF(3))$
	Counter-peak Direction	$TRAVF(2) = (1 - DFAC) * (1 - TRAVF(3))$

F.3.2 Volume-to-Capacity Ratios for Peak Period on Signalized Arterials.

The equations for volume-to-capacity for signalized arterials are defined in Table F-7.

Table F-7. Volume-to-Capacity Ratios for Peak Periods on Signalized Arterials

Direction	Volume-to-Capacity Ratio
Peak Direction	$VCRPP(1) = 0.243 \times ACR \times TRAVF(1) \times OP2WCAP/PKCAP$
Counter-peak Direction	$VCRPP(2) = 0.243 \times ACR \times TRAVF(2) \times OP2WCAP/PKCAP$

F.3.3 Zero-volume Delay Due to Traffic Signals for Signalized Arterials.

Zero-volume delay is delay associated with traffic control signals. The equation for zero-volume delay is:

$$ZVDSIG = 0.0687\ (1 - e^{-NSIG/24.4})$$

F.3.4 Travel Rate Without Incidents for Signalized Arterials.

The equations for travel rate for signalized arterials are defined in Table F-8.

Table F-8. Travel Rate Without Incidents for Signalized Arterials

Peak/Off-Peak	Condition	Travel Rate (hours per vehicle-mile)
Off-Peak Period	ACR ≤ 7	$NITR(3) = (1/FFS+ZVDSIG)\ (1 + 0.0213\ ACR^{1.05})$
	ACR > 7 and ACR ≤ 11	$NITR(3) = (1/FFS+ZVDSIG)(1 + 0.0213\ ACR^{1.05}) + 4.56E\text{-}08\ BPM\ (ACR-7)^{8.25}\ e^{-0.561\ (ACR-7)}$
	ACR > 11	$NITR(3) = (1/FFS+ZVDSIG)\ (1.05 + 0.0247\ ACR - 0.000504\ ACR^2 + 2.68E\text{-}06\ ACR^3) + 4.56E\text{-}08 \times BPM \times (ACR-7)^{8.25}\ e^{-0.561\ (ACR-7)}$
Peak Period	VCRPP(K) ≤ 0.5767	$NITR(K) = (1/FFS+ZVDSIG)\ (1 + 0.455\ VCRPP(K)^{1.02})$
	VCRPP(K) > 0.5767	$NITR(K) = (1/FFS + ZVDSIG)(0.889 + 0.680 \times VCRPP(K) + 0.0423\ VCRPP(K)^2 - 0.182\ VCRPP(K)^3) + 0.228\ BPM\ (VCRPP(K) - 0.5767)^{2.66}\ e^{3.61\ (VCRPP(K)-0.5767}$

F.3.5 Incident Delay for Signalized Arterials.

The equations for incident delay for signalized arterials are defined in Table F-9.

Table F-9. Incident Delay for Signalized Arterials

Peak/Off-Peak	Condition	Incident Delay (hours per vehicle-mile)
Off-Peak Period	ACR ≤ 11	$DINC(3) = 7.52E\text{-}06\ (ACR)^{1.11}\ e^{0.132\ ACR}$
	ACR > 11	$DINC(3) = 7.74E\text{-}09\ (ACR)^{5.20}\ e^{-0.135\ ACR}$
Peak Period	VCRPP(K) ≤ 0.5767	$DINC(K) = 0.000111\ (VCRPP(K))^{-0.878}\ e^{2.83\ VCRPP(K)}$
	VCRPP(K) > 0.5767	$DINC(K)= 1.34E\text{-}06\ (VCRPP(K))^{-2.05}\ e^{7.74\ VCRPP(K)}$

APPENDIX G

Explanation of Spreadsheets

This appendix explains the attached spreadsheet ("ODOT Operations Performance Measures.xls") in more detail. There are six workbooks within the spreadsheet, and they are named as follows:

Bend_Parkway(Hwy 4):	contains calculations for Bend Parkway.
Powell_Blvd(IHwy26):	contains calculations for Powell Boulevard.
I-5_Barbur(Hwy91):	contains calculations for the I-5 and Barbur Boulevard system analysis.
Salmon_River(Hwy39):	contains calculations for Salmon River Highway (ORE 18).
FFS with ITS data:	contains average speed by time period and station from real-time data.
I-5 ITS and HERS-ST comparison:	contains the analysis of real-time and HERS-ST estimates along I-5.

The variables used in each spreadsheet are discussed below along with the primary calculations. HPMS item numbers are also provided for appropriate variables that can be found in the *Highway Performance Monitoring System Field Manual* (http://www.fhwa.dot.gov/ohim/hpmsmanl/hpms.htm).

Workbook "Bend_Parkway(Hwy 4)"

Column	*Variable*	*Description*
<u>*HERS-ST Input*</u>		
Column A	Section_ID	Unique identifier for each segment of analysis HPMS item #5
Column B	LRS_ID	Linear referencing system number for a given corridor HPMS item #10
Column C	LRS_BMP	Linear referencing system, beginning milepoint HPMS item #11
Column D	LRS_EMP	Linear referencing system, ending milepoint HPMS item #12
Column E	Sec_Len	Section length
Column F	Rur_Urb	Rural/urban designation HPMS item #13
Column G	Func_Cls	Functional class HPMS item #17
Column H	Typ_Fac	Facility type HPMS item #27
Column I	AADT	Annual average daily traffic HPMS item #33

Column J	Num_LN	Number of through lanes HPMS item #34
Column K	LN_WD	Lane width HPMS item #54
Column L	Medn_Typ	Median type HPMS item #56
Column M	Medn_WD	Median Width HPMS item #57
Column N	PSD	Percent passing sight distance HPMS item #78
Column O	Acc_Ctrl	Access control HPMS item #55
Column P	PCPKSU	Percent single-unit trucks, peak HPMS item #81
Column Q	PCAVSU	Percent single-unit trucks, average daily HPMS item #84
Column R	PCPKCM	Percent combination trucks, peak HPMS item #83
Column S	PCAVCM	Percent combination trucks, average daily HPMS item #84
Column T	KFAC	K-factor HPMS item #85
Column U	DirFac	Directional factor HPMS item #86
Column V	NumPKLN	Number of peak lanes HPMS item #87
Column W	PctGrn	Typical peak percent green time HPMS item #91
Column X	NSignl	Number of at-grade intersections, signals HPMS item #92
Column Y	NStop	Number of at-grade intersections, stop sign HPMS item #93
Column Z	NOINTS	Number of at-grade intersections, other/no control HPMS item #94
Column AA	Capac	Capacity (this is set to zero initially and calculated internally) HPMS item #95
Column AB	HORA	Horizontal alignment adequacy HPMS item #69
Column AC	CRV_A	Length of Class A curves HPMS item #63
Column AD	CRV_B	Length of Class B curves HPMS item #64
Column AE	CRV_C	Length of Class C curves HPMS item #65
Column AF	CRV_D	Length of Class D curves HPMS item #66

Column AG	CRV_E	Length of Class E curves HPMS item #67
Column AH	CRV_F	Length of Class F curves HPMS item #68
Column AI	VERA	Vertical alignment adequacy HPMS item #71
Column AJ	GRD_A	Length of Class A grades HPMS item #72
Column AK	GRD_B	Length of Class B grades HPMS item #73
Column AL	GRD_C	Length of Class C grades HPMS item #74
Column AM	GRD_D	Length of Class D grades HPMS item #75
Column AN	GRD_E	Length of Class E grades HPMS item #76
Column AO	GRD_F	Length of Class F grades HPMS item #77
Column AP	SPD	Posted speed

HERS-ST Output

Column AQ	PKSPD	Peak period speed
Column AR	CPSPD	Counter-peak speed
Column AS	OPSPD	Off-peak speed
Column AT	AES	Average effective speed (24-hour speed)
Column AU	VCR	Peak-period V/C ratio
Column AV	TLAN	Through lanes
Column AW	PLAN	Peak direction number of lanes
Column AX	CPLAN	Counter-peak direction number of lanes
Column AY	PCAP	Peak-period direction capacity
Column AZ	CPCAP	Counter-peak direction capacity
Column BA	OPCAP	Off-peak direction capacity

Crash Information

Column BB	Total 2000 number of crashes	
Column BC	Total 2001 number of crashes	
Column BD	Total 2002 number of crashes	
Column BE	LRS_BMP	Linear referencing system, beginning milepoint HPMS item #11
Column BF	LRS_EMP	Linear referencing system, ending milepoint HPMS item #12
Column BG	2002 Total	Total number of crashes from crash report data
Column BH	2002 Rate	Crash rate per million VMT
Column BI	2002 PDO	Total number of property-damage only crashes

Column BJ	PDO Rate	Total rate of property-damage only crashes per million VMT
Column BK	2002 FAT	Total number of fatality crashes
Column BL	FAT Rate	Total rate of fatality crashes per million VMT
Column BM	2002 INJ	Total number of injury crashes
Column BN	INJ Rate	Total rate of injury crashes per million VMT
Column BO	DEL_ZV	Zero-volume delay to estimate the affect of traffic signals (24-hour delay in hours per thousand VMT)
Column BP	DEL_INC	Incident delay (24-hour in hours per thousand VMT)
Column BQ	DEL_Other	Other causes of delay (congestion) (24-hour in hours per thousand VMT)
Column BR	DEL_Total	Sum of all delays (24-hour in hours per thousand VMT)
Column BS	VMT	Vehicle-miles of travel
Column BT	TTC	Travel-time costs
Column BU	X4TOC	Operating costs, 4-tire vehicles (user cost: $ per 1000 VMT)
Column BV	TKOC	Operating costs, trucks (user cost: $ per 1000 VMT)
Column BW	AVOC	Operating costs, all vehicles (user cost: $ per 1000 VMT)
Column BX	CRAC	Crash costs
Column BY	TUC	Total user costs
Column BZ	CRAR	Crash rate per 100 million VMT
Column CA	INJR	Injury rate per 100 million VMT
Column CB	FATR	Fatality rate per 100 million VMT
Column CC	MNT	Average annual maintenance cost ($ per mile)
Column CD	EMIC	Average pollution costs ($ per 1000 VMT)
Column CE	VMTcalc	Computed VMT from 24-hour daily estimates to yearly
Column CF	Days	Used to verify the number of days over which VMTcalc (Column CE) was computed

Segment Supporting Computations

Column CG	AADT/lane	AADT per lane given HERS-ST inputs
Column CH	AADT/PCAP	AADT divided by the peak-direction capacity
Column CI	FFS	Free-flow speed computed with ODOT R-code
Column CJ	FFS_TRate	Free-flow speed travel rate (minutes per mile)
Column CK	AES_TRate	Average effective speed travel rate (minutes per mile)
Column CL	Pk_TRate	Peak-period speed travel rate (minutes per mile)

Performance Measures

Column CM	TTI (AES)	Travel Time Index as ratio of average effective speed and free-flow speed travel rates
Column CN	TTI (Pk)	Travel Time Index as ratio of peak-period speed and free-flow speed travel rates
Column CO	85% Lower PI, BI (Pk)	Buffer Index lower 85th percentile prediction interval—Only computed for freeway facilities
Column CP	Middle , BI (Pk)	Buffer Index middle prediction value—Only computed for freeway facilities

Column CQ	85% Upper PI, BI (Pk)	Buffer Index upper 85th percentile prediction interval—Only computed for freeway facilities
Column CR	V/C	V/C ratio
Column CS	AES speed	Average effective speed
Column CT	Peak speed	Peak speed
Column CU	AES TT	Average effective speed segment travel time
Column CV	Pk spd TT	Peak-period speed segment travel time
Column CW	Inc_Delay	Incident delay in hours
Column CX	Tot_Delay	Total delay in hours per thousand VMT
Column CY	Tot_Delay	Total delay in hours
Column CZ	Delay reduction due to actuated signals (percentage)	
Column DA	Delay reduction due to actuated signals (hours)	

Corridor Supporting Computations (these computations are used for weighting measures by segment VMT)

Column DB	Travel Time Index times VMT for average effective speed corridor estimate of TTI
Column DC	V/C times VMT for average effective speed and peak-speed corridor estimate of V/C
Column DD	Average effective speed times VMT for corridor estimate of speed
Column DE	AADT/PCAP for each segment to obtain corridor estimate
Column DF	TTI times VMT for the peak-period corridor TTI estimate
Column DG	Speed times VMT for the peak-period corridor speed estimate

CAD Segment Incident Data

Column DH	BMP Beginning segment milepost
Column DI	EMP Ending segment milepost
Column DJ	Total number of segment incidents (value is good from the row it appears to the next value in the column)
Column DK	Incident rate per million VMT for the segment (value is good from the row it appears to the next value in the column)

Other Cell Computations

Cell E67	Total segment length
Cell X67	Signal density (signals per mile)
Cell CU72	Number of travelers
Row 67	Numerous averages and sums of columns for average corridor statistic computations

Row 68 includes performance measures summarized for the corridor based on the average effective speed (cell CK68). These include TTI (column CM), V/C (column CR), speed (column CS), travel time (column CU), total delay (column CY), total delay reduction (column DA).

Row 69 includes performance measures summarized for the corridor based on the peak-period speed (cell CK69). These include TTI (column CN), V/C (column CR), speed (column CT), and travel time (column CV).

Cell CO76 to cell CS79 includes ATR identifiers, speed and volume estimates.

Cell CV70 to cell CY78: Estimates of base delay from HERS-ST, delay reduction, and total delay computed with various units.

Workbook "Powell_Blvd(Hwy26)"

Column headings and variable names are identical to the Bend Parkway worksheet explained above. The row references are slightly different because there are fewer segments along Powell than there were along the Bend Parkway.

Workbook "Salmon_River(Hwy39)"

Column headings and variable names for the Salmon River Highway are very similar to Bend Parkway and Powell Boulevard except for the delay reduction factors that are used. These are shown in columns CZ through DC. As explained in section 6.4 of the report, Column CZ shows the pre-incident duration time of 2.07 hours and the computed vehicle-hours of delay from reference *4*. Column DA shows a similar computation of delay in vehicle-hours for post-incident response where the incident duration was found as 1.42 hours. The difference between these values equates to an incident patrol delay reduction of 47 percent (column DB). Column DB shows the delay reduction in hours due to the patrols. Note that the values in column CZ, DA, and DB do not change by segment, but are computed for each segment as a function of the incident duration only.

Workbook "I-5_Barbur(Hwy91)"

This spreadsheet shows the computations for both I-5 (rows 4 through 48), Barbur Boulevard (rows 49 through 167) and for the two facilities combined (rows 168 to 189). As with the Salmon River Highway explanation, column headings and variable names are very similar to Bend Parkway and Powell Boulevard except for the delay reduction factors that are used. These appear in columns CZ through DH. Column CZ and DA are for the presence of incident patrols (I-5 only), columns DB and DC are for the presence of surveillance cameras (I-5 only), columns DD and DE are for the presence of ramp metering (I-5 only), and columns DF and DG are for the presence of actuated signals (Barbur Boulevard only). Column DH is the sum of the total delay reduction due to the operational treatments. Columns DI through DN are used in the "I-5 ITS and HERS-ST comparison worksheet."

Workbook "FFS and ITS Data"

Section 7.2 of the report discusses the use of the ramp metering (ITS) data for estimating the free-flow speed. This workbook presents the posted speed (column A), ramp metering station (column B), station type (column C) (they are all for freeways as opposed to the entrance ramps, which were removed), and average yearly speed for the 15-minute period of interest (columns D to CU). The data for the peak periods (6 a.m. to 9 a.m. and 4 p.m. to 7 p.m.) are highlighted in yellow. Rows 3 to 15 present the data from all calendar days while rows 18 to 30 include just weekdays (no weekends/holidays).

Workbook "I-5 ITS and HERS-ST Comparison"

This workbook contains computations to compare the performance measure estimates along I-5 from the ITS data and from the HERS-ST outputs. Comparison between these two data sources required that the performance measure estimates from HERS-ST be computed based upon the posted speed because the posted speed was used as the free-flow speed with the ITS data due to the variability found in the ITS data (discussed in section 7.2 of the report). It was also necessary to create equivalent station and section lengths in HERS-ST to match the ITS data. Using the posted speed and creating the appropriate station and section lengths in HERS-ST is performed in this spreadsheet. It should be noted that the words "with" and "without" are used in this spreadsheet to indicate if the calculation is "with operational treatments included" or "without operational treatments included."

Columns A through BZ (rows 1 through 34) were previously described for the corridor spreadsheets above. These data were simply included for I-5 for reference. Columns CA through CC were computed for reference to the posted speed. Columns CD through CQ show the computation of the performance measures as compared to the posted speed as the free-flow speed estimate. Column CE shows the ITS station ID that indicates how the ITS stations match the HERS-ST stations. The first few rows of each analysis are the southbound segments and the northbound segments follow. Computations are performed directionally to compare the two data estimation sources.

The next horizontal section of data (rows 40 to 74) contains the computations for HERS-ST computations with the peak-speeds compared to the posted speed. Columns CP to CW contain computations to estimate the peak total delay (column CV) and the peak incident delay (column CW) from a back-calculated estimate of peak delay (without operational treatments) using the posted speed as the free-flow speed and the peak speed for the peak hour. As indicated in the spreadsheet, this process uses the same percent reductions (incident and total delay) for the operational treatments as previously used for the HERS-ST analysis shown in the I-5_Barbur worksheet. The column headings in column CV and CW, shown in red, present the final results of this analysis.

The analysis in rows 40 to 74, columns DF to DM contains computations to estimate 24-hour total delay (column DL) and 24-hour incident delay (column DM). The delay reduction factors and ratio of incident delay to total delay were kept the same as found in the I-5_Barbur worksheet. The computations show that the 24-hour delay estimates from columns DL and DM were lower than those computed for the peak period (columns CV and CW). This indicated that it was not possible to obtain the delay estimates in this manner by back-calculating them from the posted speed (as an estimate of free-flow speed) and peak-period speed because of how HERS-ST internally computes the delay on a segment-by-segment basis.

The estimates of the HERS-ST total delay and incident delay from the I-5_Barbur Boulevard workbook were used to get the estimate of the delay. It is not based on the posted speed because it uses the internally-computed free-flow speed. Columns CX to DB contain calculations of the 24-hour total delay (column DA) and incident delay (Column DB) using the same reduction factors from the I-5_Barbur worksheet.

Columns CF to EL contain the computations that compare the HERS-ST estimates of the performance measures to those obtained from the ITS data source. This is done for estimates based on the 24-hour speed (rows 78 to 107) and for the peak-period speed (rows 108 to 136). The delay values in column DN and DO between the peak period and the 24-hour period again indicate that back-calculating the delay values for the peak period produces delay values in the peak period that are larger than the 24-hour period; therefore, this method does not work in this case (i.e., comparing cell DN106 to cell DN136). Therefore, it would be ideal to obtain the peak-period delay from the HERS-ST output directly rather than attempting this computation by post-processing. The HERS-ST 24-hour delay estimates in cells DN90, DN104 and DN 106 were used in Table 11 of the report.

APPENDIX H

Description of HERS-ST and Operations Performance Measures (OPM) Analysis

Introduction

The Highway Economic Requirements System-State Version (HERS-ST) is a highly sophisticated highway deficiency analysis model that allows states to identify long-term investment needs and performance, and to evaluate the impacts of alternative highway investment levels on the state highway system. The HERS-ST model simulates highway condition and performance levels and identifies deficiencies through the use of engineering principles. The model then identifies a set of alternative improvements to correct each deficiency and determines a benefit-to-cost ratio for each potential improvement. Subsequently, the most economically attractive improvement for each deficiency is accepted, the improvement implemented based on available funding, and the resulting improved performance condition for each section is re-evaluated and output by the model.

The HERS-ST model is an enhanced version of the HERS model which has been used by the Federal Highway Administration since 1995 to provide estimates of investment requirements for the nation's highway system in the biennial Condition and Performance (C&P) Report to Congress. The logical structure of HERS-ST is identical to the national version of HERS, and the input requirements for both make use of the highway section dataset in the Highway Performance Monitoring System (HPMS) format. The user-friendly Graphical User Interface (GUI) and certain input/output features are the primary difference that distinguishes HERS-ST from HERS-National.

NOTE: The HERS-ST model employs sectional analysis, where the deficiencies of a single section are evaluated independently of any adjacent sections. Network analysis is not incorporated, and mode shifting is not considered.

ODOT Deficiency Analysis History

The Oregon Department of Transportation (ODOT) has made extensive use of the deficiency analysis models for over a dozen years for planning analysis, beginning with the Highway Performance Monitoring System Analytical Process (HPMSAP or AP) in the early 1990's. Most recently, Oregon used the AP model to provide supporting data for Corridor Plans (1993-1996), the Roads Finance Study (1992-1993), the Oregon Transportation Initiative (1996), and the Oregon Highway Plan (1997-1999).

During the data analysis process for the 1999 Oregon Highway Plan (OHP), the Planning Section began using a customized version of HERS modeling software, known as HERS-OR, to develop the modernization needs for the study. ODOT has been an active participant in the HERS-ST Developer's Group.

Oregon has used the HERS-ST model in several non-traditional deficiency analysis studies. The capacity analysis FORTRAN code was rewritten in Visual Basic (VBA) so that the HERS-ST capacity analysis could be utilized for ODOT's Congestion Management System (CMS) as a stand-alone procedure used outside the formal HERS-ST environment. In the same manner, the free-flow speed calculations (FFS) within HERS-ST were rewritten in R-code to facilitate the capture of free-flow speeds for cars and trucks independently on each roadway section. Additionally, a value of travel time report was developed using the equations from HERS-ST to estimate the hourly value of time for drivers, passengers, and freight in Oregon.

The purpose of this study is to develop operation performance measures (OPM) based on internal HERS-ST calculations for the existing system condition. This study is not concerned with future analysis, which identifies deficiencies and evaluates improvements based on defined funding budget constrains (i.e., analysis for which HERS-ST is typically used).

Discussion of HERS-ST Elements

Speed

The HERS-ST model consists of a number of individual and complex sub-models, including the Pavement Deterioration, Safety, and Speed Models. The primary focus for this report is the speed model procedure, since the majority of the OPM analysis is centered on speed and delay calculations associated with this particular model.

The speed procedure within HERS-ST is based on the Aggregate Probabilistic Limiting Velocity Model (APLVM), and covers two distinct processes—free-flow speed (FFS) and average effective speed (AES). First a free-flow speed (FFS) estimation is developed to reflect the average unconstrained speed that exists on the highway system in the absence of any other traffic (i.e., congestion). Then the FFS estimates are adjusted to account for the effects of congestion delay and traffic control devices to produce the average effective speed for each roadway segment.

Speed is assumed to be affected by several key data elements, including vehicle type, curves, grades, pavement surface quality, speed limits, congestion and traffic control devices. There are three controlling factors in the APLVM model that potentially limit the free-flow speed on a roadway section: curves, pavement roughness and posted speed limit. All of these factors have the potential of lowering the sectional speed estimate to a value below what would otherwise be possible to achieve.

Logically, a poor pavement condition will prevent vehicles from going as fast as they would prefer. An independent evaluation by ODOT shows that the pavement condition factor only controls FFS estimates when the present serviceability rating (PSR) is less than 2, which is defined as a “poor” pavement condition rating. ODOT is committed to maintaining the pavement condition for all state highways at prescribed levers of fair or better, based on highway designation or classification (based on discussions associated with the 1999 Oregon Highway Plan).

ODOT has developed an R-script file that uses a subset of the HPMS data to estimate free-flow speeds at the individual sectional level. Because of ODOT’s commitment to maintain a good pavement rating on all state highways, it is assumed that the pavement condition element will never be a limiting factor for Oregon's free-flow speed. Subsequently, the pavement factor for the FFS analysis is turned off, and the PSR data element is never used in the FFS estimation.

A vehicle traveling through a curved roadway section is subjected to a centrifugal force, which acts against the vehicle, forcing it to leave the curve path of the roadway. Vehicular speed entering the curve, vehicle weight, and horizontal curve radius contribute to the external force acting upon the vehicle. These inputs can result in a reduced free-flow speed for the roadway section (or they contribute to an increased crash rate).

When the pavement is smooth and the horizontal curvature is low (below two degrees), the average speed is governed by the posted speed limits (note that enforcement is not explicitly considered in this model). See the HERS-ST Technical and Overview Reports (chapters 4 and 5, respectively) for a more detailed discussion on the speed modeling elements.

Delay

There are three kinds of delay estimated in HERS-ST: zero, incident, and congestion. Zero-volume delay is the delay associated with traffic control devices (stop signs and traffic signals). Zero-volume is the expected delay that a single vehicle would encounter even if it were the only vehicle on the road. Zero-volume delay only exists for sections controlled with stop signs or traffic signals, and as such is not calculated for uncontrolled sections. Incident delay is the delay associated with crashes. HERS-ST estimates delay due to crashes through a secondary (or inferred) process, where first HERS-ST model estimates the delay cost of crashes, and then back-calculates the delay estimates due to crash incidents from the cost calculations. Congestion (or recurring) delay is the average delay due to non-incident congestion.

The total daily traffic is broken into three demand periods for all capacity and speed analysis:

- Peak period in the peak direction;
- Peak period in the counter-peak direction; and
- Off-peak.

It should be noted that the HERS-ST model internally evaluates congestion and speed at the peak-period level, but only outputs the values for the total 24-hour period.

Outputs

The HERS-ST model develops and outputs the simulated analysis results in three types of data outputs: System Conditions, Improvement Statistics, and Section Condition. The System Condition file contains summary data results in a tabular format that cover the initial condition of the system as well as the state of the system at the end of each funding period (FP). The Improvement Statistics file contains the summary data for the System Condition file tables in an ASCII format, which are useful in other applications such as GIS. The Section Conditions file contains detailed analysis results that describe the condition of each individual record at the end of each FP, as well as the initial condition at the beginning of the analysis period.

The Section Condition data provides detailed analysis of the highway system at the dataset record level (i.e., for each section of input data). The output provides a section-by-section description of numerous data elements such as type of deficiencies evaluated, type and cost of improvements simulated and the associated benefit-to-cost ratio for selected improvements for each input section.

The System Conditions table aggregates the detailed record level data (section data) identified in the Section Condition data to a system level. It is aggregated by functional classification and funding period. The output tables describe system information or statistics such as the total vehicle miles of travel, total cost of improvements, simulated pavement conditions, and the total amount of delay on the system. The results are output in a table format. The Improvement Statistics file contains the supporting data for the System Conditions file in an ASCII format, and it also provides the aggregated system data for other useful applications, such as GIS.

Analysis

At the beginning of the analysis process, HERS-ST ver3 GUI places a copy of all pertinent files used for the HERS-ST analysis into a working directory. These files, which include the Parameter, Control, and Program systems files, along with the dataset files, remain intact until a new analysis process is implemented from within the HERS-ST GUI. Essentially, all HERS-ST analysis is conducted in the working directory. However, the main HERS-ST engine is an executable DOS program, such that the analyst can access the executable program and initiate the analysis process through the Windows Explorer or by a defined shortcut on the desktop. This approach allows the HERS-ST engine to be run outside the HERS-ST GUI environment. In addition, it also allows HERS-ST to be independently run in any directory that contains all the appropriate (program/control/parameter/data) files. The analyst simply needs to copy and paste all files from the working directory to any desirable directory and setup a desktop shortcut pointing to the HERS-ST engine (or points to a batch file that calls the HERS-ST engine).

The HERS-ST ver3 GUI contains excellent edit and error checking tools. The initial dataset was loaded into the HERS-ST GUI and the data was checked and analyzed in the HERS-ST GUI environment. During the edit and error checking process, the parameter and control files were defined for this particular project, and a copy was placed in the working directory.

Batching Process

The dataset was first run through the HERS-ST analysis to ensure that all data records were successfully processed through HERS-ST. Once a successful run was developed, the HERS-ST control files were copied to the OPM project directory and all subsequent HERS-ST analysis was run directly in the DOS environment, using a basic batching process defined by a desktop shortcut.

A number of key data elements required for the performance measure calculations, such as capacity and average effective speed, are automatically output in the sectional condition data files. However, additional key data elements, including delay and VMT, are only available at the aggregated system condition level. In order to capture delay information at the individual record level, each record must be analyzed separately so that the delay elements output through the aggregated system conditions output is compatible with the disaggregated data at the sectional conditions level. In order to accomplish this, the initial HPMS formatted dataset was parsed out to a number of small HPMS datasets, each containing a single record, such that the 311 records in the original dataset were parsed out to 311 datasets, each with one data record.

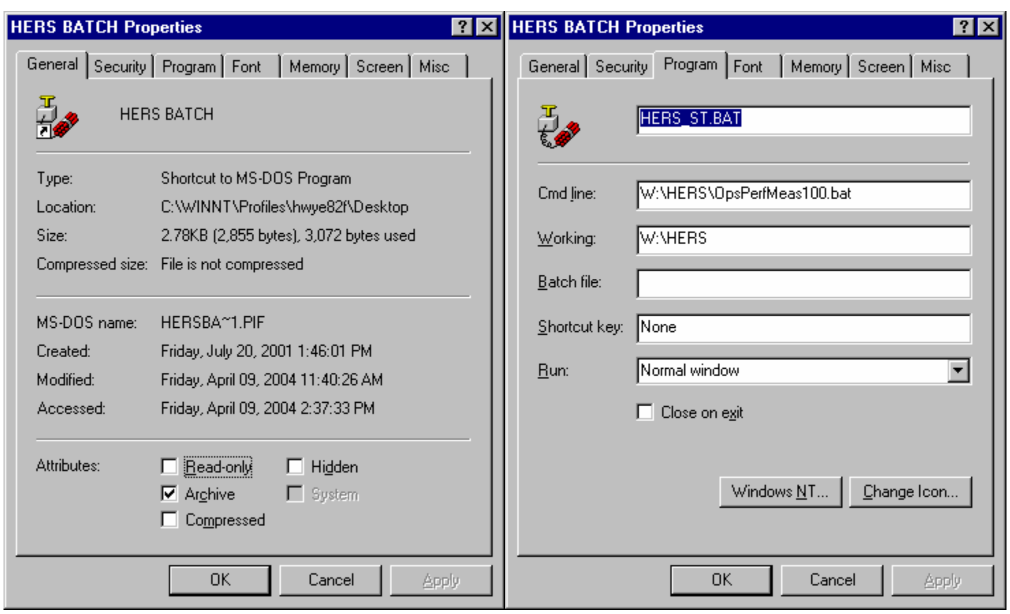
All appropriate HERS-ST control and executable files were copied into an OPM working directory and a DOS short-cut was setup on the Desktop to run HERS-ST interactively. A DOS batch file was written to process the 311 datasets through HERS-ST. The 311 system condition summary files were captured and categorized to match the disaggregated data at the sectional conditions level.

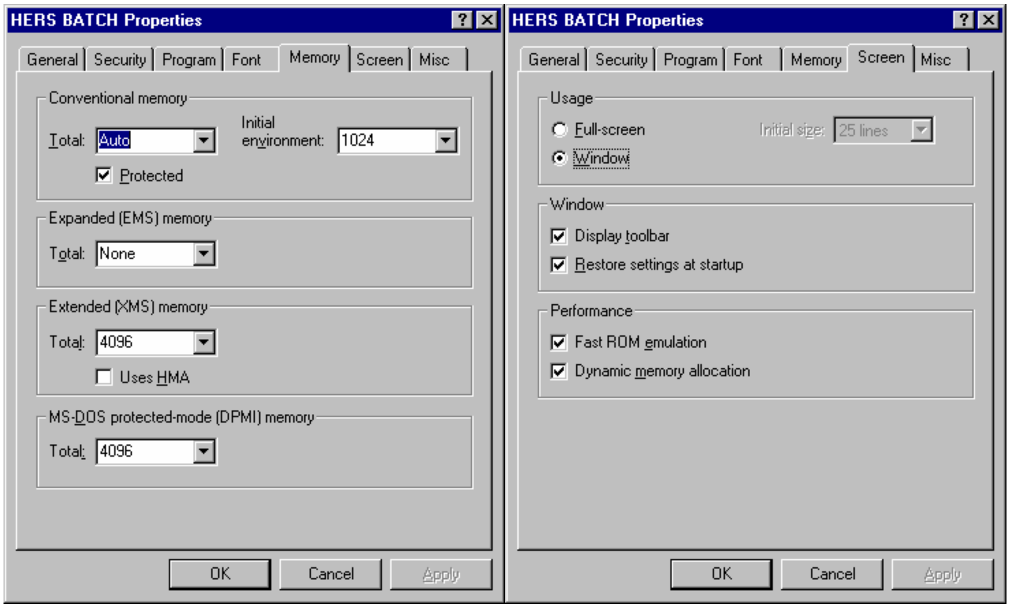
Since the system condition data is in a comma-delimited (CSV) format, a R-code script file was created to parse out the existing condition (or base year) data from the 311 individual CSV output files and write the data to an OPM summary file for data integration with the sectional output and crash data using an Access database. The system condition output includes, but is not limited to, the average speed (for peak, counter-peak and off-peak), delay (zero, incident and congestion), VMT, costs (users, travel-time, operating and crash), and rates (crashes, injuries, and fatalities). Since the OPM study is only interested in developing performance measures based on current system conditions, the base year (existing condition) analysis defined for 2002 is retained, and all future year analysis discarded.

The final data output was packaged and shipped to TTI for further analysis.

Batching Shortcuts

The following shortcut parameters are set for the batching process:




HERS BATCH Properties
General
Security
Program
Font
Memory
Screen
Misc
Conventional memory
Total:
Auto
Initial environment:
1024
Protected
Expanded (EMS) memory
Total:
None
Extended (XMS) memory
Total:
4096
Uses HMA
MS-DOS protected-mode (DPMI) memory
Total:
4096
OK
Cancel
Apply
HERS BATCH Properties
General
Security
Program
Font
Memory
Screen
Misc
Usage
Full-screen
Window
Initial size:
25 lines
Window
Display toolbar
Restore settings at startup
Performance
Fast ROM emulation
Dynamic memory allocation
OK
Cancel
Apply