# Pilot Testing of SHRP 2 Reliability Data and Analytical Products: Washington

## DETAILS

0 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-43296-2 | DOI 10.17226/22254

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SHRP 2 Reliability Project L38D

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**TRANSPORTATION RESEARCH BOARD**
Washington, D.C.
2015
www.TRB.org

## ACKNOWLEDGMENT

This work was sponsored by the Federal Highway Administration in cooperation with the American Association of State Highway and Transportation Officials. It was conducted in the second Strategic Highway Research Program, which is administered by the Transportation Research Board of the National Academies.

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# Executive Summary

The second Strategic Highway Research Program (SHRP 2) addresses the challenges of moving people and goods efficiently and safely on the nation's highways. In its Reliability focus area, the research emphasizes improving the reliability of highway travel time by reducing the frequencies and effects of events that cause travel time to fluctuate in an unpredictable manner.

Washington State Department of Transportation (WSDOT), in association with the Smart Transportation Applications and Research Laboratory (STAR Lab) at the University of Washington (UW), is one of the four research teams conducting the pilot testing for project L38. This research project mainly tested and evaluated SHRP 2 Reliability Data and Analytical Products, specifically those produced by the SHRP 2 L02, L05, L07, L08, and C11 projects. These analytical tools are designed to use for travel time reliability measurement, monitoring, enhancement, and impact assessment:

- Travel Time Reliability Measurement and Monitoring
  - **L02:** Establishing Monitoring Programs for Travel Time Reliability
- Travel Time Reliability Analysis and Project Impact Assessment
  - **L07:** Evaluation of Costs and Effectiveness of Highway Design Features to Improve Travel Time Reliability
  - **L08:** Incorporation of Nonrecurrent Congestion Factors into Highway Capacity Manual Methods
  - **C11:** Development of Improved Economic Analysis Tools
- Project Prioritization
  - **L05:** Incorporating Reliability Performance Measures into the Transportation Planning and Programming Process
  - **C11**: Development of Improved Economic Analysis Tools

This research project has two major objectives:

- To provide feedback to SHRP 2 on the applicability and usefulness of the reliability products tested, and
- To assist agencies in moving reliability into their business practices through testing of the products developed by the five SHRP 2 Reliability projects.

To test the SHRP 2 Reliability Data and Analytical Products, the SHRP 2 L38D research team employed a research procedure that consists of three major steps: (a) data compilation, integration, and quality control; (b) experiment design for testing different SHRP 2 products ; and (c) test results evaluation and suggestions for possible improvements. Throughout this research project, the L38D research team followed this procedure closely in completing the research tasks. Specifically, the research team completed the following tasks for the reliability projects listed for testing:

## SHRP 2 L02

The L02 travel time reliability monitoring procedure was evaluated using data collected from Washington freeways. To ensure the reliability of the tests, traffic detector data were processed for quality control. The data quality control method developed by the UW STAR Lab was used to identify erroneous data and correct the data whenever possible. This data quality control approach is general and fills in an important gap in the L02 procedure. Additionally, the data quality control procedure for travel time calculation used by WSDOT in the Gray Notebook was applied. Furthermore, to integrate the L02 product into WSDOT practice, the travel time reliability monitoring system (TTRMS) from L02 was implemented for monitoring the Puget Sound area freeway network travel time reliability on the WSDOT data analytics system: Digital Roadway Interactive Visualization and Evaluation Network (DRIVE Net). A new approach to calculating travel time from real-time loop data for long saturated facilities was developed and validated. Using the DRIVE Net tool, the travel time reliabilities for the I-5 and I-405 facilities from Lynnwood to Tukwila (approximately 30 miles long for each facility) were compared as a case study using the L02 methodology. Additionally, travel time reliability on a segment of I-405 was evaluated before and after a roadway improvement to measure the project's effectiveness in improving travel time reliability. The L02 methodology was then extended to several other routes in the Puget Sound region to enable broad reliability analysis for WSDOT via the DRIVE Net platform.

## SHRP 2 L05

The research team studied the L05 products carefully and confirmed the value of L05 products. WSDOT plans to test the L05 tool together with WSDOT's recently started SHRP 2 L01/L06 project. A test plan has been developed and introduced. A list of preliminary suggestions for L05 was summarized.

## SHRP 2 L07

Various traffic data have been compiled for testing L07, including WSDOT DRIVE Net Gray Notebook capacity analysis, single-loop detector data, roadway geometrics, treatments of construction projects on travel time reliability, and traffic incident data. The research team evaluated the tool by studying the cost-effectiveness of geometric design treatments in reducing nonrecurrent congestion. A set of guidelines for using the tool was developed. A median barrier construction project on northbound I-5 in Marysville was applied to test the L07 tool. Additionally, three other 1-mile long segments on I-5 were employed to evaluate the L07 tool. In addition to the simple input and output validation, usability of the tool was examined. The test results suggest that the L07 tool tends to underestimate travel time under high traffic volumes and generate overoptimistic measure of effectiveness and travel time index curves. All test results, together with a list of potential tool refinements, were summarized.

## SHRP 2 L08

Both the FREEVAL and STREETVAL software tools provided by the L08 project were carefully studied. The usability of the tools was evaluated using data collected from different study routes. For FREEVAL, tests were conducted to verify tool accuracy for two different study sites in Seattle, Washington: an urban section of I-5 with a high ramp density and a less urban section of I-405 with zero ramps. Travel times for each study site were calculated using speed data collected from dual-loop detectors. The Gray Notebook procedure employed by WSDOT for many years was used to calculate segment-level travel times from spot speeds. The comparisons between the predicted travel time distributions from FREEVAL and the ground truth travel times suggest that FREEVAL tends to be overoptimistic in its predictions of travel times. A second test comparing results between different seed days showed that the seed day does have an influence on the effect of the results. This finding suggests that multiple trial runs using several different seed days may be necessary in order to achieve confidence in the test results. In summary, based on the testing results, FREEVAL does provide a close estimation of the actual distribution on travel times, which implies that the main sources and factors influencing travel time reliability have been accounted for by the tool. In order to assess the accuracy of the STREETVAL software, a test was performed on SR-522, an urban arterial near Seattle. Results from the test were obtained by comparing the predicted travel times generated from the tool to the actual travel times obtained from automatic license plate readers (ALPRs). The results show that the tool tends to underpredict the dispersion level of the travel time distribution. The predicted travel time distribution is less dispersed than the actual travel time distribution from the ALPR data, although the tool can reasonably predict the mean travel time. The discrepancy in travel times suggests that some other factors (not accounted for) are influencing the travel times. All test results, together with a list of potential tool refinements for FREEVAL and STREETVAL, were summarized in this report.

## SHRP 2 C11

C11 accounts for travel time reliability as well as reoccurring congestion. It requires minimal data for performing assessment of impacts of highway investments, and thus allows users to perform quick assessment of the effects of highway investments. The tool comes with simple and easy scenario management features. It facilitates analyses of multiple scenarios by allowing, creating, and saving new scenarios with relative ease. The tool was evaluated using traffic data collected from the I-5 facility through Joint Base Lewis-McChord (JBLM), also known as the I5-JBLM project. Six alternatives were compared using the tool. A benefit–cost analysis was performed using benefits from the travel time reliability tool. The tool was also tested to assess if it needs any further improvements for enhancing its potential for use by transportation agencies. After extensive testing on different improvement options, the research team developed a set of recommendations for further improving the tool.

In summary, the SHRP 2 Reliability project products clearly are needed to address the practical challenges in travel time reliability monitoring and analysis that transportation agencies are facing. However, most tools require significant improvements to the application level. Details of the test data, test procedures, and test results are documented in this report.

# CHAPTER 1
# Introduction

## 1.1 General Background

One of the purposes of the second Strategic Highway Research Program (SHRP 2) is to improve the reliability of highway travel times by reducing the effects of nonrecurrent traffic events, including traffic incidents, work zones, demand fluctuations, special events, traffic control devices, weather, and inadequate base capacity.

The following five research projects in the SHRP 2 Reliability area have produced guidelines and analytical tools for travel time reliability measurement, monitoring, enhancement, and impact assessment to be tested in this project:

- **L02:** Establishing Monitoring Programs for Travel Time Reliability;
- **L05:** Incorporating Reliability Performance Measures into the Transportation Planning and Programming Process;
- **L07:** Evaluation of Costs and Effectiveness of Highway Design Features to Improve Travel Time Reliability;
- **L08:** Incorporation of Nonrecurrent Congestion Factors into *Highway Capacity Manual* Methods; and
- **C11:** Development of Improved Economic Analysis Tools.

Specifically, these projects aid in quantifying the travel time reliability characteristics, identifying possible solutions for reliability improvement, and analyzing the potential effects of implementing those solutions. The products from these five projects can be classified into three categories: travel time reliability measurement and monitoring (L02), analysis and impact assessment (L07, L08, and C11), and project prioritization (L05 and C11).

SHRP 2 L02 developed a travel time reliability measurement system (TTRMS), along with a guide, that is intended to show practitioners how to develop such systems. The analytical tool produced by the SHRP 2 L07 project is used to evaluate the cost-effectiveness of geometric design treatments for reducing nonrecurring congestion. The Excel spreadsheet-based analytical tool has incorporated SHRP 2 L03 methods, such as before/after analysis and a cross-sectional statistical model (Cambridge Systematics 2010). This tool can assist in estimating operational effectiveness and economic benefits of a variety of design treatments for specific highway segments. SHRP 2 L08 developed a procedure to estimate travel time reliability and the impacts of nonrecurrent congestion factors in the highway capacity context. Two Excel spreadsheet tools, FREEVAL and STREETVAL, have been developed to evaluate the change in travel time reliability associated with a variety of traffic characteristics using a scenario generator for freeways and signalized roadways, respectively. SHRP 2 C03 developed a case study–based economic impacts estimation web tool called T-PICS. The new tool developed by the SHRP 2 C11 project is also an Excel spreadsheet-based tool, serving as an extension of the SHRP 2 C03 tool to enable a wider range economic analysis. The tool uses separate sketch methods to predict the incident-induced delay and combines with the recurring delay to obtain mean travel time index (TTI), which serves as the predictor variable to measure all types of variations. SHRP 2 L05 provides a guide with five steps for incorporating reliability into planning and programming in order to generate support for funding to improve reliability. The primary audience groups are managers and decision makers. It also includes a technical reference for practitioners that describes the tools and data needed (recipes) to calculate performance measures.

Effective transportation is critical for maintaining Washington's economy, environment, and quality of life. Therefore, WSDOT has long been promoting a reliable, responsible, and sustainable transportation system. WSDOT's economic vitality and renowned livability plan also targets reliability improvement as the state's primary transportation goal for planning, operations, and investment. "Moving Washington" is a proven approach as well as investment principle for creating an integrated, 21st-century transportation system. It is also the framework for making transparent, cost-effective decisions that keep people and goods moving and support a healthy economy, environment, and communities.

The Puget Sound area in Washington State has several ideal sites for testing the SHRP 2 reliability research products. The various kinds of traffic data collected on the freeway and highway network in this area can be used for evaluating the analytical tools. Through this research project, the research team has made solid moves toward accomplishing the following objectives: (1) incorporate the analysis products into the business and decision-making process; (2) improve the capability of analyzing travel time reliability at facility, corridor, and network levels; and (3) test the validity and usability of the SHRP 2 reliability products.

## 1.2 Introduction of SHRP 2 Reliability Data and Analytical Products

SHRP 2 L38 focuses on testing products from five research projects: SHRP 2 L02, L05, L07, L08, and C11. The following overview of these research project products introduces the main features of each product and the relevant specifications.

### 1.2.1 SHRP 2 L02: Establishing Monitoring Programs for Travel Time Reliability

SHRP 2 L02 focuses on measuring reliability, identifying factors affecting systems' reliability, and proposing solutions for reliability enhancement (Institute for Transportation Research and Education 2013). Products developed through this effort are summarized in Table 1.1.

**Table 1.1. SHRP 2 L02 Reliability Product Summary**

| | |
|---|---|
| Products | 1. A guide and supporting methodologies;<br>2. Travel time reliability monitoring system (TTRMS); and<br>3. Approach on synthesizing route travel time distribution from segment travel time distributions. |
| Research team | North Carolina State University; Kittelson & Associates, Inc.; Berkeley Transportation Systems, Inc.; National Institute of Statistical Sciences; University of Utah, and Rensselaer Polytechnic Institute. |
| Input | 1. Infrastructure-based sources:<br>• Loop detectors,<br>• Video image processors,<br>• Wireless magnetometer detectors, and<br>• Radar detectors.<br>2. Vehicle-based sources:<br>• Vehicle-based detectors collect data about specific vehicles, either when they pass by a fixed point (automated vehicle identification, or AVI, data) or as they travel along a path (automated vehicle location, or AVL, data).<br>• Automated vehicle identification (AVI) data collection includes Bluetooth readers and license plate readers (LPRs), radio-frequency identification, vehicle signature matching data.<br>• Automated vehicle location (AVL) data include data from the Global Positioning System, connected vehicles, and cellular telephone network.<br>3. Nonrecurring event data:<br>• Incident, weather data, work zones, special events. |
| Output | 1. Segment travel time, including its distribution;<br>2. Route travel time, including its distribution;<br>3. Sources of unreliability; and<br>4. The impact of the sources of unreliability. |
| Description | The project team conducted five case studies using various data collection technologies to develop methods for assembling and visualizing travel time reliability information. |
| Memo | This work builds on data generated by current traffic monitoring systems to provide a long-term picture of travel time reliability. |
| Test locations | San Diego, California; Northern Virginia; Sacramento–Lake Tahoe, California; Atlanta, Georgia; and New York–New Jersey. |
| Accuracy | Accuracy may be limited by quality of data sets for travel times, weather, incidents, etc. |
| Strength | An agency that implements a TTRMS will understand much better the reliability performance of its systems and monitor how its reliability improves over time:<br>• What is the distribution of travel times in their system?<br>• How is the distribution affected by recurrent congestion and nonrecurring events?<br>• How are freeways and arterials performing relative to performance targets set by the agency?<br>• Are capacity investments and other improvements really necessary given the current distribution of travel times?<br>• Are operational improvement actions and capacity investments improving the travel times and their reliability? |
| Weakness | • Not considered that nonrecurring events can have large variances in severity; and<br>• Roadway improvements targeting reliability are more likely to happen at segment level than route level, but segment-level reliability analysis is not addressed. |

### 1.2.2 SHRP 2 L05: Incorporating Reliability Performance Measures into the Transportation Planning and Programming Processes

SHRP 2 L05 provides a concise description of how to incorporate reliability considerations into the transportation planning and programming process, with a focus on helping agencies make choices and tradeoffs about funding and project priority (Cambridge Systematics 2013). Overview of SHRP 2 L05 is summarized in Table 1.2.

**Table 1.2. SHRP 2 L05 Reliability Product Summary**

| | |
|---|---|
| Products | 1. The reference guide<br>2. The technical reference |
| Research team | Cambridge Systematics, Inc. |
| Input | • Reliability measure that the leadership, staff, and stakeholders understand and that yields consistent results;<br>• Reliability benefits of each project in the project list; and<br>• An approach to estimate the impact of a project on reliability, such as sketch planning method, model post-processing tools, simulation, and monitoring and management tools. |
| Output | A list of prioritized projects based on appropriately selected approaches. |
| Description | To develop the means—including technical procedures—for state DOTs and MPOs to fully integrate reliability performance measures and strategies into the transportation planning and programming processes. |
| Memo | For product 1, the audience is planning, programming, and operations managers who are responsible for making funding decisions at state DOTs and MPOs. For product 2, it is intended to support analysts who will be developing and applying the technical approach for measuring reliability and making choices and tradeoffs. |
| Test locations | Colorado DOT, Florida DOT, Knoxville, TN MPO, LAMTA (Los Angeles), NCTCOG (Dallas–Fort Worth), SEMCOG (Detroit), Washington State DOT. |
| Accuracy | Simulation method is the most accurate assessment. |
| Strength | 1. Sketch planning method: easy and fast, use generally available data;<br>2. Model post-processing tools: link-level data: more robust than 1, based on local data from the established regional model;<br>3. Simulation or multiresolution methods: provide most robust forecast of TTV, combining TDM provide most accurate assessment of long-short term impacts on reliability; and<br>4. Monitoring and management tools: easy and fast once system is developed, based on real-world data. |
| Weakness | 1. Sketch planning method: limited reliability metrics, apply to aggregated conditions;<br>2. Model post-processing tools: require a regional TDM, limited reliability metrics;<br>3. Simulation or multiresolution methods: requires regional TDM and simulation model be available; time and resource intensive; and<br>4. Monitoring and management tools: analysis capability limited by data availability and quality, cannot test future strategies to address congestion. |

### 1.2.3 SHRP 2 L07: Evaluation of the Costs and Effectiveness of Highway Design Features to Improve Travel Time Reliability

The objective of SHRP 2 L07 is to evaluate the cost-effectiveness of geometric design treatments, such as alternating shoulders, emergency pull-offs, etc., in reducing nonrecurrent congestion (Potts et al. 2013). Products of SHRP 2 L07 are summarized in Table 1.3.

**Table 1.3. L07 Reliability Product Summary**

| | |
|---|---|
| Products | Spreadsheet-based analysis tool. |
| Research team | Midwest Research Institute (MRI). |
| Input | **1.Treatments**<br>**2. Data:**<br>(1). Geometric data:<br>• Number of lanes / lane width<br>• Right/left shoulder width<br>• Number of interchanges per mile<br>(2). Traffic data:<br>• Free-flow speed<br>• Demand volume (by hour of day)<br>• Peak hour factor (by hour of day)<br>• Percentage of trucks (by hour of day) and percentage of RVs (by hour of day)<br>(3). Crash statistics for roadway segment:<br>• Total annual property damage only (PDO) crashes<br>• Total annual minor-injury crashes<br>• Total annual serious- and fatal-injury crashes<br>(4). Information about typical crash duration (time until cleared):<br>• Average crash duration (min) for PDO crashes<br>• Average crash duration (min) for minor-injury crashes<br>• Average crash duration (min) for serious- and fatal-injury crashes<br>(5). Other:<br>• Information about special events (e.g., number, percent increase in volume)<br>• Information about work zones<br>**3. Benefits and Costs** |
| Output | Evaluation results of cost-effectiveness for a treatment, such as TTI, reliability measures of effectiveness (MOEs). |
| Description | What does the tool do?<br>• Implements project L03 models<br>• Computes cumulative TTI curve for untreated and treated conditions<br>• Estimates traffic operational effectiveness of design treatments at specific locations<br>• Compares economic benefits of various design treatments at specific locations |
| Memo | In addition to the defined treatments available for analysis in the tool, users are also able to evaluate any other treatment they wish, provided treatment's effect on the three model variables can be ascertained. |
| Test locations | Seattle, Washington. |
| Accuracy | The tool tends to underestimate the vehicle travel time when traffic flow is high. |

| | |
|---|---|
| Strength | The tool can be used to measure the operational effectiveness as well as the economic benefit of design treatments for a freeway segment of interest. The tool allows highway agencies to compare the benefits and costs of implementing various nonrecurrent congestion treatments at specific locations. |
| Weakness | • The tool interface is not very user friendly. It runs into crash sometimes.<br>• Detailed output information is not applicable, which limits the tool usability. |

**Table 1.4. L08 Reliability Products Summary**

| | |
|---|---|
| Products | 1. Guide describing travel time reliability concepts for HCM audience, provides step-by-step processes for predicting travel time reliability for freeway and urban street facilities, and illustrates example applications of the procedures.<br>2. FREEVAL and STREETVAL Computational Engine. |
| Research team | Kittelson & Associates, ITRE, Cambridge Systematics. |
| Input | Main source of travel time variability, given scenario (time of day, road condition, severity, etc.), demand, capacity. |
| Output | HCM performance measure, the impacts of variability on performance over a year. |
| Description | Determining how data and information on the impacts of differing causes of nonrecurrent congestion (incidents, weather, work zones, special events, etc.) in the context of highway capacity can be incorporated into the performance measure estimation procedures contained in the HCM. |
| Memo | The methodologies contained in the HCM for predicting delay, speed, queuing, and other performance measures for alternative highway designs are not currently sensitive to traffic management techniques and other operation/design measures for reducing nonrecurrent congestion. A further objective is to develop methodologies to predict travel time reliability on selected types of facilities and within corridors. |
| Test locations | Three locations were selected for testing in the Puget Sound Region: I-5, I-405, and SR 522. |
| Accuracy | STREETVAL: Large discrepancy between software output and ground truth data.<br>FREEVAL: Software provides a reasonable estimation of the travel time reliability. |
| Strength | STREETVAL: Employs a powerful random scenario generation process that is a powerful method for accounting for all possible likely scenarios.<br>FREEVAL: Tool is able to provide a reasonable estimate of the travel time reliability. This suggests that the principal factors affecting reliability have been accounted for. |
| Weakness | FREEVAL: Weather events with marginal impact are excluded; assume incident occurrence and traffic demand are independent of weather condition.<br>STREETVAL: The methodology does not address the events (e.g., signal malfunction, railroad crossing, signal plan transition, and fog dust storms, smoke, high winds or sun glare).<br>Overall: The power in a prediction model lies in the idea that with limited information, an outcome can be deduced. A major drawback of these tools is that they require a large quantity of input data before they are able to make their predictions (this is especially true of STREETVAL) and this makes these tools both difficult and costly to implement from a practitioner's point of view. It begs the question of whether these tools be simplified, lessening the amount of input data requirements, and still give reasonable reliability estimates? |

### 1.2.4 SHRP 2 C11: Development of Improved Economic Analysis Tools Based on Recommendations from SHRP 2 L03

SHRP 2 C11 provides a sketch-level planning tool based on SHRP 2 L03 research that estimates the benefits of improving travel time reliability for use in benefit–cost analysis (Economic Development Research Group 2013). The SHRP 2 C11 products are summarized in Table 1.5.

**Table 1.5. SHRP 2 C11 Reliability Product Summary**

| | |
|---|---|
| Products | 1. Analytical tools; and<br>2. User guide. |
| Research team | Economic Development Research Group, Cambridge Systematics. |
| Input | 1. Travel time reliability<br>• Scenario data and traffic data<br>• Time/travel cost and reliability ratio<br>2. Market access<br>• Facility type, such as marine, freight rail, air passenger, air cargo, passenger rail, etc.<br>• Roadway improvements<br>3. Intermodal connectivity<br>• Impedance decay factor and impedance data<br>• Productivity elasticity<br>• Impact zones and activity data |
| Output | 1. Travel time reliability (result for base year and forecast year)<br>• Congestion metrics<br>• Total annual weekday delay (veh-hrs)<br>• Total annual weekday congestion cost for passenger and commercial vehicles, respectively<br>2. Market access (result for project/policy baseline and alternative)<br>• Accessible employment<br>• Concentration index<br>• Commuter costs<br>• Effective density/potential access scores<br>3. Intermodal connectivity<br>• Facility connectivity raw value<br>• Value of time savings for facility<br>• Weighted connectivity<br>4. Final result<br>• Value of traditionally measured benefits and wider economic benefits in target year for passenger trips and commercial (freight delivery) trips, respectively. |
| Description | Development of improved economic analysis tools based on recommendations from project C03. |
| Memo | T-PICS is a web-based sketch planning tool that allows state departments of transportation (DOTs), metropolitan planning organizations (MPOs), and other agencies involved in highway capacity planning to quickly estimate the likely range of impacts of proposed projects. |
| Test locations | Uses the L03 Data Poor models as the basis. |
| Accuracy | As a sketch planning tool, it provides good enough accuracy. |

| | |
|---|---|
| Strength | With minimal data input, the tool adds value by incorporating change in travel time reliability into project economic analyses. |
| Weakness | The calculation methodology is designed to capture the benefits of major capacity projects. It is not sensitive to the travel time reliability changes associated with improvements at roadway intersections, interchanges, and freeway ramps. |

## 1.3 Research Objectives

This research project has two major objectives:

- To provide feedback to SHRP 2 on the applicability and usefulness of the products tested; and
- To assist agencies in moving reliability into their business practices through testing of the products developed by the five SHRP 2 Reliability projects.

For testing the SHRP 2 Reliability Data and Analytical Products, the research procedure consists of three major steps: (a) data compilation, integration, and quality control; (b) experiment design for testing different products; and (c) test results evaluation and possible improvements. The L38D research team has followed the proposed procedure through the pilot testing of all the committed research products.

## 1.4 Final Report Organization

This report contains nine chapters. Chapter 1 introduces the general background for the SHRP 2 L38 project and summarizes the objectives of the research project. The general testing approach is presented in Chapter 2. Chapter 3 describes the data compilation and quality control process applied to the data used for this study. Chapters 4–8 provide the details of the research in analyzing reliability and improvement strategies, including site selection, case description, testing results, comparisons, and discussions of the L38 tools. Based on the testing results, Chapter 9 concludes the research and offers potential improvement directions for the tested SHRP 2 Reliability products.

# CHAPTER 2
# Research Approach

Given the complexity in each transportation project's design, construction, evaluation, and decision making and the small sample possible to use for testing the selected products, the research team made efforts to ensure the reliability of the test results in two aspects: (1) setting up a dedicated steering committee to provide guidance and advice to the research team and (2) developing a thorough testing procedure for different types of products.

## 2.1 Steering Committee

A steering committee for the SHRP 2 L38D research project was formed at the start of this research project. The committee members include Daniela Bremmer, Director of WSDOT's Strategic Assessment Office and chair of the TRB Committee on Performance Measurement, Patrick Morin, Operations Manager of the WSDOT Capital Program Development and Management Office, Bill Legg, Washington State Intelligent Transportation System Operations Engineer, Shuming Yan, Deputy Director of the WSDOT Urban Planning Office, etc. They are from all relevant fields including transportation planning, traffic operations, urban corridor management, performance measurement and economic impacts, and project prioritization, and are very familiar with the past and ongoing projects suitable for this study.

Principal investigator and Washington State traffic engineer John Nisbet calls regular meetings of the research team to check progress and collaborates research efforts between UW and WSDOT. He also organizes quarterly steering committee meetings to review research activities, suggest new research actions, and coordinate research efforts.

## 2.2 Test Procedure

A systematic procedure for testing the SHRP 2 Reliability products was developed based on foreseeable needs in WSDOT's practice. Please see Figure 2.1 for details. The test procedure covers both types of products: (1) models or procedures and (2) software tools. As shown in Figure 2.1, the test processes of the two types of products interact with each other because the computer software tools are typically the implementations of the methods or procedures.

### 2.2.1 Methods or Procedure Testing

Models or procedures are typically developed based on assumptions. The reasonableness of these assumptions is critical to the applicability of the methods. Specific mathematical equations employed are also important, and a tradeoff between complexity and applicability must be made carefully in developing a model or procedure. Thus, the accuracy of the model or procedure needs to be evaluated. Considering that the data used in calibrating the model may not be representative to all locations and time periods, both temporal and spatial transferability must be tested.

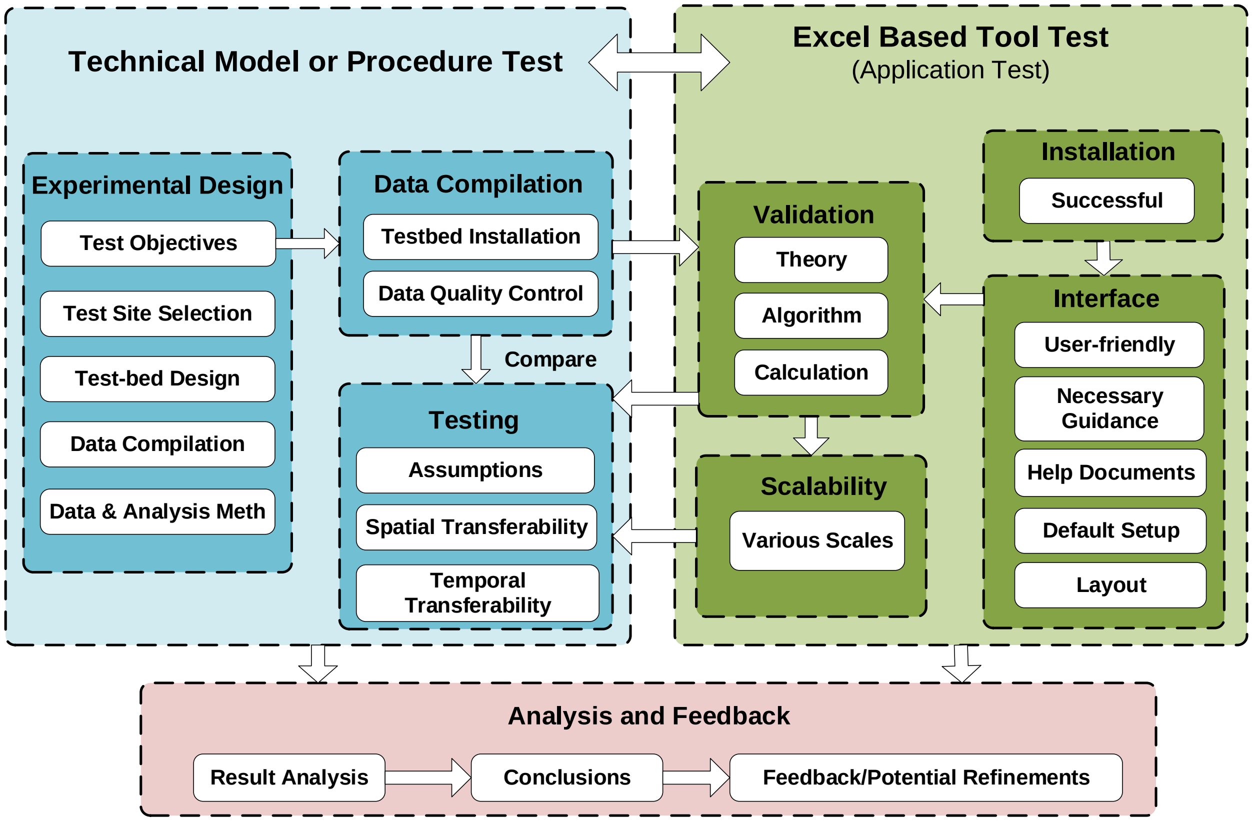


**Figure 2.1. General approach for pilot testing of the SHRP 2 L38 products.**

Following such logic, the research team developed a three-step procedure for testing the model or procedure type of products:

*2.2.1.1 Experiment Design.*

(a) *Test objectives.* This step is driven by the test objectives or the key questions to answer with the experiment. Test objectives must be clearly set as the first step of the experiment design. In designing the test objectives, steps (b) though (d) are important to consider.

(b) *Test site selection.* Random sampling from those qualified project sites is important in avoiding bias. It also allows uses of general probability theory in data analysis. Test sites should offer observations for comparative analysis. The SHRP 2 Reliability models or procedure products may include numerous control variables. To evaluate the impact of a particular variable, the conditions with and without the variable need to be observed. Also, a specific condition is better replicable to reduce the effect of uncontrolled variation and quantify uncertainty when needed.

(c) *Test-bed configuration design.* Depending on the kinds of data needed and whether or not they are observable, further instrumentation of sensors for the desired types of data may be needed.

(d) *Data collection and proposed analytical approach.* Data collection location and time period need to be determined to support the planned tests. Given the nature of the model or procedure products to be tested in this research, simple validation of the model predicted results using field data and before-and-after analysis of specific highway treatments are sufficient in this study.

#### *2.2.1.2 Data Compilation*

This step focuses on all the technical details in collecting and storing data, and making the data sets ready to use. A wide range of urban freeway and arterial data are compiled. The data collected for this study include (a) traditional static sensor data (loop, camera, etc.); (b) roadway geometric profile data; (c) incident and crash data [Washington Incident Tracking System (WITS) data]; (d) weather data; and (e) traffic operation and management data [such as active traffic management (ATM) control data].

Data quality control is an important component as low-quality data will interfere with the test procedure and may mislead the research. Data quality control procedures developed by WSDOT and UW are used to enhance data quality for the pilot testing. Data fusion and mining are performed to integrate traffic data with weather and incident data on a regional map basis to investigate travel time reliability under recurring and nonrecurring congestion conditions. More details of the data collection and quality control procedure are described in Chapter 3.

#### *2.2.1.3 Testing*

In this testing step, accuracy and transferability, including temporal and spatial transferability, of the model or procedure products will be evaluated using the data collected from researchers' study sites.

### 2.2.2 Computer Tool Testing

All the computer tool products were Microsoft Excel–based applications. The key of the tests of such products is whether an application meets the requirements that guided its design and implementation. Specifically, the requirements may include operability, usability, performance, and scalability.

An operability test includes a compatibility test of the commonly used operating systems. If the software application cannot be installed or operated in a specific operating system or Excel version, then it fails the operability test.

A usability test evaluates if the software is easy to understand and use. User interface is important for user–computer interactions and thus plays an important role in usability. Evaluation of usability is based on the following factors: (1) user interface's level of friendliness, (2) sufficient guidance and help information accessible when using the software, (3) default configurations and explanation of the input parameters needed to start the software, and (4) layout of the modules and data output.

A performance test focuses on correctness and efficiency. If a software application does not implement the correct logic or method, then it fails the performance test. Even if the method or procedure is correctly implemented, an application may still fail its performance test if the efficiency is in the beyond-tolerable range.

The scalability test for this research project refers to whether the software tool can be applied to a much smaller or much bigger project than the ones used to develop them. Scalability is important for future applications to transportation projects with varying scales.

### 2.2.3 Result Analysis and Feedback

A set of measures of effectiveness (MOEs) is carefully selected for each test. The computed MOEs will be compared with those used by WSDOT in practice. Over the past decades, WSDOT has completed a number of projects that are appropriate for testing and before-and-after analysis on travel time reliability. Specifically, the following projects are chosen as study projects for SHRP 2 L38:

- Corridors used for the WSDOT Gray Notebook production are used to test SHRP 2 L02 products. WSDOT has been monitoring corridor travel time for the quarterly Gray Notebook performance evaluation report since 2001. The Gray Notebook provides updates on system performance and project delivery on the corridor and statewide levels. Additionally, the Gray Notebook is used for testing and evaluating products of SHRP 2 L02.
- Among the Moving Washington projects, corridors along I-5 and I-405 and State Route 522 are used for testing the methods and analytical tools from SHRP 2 L08.
- I-5 JBLM is chosen as a case study for testing the effectiveness and usability of the products from SHRP 2 L05 and C11. To test the five-step procedure from SHRP 2 L05, a couple of projects in this region have been prioritized within the 10-year investment strategy. By applying the SHRP 2 C11 tool on I-5 JBLM projects, both traditionally measured benefits and wider economic benefits over the past years can be analyzed, and the tool's usability and effectiveness can be tested.

At the end of each test, problems identified through the test and recommended improvements are made to help the SHRP 2 Reliability program make these tools more useful in future practice.

# CHAPTER 3
# Data Compilation and Integration

## 3.1 Test Site Selection

Table 3.1 shows all the reliability products selected to test and their test objectives. Following the needs of testing all the products, the SHRP 2 L38D research team and its steering committee met and generated a list of candidate test sites. Among those qualified candidate sites, a number of test sites are selected and considered representative to normal roadway conditions in Washington. A brief description of each site is given below:

**Table 3.1. The Reliability Products Selected to Test and the Test Objectives**

| Products | Description | Test Objectives |
|---|---|---|
| L02 | Establishing monitoring programs for travel time reliability. | Effectiveness |
| L05 | The guide for state DOTs and MPOs to fully integrate reliability performance measures and strategies into the transportation planning and programming processes. | Usability, Performance |
| L07 | Evaluation of the cost-effectiveness of geometric design treatments, such as alternating shoulders, emergency pull-offs, etc., in reducing nonrecurrent congestion. | Operability, Usability, Performance |
| L08 | Guidance on incorporating travel time reliability into *Highway Capacity Manual* (HCM) analyses. | Operability, Usability, Performance |
| C11 | Development of improved economic analysis tools based on recommendations from project C03. | Usability, Performance |

- **Test Site A**: I-5 between the interchanges with I-405. This facility operates in oversaturated conditions during both morning and afternoon peak periods near downtown Seattle. Loop detectors are deployed every half-mile on the mainstream lanes and on the on-and-off ramps. This test site is used for testing products of L02, L07, and L08.
- **Test Site B:** I-405 between the interchanges with I-5. This facility also operates in oversaturated conditions during morning and afternoon peak periods near downtown Bellevue. Loop detectors are deployed every half-mile on the mainstream lanes and on the on-and-off ramps. This test site is used for testing products of L02 and L08.
- **Test Site C:** I-5 Joint Base Lewis-McChord (JBLM). As the single largest employer in Pierce County and the third largest in Washington State, JBLM plays an important role in the region's communities. I-5 JBLM is the major thoroughfare for freight and commuter traffic in this region. In recent years, significant increases in traffic congestion have been witnessed due to the regional growth, with longer commute times, longer duration of

congestion, impacts to freight movement, military operations, and the overall economy. This test site is used for testing products of L05 and C11.

- **Test Site D:** SR-522 between the intersections with 68th Avenue NE and 83rd Place NE. This is a busy signalized corridor serving as an alternative of I-90 and SR-520 for traffic crossing Lake Washington. It also connects I-5 and I-405. It gets congested during the peak hours and carries relatively low demand during nighttime. This test site is used for testing products of L08.

## 3.2 Data Set Creation

Based on the selected test sites and the needs of data for the tests, the L38D research team reviewed available traffic data in each site and developed further data collection plans to ensure the coverage and quality of data. In general, study data are collected from two types of facilities: urban freeways and signalized arterials.

- **Urban freeway data***:* WSDOT maintains a loop detector station approximately every half-mile in the central Puget Sound area freeways. Urban freeway traffic volume and occupancy data are obtained from the WSDOT loop detector network via the STAR Lab fiber connections to the WSDOT Northwest region's traffic system management center (TSMC), where loop data are stored and disseminated. In addition to the loop detector data, INRIX probe vehicle speed data, traffic incident data, weather data, and roadway geometric data are archived and used for urban freeway analysis.
- **Signalized arterial data:** Signalized arterial traffic data are acquired from two sources: in-road loop detectors and ALPRs. Loop detectors provide volume and occupancy data. ALPRs offer travel time measurements. Besides these two data sets, weather and roadway geometric data also are obtained and used in the analysis of signalized arterials. However, these existing data sets are not sufficient for arterial analysis. Video-based on-site data collection was conducted to obtain directional vehicle movements at signalized intersections on this corridor.

  Details of the data sets created for this research project follow.

### 3.2.1 Data Set A: Loop Detector Data

Data Set A consists of direct loop detector measurements (volume and occupancy for single loops and traffic speed and bin volumes for dual loops) and delay estimates based on loop detector data for Test Sites A (I-5), B (I-405), and D (SR-522). Data set creation involves obtaining, cleaning, and integrating data collected by the research team. There are several challenges within this process. Among them are processing, reviewing, and reducing raw data into summaries suitable for analysis and conflating traffic data with geospatial data.

Inductive loop detectors are widely deployed in Washington State for the purpose of monitoring traffic conditions and freeway performance. WSDOT maintains and manages loop detectors on state highways as well as those on Interstate freeways within Washington State. For the purpose of traffic management, the State of Washington is divided into six regions: Northwest, North Central, Eastern, South Central, Southwest, and Olympic. Relevant to this project, there are approximately 4,200 single or dual-loop detectors installed in the Northwest region that are used to monitor traffic conditions around the Seattle metropolitan area.

There are two general types of loop detectors in Washington State, single loop and dual loop. Single-loop detectors are only capable of detecting whether a vehicle is present or absent, which allows volume and occupancy to be measured directly. Dual-loop detectors, on the other hand, are composed of two single-loop detectors placed a short distance apart, thereby allowing travel speed to be estimated from the difference in arrival time between upstream and downstream detectors. Vehicle length can also be estimated from dual-loop detector data, based on the estimated speed and measured detector occupancy.

Loop detector data in Washington State is available at both 20-second and 5-minute aggregation intervals. Note that all data is collected at the 20-second aggregation level, and is further aggregated into 5-minute periods. The key information for the 20-second and 5-minute aggregation intervals is listed in Table 3.2 and Table 3.3, respectively. WSDOT primarily uses the 5-minute aggregation level loop data for freeway performance monitoring and reporting (Wang et al. 2008).

The LOOPID field in Table 3.2 and Table 3.3 is a unique identifier for each loop detector that can be matched to a detector cabinet, and multiple loop detectors can be connected to a given cabinet. A cabinets table contains descriptive and location information for each cabinet, so associating loops with the cabinets they are connected to facilitate locating the loops using cabinet milepost and route. The key information contained in the cabinets table is listed in Table 3.4.

**Table 3.2. 20-Second Freeway Loop Data Description**

| **Table: SingleLoopData and StationData (Single Loop)** | | |
|---|---|---|
| **Columns** | **Data Type** | **Value Description** |
| LOOPID | smallint | Unique ID number assigned in order of addition to LoopsInfo table |
| STAMP | datetime | 24-hour time in integer format as YYYYMMDD hh:mm:ss (in 20-second increments) |
| DATA | tinyint | Indicate whether a record is present or not |
| FLAG | tinyint | Validity flag (0–7): 0 = good data; otherwise, bad data |
| VOLUME | tinyint | Integer volume observed during this 20-second interval |
| SCAN | smallint | Number of scans when a loop is occupied during each period (60 scans per second multiplied by 20 seconds per period equals 1,200 scans) |

| Table: TrapData (Dual Loop) | | |
|---|---|---|
| **Columns** | **Data Type** | **Value Description** |
| SPEED | smallint | Average speed for each 20-second interval (e.g., 563 means 56.3 miles per hour) |
| LENGTH | smallint | Average estimated vehicle length for each 20-second interval (e.g., 228 means 22.8 feet) |

In addition to reporting the single and dual-loop detector observations at the individual loop level, loop detectors data are aggregated at the cabinet level to a loop group or station. For each cabinet, the station volume is the sum of total volumes for the associated loops, and the occupancy (or scan) is the average of total occupancies (scans) for the associated loops. Note in Table 3.2 and Table 3.3 that both detector level (SingleLoopData and STD_5Min) and station-level (StationData and STN_5Min) data are reported for single-loop detectors.

**Table 3.3. 5-Minute Freeway Loop Data Description**

| Table: STD_5Min and STN_5Min (Single Loop) | | |
|---|---|---|
| **Columns** | **Data Type** | **Value Description** |
| LOOPID | smallint | Unique ID number assigned in order of addition to LoopsInfo table |
| STAMP | datetime | 24-hour time in integer format as YYYYMMDD hh:mm:ss (increased by 5 minutes) |
| FLAG | tinyint | Good/bad data flag with 1 = good and 0 = bad (simple diagnostics supplied by WSDOT) |
| VOLUME | tinyint | Integer volume observed during each 5-minute interval |
| OCCUPANCY | smallint | Percentage of occupancy expressed in tenths to obtain integer values (6.5% = 65) |
| PERIODS | smallint | The number of 20-second readings incorporated into this 5-minute record (15 is ideal, less than 15 almost always indicates that volume data are unusable unless adjusted to account for missing intervals) |
| **Table: TRAP_5Min (Dual Loop)** | | |
| **Columns** | **Data Type** | **Value Description** |
| SPEED | smallint | Average speed for each 5-minute interval (e.g., 563 means 56.3 miles per hour) |
| LENGTH | smallint | Average estimated vehicle length for each 5-minute interval (e.g., 228 means 22.8 feet) |

WSDOT makes 20-second and 5-minute loop detector data available for download using an online FTP website. Detector data are periodically retrieved from the posted FTP website, formatted, and stored in the STAR Lab Microsoft SQL Server databases using an automated computer program written in Microsoft Visual C#. For the pilot testing of SHRP 2 L02, L07, L08, and C11 products, traffic volume data along the Test Sites A, B, and D corridors were collected. Figure 3.1 illustrates most of the loop locations along I-5 and I-405 in the Northwest region of Washington State. Five-minute traffic volume data were collected for the time period from January 2009 to June 2013. Figure 3.2 illustrates the traffic flow map based on the 5-minute loop data collected at 5:30 p.m. December 11, 2012. Loop detectors along SR-522 are shown together with the other available sensors in Figure 3.3.

**Table 3.4. Cabinet Data Description**

| **Columns** | **Data Type** | **Value Description** |
|---|---|---|
| CabName | varchar | Unique ID for each cabinet |
| UnitType | varchar | Type for each loop (i.e., main, station, speed, and trap) |
| ID | smallint | Unique ID number assigned in order of matching the loop data table |
| Route | varchar | The state route ID (e.g. 005 = Interstate 5) |
| direction | varchar | Direction of each state route |
| isHOV | tinyint | Bit indication whether loop detector is on an HOV lane (1 = HOV, 0 = not HOV) |
| isMetered | tinyint | Bit indication whether loop detector is on a metered ramp (1 = metered, 0 = not metered) |

### 3.2.2 Data Set B: Intelligent Transportation Systems (ITSs) Data

Data set B consists of ALPR data from roadway surveillance systems along the SR-522 corridor chosen for this study (Test Site D) as shown in Figure 3.3. On this section of SR-522, ALPR data have been archived since September 1, 2012. The ALPR data in particular were selected for use in testing the STREETVAL software application designed by the SRHP 2 L08 research team.

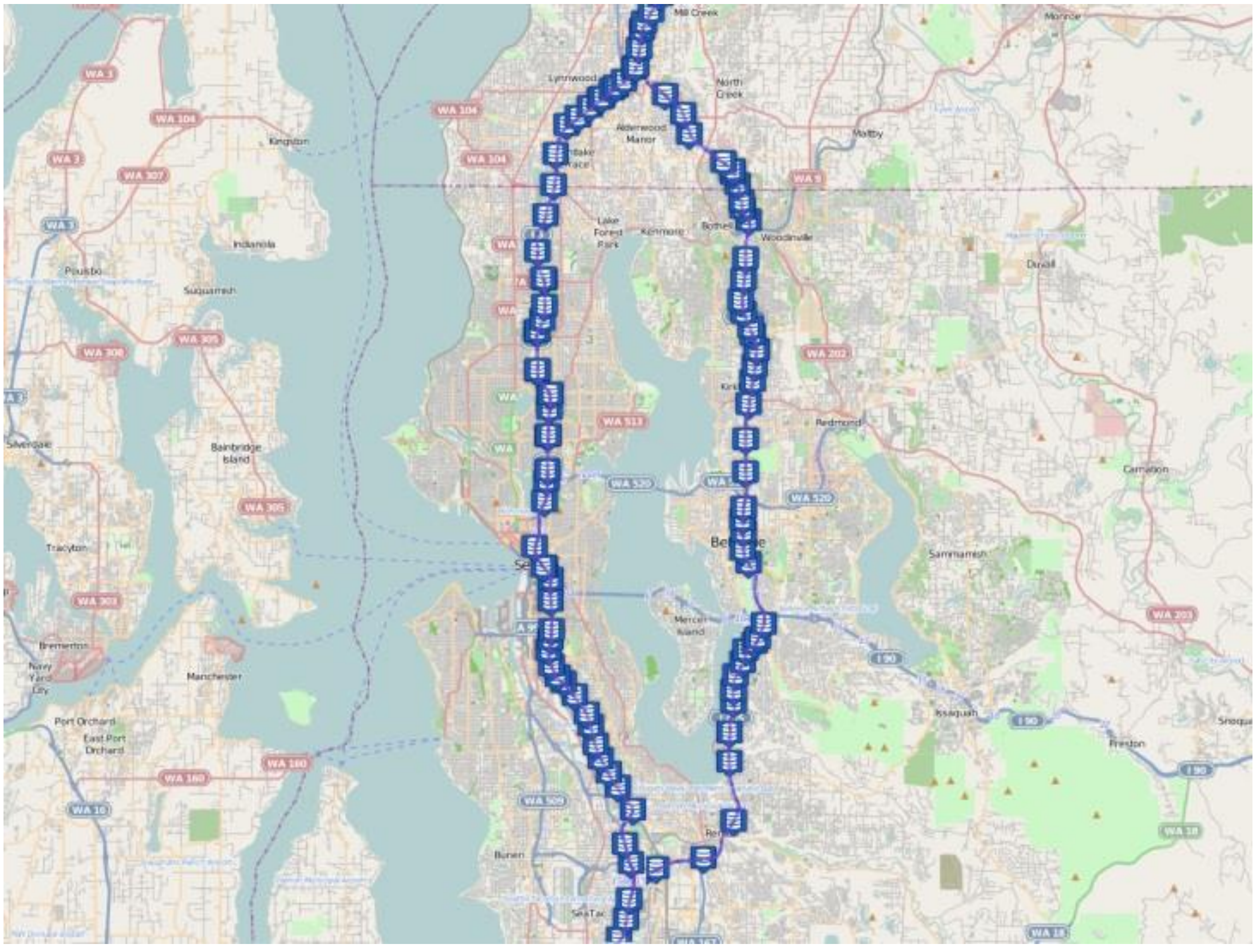


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**Figure 3.1. Loop detectors in Northwest Washington State.**

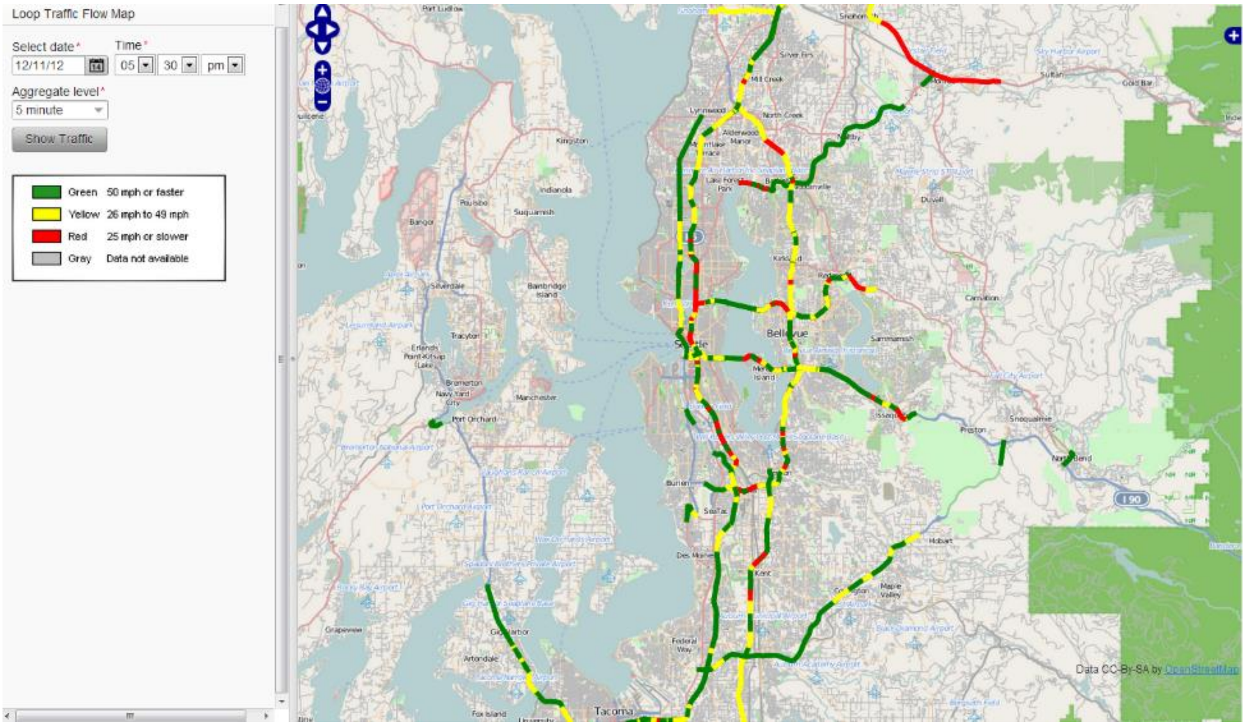


**Figure 3.2. Traffic flow map based on loop detector data.**

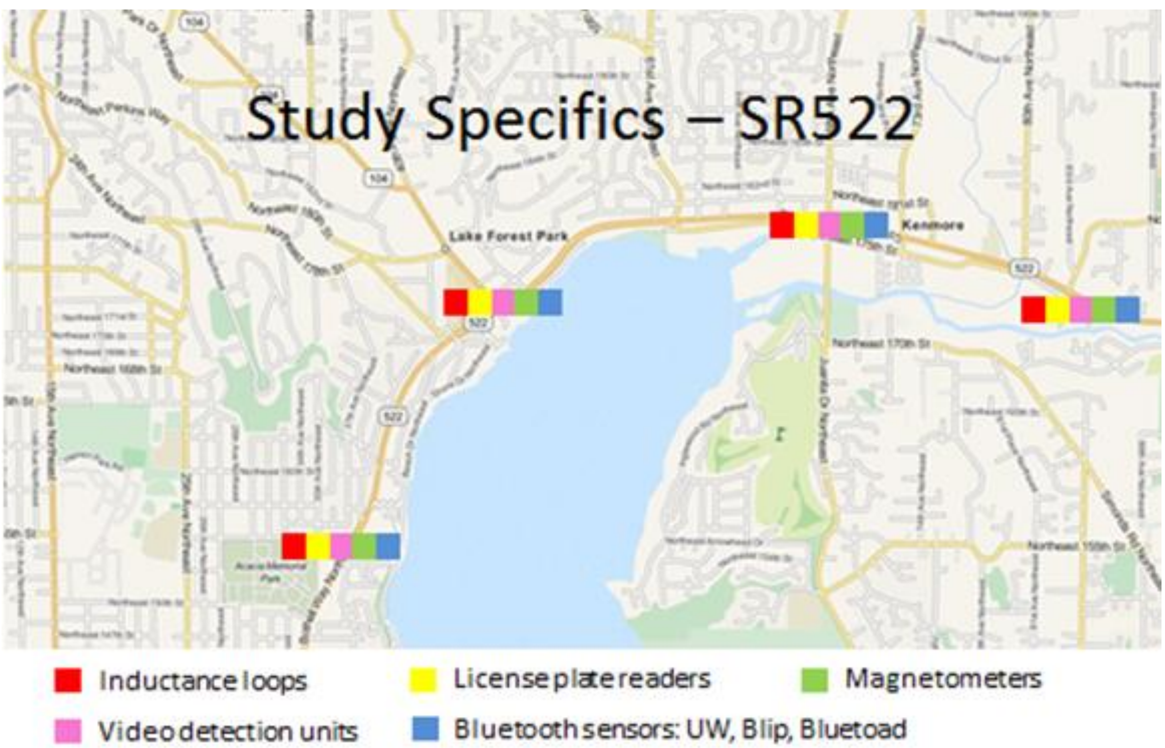


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**Figure 3.3. Traffic detectors along the SR-522 corridor.**

ALPR technology uses high-definition cameras, typically mounted on top traffic signal gantries and placed directly over the roadway so that the appropriate angle of sight can be achieved (Figure 3.4 shows a mounted ALPR camera). The cameras collect video data, which are then processed in real time using a license-plate-reading algorithm. Each time a plate is identified, it is stored in memory along with the time stamp of when it was identified. For travel time data collection purposes, these plate-reading cameras are installed at several intersections along the test site corridor. Link travel times are then obtained from comparing the data collected at two different intersections; if a plate is identified in both data sets, then the travel time is computed as the difference in the time stamps between the two intersections.

Approximately 8 months of travel time data were available and downloaded from the WSDOT database. These data span from August 16, 2013, to March 31, 2014. These data were uploaded onto the STAR Lab database where they were then queried and analyzed. Table 3.5 shows the information and basic data types available from the ALPR data set. Given that these data are to be used for test verification purposes, it was ensured that the times the data were collected match the selected study period and reliability reporting period defined in the project's temporal scope.

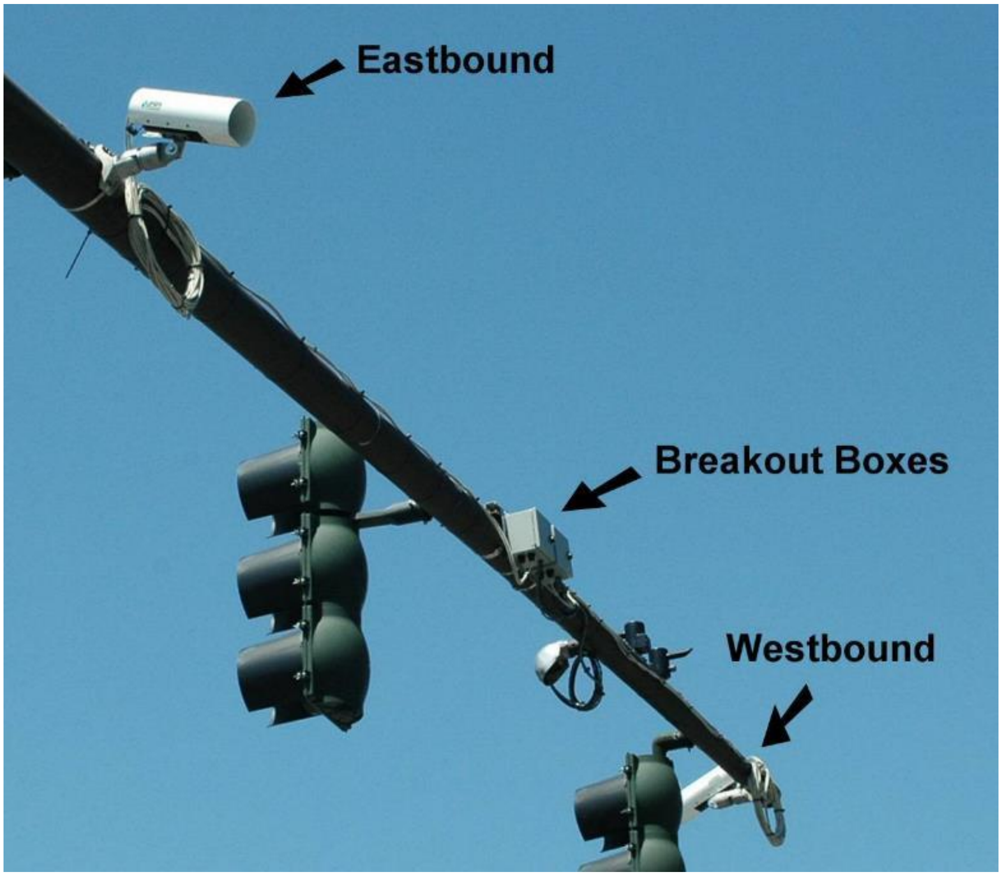



**Figure 3.4. ALPR cameras mounted at the 61st Avenue, NE, and SR 522 intersection.**

**Table 3.5. ALPR Data Descriptions**

| Columns | Data Type | Value Description |
|---|---|---|
| Stamp | Datetime | Date and time of observation |
| ID | int | Unique ID for each route, defined by a unique combination of location of origin and destination |
| TravelTime | int | Travel time on the section in seconds |
| Trips | int | Number of trips during observation period |
| UpCount | int | Number of license plates read by upstream reader |
| DownCount | tinyint | Number of license plates read by downstream reader |
| Lanes | | Number of lanes |
| Flag | tinyint | Error identification flag |

### 3.2.3 Data Set C: INRIX Data

INRIX is an international company for traffic analytics and data located in Kirkland, Washington. It gathers traffic information from around 100 million GPS-equipped vehicles traveling the roads in 32 countries around the world. Rather than depending on just one source for data, INRIX combines multiple data feeds to provide more comprehensive travel advice to drivers available. INRIX collects data streams from local transportation authorities, sensors on road networks, fleet vehicles such as delivery vans, long haul trucks and taxis, as well as consumer users of the INRIX traffic apps. INRIX crunches these data and translates the information into easy-to-understand travel advice that drivers can access through radio reports, real-time sat-nav systems in cars, and through INRIX's apps.

This data set consists of 1-minute resolution probe vehicle speed data for the section of I-5 south of Seattle between SR 510 and SR 512, provided by INRIX. To aggregate and fuse heterogeneous transportation data, INRIX developed a series of statistical models to compute real-time traffic information such as speed and travel time based on measurements from GPS devices, cellular networks, and loop detectors. The resulting speed data were aggregated into 5-minute intervals for 2008, 2009, and 2010 and into 1-minute intervals for 2011 and 2012. WSDOT was authorized to use and archive the data from January 1, 2009, to December 31, 2012, in the STAR Lab database. The key information for INRIX data is presented in Table 3.6.

A traffic speed map based on the INRIX data for Northwest Washington State at 5:30 p.m. on December 11, 2012, is shown in Figure 3.5.

**Table 3.6. INRIX Data Description**

| Columns | Data Type | Value Description |
|---|---|---|
| DateTimeStamp | datetime | 24-hour time in integer format as YYYYMMDD hh:mm:ss |
| SegmentID | varchar | Unique ID for each segment-Traffic Message Channel (TMC) code |
| Reading | smallint | Average speed for each segment |

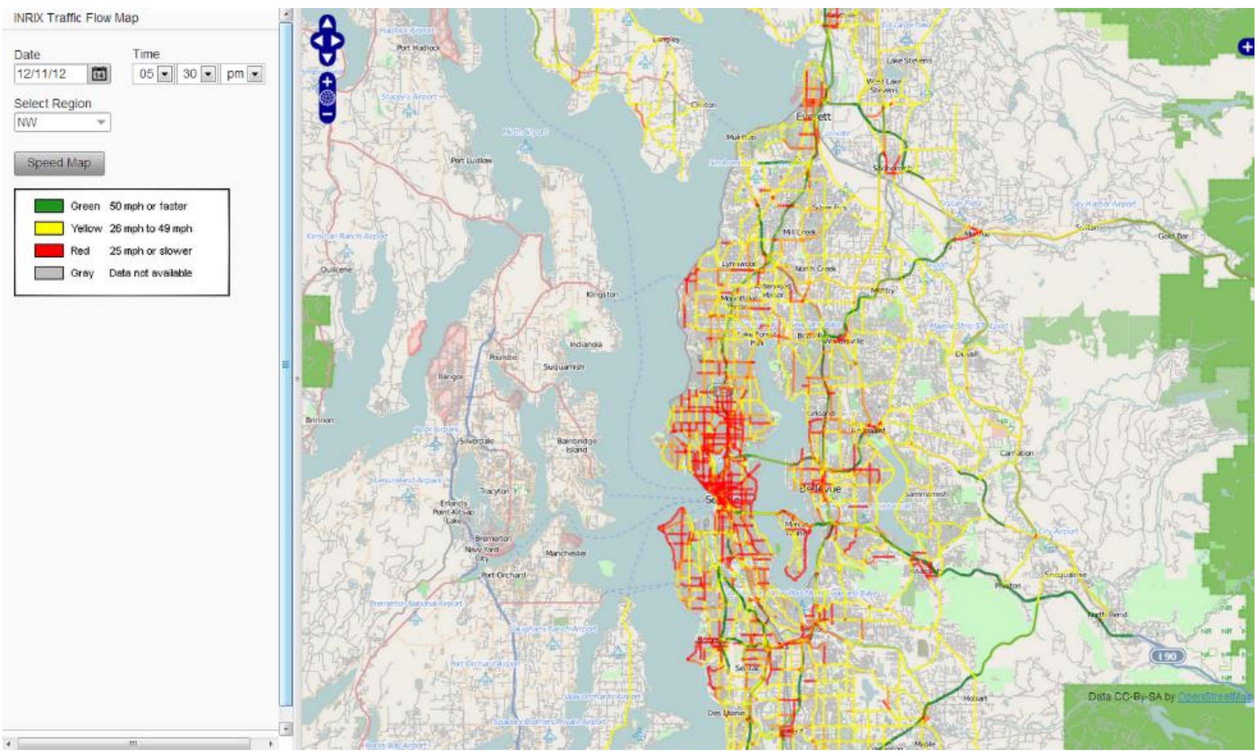



**Figure 3.5. Traffic speed map based on INRIX data.**

INRIX has adopted the Traffic Message Channel (TMC), a common industry convention developed by leading map vendors, as its base roadway network. Each unique TMC code is used to identify a specific road segment. For example, in Table 3.7, TMC 114+05099 represents the WA-522 road segment with start location (47.758321, -122.249705) and end location (47.755733, -122.23368). However, WSDOT roads follow a linear referencing system based on mileposts poses, so substantial work is required to combine these two sources of data. This was completed using geographic information system (GIS) software, and the results were stored in the DRIVE Net database.

**Table 3.7. TMC Code Examples**

| TMC | Roadway | Direction | Intersection | Country | Zip | Start Point | End Point | Miles |
|---|---|---|---|---|---|---|---|---|
| 114+05099 | 522 | Eastbound | 80th Ave | King | 98028 | 47.758321,-122.249705 | 47.755733,-122.23368 | 0.768734 |
| 114-05095 | 522 | Westbound | WA-523/145th St | King | 98115 | 47.753417,-122.27005 | 47.733752,-122.29253 | 1.608059 |

### 3.2.4 Data Set D: Incident Data

This data set was extracted from the WITS and describes the basic characteristics of traffic incidents. WITS data provide a standardized source of information for traffic incidents in Washington State and include the majority of incidents that happen on its freeways and state highways (totaling 550 and 376, respectively, by March 2013). For each incident, the Washington State incident response (IR) team logs details such as incident location, notified time, clear time, and closure lanes. For this project, the WITS data sets from 2002 to 2013 were obtained and integrated into the DRIVE Net database. Several key columns are listed in Table 3.8.

**Table 3.8. WITS Data Description**

| Columns | Data Type | Value Description |
|---|---|---|
| SR | varchar | State route ID, e.g., 005 = Interstate 5 |
| Direction | varchar | Route direction (NB = northbound, SB = southbound, WB = westbound, EB = eastbound) |
| MP | float | Milepost |
| Notified_Time | datetime | The time when an incident was reported to the IR program |
| Arrived_Time | datetime | The time when an IR truck arrived at the incident location |
| Clear_Time | datetime | The time when all lanes became open to traffic |
| Open_Time | datetime | The time when the incident had been fully cleared and the IR teams left the incident scene |

### 3.2.5 Data Set E: Weather Data

This data set consists of weather data from stations in Washington State. Weather data were sourced from a website maintained be the UW Atmospheric Sciences Department, which provides access to hourly observations from 209 weather stations through the National Oceanic and Atmospheric Administration. Weather data are automatically fetched from the website and stored in a STAR Lab database using a JAVA-based computer program written for this purpose. Several key pieces of information are shown in Table 3.9. Weather data are visualized geographically on the DRIVE Net system using the latitude and longitude information associated with each weather station and can be viewed at www.uwdrive.net.

**Table 3.9. Weather Data Description**

| Columns | Data Type | Value Description |
|---|---|---|
| name | Varchar | The weather station identifier |
| timestamp | Datetime | 24-hour time in integer format as YYYYMMDD hh:mm:ss |
| visibility | Smallint | Visibility in miles |
| temp | Smallint | Temperature in degrees Fahrenheit |
| dewtemp | Smallint | Dew point temperature |
| wind_direction | Smallint | Direction wind is coming from in degrees; from the south is 180 |
| wind_speed | Smallint | Wind speed in knots |
| pcpd | Smallint | Total 6-hour precipitation at 00z, 06z, 12z and 18z; 3-hour total for other times. Amounts in hundredths of an inch. |

### 3.2.6 Data Set F: Roadway Geometric Data

This data set contains roadway geometry sourced from WSDOT's GIS and Roadway Data Office (GRDO). The GeoData Distribution Catalog is maintained by GRDO to promote data exchange and can be accessed online at http://www.wsdot.wa.gov/mapsdata/geodatacatalog/. These data are made available in the form of Esri shapefiles, which is an industry standard digital format for geospatial data. Available geometric data sets include lane count, roadway widths, ramp locations, shoulder widths, and surface types. In order to allow geometric elements to be located using the WSDOT linear referencing systems, state route identification and milepost information are included in this data set. A substantial quantity of such geometric data have been obtained and stored in a spatial database as part of the STAR Lab DRIVE Net system, and made available for this project.

## 3.3 Data Quality Control

For this project, a great deal of emphasis has been placed on data quality control (DQC). Fortunately, much of the necessary data quality assurance procedure has previously been developed and implemented in the DRIVE Net system. Most notably, a two-step DQC procedure for loop detector data is developed as illustrated in Figure 3.6. The raw loop data are first subjected to a series of error detection tests to identify missing and erroneous data. These data are flagged for further corrections and remedies. Several statistical algorithms are developed to estimate the missing data and replace those erroneous records. The corrected data are periodically stored in the database for use in further analysis.

The 20-second and 5-minute loop data as well as the ALPR data are all processed for quality control purposes.

### 3.3.1 Loop Detector DQC Procedure

Figure 3.6 shows how incoming loop detector data are processed in the DQC procedure. Error detection algorithms identify and remove erroneous observations based on controller hardware diagnostics and value thresholding, and then sensitivity issues are detected and corrected using a Gaussian Mixture Model algorithm. All loop detector quality control is completed according to the methodologies outline in Wang et al. (2013). Raw (unadjusted) loop detector data are retained throughout the process as back up as well as to quantify the efficacy of the quality control algorithms. These raw data also serve as a benchmark for comparison purposes in performance measurements and in the effectiveness of data quality control algorithms (Wang et al. 2013).

When data are retrieved from the WSDOT FTP site, basic error detection results are already present in the form of simple hardware diagnostics error flags. This process is run at the cabinet level and reports the presence of common loop detector quality issues such as short pulses, loop chatter, and values outside of allowable volume/occupancy ranges as well as whether or not the loop has been manually deactivated (Ishimaru and Hallenbeck 1999). Based on these flags, a loop reporting at least 90% good data is considered acceptable for use in analysis (with erroneous data removed).

A series of additional error detection procedures are performed on the data before uploading into the DRIVE Net platform, primarily based on value thresholding. These procedures are outlined below; for additional information see Wang et al. (2013).

Values outside the established thresholds are marked as missing, though in many cases this does not mean the observations are the result of a hardware malfunction. For example, when no vehicles pass over the detector in a given interval (which frequently happens during low-volume time periods), the volume, occupancy, and speed will all be reported as zero. This simply means that no data are available for that interval, and in this case data must be marked as missing. The thresholding criteria, based on Chen et al. (2003), are as follows:

A. Volume is reported as zero, with occupancy greater than zero.
B. Volume and occupancy are reported as zero (between 5:00 a.m. and 8:00 p.m.
C. Reported occupancy exceeds 0.35.

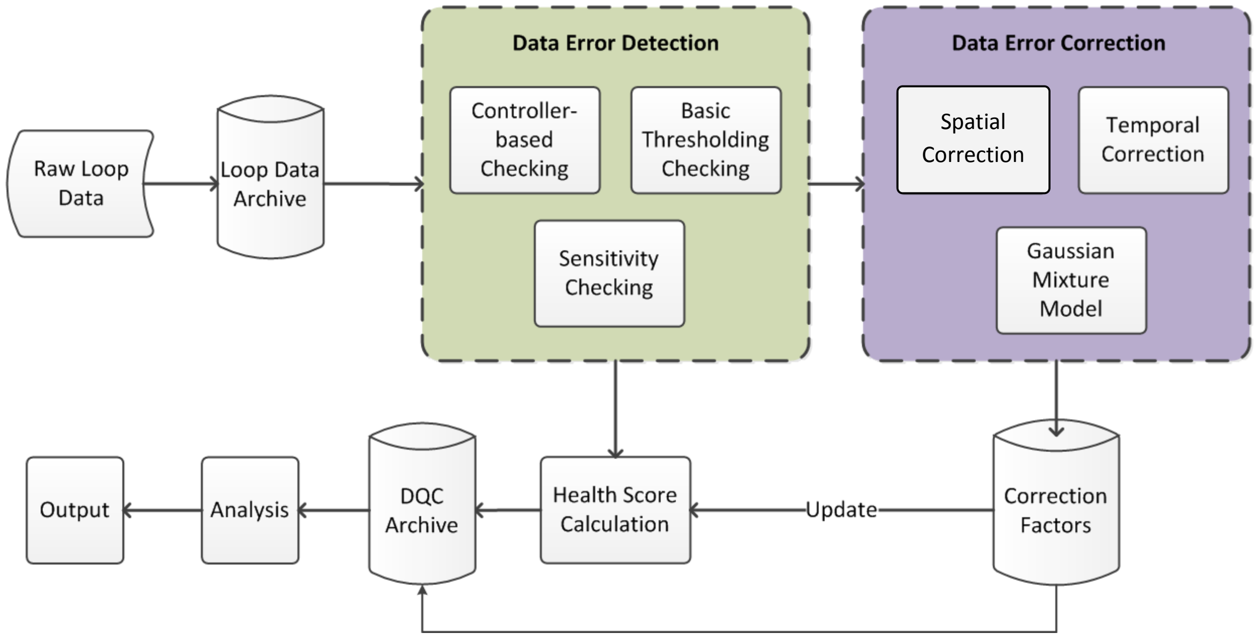



**Figure 3.6. Loop data quality control flow chart (Wang et al. 2013).**

Loop data are retrieved between the hours of 5:00 a.m. and 8:00 p.m., as the above listed threshold criteria are not particularly instructive during night time when volume and occupancy are consistently very low. During this time period, there are 2,700 and 180 records for 20-second and 5-minute loop data, respectively, per detector. Because the researchers expect the number of zero volume/occupancy intervals to be low during the reporting time period, a basic measure of loop detector health can be developed based on the number of type A, B, and C errors reported. Based on this, loop detectors reporting a high number of these error types are discarded according to the methodology described in Wang et al. (2013).

The above listed procedures are primarily oriented toward hardware and communications errors and do not address systematic sensitivity issues. To address this, a statistical Gaussian Mixture Model (GMM) algorithm is implemented based on Corey et al. (2011). This algorithm is designed to identify undersensitive and oversensitive detectors and to correct the resulting observations when possible. The procedure is implemented on a monthly basis and classifies detectors as (1) good, (2) suffering from correctable errors, or (3) suffering from uncorrectable technical issues. Correction factors are produced for detectors classified as type (2). For more information about this algorithm and the specifics of implementation see Wang et al. (2013). Based on the three quality control procedures described above, a health score for each loop detector observation is computed as an indicator of reliability and stored in the loop detector database.

For loop detectors reporting a sufficient number of nonmissing observations, corrections are applied to recover the records flagged by the error detection algorithm. Different corrections are applied based on the scenario and the availability of adjacent observations, listed below:

1. Replacement by spatial interpolation,
2. Replacement by temporal interpolation, and
3. GMM sensitivity correction.

A brief discussion of each of these correction approaches follows.

#### *3.3.1.1 Spatial Interpolation*

For loop detector records flagged by the error detection algorithm or simply missing from the data set because of hardware malfunction, records from adjacent detectors are used to replace the missing observations when possible. There are two ways in which this is done, the selection of which depends on the availability of nearby detector observations marked as "good."

In scenario 1, interpolation is performed using data from lanes adjacent to that of the missing or erroneous record. This is the preferred approach, as there is in general a high correlation between speed, volume, and occupancy in adjacent lanes at any given location. However, this is not always possible, because certain error types (e.g., communications failure) often impact all detectors on a given cabinet. In this case, multiple detectors at the cabinet of interest will report missing or erroneous records for one or more intervals.

In scenario 2, interpolation is performed using data from detectors positioned upstream and downstream of the missing or erroneous record. This approach is applied when the method applied in scenario 1 is impossible because of a lack of adjacent lane records.

#### *3.3.1.2 Temporal Interpolation*

Temporal interpolation is used to fill in missing values when only a single consecutive observation is missing. That is, it is only applied when records are present before and after the missing or erroneous observation in the time series. This method is preferable to spatial interpolation but cannot be applied when multiple consecutive observations are marked missing. Note that if a detector has been marked as malfunctioning because of a high number of observations flagged as "bad" then spatial interpolation cannot be performed.

Spatial and temporal interpolation are imputation processes for filling in missing values, where data are not present in the data set because of either a hardware malfunction or having been removed by the error detection algorithms. What is presented here is a very brief summary; refer to the Wang et al. (2013) for a more thorough description of the methodology and implementation.

#### *3.3.1.3 GMM Correction*

The GMM algorithm simulates the distribution of occupancy as a mixture of Gaussian distributions. This allows the ratio between normal and biased occupancy to be calculated and used to correct records from oversensitive or undersensitive loops. The GMM algorithm produces a flag assigned to each detector by month, designating the detector as one of the following: (1) good, (2) suffering from correctable errors, or (3) suffering from uncorrectable technical issues. For those detectors classified as (2), a correction factor is estimated based on the ratio between normal and biased occupancy. The correction factor is computed based on knowledge of vehicle length distributions and is estimated monthly using intervals during which only a single vehicle passed over the detector (i.e., during low-volume periods). For a thorough description of the GMM procedure refer to Wang et al. (2013) and Corey et al. (2011).

The GMM algorithm is implemented in a software package written in SQL, JAVA, and R programming languages. A graphical user interface (GUI) has been developed to ease execution; see Figure 3.7.

### 3.3.2 ITS DQC Procedure

While ALPR travel time estimates are in general reliable, some unrealistically high travel times are recorded because of the opportunity for vehicles to make incomplete trips through a corridor. Typically, this happens when a vehicle stops along the corridor for a period of time (such as at a local business) and then continues along the route. The ALPR quality control methodology, then, is primarily focused on identifying and eliminating these outlying travel times. Based on the FHWA’s Mobility Monitoring/Urban Congestion Program (Turner et al. 2004), the following quality control criterion is defined for probe data: Any two consecutive travel times cannot differ by more than 40%. Another criterion, based on methods proposed by UW researchers, is to restrict travel times to not more than one standard deviation above or below the moving average of the 10 previous entries. However, these methods were not designed for the sparse data coverage typical of arterial ALPR data, and so without a sufficient number of immediate adjacent observations, many outliers are able to pass through this method undetected. In response, an additional arterial data quality control methodology was developed that focuses on the overall spread of the data. Based on an examination of the arterial data, the following quality control procedures were developed and conducted on the ALPR data:

- Any extremely low or high travel times are removed based on visual inspection.
- After ranking of all travel times for a section any value greater than the 75th percentile plus 1.5 times the interquartile distance or less than the 25th percentile minus 1.5 times the interquartile distance are removed. By using quartile values instead of variance to describe the spread of the data, this technique is made more robust.
- As described above, records in which two consecutive travel times change more than 40% were removed.

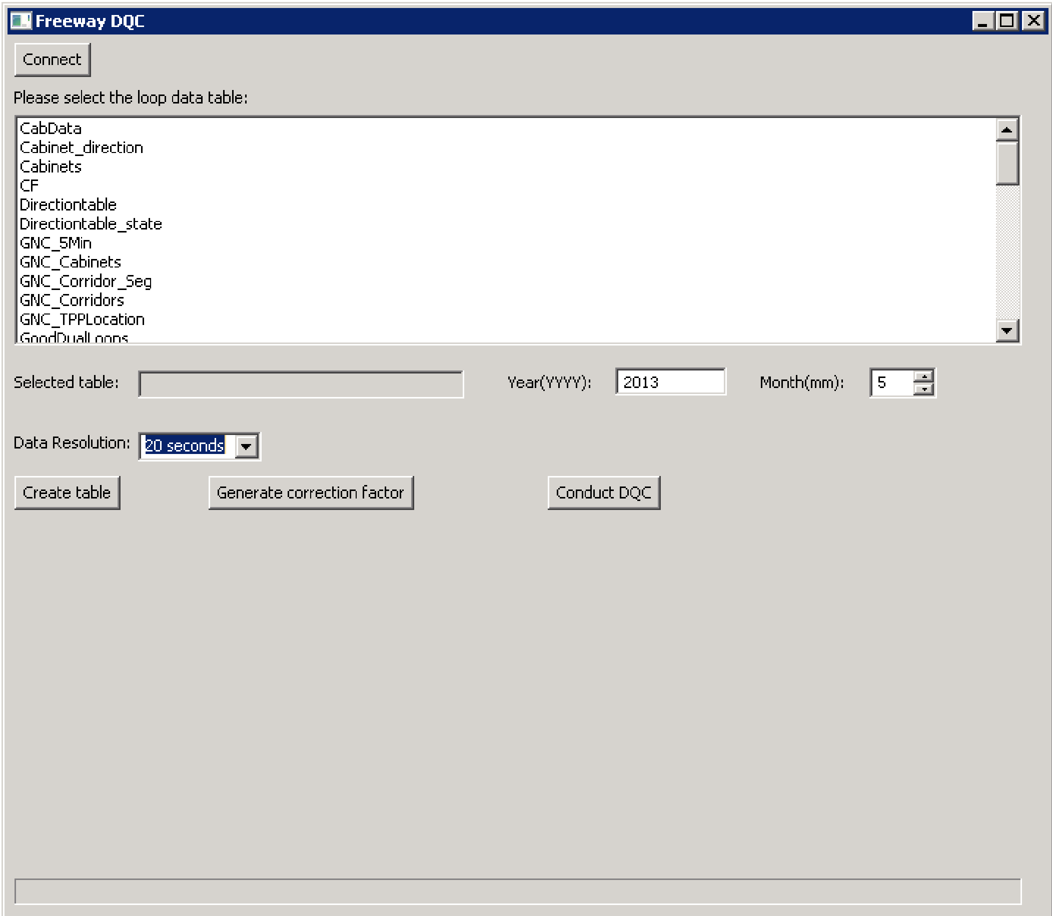



**Figure 3.7. GUI for freeway data quality control.**

## 3.4 Speed and Travel Time Calculations

Using the previously identified data sets, speed and travel time for various segments and routes must be computed for multiple facilities and data types. A new approach to calculate travel time from real-time loop data is described in subsection 3.4.1. Calculation of free-flow speed is described in subsection 3.4.2.

### 3.4.1 A Travel-Based Approach to Calculating Travel Time from Single-Loop Detector Data

For testing the SHRP 2 products, route-level travel time data are needed. The research team developed a new approach to calculate travel time from single-loop data as described below.

In many locations, single-loop detectors are one of the most convenient data sources for travel time calculation. They collect volume and occupancy data that can be converted to an average speed. By dividing the distance between detectors by the average speed, segment travel times can be calculated. From here, the simplest and most common way to calculate a route travel time at a specific time is to calculate all of the segment travel times along the route at the time the route starts and sum them together to get the route travel time. This method requires minimal calculation effort and is often very accurate when the level of congestion remains stable. However, when the level of congestion changes quickly, the predicted segment travel times at the end of the route will be quite inaccurate. The travel-based approach described in this section aims to address this shortcoming.

The first step in calculating a travel-based route travel time begins with the raw data from single-loop detectors. These detectors measure volume and occupancy in each lane; the results can then be converted to speed using the *g*-factor formula (Equation 3.1).

$$Speed = \frac{flow}{occupancy} \cdot \frac{1}{g} \tag{3.1}$$

The *g*-factor is a parameter based on the average length of vehicles passing over the detector and generally ranges from 2.0–2.5. Before calculating travel times, the average vehicle length for a route should be studied and an appropriate *g*-factor should be chosen. Since the travel time calculation relies on spot speeds, a greater density of detectors along a route will yield more accurate travel times. At minimum, the density should be greater than one per mile, but a density closer to two per mile is preferable. Once speeds have been determined for each lane, they can be averaged together at each location. If an HOV lane exists, it should be excluded from this average in order to get the travel time for general vehicles. Quality control procedures can then be applied to the speed data. For this study, the following procedures were used, adopted from WSDOT travel time calculation methods:

- If occupancy is less than 12%, then the speed is set to 60 mph;
- If occupancy is greater than 95%, then the speed is set to 0 mph;
- If the calculated speed is less than 10 mph, then the speed is set to 10 mph; and
- If the calculated speed is greater than 60 mph, then the speed is set to 60 mph.

After cleaning up the data, the segment travel time between two adjacent detectors can then be calculated by taking the distance between the detectors and dividing them by the average of the speeds they record (Equation 3.2). This result will be referred to as the segment travel time. Once these segment travel times have been calculated, they can be summed together over large distances to obtain the travel time for entire routes or corridors.

$$Segment\ travel\ time\ (min) = 60 * \frac{MP_2 - MP_1}{(S_1 + S_2)/2} \tag{3.2}$$

where: *MP* = milepost of the detector
*S* = speed from detector in mph

As mentioned earlier, the simplest and most common way to calculate a travel time at a specific moment is to calculate all of the segment travel times along the route (using Equations

3.1 and 3.2) at that time and then sum them together to get the route travel time. However, this method often yields travel times that vary significantly from ground truth times when a route's congestion is in flux (especially on either end of peak travel periods). To overcome this problem, when calculating travel times from previously collected data (as opposed to real-time results) the segment travel times can be calculated when vehicles actually reach that segment rather than when they begin the route. This is clarified by an example below. Consider Table 3.10, which lists segment travel times (STTs) for eight segments and how they change over a 25-minute period as congestion increases.

**Table 3.10. Segment Travel Time Table for Example Route**

| Time | STT 1-2 | STT 2-3 | STT 3-4 | STT 4-5 | STT 5-6 | STT 6-7 | STT 7-8 | STT 8-9 |
|---|---|---|---|---|---|---|---|---|
| 3:50 p.m. | 1.8 | 2.0 | 2.2 | 4.4 | 4.6 | 1.8 | 2.0 | 4.2 |
| 3:55 p.m. | 2.0 | 2.2 | 2.4 | 4.6 | 4.8 | 2.0 | 2.2 | 4.4 |
| 4:00 p.m. | 2.2 | 2.4 | 2.6 | 4.8 | 5.0 | 2.2 | 2.4 | 4.6 |
| 4:05 p.m. | 2.4 | 1.6 | 2.8 | 5.0 | 4.2 | 2.4 | 2.6 | 4.8 |
| 4:10 p.m. | 2.6 | 1.8 | 2.0 | 5.2 | 4.4 | 2.6 | 2.8 | 4.9 |
| 4:15 p.m. | 1.8 | 2 | 2.2 | 4.4 | 4.6 | 2.8 | 3 | 5.2 |

Using the simple method, the calculated travel time for a vehicle beginning this route at 3:50 p.m. would be the sum of the first row of the table: 23 minutes. However, using the travel-based method, the travel time for a vehicle starting at 3:50 p.m. would be calculated as follows. Segment 1-2 is completed in 1.8 minutes, which is before 3:55 p.m. Thus, segment 2-3 is assumed to be completed in 2.0 minutes. The elapsed time is still before 3:55 p.m., and segment 3-4 is assumed to be completed in 2.2 minutes for a running total of 6 minutes. Now the elapsed time is between 3:55 and 4:00 p.m., so segment 4-5 is assumed to be completed in 4.6 minutes. This brings the elapsed time to 10.6 minutes, which is between 4:00 and 4:05 p.m., so segment 5-6 would be completed in 5 minutes. Following this procedure (the highlighted path), the travel-based route travel time is calculated as 26 minutes for a trip starting at 3:50 p.m., rather than the 23 minutes for the simple method. This travel time result should then be stored with the time that travel along the route began. Note that both of these methods generate an average expected travel time, and thus individual drivers will experience at least some variation around this average.

This travel-based method for calculating route travel times responds to the dynamic nature of the congestion along a route. Therefore, it is expected to be a closer match to ground truth travel times during periods where congestion changes quickly. Figure 3.8 summarizes the entire method of calculating travel times, starting with the raw single-loop detector data.

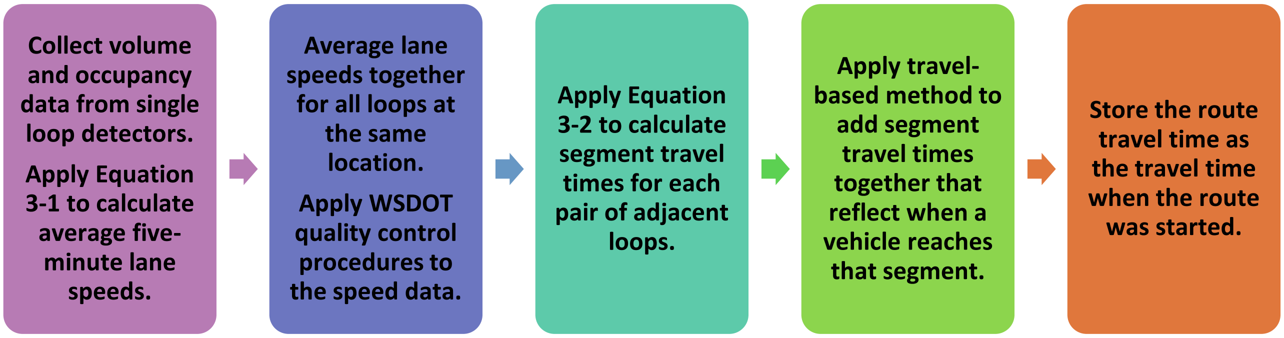



**Figure 3.8. Diagram of travel-based route travel time calculation.**

### 3.4.2 Calculation of Free-Flow Speed

The distribution statistics for the TTI depend on measuring travel time relative to an ideal or free-flow speed. For urban freeways, the research team uses a constant value for all sections of 60 mph. This is a well-established threshold for measuring congestion on urban freeways. For signalized highways, the situation is more complex because of variation in speed limits and signal-influenced delay, even at very low volumes. For these sections, researchers applied the 85th percentile speed as the free-flow speed. In all cases, if section speeds are greater than the free-flow speed, then the TTI is set to 1.0; no credit is given for going faster than the free-flow speed.

## 3.5 Final Data Set for Analysis

As the preceding discussion demonstrates, an array of data sets at various levels of spatial and temporal aggregation has been created. The end result of the processing and fusing is a high-quality preprocessed data set to be used in the analyses. A relatively high level of aggregation is required because reliability is defined over a long period of time to allow all pertinent factors to exert influence on it. Each observation in the analysis data set is for an individual section for an entire year for each of the daily time slices studied: peak hour, peak period, midday, weekday, and weekend/holiday. Data set characteristics under consideration include the following attributes that are intended to capture characteristics for an entire year on the study sections:

- Reliability metrics
  - Mean, standard deviation, median, mode, minimum, and percentiles (10th, 80th, 95th, and 99th) for both travel time and the TTI
  - Buffer indices (based on mean and median), planning time index, skew statistic, and misery index
  - On-time percentages for thresholds of median plus 10%, median plus 25%, and average speeds of 30 mph, 45 mph, and 50 mph
- Operations characteristics

    - Area-wide and section-level service patrol trucks (average number of patrol trucks per day)
    - Area-wide and section-level service patrol trucks per mile (average number of patrol trucks per day divided by centerline mile)
    - Traffic Incident Management Self-Assessment scores
    - Quick clearance law (yes/no)
    - Property damage only move-to-shoulder law (yes/no)
    - Able to move fatalities without medical examiner (yes/no)
    - IRT staff per mile covered
    - Number of ramp meters, DMSs, and closed-circuit televisions.
- Capacity and volume characteristics
    - Start and end times for the peak hour and the peak period
    - Calculated and imputed vehicle-miles traveled (VMT)
    - Demand-to-capacity and average annual daily traffic (AADT)-to-capacity ratios
    - Average of all links on the section
    - Highest for all links on the section
    - AADT-to-capacity ratios for downstream bottlenecks as segregated by ramp merge area
- Incident characteristics
    - Number of incidents (annual)
    - Incident rate per 100 million vehicle-miles
    - Incident lane-hours lost (annual)
    - Incident shoulder-hours lost (annual)
    - Mean, standard deviation, and 95th percentile of incident duration
- Work zone characteristics
    - Number of work zones (annual)
    - Work zone lane-hours lost (annual)
    - Work zone shoulder-hours lost (annual)
    - Mean, standard deviation, and 95th percentile of work zone duration
- Weather characteristics
    - Number of annual hours with precipitation amounts greater than or equal to 0.01 inches, 0.05 inches, 0.10 inches, 0.25 inches, and 0.50 inches
    - Number of annual hours with measurable snow
    - Number of annual hours with frozen precipitation
    - Number of annual hours with fog present

## 3.6 Data Acquisition and Integration

As described in the previous subsections, several sizable data sets from a variety of sources were archived for this project. To address the challenges of integrating and fusing these diverse data sets, the STAR Lab DRIVE Net platform is used as a data repository, visualization, and analysis tool. Figure 3.9 shows an interface snapshot of DRIVE Net Version 3.0.

DRIVE Net is an online e-science platform for data access, analysis, visualization, and quality control, and is already home to a great deal of public and private transportation data. In addition to its utility as a data storage and integration tool, DRIVE Net was in employed in both analysis and visualization roles at various stages of this project. DRIVE Net is currently housing multiple data sources through various methods of data retrieval, for example, traditional flat file exchange, passive data retrieval, active data retrieval, and direct data archival. A variety of data sources are digested and archived into the STAR Lab server from WSDOT and third-party data providers through different data acquisition methods, as depicted in Figure 3.10.

All of the aforementioned data quality procedures are implemented in the DRIVE Net system, allowing analysts access to a variety of high-quality data sources in an integrated environment. Quality control is performed on data before they are made available on the platform, removing the need for substantial preprocessing work and providing a high level of confidence for researchers and practitioners.

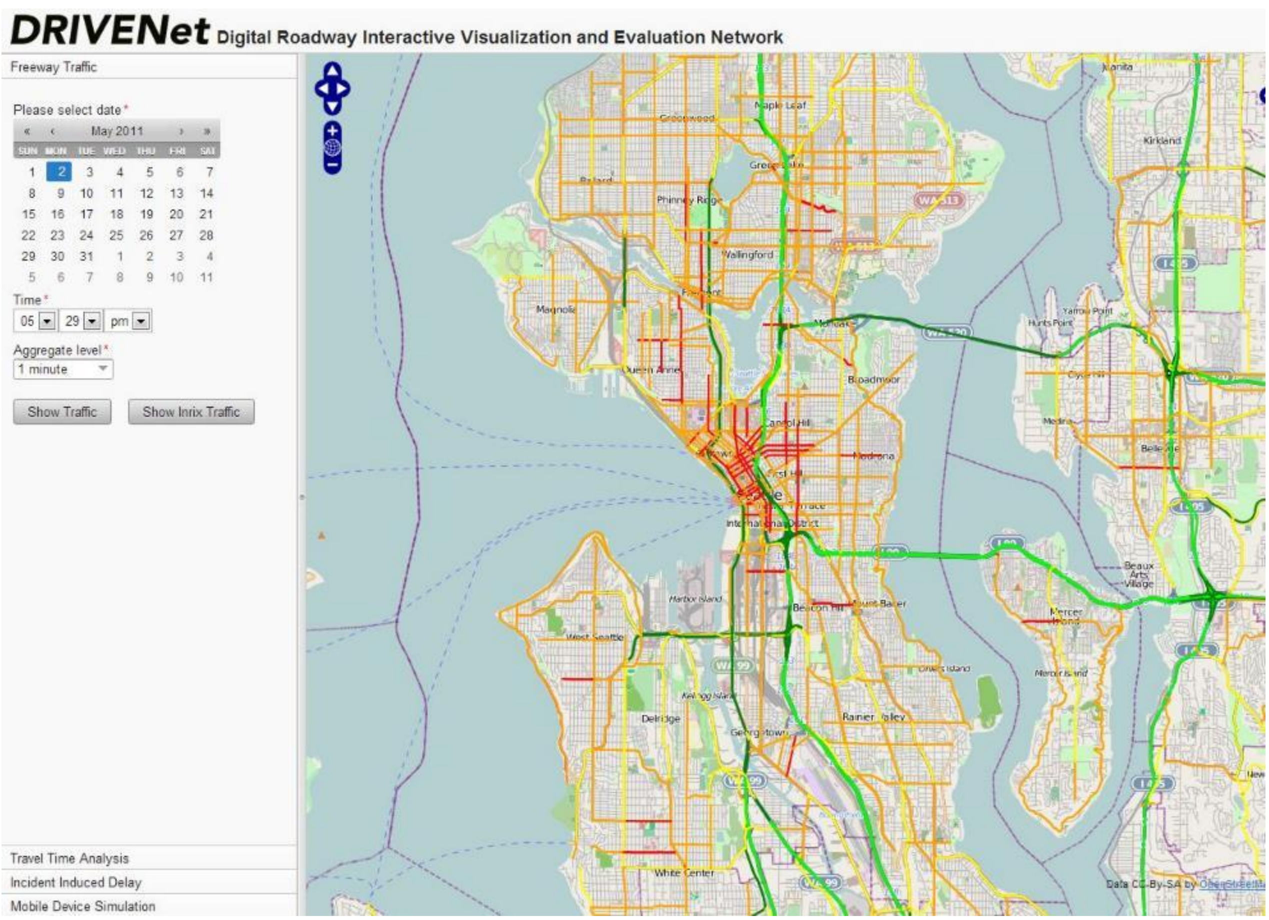



**Figure 3.9. DRIVE Net interface with color-coded traffic flow feed from WSDOT.**

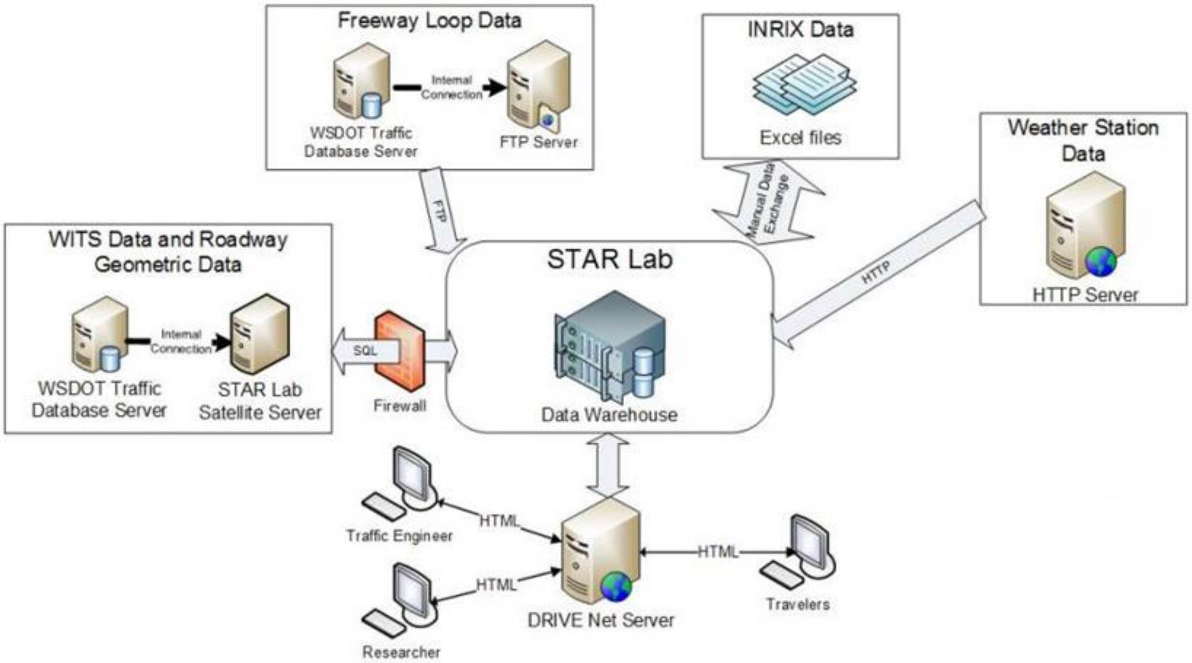



**Figure 3.10. Data acquisition methods for the DRIVE Net system (Wang et al. 2013).**

# CHAPTER 4
# Pilot Testing and Analysis on SHRP 2 L02 Product

## 4.1 Introduction

The L02 project aims at developing tools and procedures for creating a system that monitors travel time reliability and quantifies the impact of varying conditions on the reliability. Ultimately, the L02 tools are intended to help transportation agencies answer five basic questions:

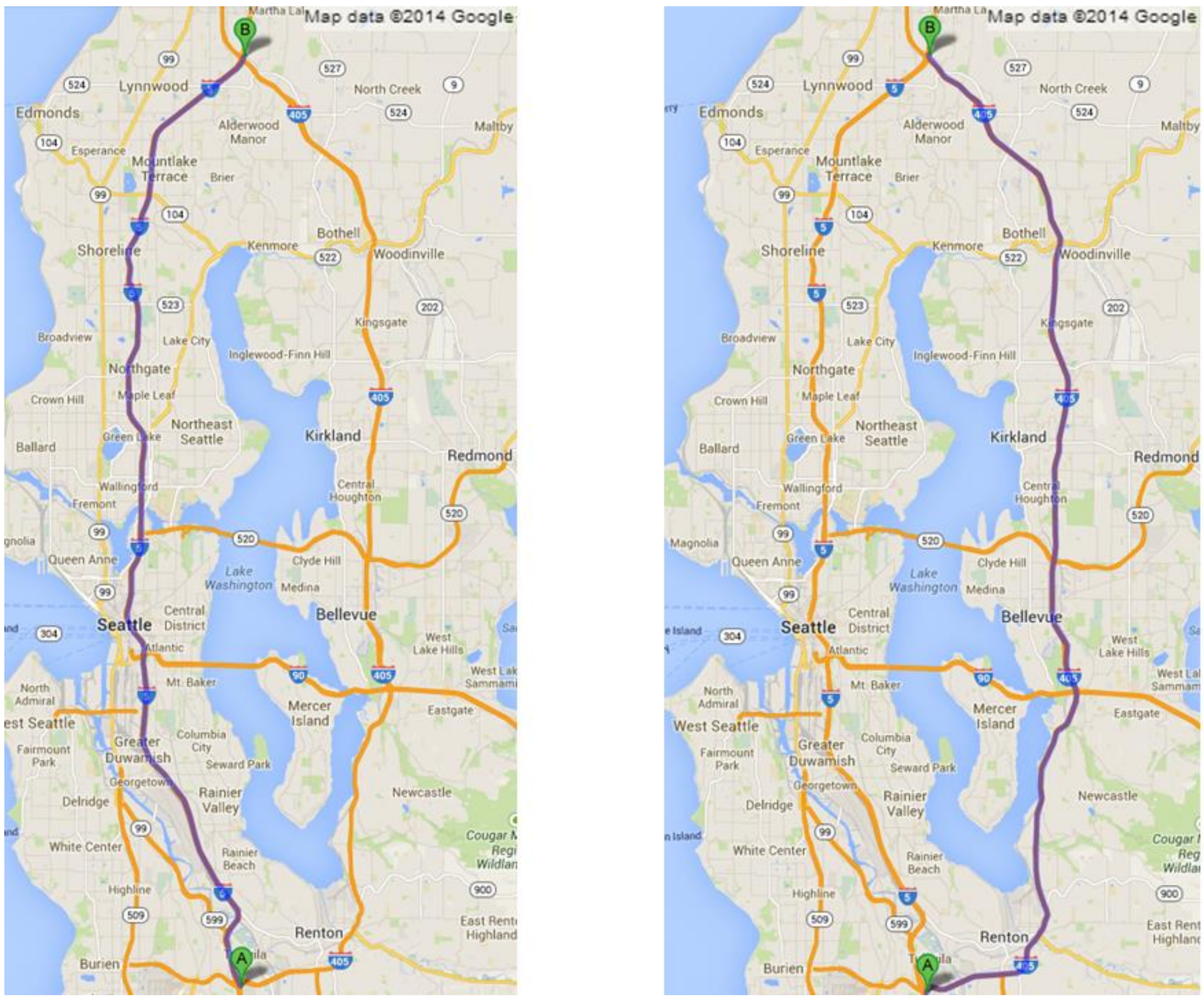
1. What is the distribution of travel times in their system?
2. How is the distribution affected by recurrent congestion and nonrecurring events?
3. How are freeways and arterials performing relative to performance targets set by the agency?
4. Are capacity investments and other improvements really necessary given the current distribution of travel times?
5. Are operational improvement actions and capacity investments improving the travel times and their reliability?

The L02 project's effectiveness at answering each of these questions was evaluated, and solutions to shortcomings are recommended. The three L02 products were also tested by applying them to a TTRMS. The three products tested include the guide and its methodology, the TTRMS and its effectiveness in monitoring reliability, and the approach to synthesizing of route-level travel times from segment-level travel times. This system helps quantify travel time reliability for a relatively large-scale network, visualize the causes of congestion, and identify segments where a performance improvement is desired.

## 4.2 Test Sites

Test Sites A and B are selected for L02 product testing. Test Site A includes I-5 northbound and southbound from Lynnwood to Tukwila, and Test Site B covers the entirety of I-405 northbound and southbound. Test Site A runs 26.5 miles between the southern and northern termini of I-405 and experiences a peak AADT of 228,000 vehicles near milepost 163, just south of the I-5/I-90 interchange. Similarly, the I-405 route (Test Site B) is 29.4 miles long and experiences a peak AADT of 200,000 vehicles near milepost 12, just north of the I-405/I-90 interchange. These routes are illustrated in Figure 4.1.

Data were not collected for the I-5 reversible express lanes, which on weekdays run southbound from approximately 5:00 a.m. to 11:00 a.m. and northbound from approximately 11:15 a.m. to 11:00 p.m. However, these time periods are often delayed or modified because of incidents and special events. These express lanes run approximately 7 miles from milepost 165 to milepost 172 and carry between two and four lanes of traffic with the number of lanes increasing as the roadway approaches the downtown Seattle exits and entrances. Because of the variable nature of operation times, the limited access nature of this facility, and the integration with traffic on mainline I-5, incorporating these express lanes into the travel time calculations would likely decrease the accuracy of the results. Therefore, travel times were not calculated for the I-5 express lanes. Instead, express lane traffic is considered interacting with the mainstream traffic as on-ramp or off-ramp flows.




(a) (b)

Map data © 2014 Google

**Figure 4.1. Map of (a) Test Site A (I-5 facility) and (b) Test Site B (I-405 facility).**

## 4.3 Data Description

In this test, 5-minute loop data serve as the basis for the travel time calculations. The procedure follows the L02 Guide for travel time monitoring, in which “5-minute interval” is stated as the minimum resolution to accurately capture the effects of weather and incidents on travel time reliability. The timeframe of interest is the entire 24-hour day with data from January through

December 2012. Researchers chose to analyze data for weekdays Tuesday through Thursday. Some studies separated Monday and Friday from other weekdays when predicting traffic patterns, because traffic patterns during Monday and Friday may deviate from other weekdays. This way, researchers were able to capture the most and least congested periods of the day while eliminating the traffic inconsistencies that are frequently observed on Mondays, Fridays, and weekends. Data from any existing HOV lanes were also excluded. This single-loop data were then converted to speed using Athol's method (Athol 1965) with a *g*-factor of 2.2. The WSDOT travel time estimation methodology specifies the minimum and maximum speeds to use for travel time calculation. Speeds higher than the maximum speed are truncated to the maximum speed value of 60 mph. Those speeds lower than the minimum speed threshold are replaced with the minimum speed of 10 mph. Segment travel times were then generated by measuring the distance between two adjacent loop locations and dividing that by the harmonic mean of the speeds measured at these locations. Finally, route-level travel times are calculated using a piecewise trajectory algorithm that sums the segment-level travel times along the route.

## 4.4 Regime Characterization

According to the L02 Guide, a regime is defined as a pair of conditions that consists of a recurring congestion level and a nonrecurring condition. For the recurring congestion, each travel time measurement is tagged with a congestion level (free-flow, low, moderate, and high) based on the time of day and average travel time based on the entire year, as defined in Table 4.1.

**Table 4.1. Determination of Congestion Levels for I-5 and I-405**

| Congestion Level | Average Annual Travel Time |
|---|---|
| Free-flow | <30 min |
| Low | 30–35 min |
| Moderate | 35–40 min |
| High | >40 min |

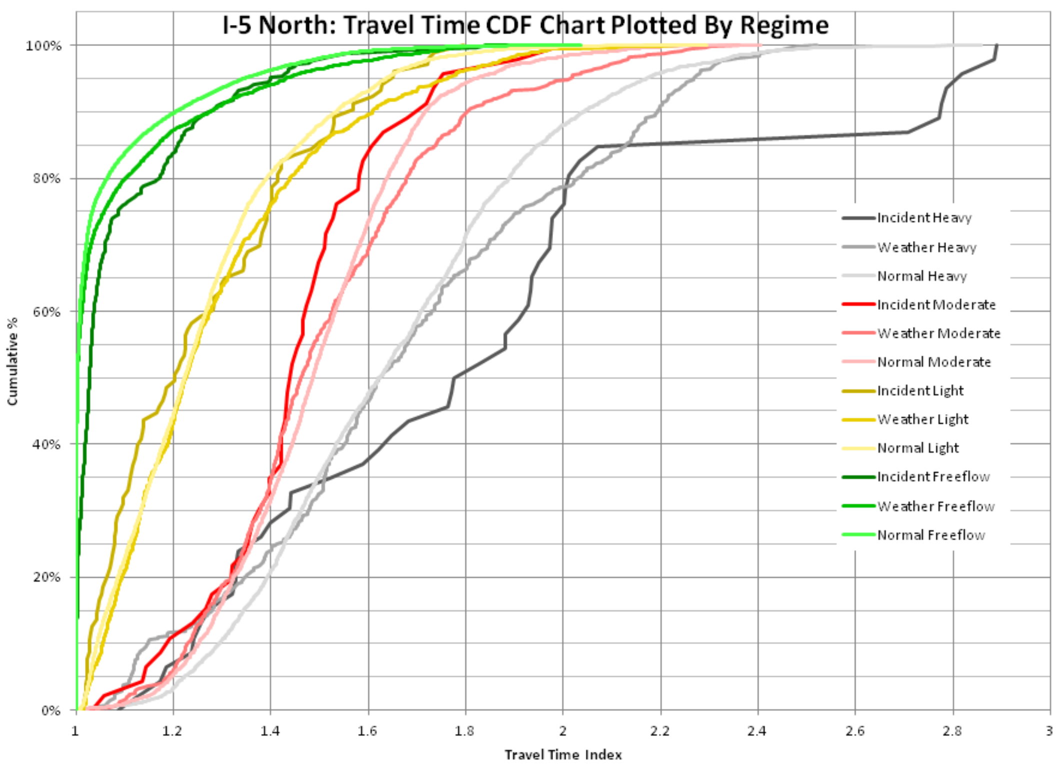
It is important to note that the times for congestion levels are not determined day to day but rather reflect the annual average conditions as specified in the L02 Guide.

For the nonrecurring condition, data is tagged as "normal" (no nonrecurring event occurred), "weather" (a weather event is occurring that negatively affects traffic), "incident" (there is a lane-blocking incident affecting the study facility), and "overlap" (if weather and incident occur simultaneously).

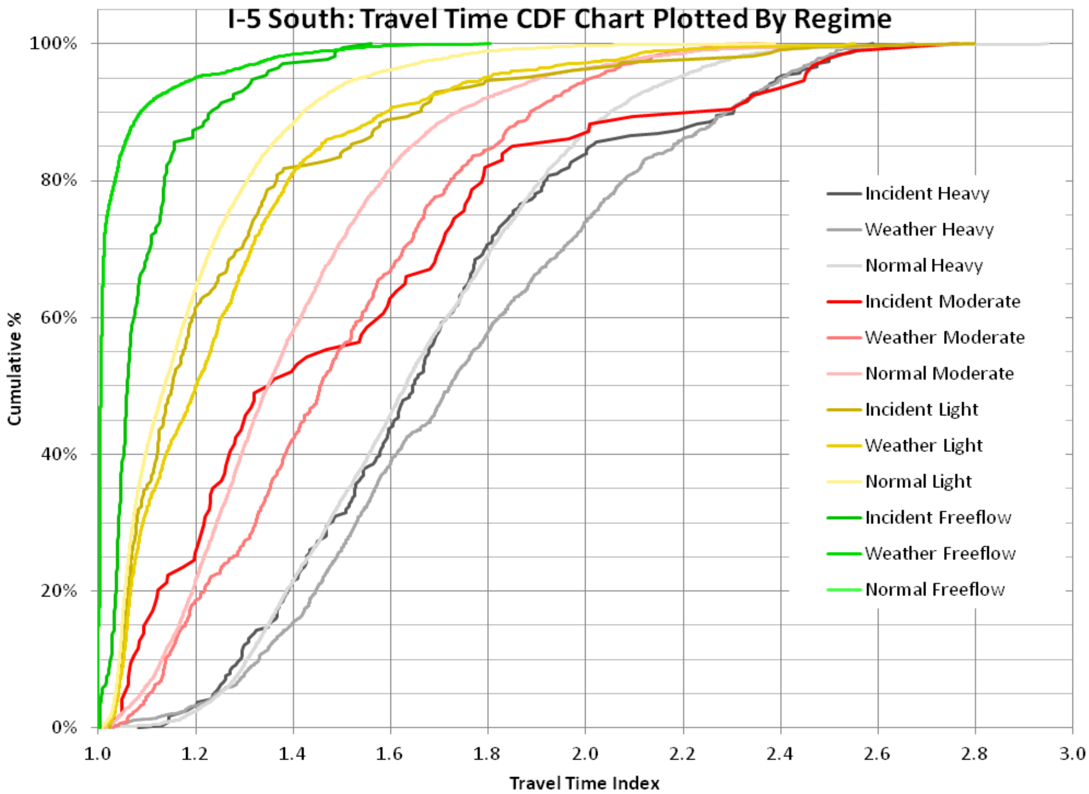
Incidents are tagged using data from the WITS system. Data are tagged as having an incident in progress if there is an incident blocking a lane or lanes on the route or within 2 miles downstream of the route, during the 5-minute period. Data are tagged as "weather" if there is measurable precipitation during a 1-hour period or if fog was recorded. The data are taken from local weather stations, which only report every hour. Once all data are tagged with a recurring congestion level and a nonrecurring condition, the data could be plotted as a cumulative distribution function (CDF) chart, the key visual output of the L02 methodology.

## 4.5 Testing Results and Discussion

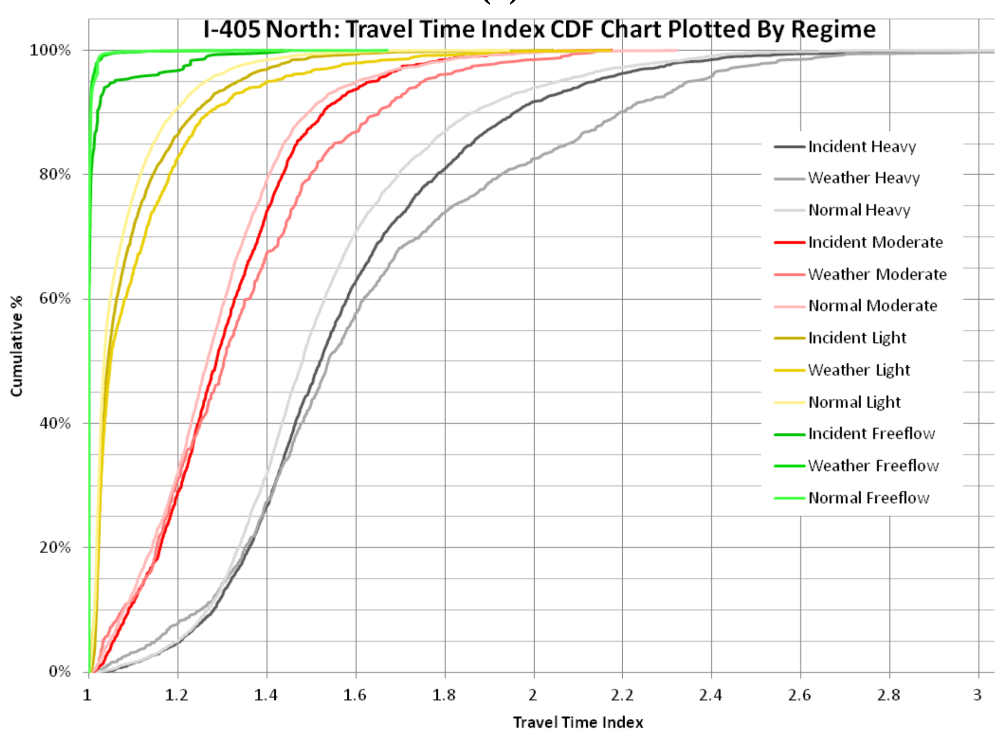
After categorizing all the travel time data into the appropriate regimes, many useful charts can be drawn in analyzing each facility's travel time reliability and comparing the reliability between the facilities. The travel time CDF is the key output of L02 and the most information-rich chart. Figure 4.2 shows each facility's TTI CDF (developed following the L02 procedure).



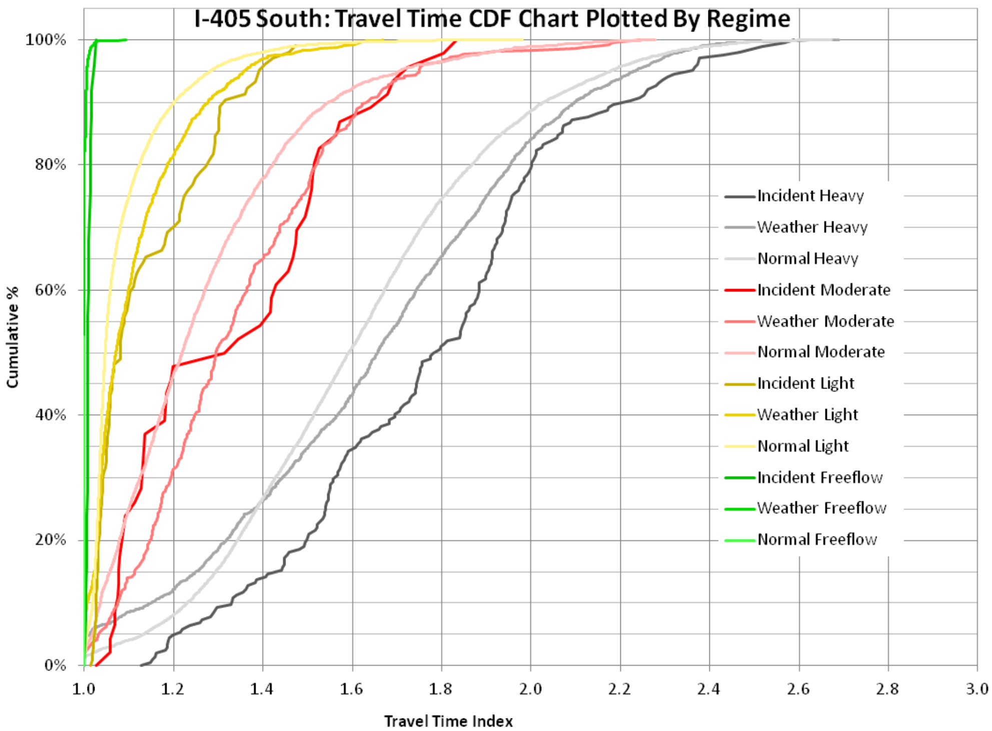

**(a)**


I-5 South: Travel Time CDF Chart Plotted By Regime
Cumulative %
Travel Time Index
Incident Heavy
Weather Heavy
Normal Heavy
Incident Moderate
Weather Moderate
Normal Moderate
Incident Light
Weather Light
Normal Light
Incident Freeflow
Weather Freeflow
Normal Freeflow

**(b)**


I-405 North: Travel Time Index CDF Chart Plotted By Regime
Cumulative %
Travel Time Index
Incident Heavy
Weather Heavy
Normal Heavy
Incident Moderate
Weather Moderate
Normal Moderate
Incident Light
Weather Light
Normal Light
Incident Freeflow
Weather Freeflow
Normal Freeflow

**(c)**




(d)

**Figure 4.2. TTI CDFs for all test facilities: (a) I-5 North, (b) I-5 South, (c) I-405 North, and (d) I-405 South.**

These graphs are useful since they contain important information about the travel time reliability of each route. For example, it is easy to look at the chart for I-405 South and infer that the interquartile range for TTI under heavy congestion and adverse weather is about 1.4–1.9. It is also useful to show the relative reliability of each regime. Looking at the I-405 South chart again, travel times with adverse weather and heavy congestion are generally slower and consistently less reliable, as indicated by higher TTI above the 25th percentile and a broader distribution (less steep curve) for the "Weather Heavy" curve versus the "Normal Heavy" curve.

While the CDF graphs have proven useful for quickly interpreting reliability, they were found to be less effective tools for making policy decisions and evaluating roadway improvements. The CDF graphs reveal limited information about the frequency with which a regime occurs, or its total contribution to delay. For instance, if an agency decides to improve reliability by mitigating the effects of incidents, it is crucial to quantify the impact incidents have on travel delay. Figure 4.3 and Figure 4.4 address this by showing the relative frequency with which each regime occurs and the contribution of each regime to the total travel delay. Figure 4.5 demonstrates the average travel delay for each regime on I-405 North. It can be observed that the I-405 North normally experiences the largest travel time delay under the heavy traffic conditions.

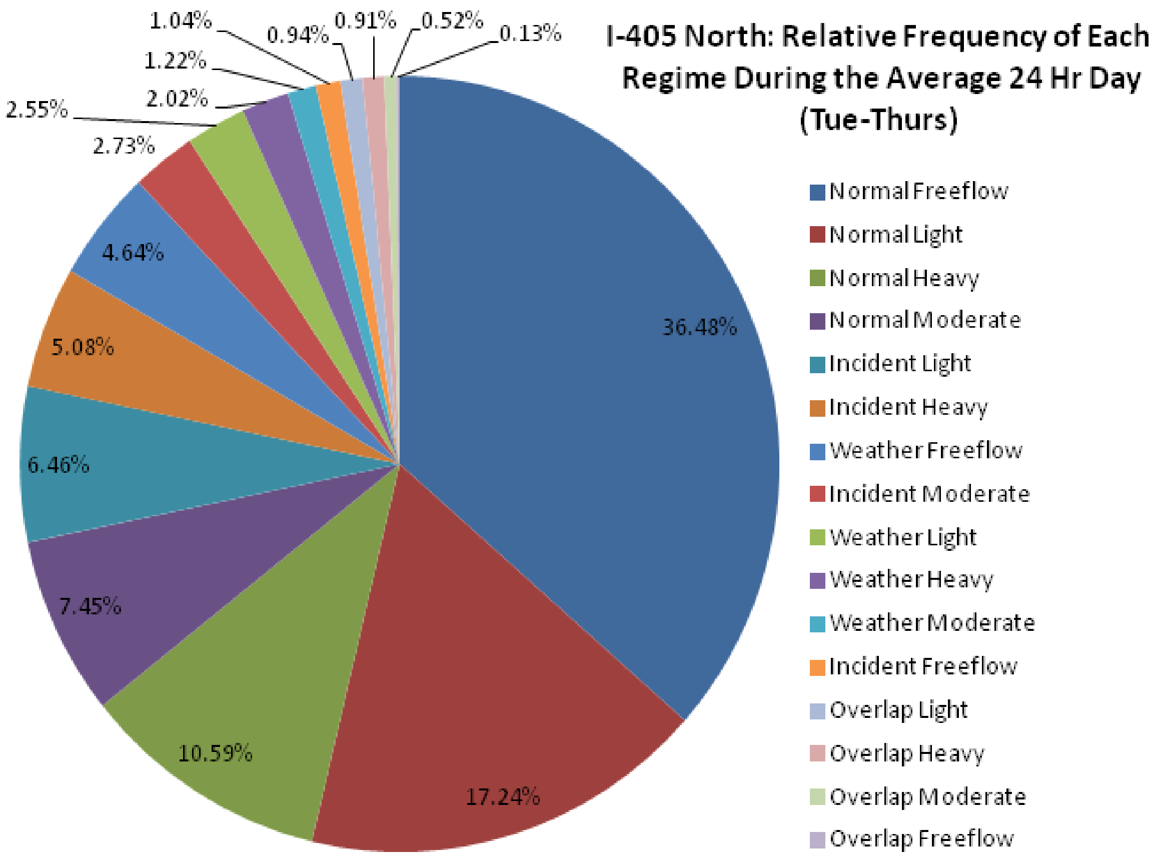



**Figure 4.3. Relative frequency of each regime on I-405 North.**

The CDF graphs are useful for qualitative analysis of reliability. However, it is found that these graphs have some shortcomings in making the quantitative assessments that are desired when evaluating roadway improvements. To test the effectiveness of L02 in evaluating roadway improvements, the research team has examined the "I-405–NE 8th St. to SR 520 Braided Ramps–Interchange Improvements" project, which was completed in early 2012. Specifically, this project aimed to improve traffic flow by building new multilevel "braided" ramps to separate vehicles entering and exiting northbound I-405 between NE 8th Street and SR 520 in Bellevue. Figure 4.6 shows the layout of this improvement project.

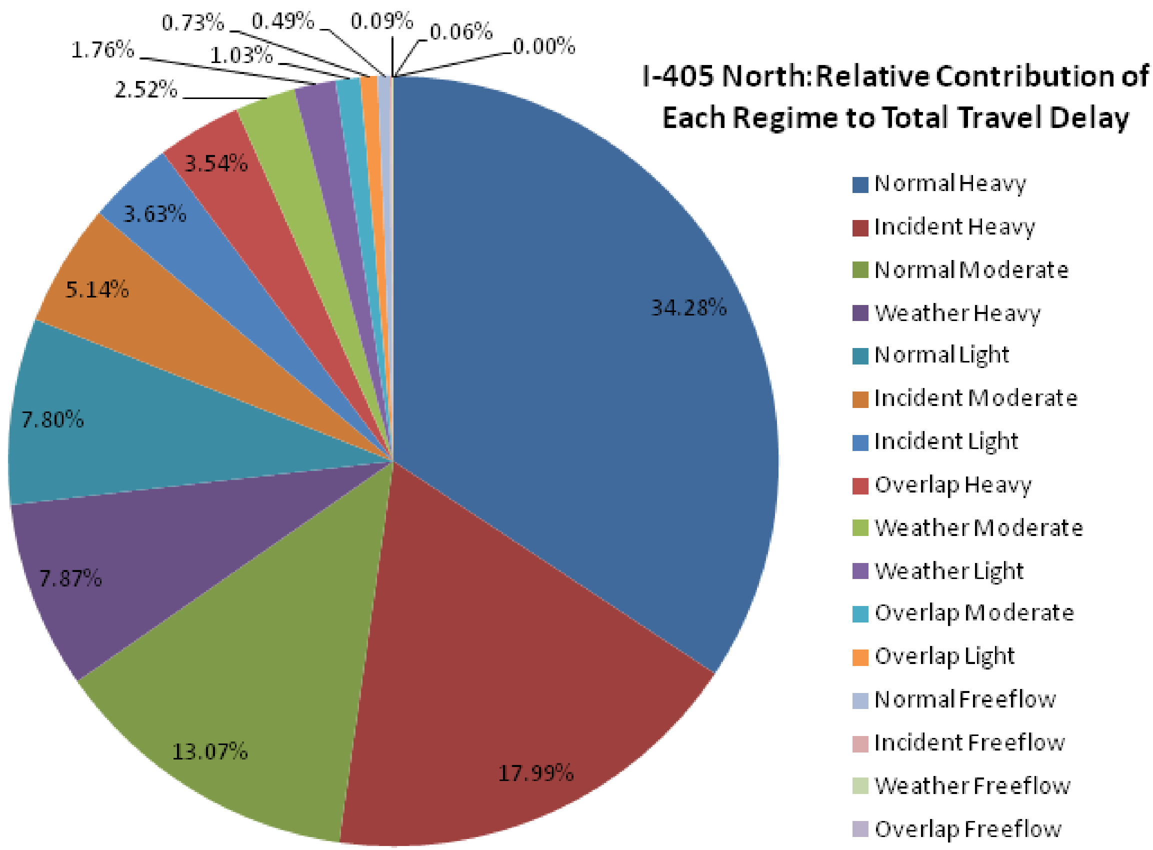



**Figure 4.4. Relative contribution of each regime to travel delay on I-405 North.**

In order to test the impact of this improvement on reliability, travel times were calculated for I-405 northbound from milepost 12.28 to milepost 15.36. For comparison, the physical extent of this project extends from milepost 13.9 to milepost 14.9. Tuesday–Thursday data were collected January–September 2011 and 2012 for before and after. The gap was created because key elements of this project began opening in early October. These data were then processed in the same method as the route-level data, and CDFs were plotted for normal, incident, and weather regimes. The CDF plots under normal and incident conditions for this analysis are shown in Figure 4.7 and Figure 4.8 and reveal significant improvements in reliability after the project. For example, in Figure 4.8 the interquartile range for TTI under heavy congestion shifted from 1.17–2.04 before the project to 1.06–1.67 after.

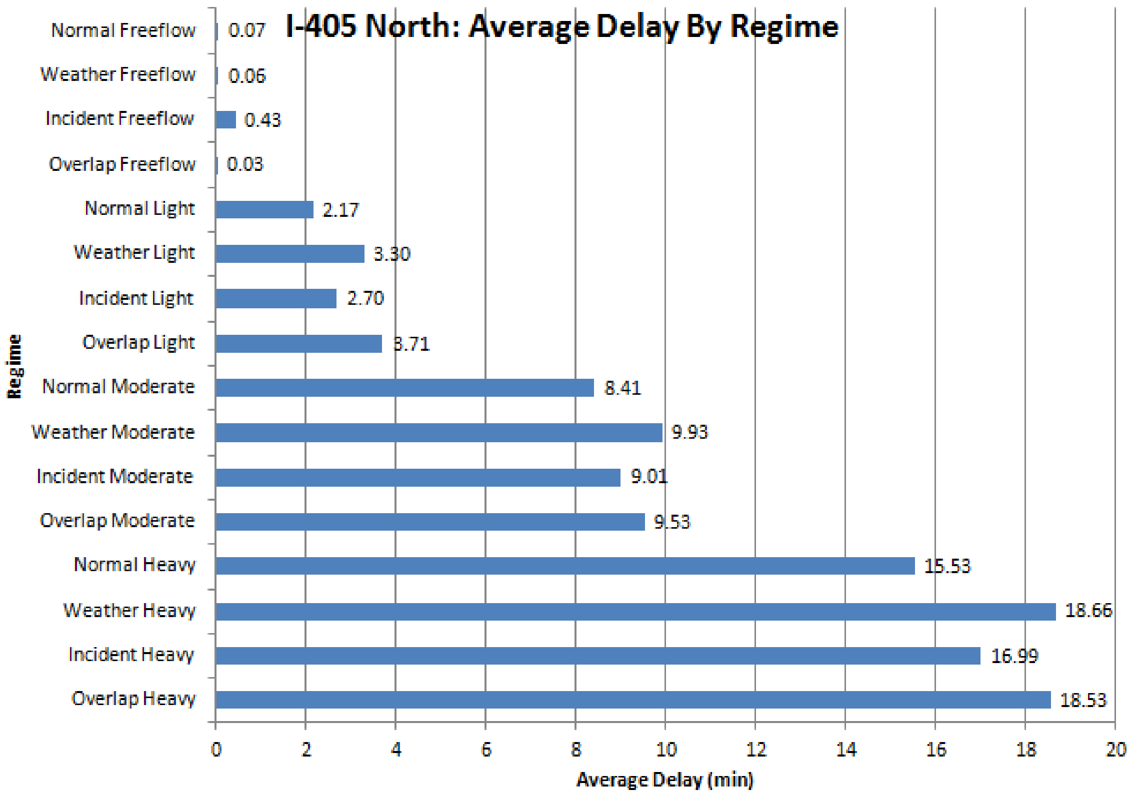



**Figure 4.5. Average travel delay for each regime on I-405 North.**

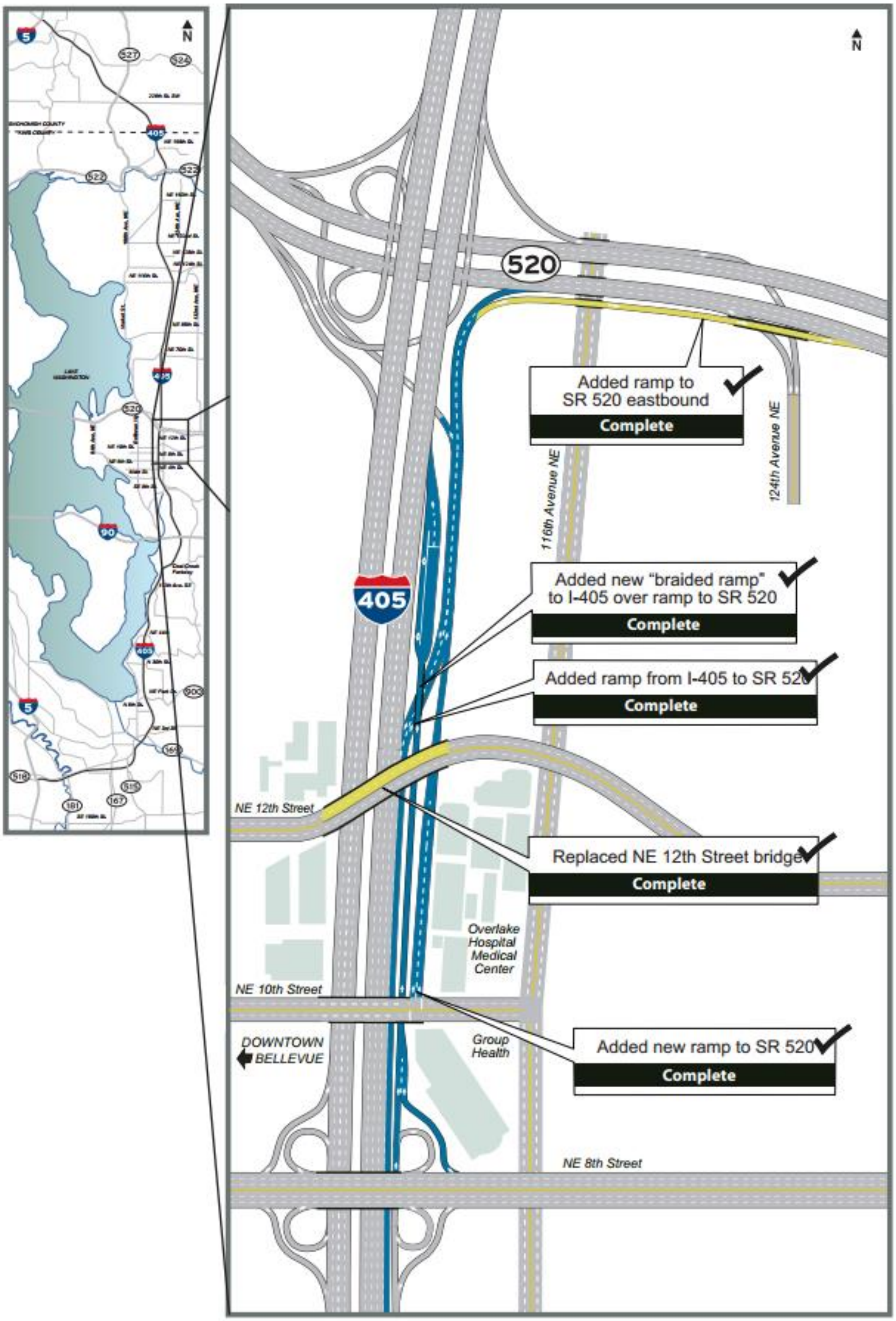



**Figure 4.6. Design and layout of I-405 Braided Ramps Project.**

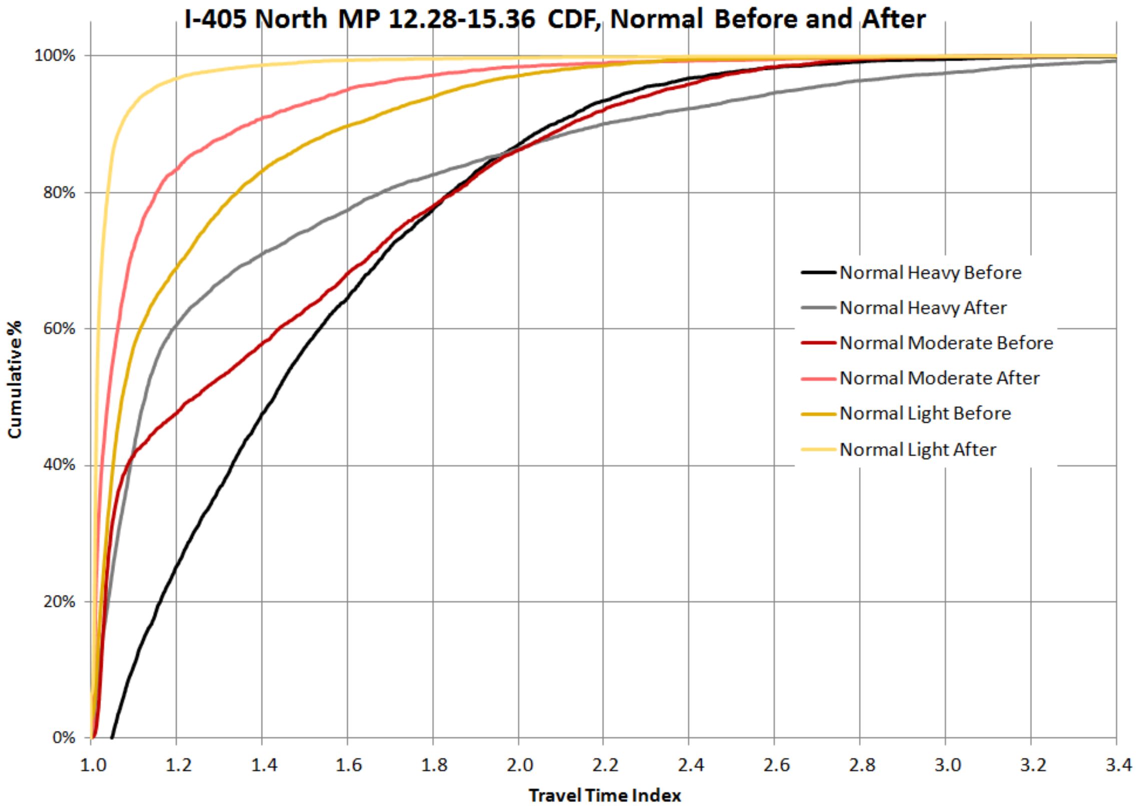



**Figure 4.7. Before-and-after TTI CDF for I-405 Braided Ramps Project under normal conditions.**

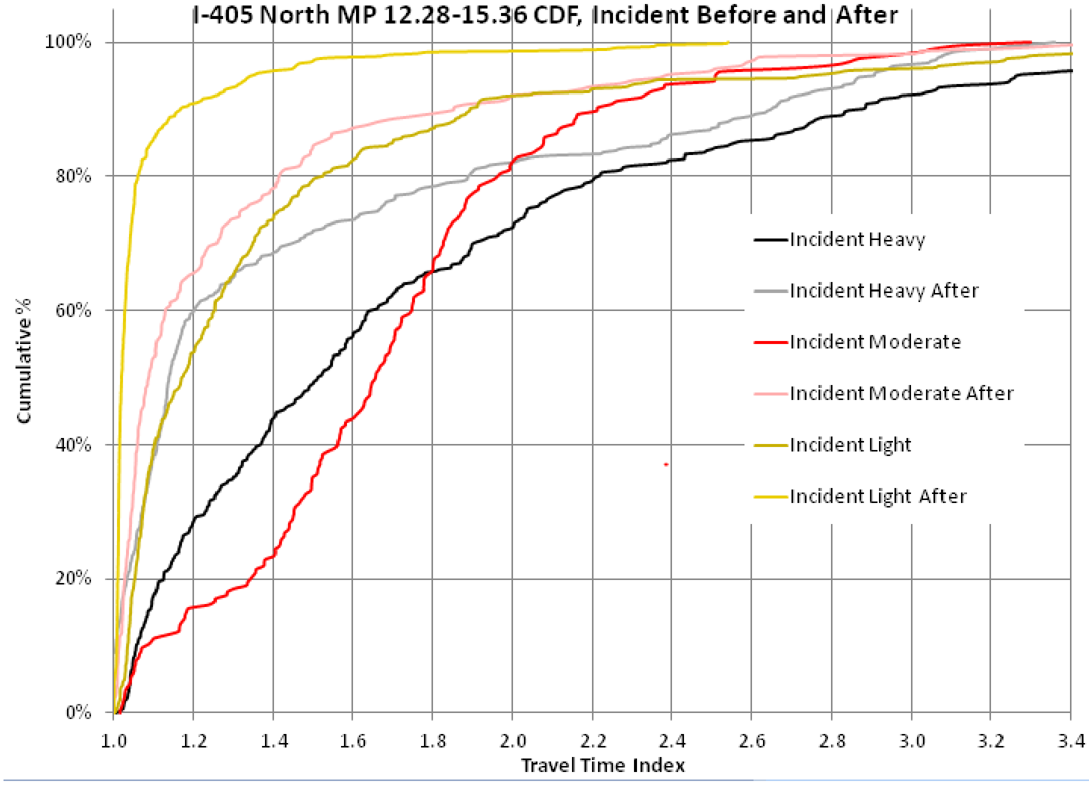



**Figure 4.8. Before-and-after TTI CDF for I-405 Braided Ramps Project under incident conditions.**

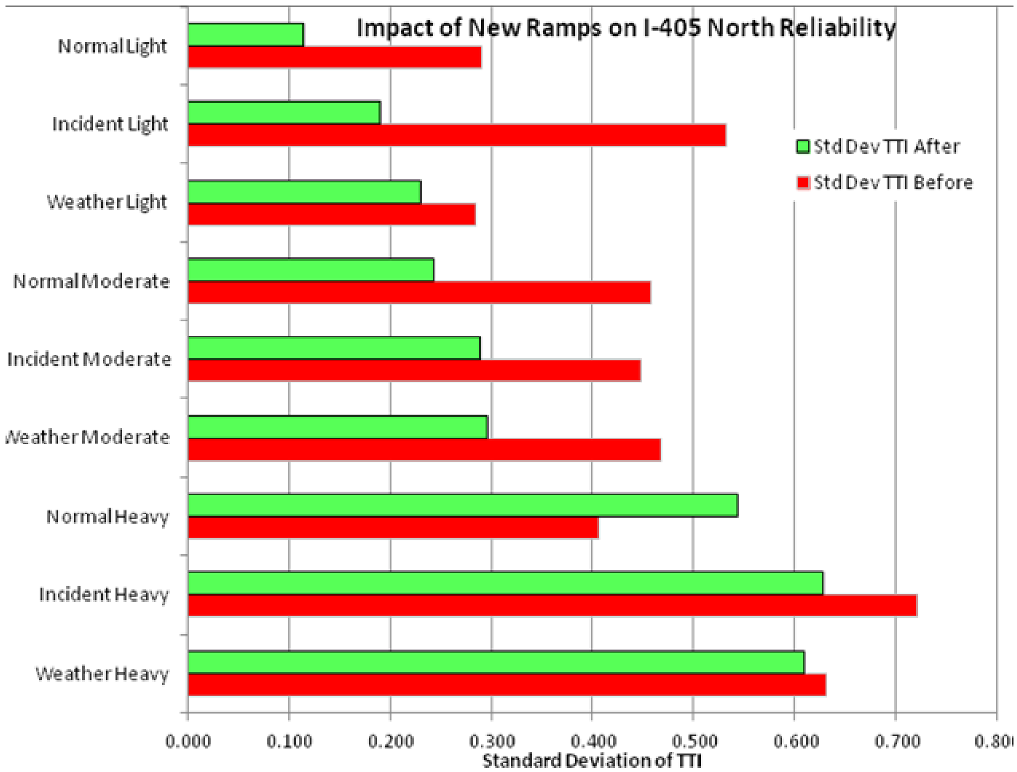



**Figure 4.9. TTI standard deviations for each regime before and after I-405 ramp project.**

However, the research team found that the CDF graph makes it somewhat difficult to extract quantitative values for reliability. In addition, graphing all regimes simultaneously would require plotting 18 curves on a single graph, which makes the charts less useful. Plotting the standard deviations by regime as a bar graph was found to be more effective for this application. The results are shown in Figure 4.9. This graph shows clear reliability improvement in 8 out of 9 regimes, with only the Normal Heavy regime getting less reliable. An examination of the CDF graph reveals TTI in this regime actually improved up to the 85th percentile, proving that the CDF is still a valuable tool for understanding the whole picture.

## 4.6 Practical Applications of the L02 Methodology

The L02 project's TTRMS was implemented on the Digital Roadway Interactive Visualization and Evaluation Network platform, which is currently being developed as WSDOT's data analytics system. DRIVE Net is a framework for a regionwide web-based transportation decision system that adopts digital roadway maps as the base and provides data layers for integrating multiple data sources, including traffic sensor data, incident data, accident data, and travel time data. DRIVE Net provides a practical solution to facilitate data retrieval and integration, and enhances data usability. The system provides users with the capability to store, access, and manipulate data from anywhere as long as they have Internet connections. The goal of the platform is to remove the barriers existing in the current data sets archived by WSDOT and to achieve the integration and visualization of information needed for decision support.

The DRIVE Net system adopts the "thin client and fat server" architecture with three basic tiers to the web application: presentation tier, logic tier, and data tier (see Figure 4.10). Analytical tools developed include incident-induced delay forecasting using deterministic queuing theory and GPS-based truck performance measures.

By implementing the reliability data generated by L02 onto DRIVE Net, transportation agencies and roadway users have access to the reliability data that have been generated from the project. Providing this easy access to the data is useful in planning future projects to improve reliability as well as in measuring their effectiveness. Regular road users may create a personal DRIVE Net account with customized travel route information to see travel time statistics on their commuting routes and explore potential alternative routes. The reliability data and analysis performed for L02 has been extended from the original study of the I-5/I-405 alternative facility to include SR 520, portions of I-90 and SR 167, and an extended segment of I-5 stretching over 100 miles. Figure 4.11 illustrates this coverage in green.

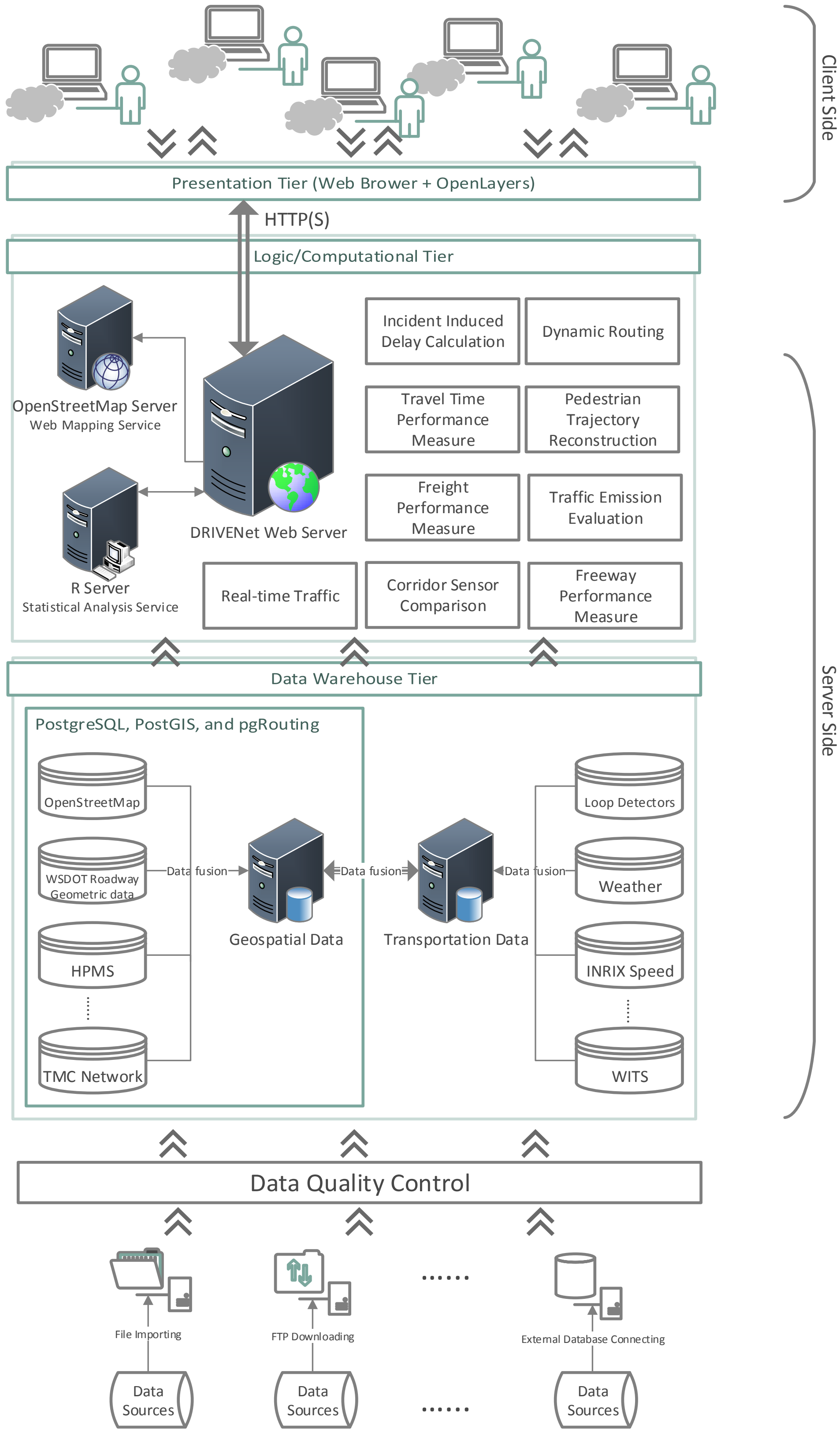



**Figure 4.10. DRIVE Net architecture (Wang et al. 2013).**

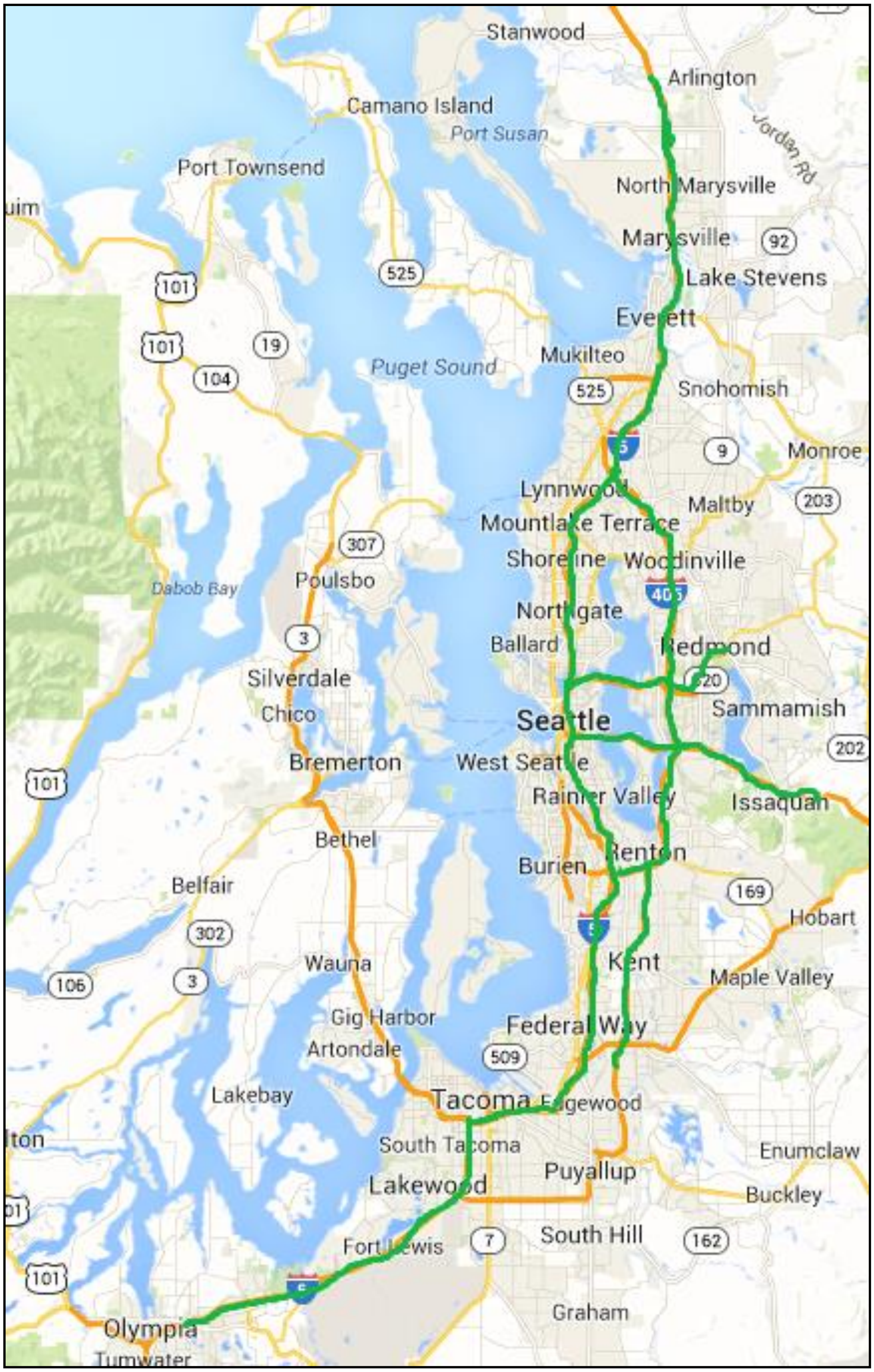


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**Figure 4.11. Routes available on the DRIVE Net platform for L02 reliability analysis.**

Using these new data, transportation agencies and roadway users can explore reliability anywhere along these implemented routes simply by inputting mileposts or clicking on the map. Travel time reliability information is available in two different forms:

1. Users can directly view the travel times for varying levels of reliability for a custom route by specifying a starting and ending milepost. A snapshot of this feature is shown in Figure 4.12.
2. Users can specify a starting milepost along with a given amount of travel time, and DRIVE Net can determine how far the user can travel with varying levels of reliability. A snapshot of this feature is shown in Figure 4.13.

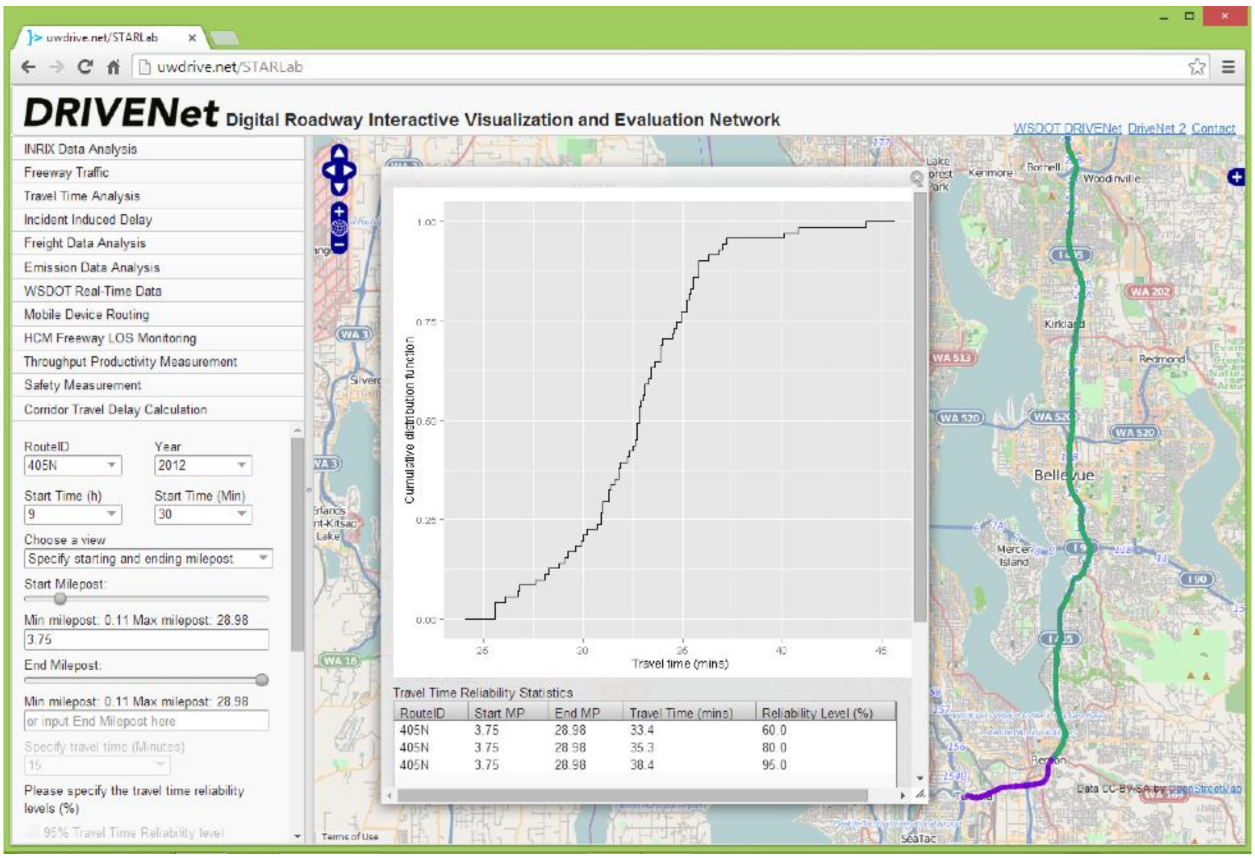


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**Figure 4.12. Travel times for varying levels of reliability for a custom route.**

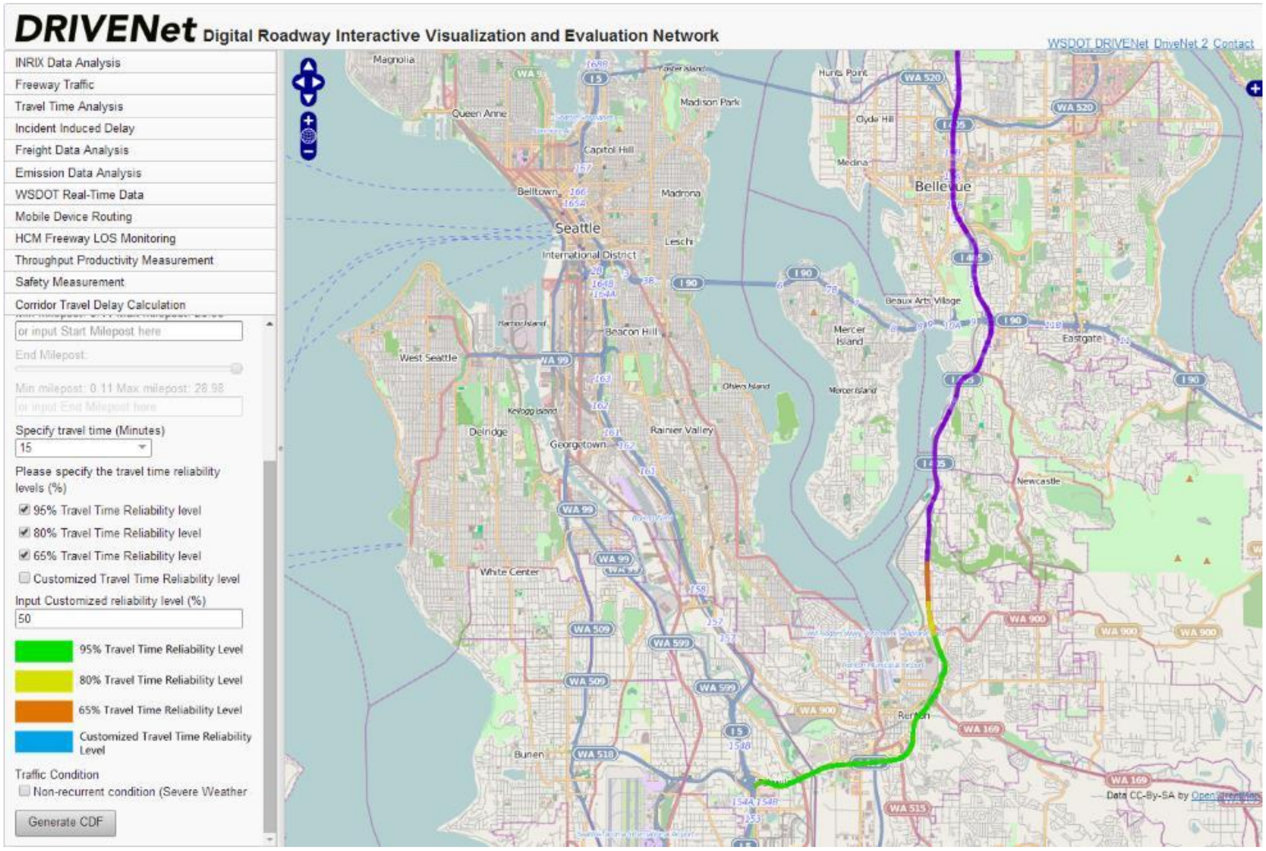

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**Figure 4.13. Travel distance with varying levels of reliability.**

With the depth of reliability information made available on DRIVE Net, transportation agencies can better understand the performance of their roadway networks, and drivers can make better route choices when planning their commutes. For more information, the DRIVE Net platform can be accessed at http://uwdrive.net/STARLab.

## 4.7 Evaluation of the L02 Objectives

Overall, the L02 tools have few shortcomings and effectively help transportation agencies answer five basic questions:

1. What is the distribution of travel times in their system?
2. How is the distribution affected by recurrent congestion and nonrecurring events?
3. How are freeways and arterials performing relative to performance targets set by the agency?
4. Are capacity investments and other improvements really necessary given the current distribution of travel times?
5. Are operational improvement actions and capacity investments improving the travel times and their reliability?

The distribution of travel times and how it is affected by recurrent congestion and nonrecurring events is clearly and efficiently shown by creating the CDF charts using the L02 methodology. Comparing performance targets to actual freeway performance is then easily accomplished, as long as targets are expressed in a way that is compatible with the L02 output. For example, agencies should express desired performance in terms of performance at various percentiles, or as the standard deviation of travel time. The need for capacity investments and other improvements is not perfectly addressed by the L02 tools. The research team felt it was necessary to analyze the relative contribution of each regime to the overall reliability and delay. This could not be directly taken from the L02 methods; however, it did provide a strong foundation for such analysis. Finally, the L02 methodology and CDFs were helpful in determining the effectiveness of improvements and investment. However, it is important to note that L02 specifies route-level analysis, which is a much larger scale than most improvements. The research team chose to examine improvements near the segment level and found that plotting standard deviations of travel times could be more helpful for detailed analysis.

# CHAPTER 5
# Pilot Testing and Analysis on SHRP 2 L05 Product

## 5.1 Introduction

SHRP 2 L05 provides a concise description of how to incorporate reliability considerations into the transportation planning and programming process, with a focus on helping agencies make choices and tradeoffs about funding and project priority.

Through the development of this guide for incorporating reliability into the planning process, WSDOT, along with the Moving Washington initiative, has been mentioned several times as an example to illustrate how agencies incorporated the notion of reliability into their policy statements. From the Gray Notebook to the Annual Congestion Report, WSDOT has been using different performance measures to convey reliability trends at corridor and statewide levels. It is without a doubt that WSDOT has already considered reliability as one of the top priorities in the strategic planning process.

WSDOT has been in the process of defining an investment philosophy and framework that is intended to incorporate operational, demand management, and traditional capacity approaches to produce integrated and incremental corridor investment plans. WSDOT recognizes that accomplishing this requires the ability to work across organizations and ensure individual program activities, processes, and expertise are aligned and integrated toward common system performance objectives and outcomes.

The SHRP 2 L01 (Integrating Business Processes to Improve Reliability) (Kimley-Horn and Associates 2011)/L06 (Institutional Architectures to Advance Operational Strategies) (Parsons Brinckerhoff, & Delcan Corporation 2012) project focuses on organizational structure and capabilities associated with integration of reliability and deployment of operational strategies from a transportation agency perspective. WSDOT was selected as an early implementer and intends to focus efforts on integrating operations and operational strategies into the planning, programming, and project development processes. This project has since been refined to focus specifically on operations program capabilities, processes and products, and the level of maturity relative to what is necessary to engage effectively in planning processes. Associated with this and incorporating L05 products would be an assessment of key planning processes to consider how to incorporate reliability from a performance perspective, and to ensure integration of operational and demand management strategies within planning processes. Performance measurement as it relates to reliability will be part of this effort. Through this effort, WSDOT intends to identify gaps in methods, process, organization, and competencies, with the outcome of this effort including the development of a work plan delineating steps to improve organizational capabilities. The initial project kick off meeting was held on October 29, 2013, with the workshop scheduled for mid-June of 2014.

## 5.2 SHRP 2 L01/L06 Early Implementation Project

Given that traffic congestion associated with weather, crashes, and special events creates more than 50% of all motorist delay, processes to better manage traffic operations and leverage existing capacity will make the highway system more reliable and reduce the cost of congestion for drivers, freight operators, and other users. Several new tools to help agencies advance their business practices and their organizational structures are now available from SHRP 2. Taken together, they provide a structure to modernize current practices, mainstream traffic operations in the state or local department of transportation, and, ultimately, help agencies better plan for and address nonrecurrent congestion on their systems.

A new suite of guides and tools will assist transportation agencies in evaluating and improving their organizational capabilities to conduct effective and efficient operations, which includes integrating travel time reliability into planning, programming, and project delivery processes while overcoming interdepartmental and interagency barriers to improving highway operations. The new guides and tools include:

- The tools for an agency staff to conduct an assessment of their organizational structure and business practices for effectiveness in managing travel time reliability through traffic operations;
- Case studies that show how other states have adjusted their business processes to better handle traffic incident management, work zone management, and other business functions related to travel time reliability; and
- A system and templates for advancing an agency's ability to improve systems operations and management.

The first product, Integrating Business Processes to Improve Travel Time Reliability (L01), focuses on integrating business processes to allow DOTs to improve reliability through management of incidents, weather, work zones, special events, traffic control devices, fluctuations in demand, and bottlenecks.

The second product, Institutional Architectures to Advance Operational Strategies (L06), provides a comprehensive and systematic examination of ways agencies can be more effectively organized to successfully execute operations programs that improve travel time reliability. It includes a self-evaluation guide and identifies all the elements needed to improve activities for business processes, systems and technology, performance management, culture, organization and workforce, and collaboration.

The focus of this effort will be internal to WSDOT. However, there will be opportunity for MPO and local agency involvement at various stages of development, such as at the concept stage as objectives associated with the Moving Washington framework are refined and as researchers develop and refine strategies, methodologies, processes, and roles necessary to integrate reliability and operations into to the broader context of overall investment planning.

## 5.3 SHRP 2 L05 Project Comments

Recognizing that much of the implementation focus for WSDOT will occur with the deployment of the L01/L06 Capability and Maturity workshop, a cursory level of review of the *Guide to Incorporating Reliability Performance Measures into the Transportation Planning and Programming Processes* was conducted. From this review, WSDOT offers the following comments.

Overall, the guide provides a very sound comprehensive approach to incorporating reliability into planning and programming processes. The descriptions aimed at explaining the various forms the measure might take, how to communicate the measures in clear understandable terms, and the significance of the measure as an importance gap-filling process to comprehensively considering system performance were very well presented.

Recognizing that Reliability is a rapidly evolving term, there will be opportunities to continue to refine how this is presented. These may include the following:

- There are likely limitations to how reliability can be estimated using existing tools. The guide suggests accomplishing this through existing microsimulation models. Experience indicates that there are challenges with these approaches not only from the level of intensity required to conduct an analysis using these tools but also from the potential unknowns that may factor into actual performance. Model calibration would be a challenge. This would make associating the value of different potential improvement strategies challenging as well.
- Other opportunities for further development could also focus on when in planning horizon of a facility reliability and the ability to estimate outcomes of different improvement alternatives best fit. It seems clear the application and value when considering existing performance and near term implementation of improvement strategies. How reliability can be considered as longer term forecasted and estimated performance measure seems less clear.
- There also seems to be potential for the use of reliability measures as leading performance indicators for corridors with emerging congestion. When and how to apply these measures in developing corridors may provide benefit from the perspective of the timing of when to begin considering operational strategies ahead of the onset of routine congestion.

# CHAPTER 6
# Pilot Testing and Analysis on SHRP 2 L07 Product

## 6.1 Tool Introduction and Interface

The objective of SHRP 2 L07 is to evaluate the cost-effectiveness of geometric design treatments in reducing nonrecurrent congestion. The L07 products help estimate traffic operational effectiveness and measure economic benefits of various design treatments. In addition to the research report, L07 produced an Excel-based software tool to automate the analysis process.

A snapshot of the tool interface is shown in Figure 6.1.

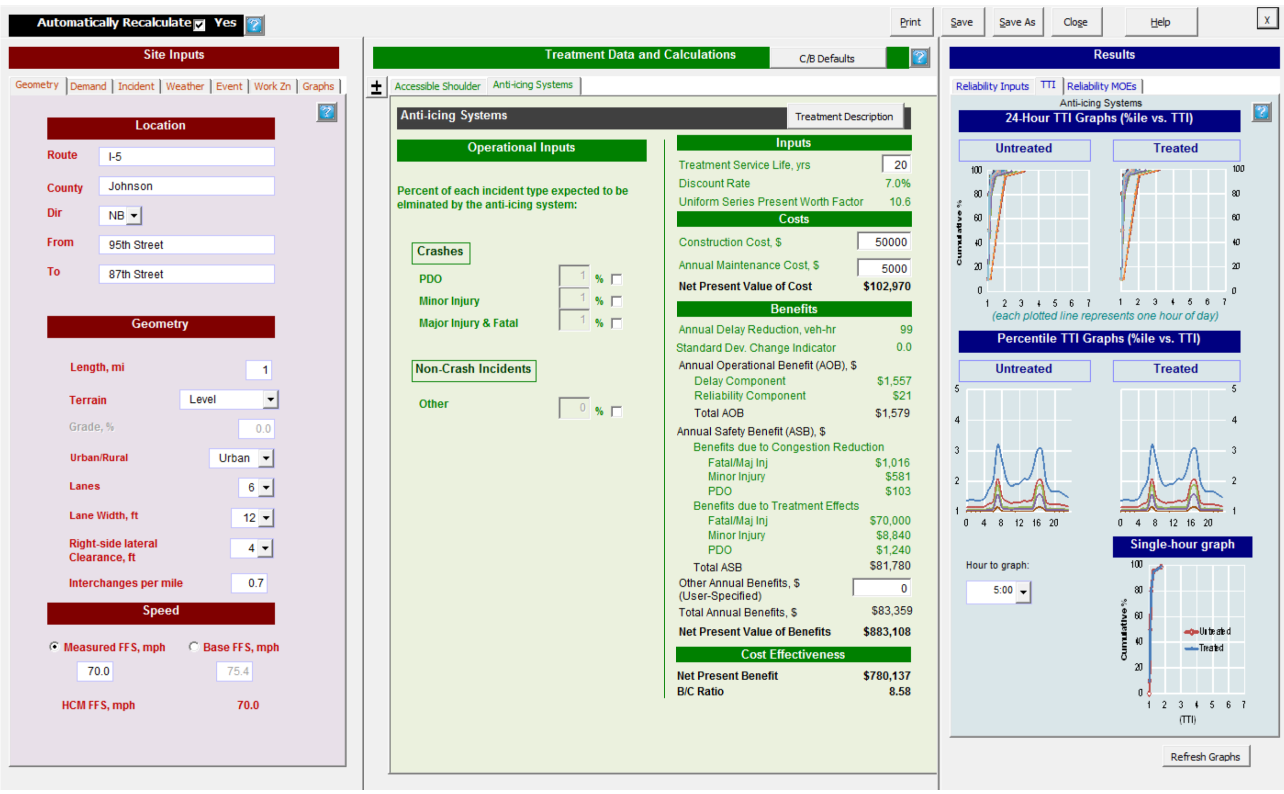


**Figure 6.1. SHRP 2 L07 product interface.**

The design treatments considered in the L07 product can be put into four categories as follows:

- Shoulder-related treatments
  - Accessible shoulder (for removal of vehicles)
  - Alternating shoulder (for work zones)
  - Drivable shoulder (for diversion of vehicles)
- Crash-related treatments
  - Crash investigation site (urban area)

  - Emergency pull-off (rural area)
  - Extra high median barrier (eliminate rubbernecking)
  - Incident screen (at the roadside)
- Emergency treatments
  - Emergency access (for emergency vehicles)
  - Emergency crossovers (keep open to all vehicles)
  - Control (gated) turnarounds (used in emergency for all vehicles)
- Treatments for special sites
  - Runaway truck ramp (used in steep downgrade roads)
  - Wildlife crash reduction
  - Anti-icing systems
  - Snow fence
  - Blowing sand

## 6.2 Tool Operability

The research team has installed the L07 tool on different operating systems (e.g., 32-bit and 64-bit Windows 7, 64-bit Windows 8, and the OS X 10.6.8 operation system for Mac computers) with different versions of Microsoft Office (e.g., Microsoft Office 2010 and Office 2011 for Mac). The tool can be installed and run successfully for most operating systems. Except for the 64-bit Windows 8 and the OS X 10.6.8, the installation was unsuccessful and a warning textbook popped up as shown in Figure 6.2 and Figure 6.3.

In addition, the L07 tool occasionally failed to operate when it was installed on 32-bit and 64-bit Windows 7. The warning message is shown in Figure 6.4. Researchers found that the run-time error '1004' problem can be solved in Excel 2010 by manually selecting "Trust access to the VBA object model" and then choosing "Enable all macros" in the Excel's trust center.

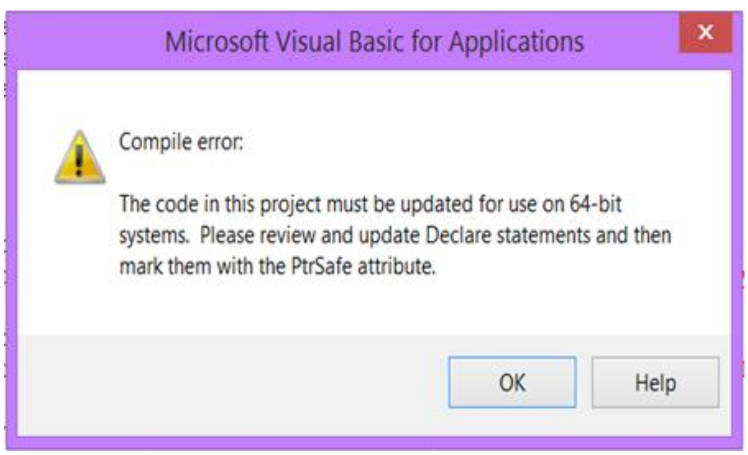


**Figure 6.2. Warning dialog for the 64-bit Windows 8 operating system.**


**Figure 6.3. Warning dialog for the OS X 10.6.8 operating system.**

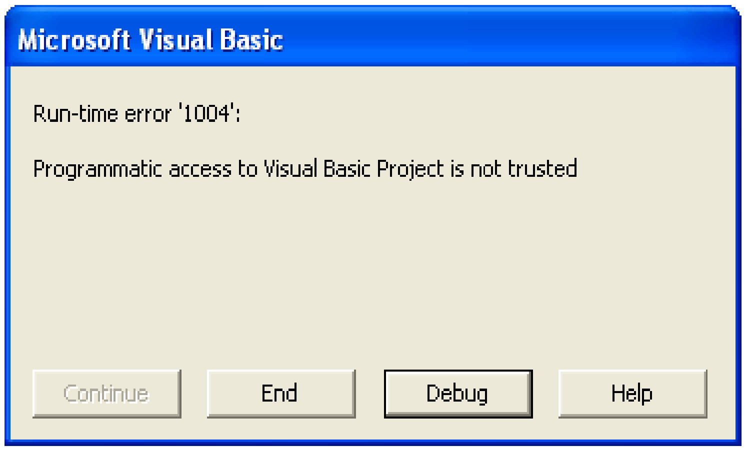


**Figure 6.4. Warning dialog for Windows 7 operating system.**

## 6.3 Tool Usability

### 6.3.1 User Friendliness

In general, the L07 guide can provide meaningful and useful introductions for using the tool, and the tool is found to be easy to understand and use. The interface is user friendly, and most of the icons are shown assisted with useful guides. While using the tool, however, the research team found the following limitations:

- The tool interface cannot be moved, minimized, or resized;
- If multiple treatments are chosen, only the first treatment can be saved;
- Users cannot output results to a separate file; and
- Users cannot enlarge the figures or output the source data.

These limitations certainly affect the usability of the tool, particularly when an analysis involves lots of data input and similar data can be reused for multiple analyses.

### 6.3.2 Tool Accuracy

The default values of truck ratio and recreation vehicle (RV) ratio are not consistent with the HCM 2010. In the tool, the default values of truck ratio and RV radio are set as 2.0% and 1.0%, respectively; the HCM 2010 recommended values are shown in Figure 6.5 for highways and in

Figure 6.6 for freeways.

**Exhibit 14-16**
Required Input Data and Default Values for Multilane Highway Segments

| Required Data | Default Values |
|---|---|
| **Geometric Data** | |
| Number of lanes in one direction | 2 or 3 (in one direction), must have site-specific value |
| Lane width | 12 ft |
| TLC | 12 ft |
| Access-point density | 8 access points/mi (rural)<br>16 access points/mi (low-density suburban)<br>25 access points/mi (high-density suburban) |
| Terrain or specific grade (%, length) | No default, must have site-specific value |
| Base FFS | 65 mi/h |
| **Demand Data** | |
| Length of analysis period | 15 min |
| PHF | 0.88, rural; 0.95, suburban |
| Percentage of heavy vehicles | 10%, rural; 5%, urban* |
| Driver population factor | 1.00 |

Note: *Alternative state-specific default values for percentage of heavy vehicles are given in Chapter 26, Freeway and Highway Segments: Supplemental.

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**Figure 6.5. HCM 2010 suggested default values for heavy vehicles percentage for highways.**

*Assumptions for urban freeways:*

- Total ramp density = 3.00 ramps/mi (i.e., ⅓-mi average spacing between ramps);
- 5% trucks, no recreational vehicles (RVs), and no buses;
- *PHF* = 0.95; and
- $f_p = 1.00$.

*Assumptions for rural freeways:*

- Total ramp density = 0.20 ramp/mi (i.e., 5-mi average spacing between ramps);
- 12% trucks, no RVs, and no buses;
- *PHF* = 0.88; and
- $f_p = 0.85$.

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**Figure 6.6. HCM 2010 suggested default values for trucks and RVs percentage for freeways.**

The description of treatment "Movable Cable Median Barrier" is confusing. The barrier (see Figure 6.7) is defined as "a special designed wire cable barrier system, which can be removed to allow median crossovers." A "T" threshold was introduced to indicate the time when the barrier would be moved to allow median crossover. The barrier would not be moved unless the incident duration reaches T. The default values of T can be found in Figure 6.8. Nevertheless, while looking at the default values, the research team found that the T threshold for PDO is smaller than that for major injury or fatality. This confused the research team as most major injury or fatal incidents would last longer than PDO incidents and thus are associated with longer delays. Allowing median crossover sooner in major injury or fatality incident scenarios is certainly beneficial in the research team's opinion. So, the T threshold for major injury and fatality should be smaller than or equal to that for PDO.

**Figure 6.7. Example of movable cable median barrier.**

| | PDO | Minor Injury | Major Injury/ Fatal |
|---|---|---|---|
| v/c threshold for treatment usage | 1.0 | 1.0 | 1.0 |
| "T", treatable incident duration | 1.0 | 1.5 | 2.0 |

**Figure 6.8. Suggested thresholds for movable cable median barrier treatment.**

According to the L07 guide, several coefficients for safety effect estimating are provided as in Figure 6.9. But, there is not enough evidence supporting these coefficient values. The

L07 team should help provide more details about how they get these values and the reasons for setting up such coefficients so that users can decide whether they need to update these factors regarding different roadway geometries, locations, weather characteristics, culture, and more.

**Class II: ILHL**

| Treatment | Class/Case | Portion of incidents using/affected by treatment, $p_i$: Crashes PDO | Crashes Min | Crashes Maj/Fat | Non-crashes NLB | Non-crashes LB | Non-crashes Other | Ratio of applicable duration to $T_{incident,i}$: PDO | Min | Maj/Fat |
|---|---|---|---|---|---|---|---|---|---|---|
| Anti-Icing Systems | IA | 0.10 | 0.10 | 0.10 | - | - | - | | | |
| Blowing Sand | IA | 0 | 0 | 0 | - | - | - | | | |
| Extra High Median Barrier | IA | Apply to opposite-direction incidents | | | | | | | | |
| Snow Fence | IA | 0.10 | 0.10 | 0.10 | – | – | – | | | |
| Wildlife Collision Reduction | IA | * | * | * | – | – | * | | | |
| Runaway Truck Ramp | IB | 0.001 | 0.001 | 0.001 | – | – | – | 4 | 4 | 4 |

| Treatment | Class/Case | Portion of incidents using/affected by treatment, $p_i$: Crashes PDO | Crashes Min | Crashes Maj/Fat | Non-crashes NLB | Non-crashes LB | Non-crashes Other | Incident Duration with Treatment, $T^*$ (min): Crashes PDO | Crashes Min | Crashes Maj/Fat | Non-crashes NLB | Non-crashes LB | Non-crashes Other |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Emergency Access between Interchanges | IC | 0.05 | 0.10 | 0.20 | – | – | – | 5 | 5 | 5 | – | – | – |
| Accessible Shoulder | ID | 0.50 | 0.30 | 0.10 | – | 0.60 | 0.25 | 25 | 35 | 45 | - | 20 | 20 |
| Alternating Shoulder | ID | 0.35 | 0.25 | 0.05 | – | 0.50 | 0.20 | 25 | 35 | 45 | 15 | 20 | 20 |
| Crash Investigation Site | ID | 0.40 | 0.20 | 0 | 0.20 | 0.40 | 0.10 | 25 | 35 | 45 | 15 | 20 | 20 |
| Emergency Pull-off | ID | 0.40 | 0.20 | 0 | – | 0.15 | 0.10 | 25 | 35 | 45 | 15 | 20 | 20 |

| Treatment | Class/Case | PDO | Min | Maj/Fat | Deployment Time, min | Ratio of applicable duration to average incident length: PDO | Min | Maj/Fat | % lost capacity restored, $p_{r,i}$: PDO | Min | Maj/Fat |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Incident Screens | IE | 0 | 0.05 | 0.10 | 20 | 2 | 2 | 2 | 10 | 10 | 10 |

| Treatment | Class/Case | PDO | Min | Maj/Fat | NLB | LB | Other | Applicable duration, hrs: PDO | Min | Maj/Fat | v/c threshold of application: PDO | Min | Maj/Fat |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Emergency Crossovers | IF | 0 | 0.01 | 0.05 | – | – | – | 1.0 | 1.5 | 2.0 | 1.0 | 1.0 | 1.0 |
| Controlled/Gated Turnarounds | IF | 0 | 0.01 | 0.05 | – | – | – | 1.0 | 1.5 | 2.0 | 1.0 | 1.0 | 1.0 |
| Driveable Shoulder | IF | 0.05 | 0.15 | 0.25 | – | 0.05 | 0.05 | 1.0 | 1.5 | 2.0 | 1.0 | 1.0 | 1.0 |
| Movable Cable Median Barrier | IF | | | | – | – | – | 1.0 | 1.5 | 2.0 | 1.0 | 1.0 | 1.0 |

**Figure 6.9. Suggested default coefficients in L07 guide.**

## 6.4 Performance Test

Testing of L07 tool performance is conducted in three folds: (1) a comparison study is made with the DRIVE Net system to test the MOE sub-output, (2) a comparison study is made with on-site single-loop detector data to test the tool's production of the TTI curve, and (3) a case study is conducted to test the benefit–cost sub-output.

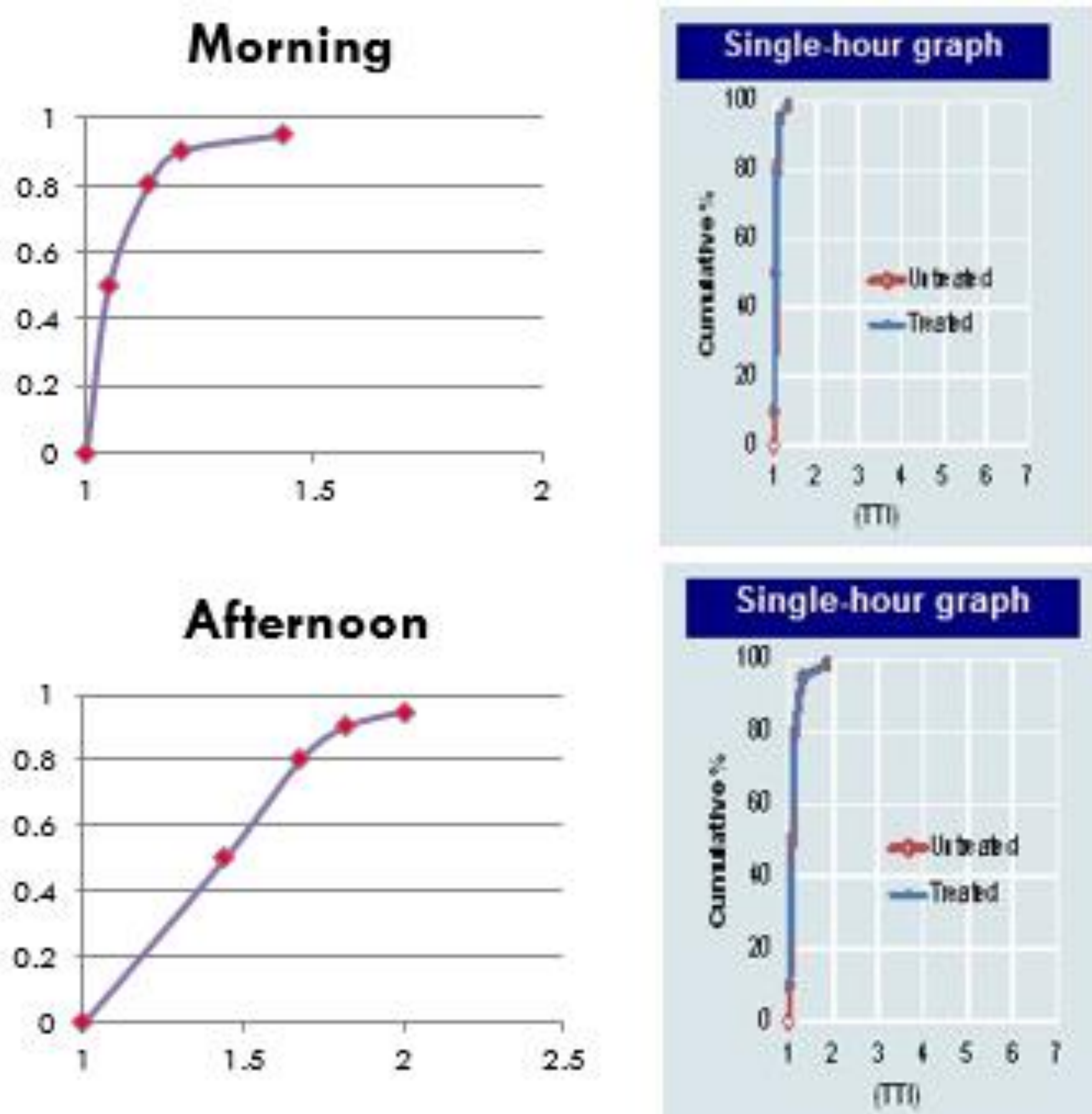
### 6.4.1 Output Comparison with DRIVE Net

The key feature of the L07 tool is to estimate the TTI curves both before and after the design treatment. As the DRIVE Net system can also calculate the same MOE for WSDOT's productions of the Gray Notebooks, the research team compared TTI curves produced by the DRIVE Net and the L07 tool.

Gray Notebook capacity analysis includes a travel time analysis method using both loop and INRIX data. The procedure for calculating travel time distribution is quite similar to the methodology recommended by L07. Vehicle average travel time is calculated and updated for each 5-minute period. Then the travel time cumulative distribution is summarized for each time slot in all weekdays throughout the year. The results are more accurate than the travel time estimation results based solely on the output from loop detector, since travel time is calculated using real-time vehicle speed collected from GPS devices when possible. Gray Notebook has been published for many years. The travel time estimates for the selected corridors have been verified through different means in WSDOT. So the Gray Notebook travel time data is a great benchmark data set to compare with calculation results from the SHRP 2 Reliability products.

A Gray Notebook data source facility within the L07 test sites is an I-5 segment from milepost 184 to milepost 185.5. DRIVE Net computes two sets of TTI for morning peak (8:20 a.m.) and afternoon peak (5:30 p.m.), respectively. Figure 6.10 shows the outputs of DRIVE Net (*a*) and the L07 tool (*b*).

Figure 6.10 shows that it is difficult to tell whether the L07 tool gives an accurate estimation of the TTI curve, because the L07 tool does not allow users to resize/enlarge the output graphs nor output the source data. However, when looking at the 50th percentile TTI values for the afternoon period, the research team finds that DRIVE Net reports larger TTI values than those from the L07 tool. Since the selected I-5 facility is very congested during evening peak, and DRIVE Net system is based on daily data over an entire year (workdays), the research team believes that the DRIVE Net output is closer to the ground truth.




**(a) Output of DRIVE** **(b) Output of L07 Tool**

**Figure 6.10. Output of DRIVE Net system (a) and L07 tool (b).**

### 6.4.2 Comparison with On-Site Single-Loop Detector Data

The TTI curve computed from the on-site single-loop detector measurements is compared with the TTI curve from the L07 tool. Vehicle travel time is calculated using the procedure recommended by the SHRP L02 Guide. Start and end points for single-loop detector data calculation are defined by users thus the method can be easily applied to specific freeway segments.

The study site is located on I-5 from milepost 158 to milepost 160. Figure 6.11 shows the traffic volume data detected by single-loop detectors. Each hourly volume data is the 30th highest traffic volume of the year 2012, which is a required input for the L07 tool.

Figure 6.12 shows the TTI curves calculated from single-loop data and the L07 tool. Three different hours (3:00 a.m., 8:00 a.m., and 5:00 p.m.) represent low traffic demand, morning and afternoon peaks respectively. For the low traffic demand, the two graphs are similar as they both report a small TTI value. The sudden change in the left graph is because of rounding errors in travel speed calculation. For higher traffic demand periods (8:00 a.m. and 5:00 p.m.), L07 predicts a much smaller TTI value. Again, since the selected I-5 facility is very congested during peak hours, and the single-loop detector result is based on daily data over an entire year (workdays), the research team believes that the output from single-loop detector is closer to the ground truth values. Both DRIVE Net and single-loop detector data suggest that the L07 tool tends to underestimate the travel time during peak hours.

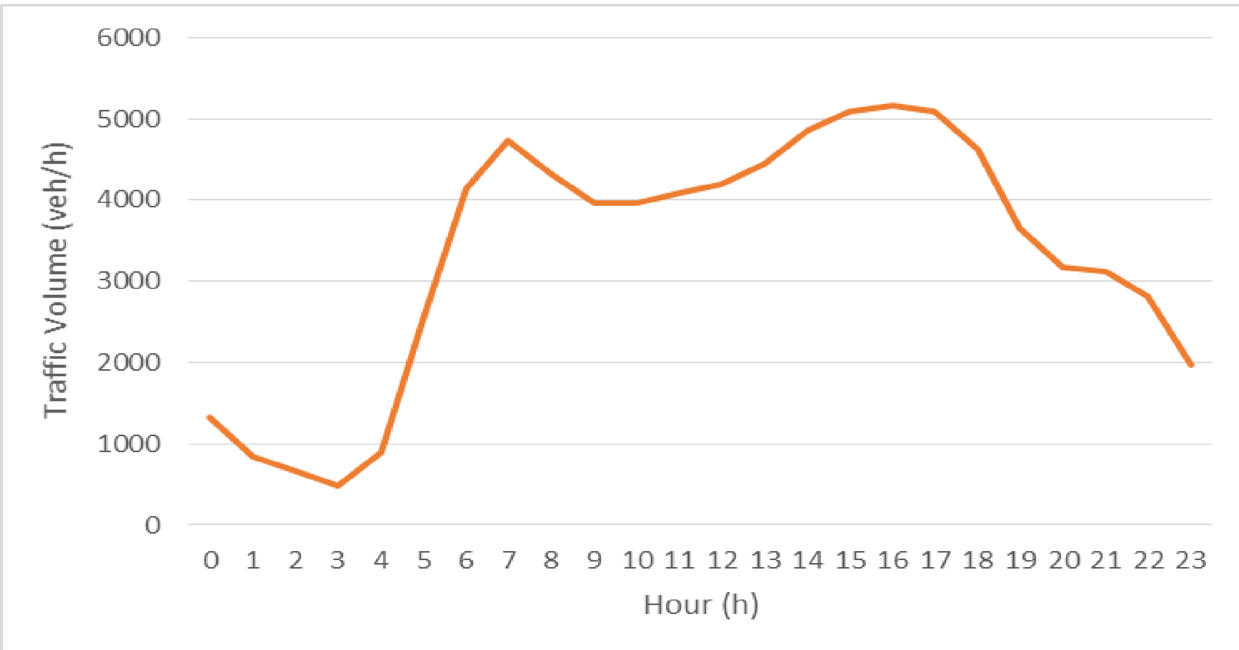



**Figure 6.11. Traffic volume for the studied site.**

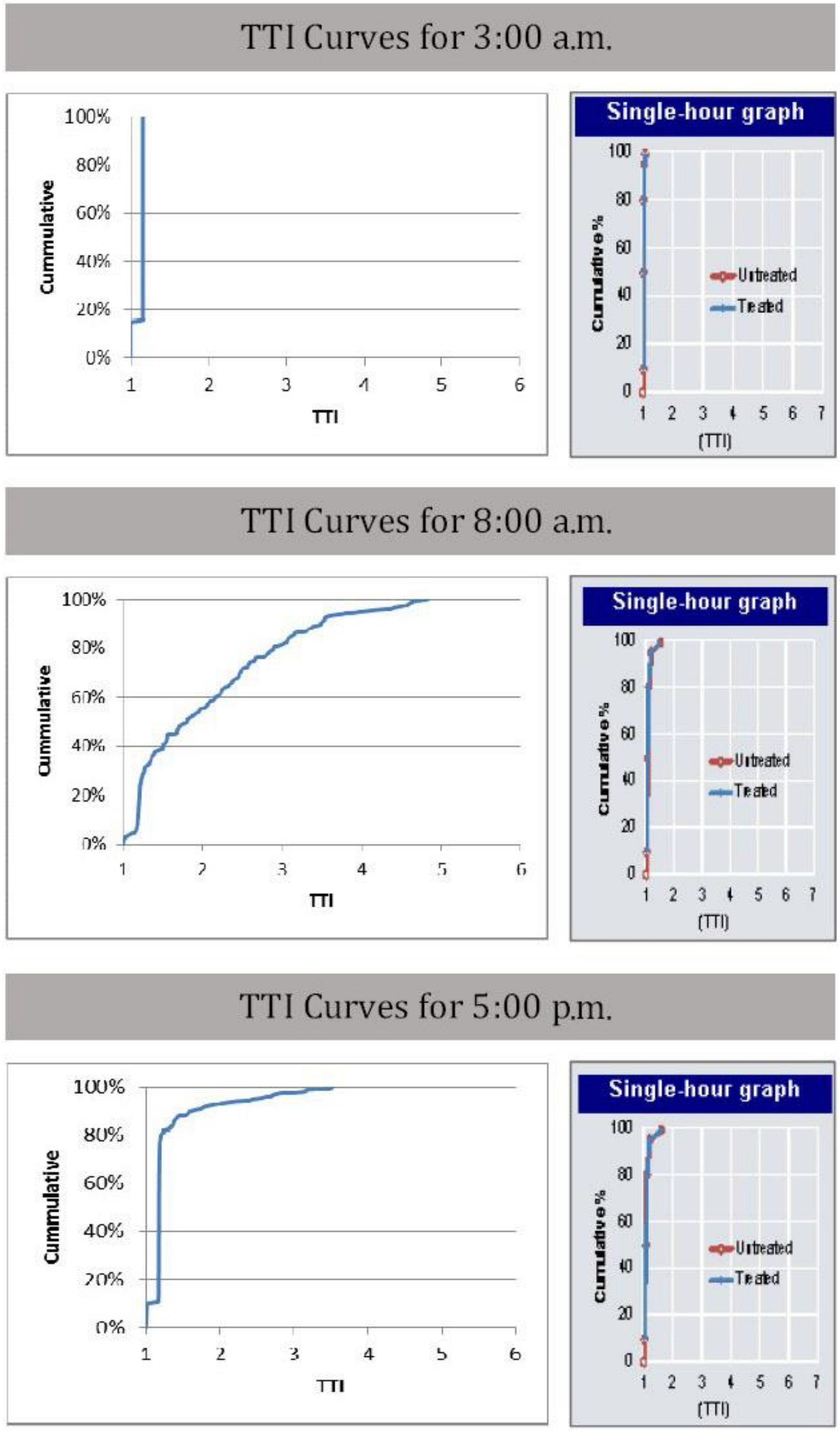



**Figure 6.12. Comparison of outputs from single-loop detector data and L07 tool.**

### 6.4.3 Case Study

To test the effectiveness of the L07 tool, the research team prefers finding a completed project with the same scope within Washington State. However, as the tool involves only 16 specific design treatments as mentioned in Section 6.1, an effective comparison requires a rigorous selection among previous construction projects. Also, the treatment should start and be completed after January 1, 2009, since data before 2009 were not archived.

When looking at all of the 475 projects completed from 2009 to 2013 in Washington State (http://www.wsdot.wa.gov/Projects/completed.htm), only two wildlife projects in rural areas are found to be with the same scope as those listed in the L07 tool. Unfortunately, there is no archived traffic data in the locations of these projects.

The research team studied the methodology in L07 and found that the output for L07 benefit–cost analysis was basically determined by the difference of TTI curves and the number of traffic incident reductions. The TTI curves are determined by traffic volume and nonrecurrent events. Thus, the I-5–Marysville to Stillaguamish River–Median Barrier project was selected as the case study project. This project started in June 2009 and was completed in November 2010. Figure 6.13 describes the testing procedure.

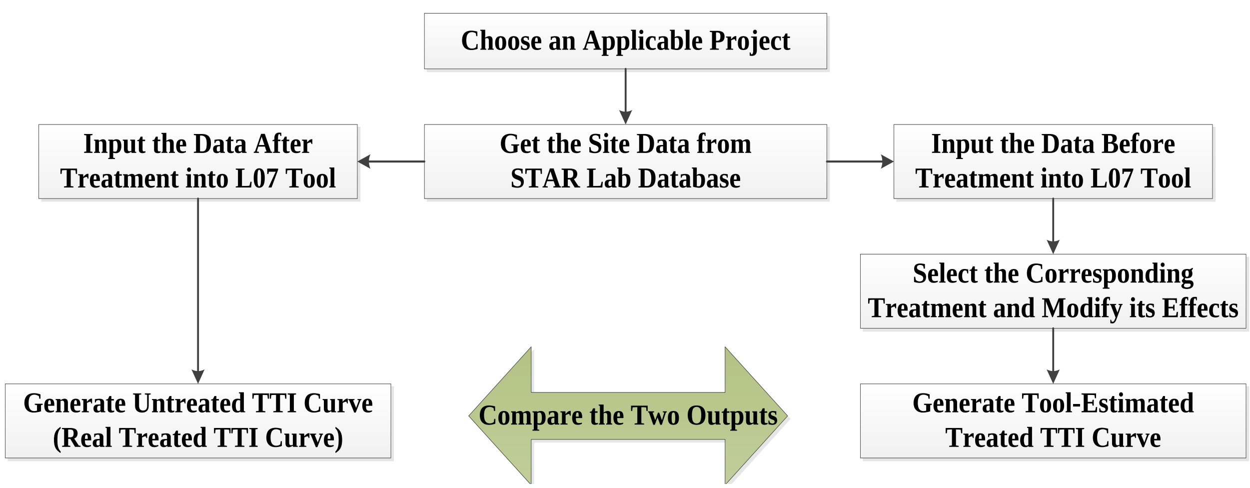



**Figure 6.13. Testing procedure for L07.**

#### *6.4.3.1 Case Study Project*

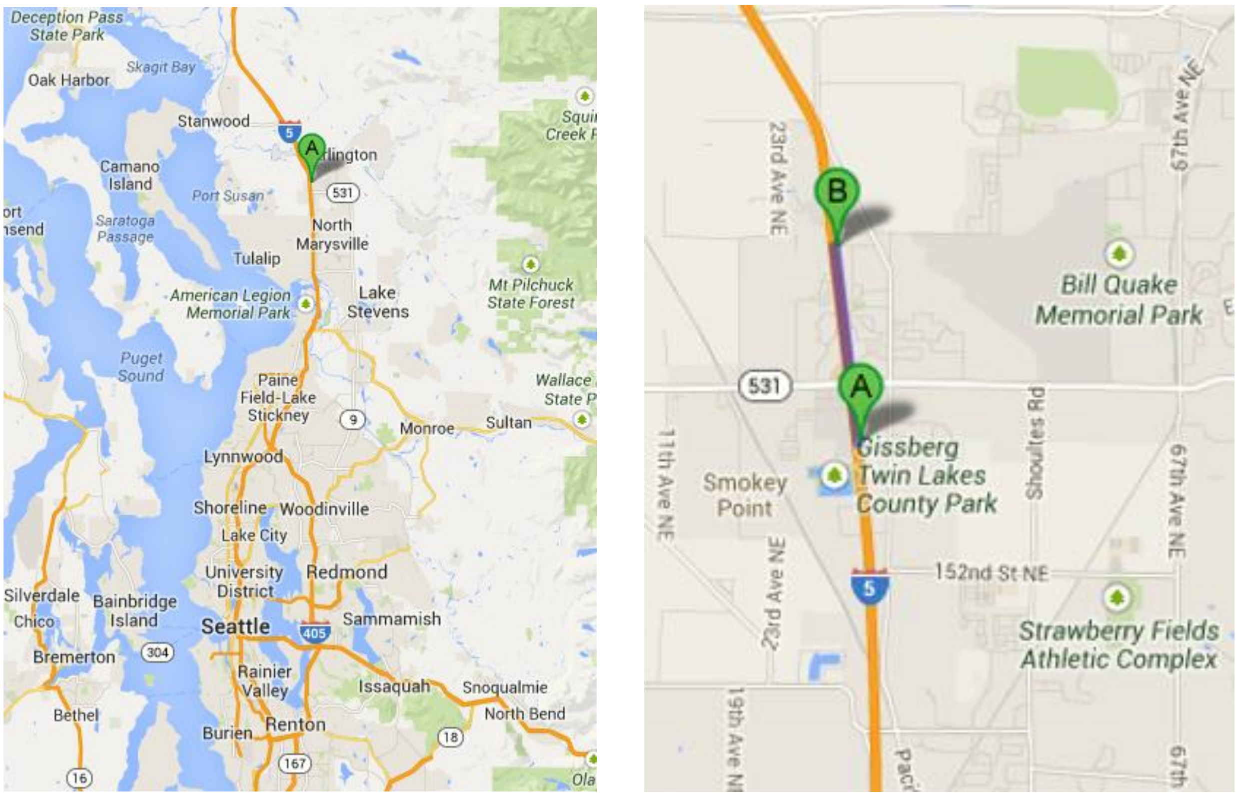
The construction project used for this case study is located on I-5 between Marysville and Stillaguamish River, from milepost 199 to milepost 209. There are three northbound lanes in this location. The segment between milepost 206 and milepost 207 was chosen as the test segment. Figure 6.14 illustrates the case study site location on Google Maps.

#### *6.4.3.2 Test Scenario*

The project installed a concrete median barrier along a 10-mile stretch of northbound I-5 in the Marysville area and removed the existing low-tension cable median barrier at the same time.

Existing southbound cable barrier was left in place to provide redundant protection. The project also widened the median shoulders to 10 feet, bringing them to current standards.

Total cost of the construction work was $16.4 million, with $2.5 million of additional funding from the 2009 American Recovery and Reinvestment Act; traffic cameras, electronic message signs, and traffic sensors also were installed along I-5 in Marysville.




Map data © 2014 Google

**Figure 6.14. Test site location and detail for L07.**

### *6.4.3.3 Timeline*

The 2008 supplemental legislative budget included $26.9 million to install concrete barrier along the 10 miles of northbound I-5 in Marysville. The project was advertised for competitive bidding in April 2009 and awarded to Tri-State Construction in June 2009. Construction began in July 2009 and was completed in November 2010.

### *6.4.3.4 Traffic Demand Data*

Loop data from milepost 206 to milepost 207 were used for the testing. Traffic volume data before construction were obtained from January 2009 to June 2009. Data after construction were obtained from January 1, 2011, to December 31, 2011. Following the L07 guide, hourly demand was selected as the 30th highest volume in the year.

The hourly traffic demand for the test site is shown in Figure 6.15. When comparing the curves before and after construction, we found that the curves are very similar, only the peak hour demand slightly increased after the construction. Thus, the treatment did not result in a significant increase in traffic demand.

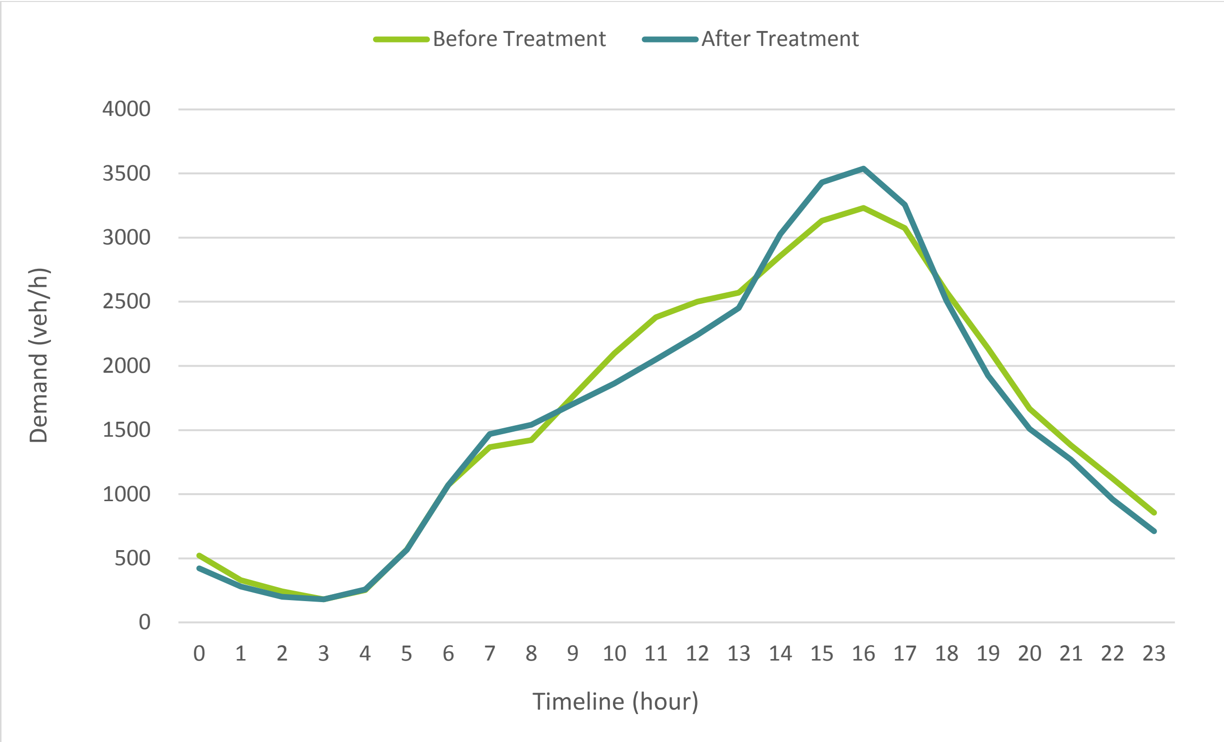



**Figure 6.15. Hourly traffic demand before and after the treatment.**

### *6.4.3.5 Geometry Data*

The geometry data inputted into the L07 tool cannot be saved. These data are used to compute free-flow speed for the segment.

### *6.4.3.6 Traffic Incident Data*

Incidents for the segment can be found from the WITS database. Numbers of different types of incidents before and after treatment are listed in Table 6.1. Incident numbers before the treatment are estimated as the average number for 2006 through 2008; incident numbers after the treatment are estimated as the average number for 2011 and 2012.

**Table 6.1. Incident Numbers for I-5 Mileposts 199–209**

| | Before | | | | After | | | Decrease |
|---|---|---|---|---|---|---|---|---|
| **Year** | **2006** | **2007** | **2008** | **Mean** | **2011** | **2012** | **Mean** | **%** |
| **Property damaged only** | 17 | 23 | 30 | 23.3 | 2 | 8 | 5 | 78.6 |
| **Minor injury** | 6 | 3 | 7 | 5.3 | 3 | 2 | 2.5 | 53.1 |
| **Fatality** | 1 | 1 | 2 | 1.3 | 0 | 0 | 0 | 100 |
| **Non-crash** | 575 | 625 | 627 | 609 | 136 | 130 | 133 | 78.2 |
| **Total** | 599 | 652 | 666 | 639 | 141 | 140 | 140.5 | 78.0 |

Summarizing Table 6.1, the conclusion can be drawn that the treatment had a significantly positive effect on reducing traffic incidents, especially severe incidents. Looking at the data in Table 6.1, all kinds of crash incidents were reduced by 50% or more after the concrete median barrier was built.

For the tool testing purpose, actual incident numbers for the test site are applied to replace default values. For crash costs, the default values suggested by the L07 guide are used.

#### *6.4.3.7 Weather, Event, and Work Zone Data*

For weather data, defaults provided by the tool are used. The nearest location to provide the weather data is selected as Seattle. No event or work zone happened on the segment during the testing period.

#### *6.4.3.8 Treatment Selection*

In choosing the proper treatment, the research team tried "Extra High Med Barrier" treatment within the tool first, because the definition of it seems to be the closest to the actual treatment. However, the "Extra High Med Barrier" treatment in the tool only targets gawk-inducing incidents, which contribute only a small proportion to all the incidents. At the same time, if the input value for incident reduction is close to 100%, the software crashes (see Figure 6.16).

To make the testing more precise, the research team chose another treatment called "Anti-icing Systems" for the testing. Although the definition of treatment does not come close to the actual median barrier project, the objective of the projects is the same, which is to avoid/reduce traffic incidents. Therefore, the Anti-icing System is selected for the testing.

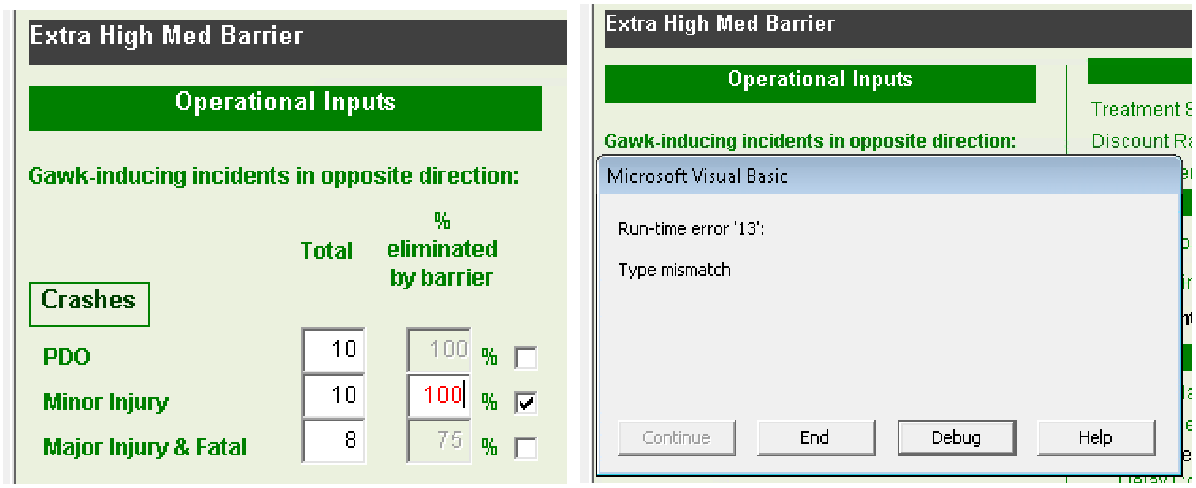



**Figure 6.16. L07 tool crash when crash reduction percentage is input at or near 100% (as in box for Minor Injury crashes at left).**

### *6.4.3.9 Tool Outputs*

#### 6.4.3.9.1 Benefit–Cost

Figure 6.17 shows the tool output for the benefit–cost analysis. The "Net Present Value of Cost" is set as $16.4 million. The "Net Present Value of Benefits" is about $13 million, and the "Net Present Benefit is –$3.4 million." Thus, the tool failed to provide positive benefit for this project.

#### 6.4.3.9.2 Travel Time Index

The tool generates untreated and treated TTI curves for before-and-after analysis [see Figure 6.18(*a*)].

To test the software accuracy, the research team inputted the after-treatment demand data as the before-treatment demand and let the tool generate the TTI curve [see Figure 6.18(*b*)]. Both of the graphs are drawn based on the peak hour data at 4:00 p.m. Theoretically, the treated TTI curve in Figure 6.18 (*a*) should be the same as the untreated TTI curve in Figure 6.18 (*b*). However, while comparing the blue curve on the right with the red curve on the left, it is obvious that the 100th percentile TTI values (see the red circles) are different. One is close to 1.4 and the other is close to 1.2. More details cannot be seen from the tool since these output curves cannot be enlarged nor outputted.

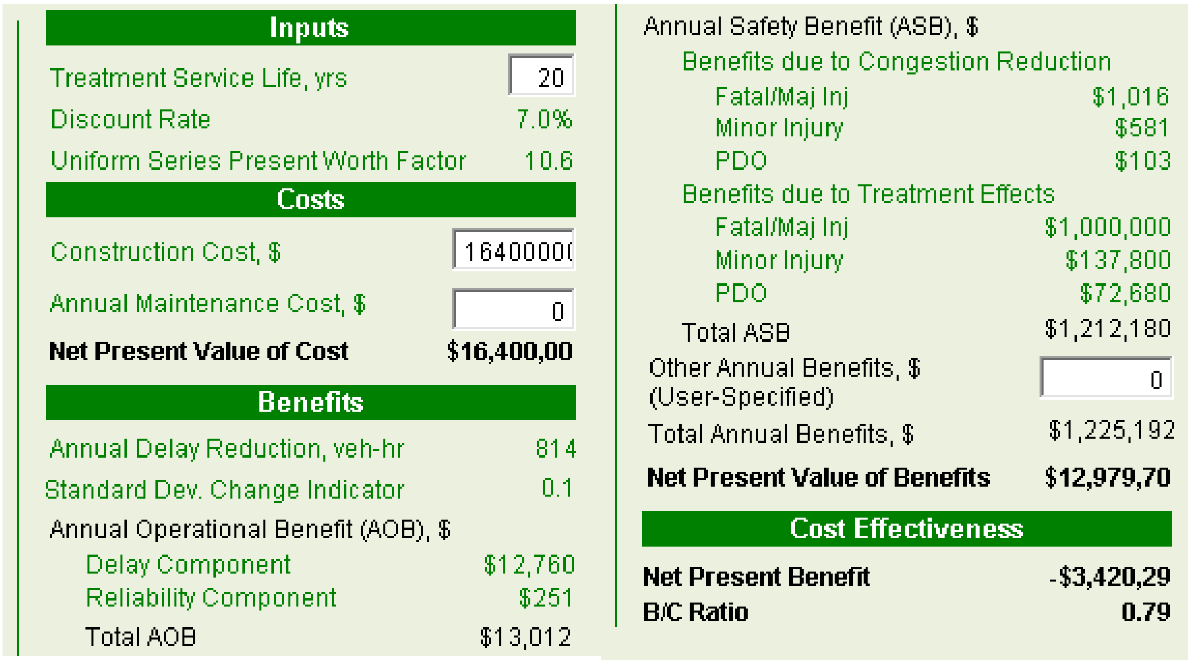
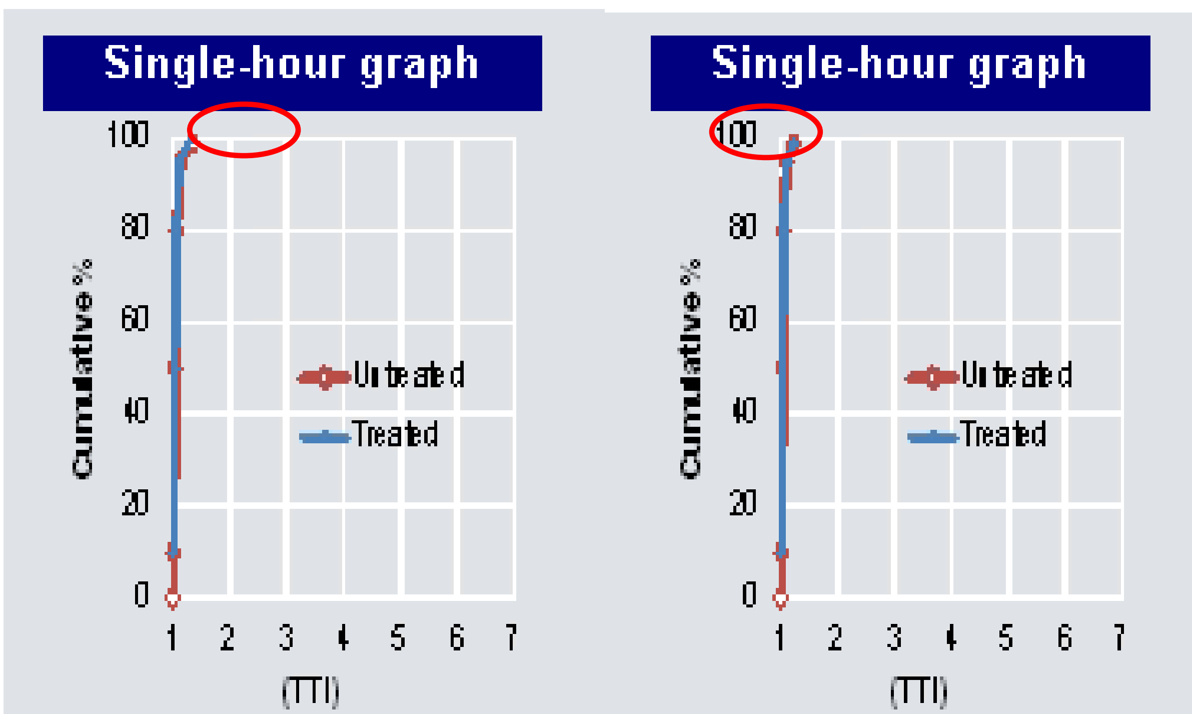



**Figure 6.17. L07 tool output for benefit–cost analysis.**




(a) (b)

**Figure 6.18. L07 tool output for TTI analysis: (a) Uses before-treatment demand data as input; (b) Uses after-treatment demand data as input.**

## 6.5 Test Conclusions

The research team believes that the L07 methodology on computing TTI curves should be further studied and compared. Neither the output comparison between L07 and DRIVE Net nor the software accuracy comparison between L07 before-treatment curve [see Figure 6.18 (*b*), red curve] and L07 after-treatment curve [see Figure 6.18 (*a*), blue curve] yields a positive conclusion. At the same time, the research team suggests that the L07 project team help revise the tool and allow the user to obtain more detailed output information from it.

In the L07 tool, the treatment “Extra High Med Barrier” only deals with gawk-inducing incidents. However, such treatment in reality can also help prevent other types of incidents. For example, some high concrete median barriers can also prevent vehicles from running into the opposite direction, so that some severe accidents can be prevented. Therefore, more potential effects of the proposed design treatments in L07 are recommended for consideration.

In the case study, the test project did not provide meaningful results in the cost–benefit analysis. It may be because of an underestimation of the project effect on preventing major injury and fatal incidents. According to the default values set in the L07 tool, crash cost for fatal and major injury incidents are much more than minor-injury incidents (crash cost for fatal and major injury incident is about 40 times of that for minor incident) and PDO incident (crash cost for fatal and major injury incident is about 200 times of that for PDO incident), reducing the number of fatal and major injury incidents is critical for safety-related benefit. Thus, the change in the number of fatal and major injury incidents is tested. The result can be found in Table 6.2, where the average incident reduction effect is set as 70% (according to Table 6.1).

It can be concluded that the net present benefit is sensitive to the number of fatal and major injury incidents. This is consistent with the fact that fatal and major injuries contribute the most to total cost. For most fatal injuries, the cost mostly depends on the number of deaths during the crash; however, the L07 tool suggests using uniform cost values for incidents with the same severity level. Thus, the research team recommends that the L07 tool should allow users to modify the cost of incidents and provide a modification factor for user to input location-specific cost values for different severity levels of incidents.

**Table 6.2. Effect of Fatal and Major Injury Incident Number on Treatment Benefit**

| Number of Fatal and Major Injury Incidents Per Year | 0 | 1 | 2 | 3 |
|---|---|---|---|---|
| **Net Present Benefit ($ million)** | –13.6 | –3.4 | 7.6 | 18.3 |

# CHAPTER 7
# Pilot Testing and Analysis an SHRP 2 L08 Product

## 7.1 Introduction

SHRP 2 L08 develops methods on incorporating travel time reliability into the HCM's analytical procedures. A guide is developed to provide step-by-step processes for predicting travel time reliability for freeway and urban street facilities. The basis of the methodology is the nonrecurrent congestion factors that cause the unreliability of travel time. By using a scenario generator to allow user input on the specifics of the scenario (e.g., weather, time of day, lane closure, and duration of incidents), the HCM's full range of performance measures can be generated and the impacts of variability on facility performance over the course of a year can be estimated. Excel-based HCM computational engines (e.g., FREEVAL and STREETVAL for freeway and urban street, respectively) are developed to automate the generation of reliability scenarios and to calculate the reliability results. Figure 7.1 illustrates the components of the methodology developed in SHRP 2 L08.

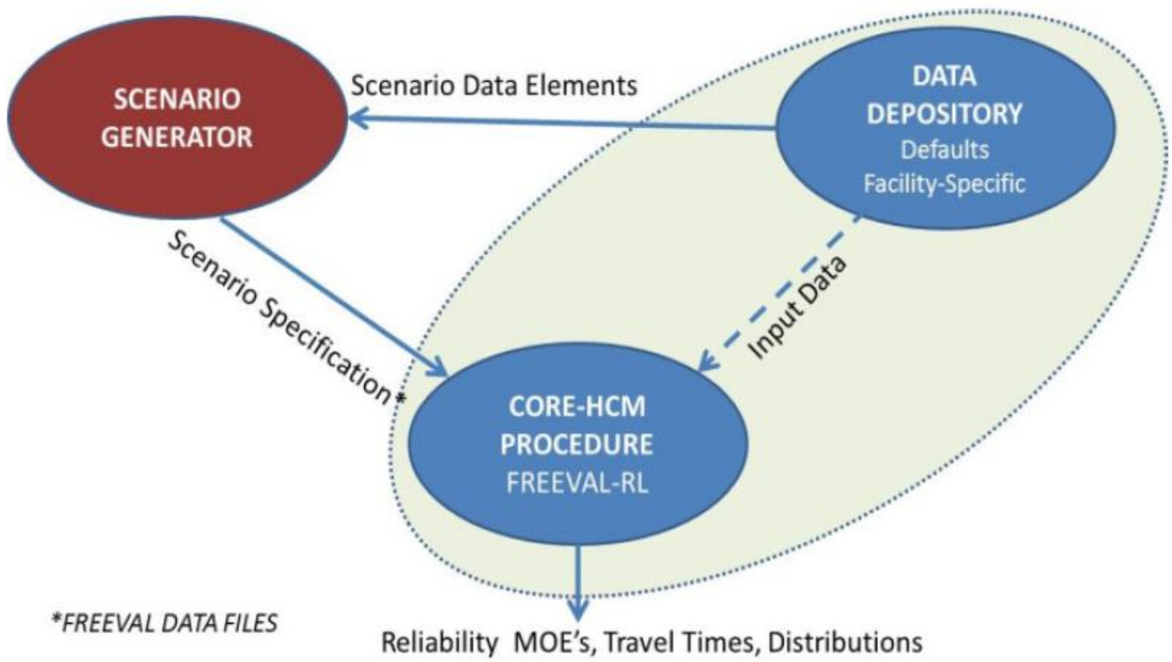



**Figure 7.1. Methodology components in SHRP 2 L08 (Kittelson & Associates, Inc. 2013).**

## 7.2 Tool Operability

Both of the L08 reliability tools, STREETVAL and FREEVAL, were tested on Windows 7 and Windows 8 operating systems as well as on a Mac computer running the most current operating system, OS X 10.9. The specifications of the computers tested—operating system, system type, and version of MS Office installed—are listed in Table 7.1.

**Table 7.1. Specifications of Computers Used in Installation Tests**

| **Operating System** | **Windows 8** | **Windows 7** | **Windows 7** | **OS X 10.9** |
|---|---|---|---|---|
| System type | 64-bit | 32-bit | 64-bit | N/A |
| MS Office version | MS Office 2010 | MS Office 2010 | MS Office 2010 | Office 2011 for Mac |

Both STREETVAL and FREEVAL ran successfully on Windows 7 operating system for the 32- and 64-bit system types. In attempting to run STREETVAL on Windows 8, the program gave the following error message shown in Figure 7.2. FREEVAL, on the other hand, ran on Windows 8 with no problems.

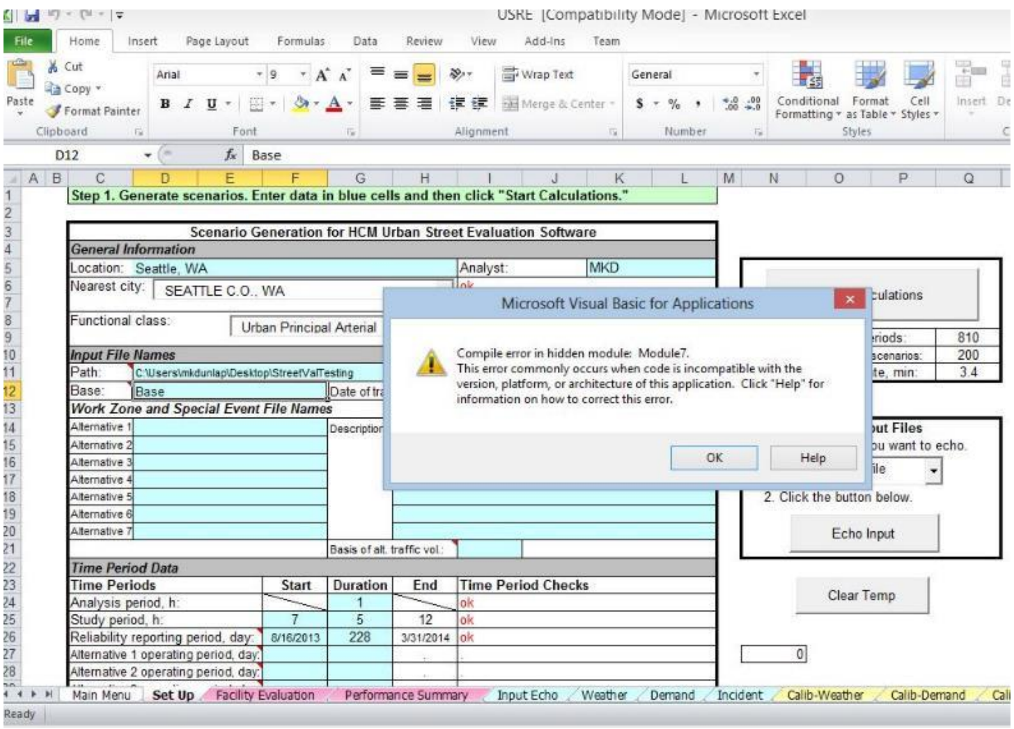



**Figure 7.2. Compilation error message for Windows 8 test for STREETVAL.**

Neither STREETVAL nor FREEVAL was able to run on the Mac computer. When attempting to run FREEVAL, the interface was responsive, enabling the user to enter the name and general project information for Step 1; however, when the user progressed to Step 2, the program would crash. The results of running STREETVAL were equally disappointing: The Urban Streets Computational Engine (USCE) macro buttons were unresponsive to the user's actions. The research team believes these errors are because of compatibility issues between the Mac operating system, which is UNIX based, and the Windows operating system that the software was created with. Given that the vast majority of computers used today are Windows based, this incompatibility is not a major concern.

## 7.3 FREEVAL Introduction and Interface

Learning to use the FREEVAL tool is challenging because of the complexity of the tool itself and the lack of clear instruction on how help information can be obtained. Although a user manual on FREEVAL exists, the user manual requires knowledge that borrows from several other chapters of the HCM, which may not be available when using the tool.

Use of the tool itself can be broken down into five steps that a user must follow in order to conduct a reliability assessment of a freeway section:

- Step 1: Enter project summary information;
- Step 2: Create seed file;
- Step 3: Manage scenario;
- Step 4: Create FREEVAL input file; and
- Step 5: Generate scenarios and results.

Step 1 is straightforward; the user enters his or her name and gives a brief summary of the project for informational purposes.

In Step 2, the user must enter in the study period, start and end times of the reliability reporting period, the demand seed day, the number of HCM segments, terrain type, and whether there is ramp meter control in the study section. It should be noted that when specifying the number of HCM segments, the user must select three or more to make the tool work. If the user selects two segments (as shown in Figure 7.3) the program will seem fine. However, once the user gets to the last step an error message will appear and the user will have to start all over. Also, if the user forgets to specify the ramp meter control (as shown in Figure 7.4), the program does not warn the user that something is wrong until the last step. Fixing these issues would make this tool much more user friendly.

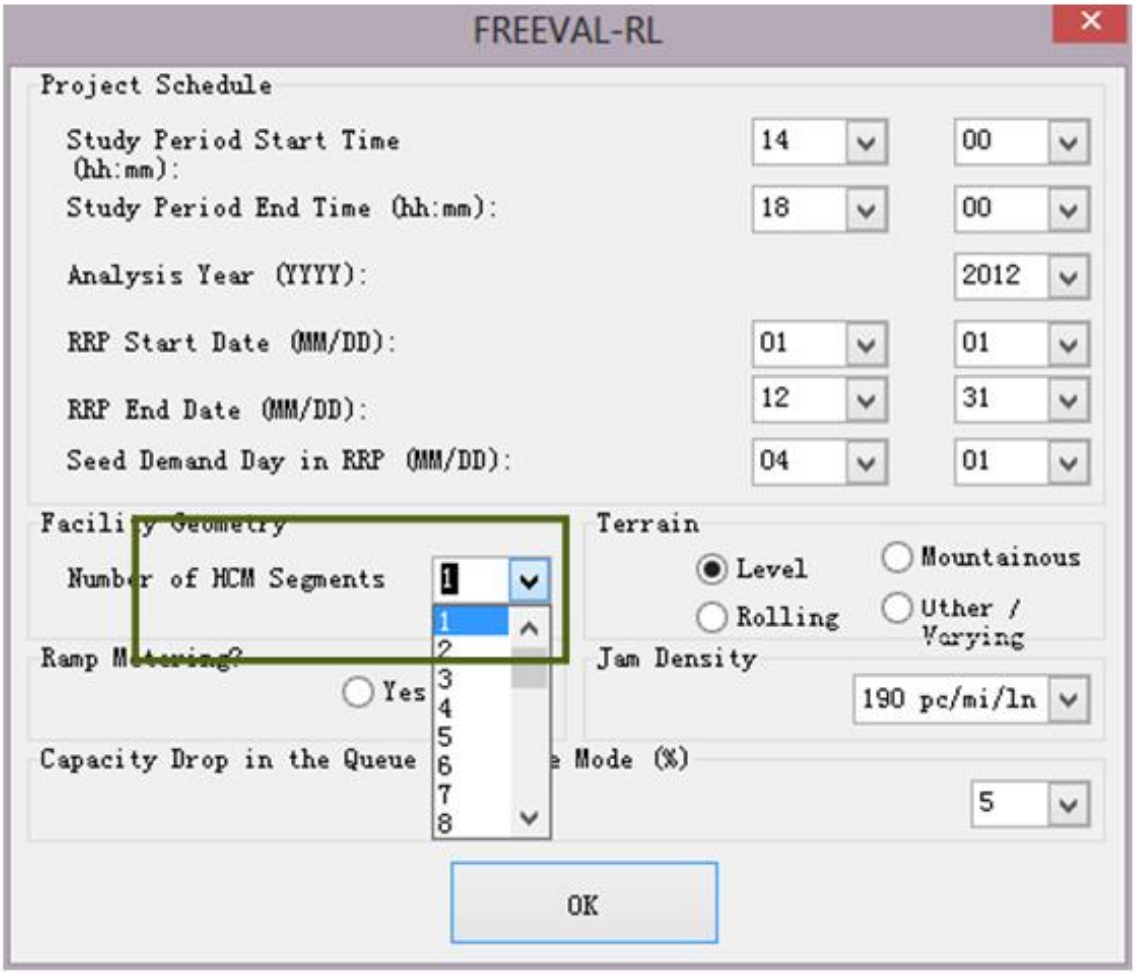



**Figure 7.3. FREEVAL segment number selection.**

In order to finish making the seed file in Step 2, the user must enter the 15-minute hourly volumes for the entire study period of the specified seed day. In addition to demand data, the user also must specify the percentage of trucks on the study section and the length of each HCM segment. The demands must be manually entered in multiple Excel spreadsheets. There is one sheet for every 15-minute increment in the study period. If the specified study period is 6 hours, the user must input data into 24 separate spreadsheets, and this can be very time consuming. Consolidating these multiple spreadsheets would streamline the data entry process and allow the user to copy and paste demand values into the form.

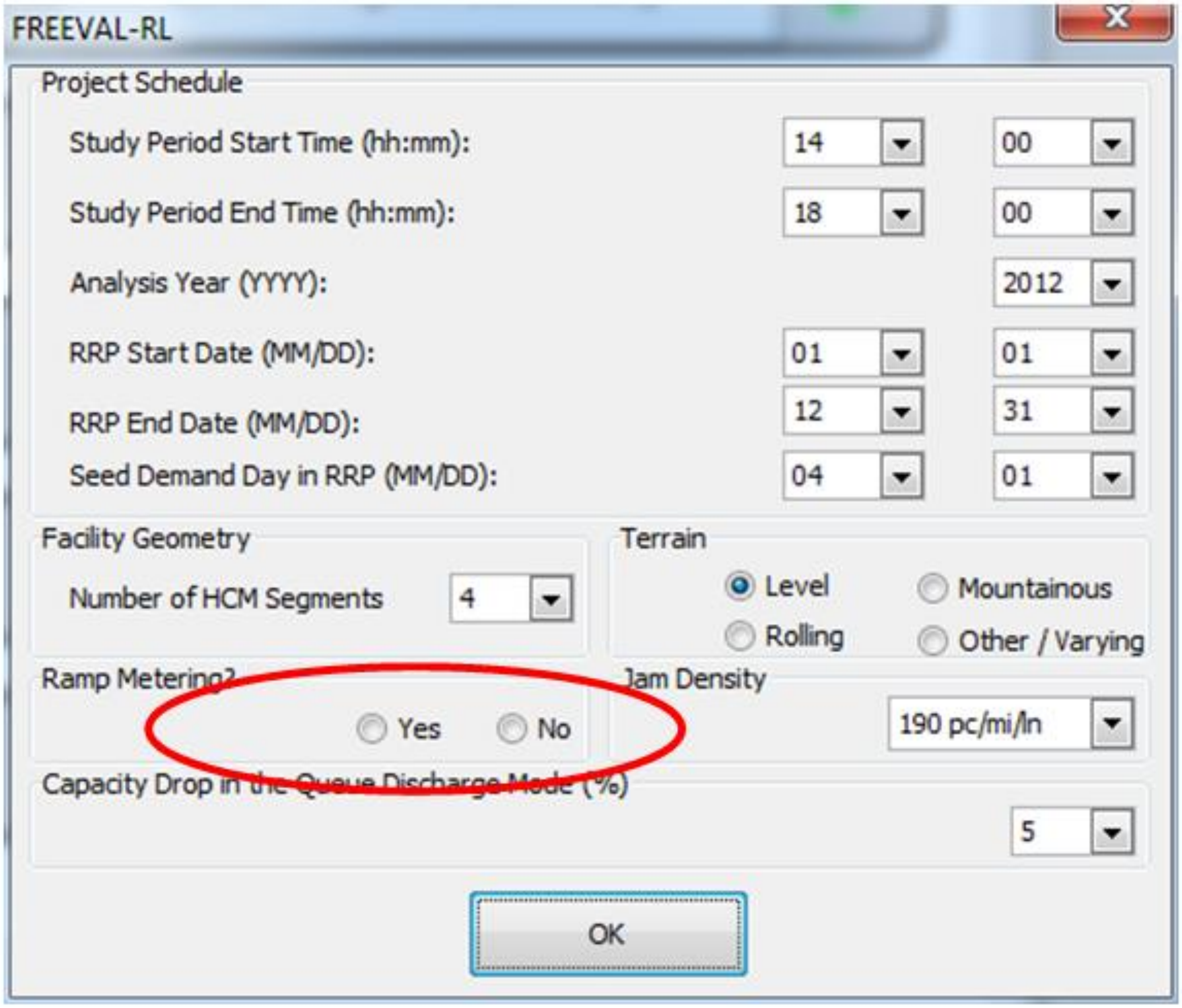



**Figure 7.4. FREEVAL ramp metering option selection.**

Step 3: In this step, the user opens a new macro program called the scenario generator and loads into this program the seed file created in Step 2. Next, the user must enter the demand ratios for the different times of the year to describe how the daily demand fluctuates across the year (as shown in Figure 7.5) and the user must specify the number of demand patterns to describe how travel behavior changes throughout the year and between days of the week. Weather data must also be inputted, and the user has the option of manually entering the probability of occurrence of the 11 different weather events if known, or the user can use the weather data generated from the built-in historical weather database, which includes the 10 years of weather data from a multitude of U.S. cities. Finally, the user must enter the incident data. This part of the data entry is very flexible and can be used with data-rich areas, and it also includes a prediction model that will predict the incident probabilities if crash data are unavailable.

The Analyst can either accept the default demand multipliers (DM) for each combination of weekdays and months of year, or insert facility-specific factors if available. (Reference is to facility AADT)

| DM | | Day of Week | | | | |
|---|---|---|---|---|---|---|
| | | Monday | Tuesday | Wednesday | Thursday | Friday |
| Month | January | 0.822158 | 0.822158 | 0.838936 | 0.864104 | 0.964777 |
| | February | 0.848710 | 0.848710 | 0.866031 | 0.892012 | 0.995936 |
| | March | 0.920502 | 0.920502 | 0.939288 | 0.967466 | 1.080181 |
| | April | 0.975575 | 0.975575 | 0.995484 | 1.025349 | 1.144807 |
| | May | 0.973608 | 0.973608 | 0.993477 | 1.023281 | 1.142499 |
| | June | 1.021796 | 1.021796 | 1.042649 | 1.073929 | 1.199047 |
| | July | 1.132925 | 1.132925 | 1.156046 | 1.190728 | 1.329453 |
| | August | 1.032614 | 1.032614 | 1.053688 | 1.085299 | 1.211741 |
| | September | 1.063101 | 1.063101 | 1.084797 | 1.117341 | 1.247516 |
| | October | 0.995243 | 0.995243 | 1.015554 | 1.046021 | 1.167888 |
| | November | 0.995243 | 0.995243 | 1.015554 | 1.046021 | 1.167888 |
| | December | 0.978525 | 0.978525 | 0.998495 | 1.028450 | 1.148269 |

**Figure 7.5. FREEVAL demand multiplier.**

Step 4: The user selects a minimum probability threshold for a given scenario to eliminate unwanted low probability scenarios and generate the list of scenarios. After generating the list of all scenarios, the user can change the probability threshold to either include more or less scenarios, or, if the user is satisfied, click “Create FREEVAL input file” to create the input file.

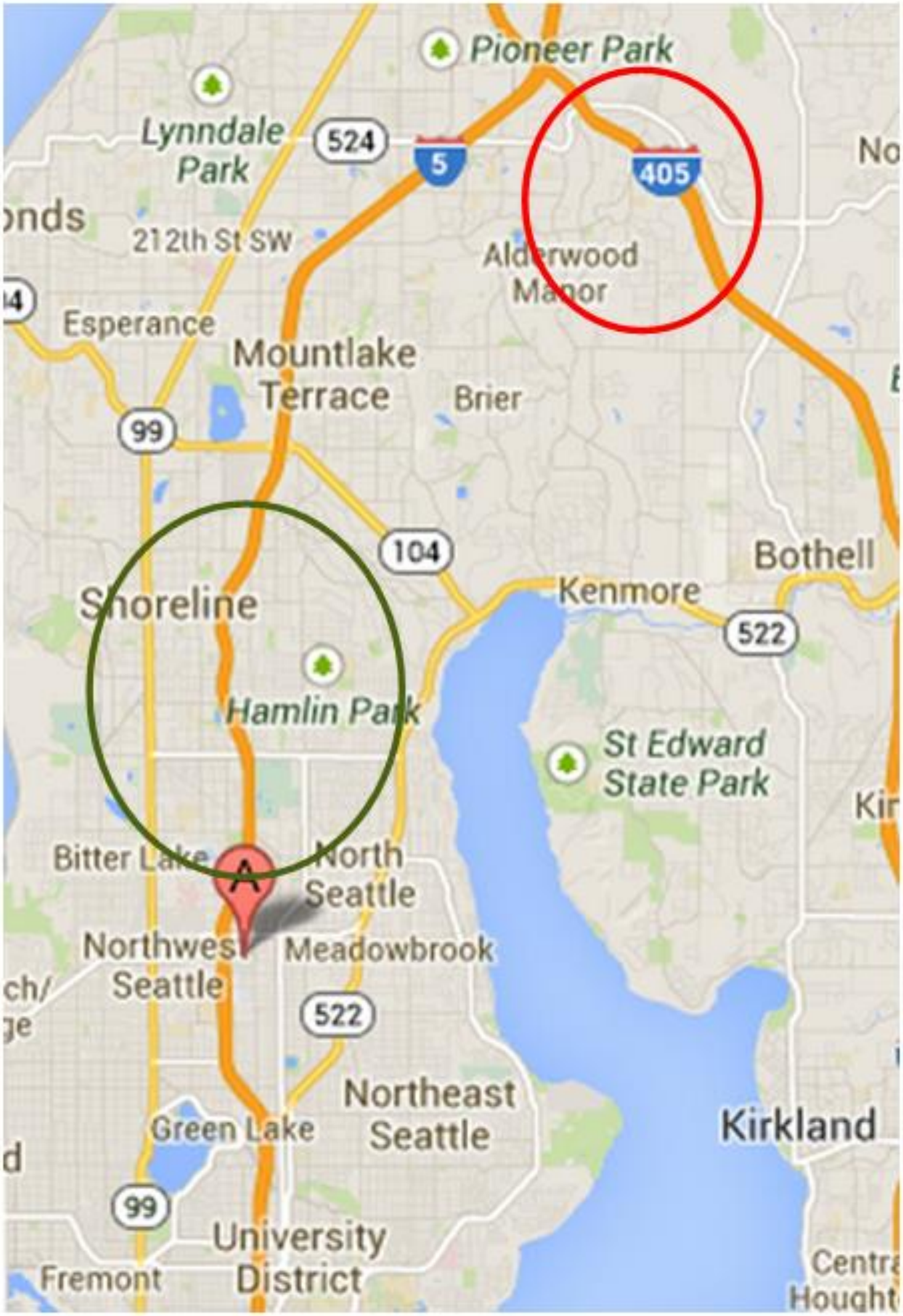
Step 5: The final step in the program involves the user loading the input file created in Step 4 back into the original FREEVAL macro and evaluating the scenarios by clicking “Click generate scenarios.” This part of the program takes the longest to complete, and each scenario in the input file may take 20–60 seconds to be evaluated.

The primary issues identified with tool use were those addressed in Step 2; warning messages displayed by the program would alert the users of their mistakes for them to fix. Also, consolidating the demand input sheets would definitely streamline the data entry process of this program, which can easily take several hours depending on the length of study period and number of HCM segments.

One issue not addressed in any of the literature regarding FREEVAL is how long of a study section is good for a particular reliability test. It would seem intuitive that for urban areas with more access ramps, longer study sections would be preferred, and for more rural areas, a shorter study section might suffice. More guidance on selecting the appropriate study period would be helpful. In addition, the software does not address causes of congestion that may occur outside of the study section; a weaving section located upstream of the test site might be a source of recurring congestion and will be ignored in an analysis. Because of this, the results of the reliability test may be skewed.

## 7.4 Performance Test for FREEVAL

Tests were completed to determine the accuracy of the FREEVAL reliability software by comparing the outputted travel time reliability from the software to the actual travel time reliability computed from historical dual-loop detector data. The tests were conducted for two separate study locations in Seattle, Washington, and are circled in the map (Figure 7.6). The green circle shows the I-5 study site, which goes from the Northgate Mall to Shoreline (roughly 3 miles long), and the red circle indicates the I-405 study site (roughly 2 miles long), which is located just outside the city in a less urban environment.




Map data © 2014 Google

**Figure 7.6. Map of two study locations (pin located at Northgate Mall).**

### 7.4.1 Test 1. I-405 Facility, Seattle (Mileposts 27–29) of Test Site B

The I-405 facility was selected as a study location because it contains relatively good dual-loop detector data, and it is also known to be one of the most congested facilities in Washington State, which makes it more interesting to study from a reliability point of view. The chosen study location is about 2 miles long and stretches from milepost 27 to milepost 29 on I-405.

Volume data were obtained from the loop detectors to satisfy the demand data requirements of the software, and the demand ratios were calculated accordingly. The supplied default values were used for the demand profile data. The Highway Economic Requirements System (HERS) prediction model, built into the software, was used to predict the quantity of incidences along the facility. The FREEVAL software generated a total of 454 scenarios for the analysis, including 360 different incident scenarios and 94 different weather scenarios. The details of this reliability test, including the study period and the reliability reporting period, can be seen in Table 7.2.

**Table 7.2. Summary of Reliability Test on I-405**

| **Reliability Test 1 Summary** | |
|---|---|
| **Study section** | Interstate 405 (miles 27–29) |
| **Study period** | 2:00 p.m.–8:00 p.m. |
| **Reliability reporting period** | All week days in 2011 (~260 days) |

The reliability outputs of the software were compared to the ground truth reliability for consistency. The ground truth reliability was calculated using speed data collected from dual-loop detectors located on the facility. A sample of the dual-loop data is shown in Figure 7.7. The flag value of 0 indicates that the loop is malfunctioning. Comparison will be conducted only with the data obtained from good condition loop stations.

The WSDOT Gray Notebook procedure for calculating travel time reliability was used in order to determine the distribution of travel times for the facility. Figure 7.8 illustrates the calculated distribution of travel times along the 2-mile facility. This is considered the ground truth reliability.

| | LOOPID | STAMP | FLAG | AVGSPEED |
|---|---|---|---|---|
| 5... | 8605 | 2012-03-07 16:15:00.000 | 1 | 376 |
| 5... | 8605 | 2012-03-07 16:20:00.000 | 1 | 381 |
| 5... | 8605 | 2012-03-07 16:25:00.000 | 0 | 363 |
| 5... | 8605 | 2012-03-07 16:30:00.000 | 0 | 169 |
| 5... | 8605 | 2012-03-07 16:35:00.000 | 1 | 411 |
| 5... | 8605 | 2012-03-07 16:40:00.000 | 1 | 386 |
| 5... | 8605 | 2012-03-07 16:45:00.000 | 1 | 373 |
| 5... | 8605 | 2012-03-07 16:50:00.000 | 1 | 365 |
| 5... | 8605 | 2012-03-07 16:55:00.000 | 1 | 356 |
| 5... | 8605 | 2012-03-07 17:00:00.000 | 1 | 382 |

**Figure 7.7. Sample of dual-loop data on I-405.**

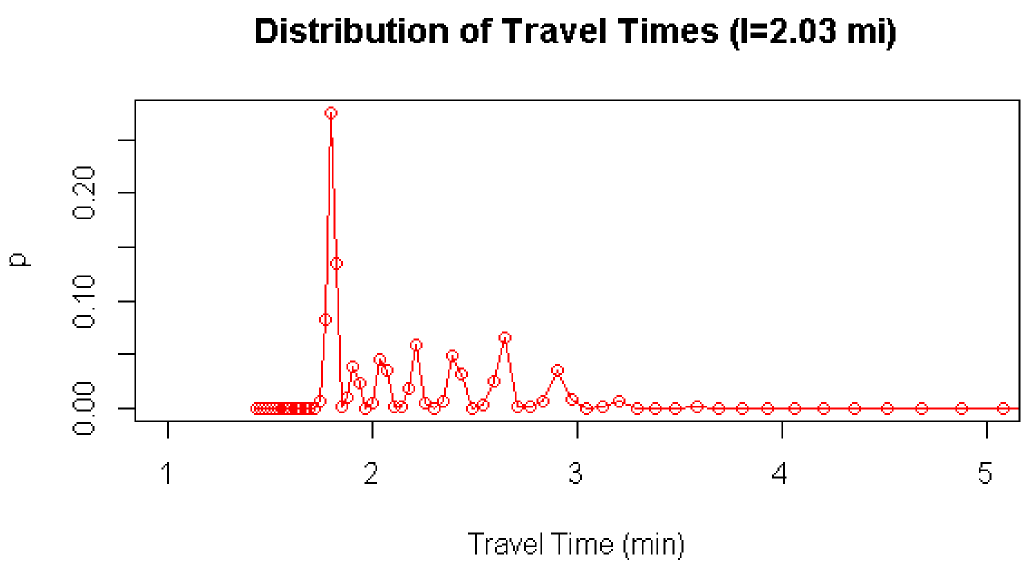
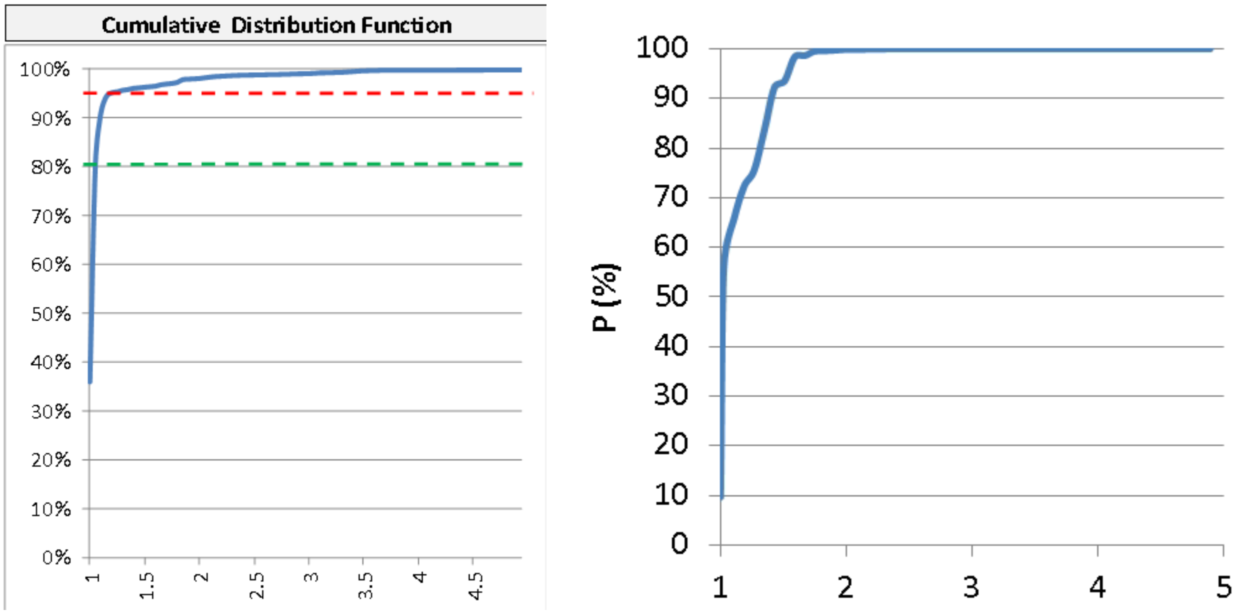



**Figure 7.8. Distribution of travel times for I-405 study site.**

Figure 7.9 compares the cumulative distributions between the ground truth data (*b*) and the generated software output (*a*).




**(a)** **(b)**

**Figure 7.9. Comparison of cumulative distributions for TTI on I-405: (a) FREEVAL output; (b) Dual-loop data.**

Table 7.3 clearly shows that the FREEVAL estimate of reliability tends to be overly optimistic; its TTI values are almost all smaller than the ground truth. The semi-standard deviation (the standard deviation taken about the free-flow travel time instead of the mean) estimated by FREEVAL is more or less the same with the ground truth value while the 80th percentile TTI and 95th percentile TTI values for the ground truth data are larger than FREEVAL outputs.

**Table 7.3. Performance Measure Comparison**

| Performance Measure | FREEVAL | Ground Truth |
|---|---|---|
| Mean TTI | 1.11 | 1.16 |
| 50th percentile TTI | 1.08 | 1.03 |
| 80th percentile TTI | 1.14 | 1.30 |
| 95th percentile TTI | 1.25 | 1.55 |
| Semi-standard dev. | 0.45 min | 0.46 min |

### 7.4.2 Test 2. I-5 Facility, Seattle (Mileposts 173–176) on Test Site A

The second study facility is I-5 near the Northgate Mall. This site was chosen because it is a well-known congested section of roadway, and it has a high density of access ramps that makes it different from the I-405 test site, which had no access ramps. The on-ramps and off-ramps for the Northgate Mall are located along the facility, and the mall traffic causes this section of roadway to be rather chaotic.

Volume data were collected in a similar manner as those in Test 1 in order to satisfy the demand data requirements of FREEVAL. The incident data were predicted using the HERS model, and the default values were used for the demand profile values. A summary of this test is shown in Table 7.4.

**Table 7.4. Summary of Reliability Test on I-5**

| **Reliability Test 2 Summary** | |
|---|---|
| Study section | Interstate 5 (miles 173–176) |
| Study period | 2:00 p.m.–8:00 p.m. |
| Reliability reporting period | All week days in 2012 (~260 days) |

The ground truth reliability was calculated similarly as in Test 1 that uses dual-loop detector data for the facility travel time reliability calculations. The distribution of travel times calculated using the WSDOT Grey Notebook procedure for the approximately 3-mile-long study section is shown as Figure 7.10.

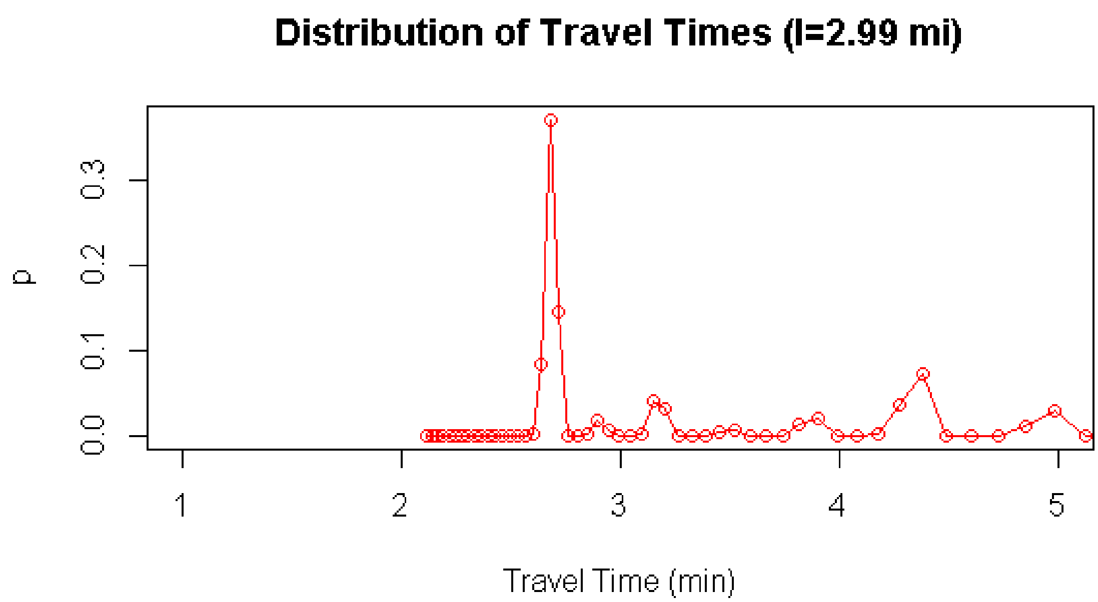
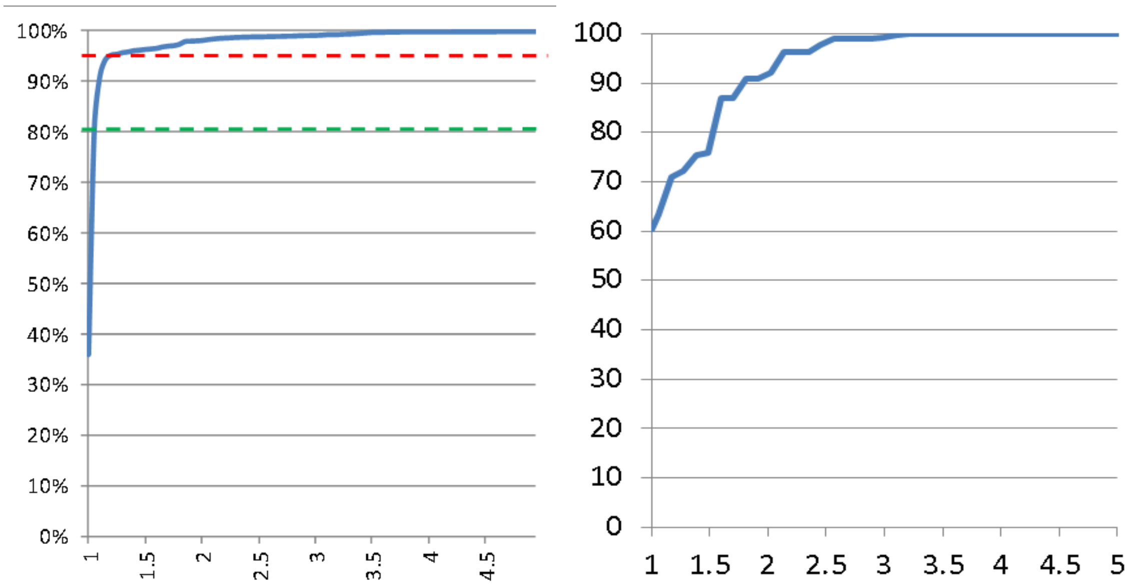



**Figure 7.10. Distribution of travel times for I-5 study site.**

Figure 7.11 compares the cumulative probability distributions between the ground truth data (*b*) and the generated software output (*a*).

Similar to the I-405 test results, FREEVAL tends to be conservative when estimating travel time reliability and often predicts smaller TTI values than the ground truth data as shown in Table 7.5. The exception of this is the 50th percentile TTI for which the ground truth value is smaller. FREEVAL also predicts a much smaller variability in travel times as is noted by the difference in the semi-standard deviation values.




**(a)** **(b)**

**Figure 7.11. Comparison of cumulative distributions for TTI on I-5: (a) FREEVAL output; (b) Dual-loop data.**

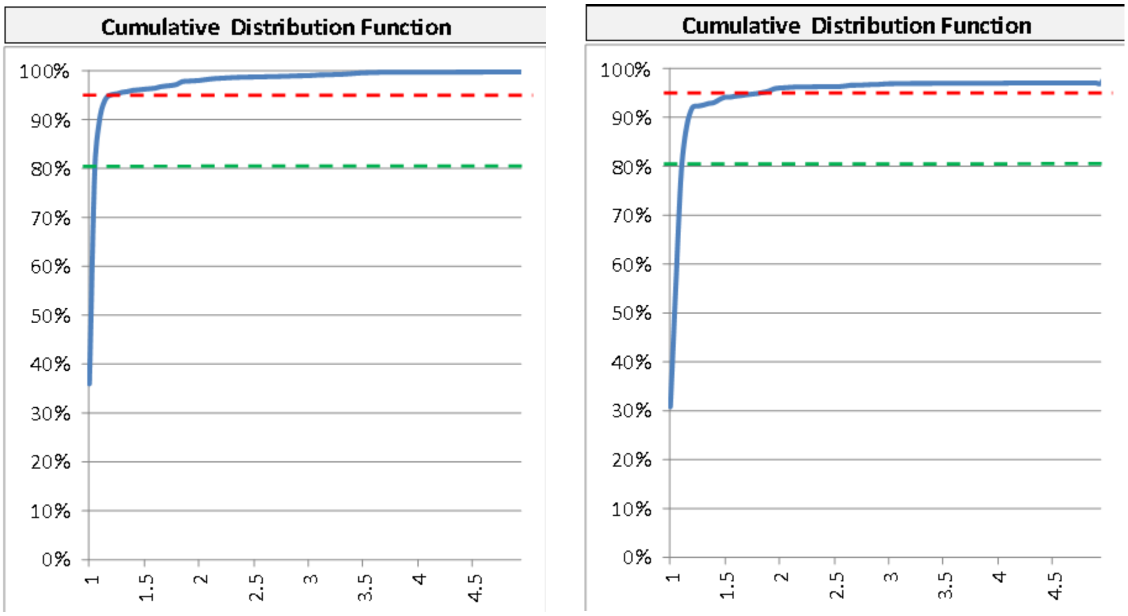
**Table 7.5. Performance Measure Comparison on I-5**

| Performance Measure | FREEVAL | Ground Truth |
|---|---|---|
| Mean TTI | 1.12 | 1.25 |
| 50th percentile TTI | 1.06 | 1.00 |
| 80th percentile TTI | 1.10 | 1.53 |
| 95th percentile TTI | 1.23 | 2.13 |
| Semi-standard dev. | 0.19min | 1.97min |

## 7.5 Precision Testing for FREEVAL

One of the primary steps in completing a reliability analysis on FREEVAL is inputting the demand data for the specified seed day. A convenient facet of the seed day is that it only requires the user to enter data for one day versus many days in the reliability reporting period. A caveat of this is that depending on the particular traffic demand occurring on the seed day, the results of FREEVAL may change drastically.

In addressing this issue, it is of relevance to determine the sensitivity of a given test run to the selection of the seed day. An additional test run was completed on the I-405 study site using demand data from a new seed day, but keeping all other data inputs the same. The TTI curves of each of these tests are shown as Figure 7.12 for comparison.




**(a)** **(b)**

**Figure 7.12 Comparison of cumulative distributions for TTI on different seed days: (a) 4-18-2012 Wednesday; (b) 2-22-2012 Tuesday.**

A comparison of the outputted reliability performance measures for each of the two trial runs is shown in Table 7.6.

**Table 7.6. Test Result Comparison between Seed Days**

| Performance Measures | Run 1<br>4-18-2012 Wednesday | Run 2<br>2-22-2012 Tuesday |
|---|---|---|
| Mean TTI | 1.11 | 1.12 |
| 50th percentile TTI | 1.08 | 1.08 |
| 80th percentile TTI | 1.14 | 1.15 |
| 95th percentile TTI (PTI) | 1.25 | 1.27 |
| Misery index | 1.90 | 1.96 |
| Semi-standard deviation | 0.45 | 0.45 |
| Reliability rating | 95.75% | 90.30% |
| Percent VMT at TTI >2 | 1.04% | 1.27% |

Figure 7.12 and Table 7.6 show that the difference on MOEs between the two trial runs is not large; nonetheless, the selection of the seed day can affect the results. Also, it is not sufficient to only complete one trial run. Doing so may grossly misrepresent the actual reliability of a facility. Multiple runs must be completed, and the results must be analyzed statistically in order to be confident in the results of a FREEVAL reliability test.

The only instructions given to the user for selecting the seed day are that the seed day should be included in the reliability reporting period and that it should be a day in which no special events, such as big sports games, are occurring. There is no indication that multiple runs should be completed using the demand data from several different seed days in order for a test to be reliable. This should be clearly addressed in the L08 documents.

## 7.6 Test Conclusions for FREEVAL

In summary, although it is impossible to evaluate the accuracy of FREEVAL based on the results of two tests, it is fair to say that the reliability estimates of the software seem reasonable compared to the ground truth reliability determined from the dual-loop detector data. Overall, FREEVAL tends to be overoptimistic in its estimates and produced consistently smaller TTI values and smaller semi-standard deviations.

## 7.7 STREETVAL Introduction and Interface

The Urban Streets Reliability Engine tool (STREETVAL) was developed for the purpose of assessing the long-term travel time reliability along a signalized arterial. In order to carry out its procedure for predicting long-term travel time reliability, two specific methodologies are implemented and are referred to in the literature as the reliability methodology and the HCM methodology. These two methodologies are described briefly below; a more detailed description can be found in the in the STREETVAL user guide.

1. The reliability methodology uses a random statistical procedure, guided by an inputted base data set, to simulate the traffic demand, weather, and incident conditions over each of many small time periods (analysis periods) within the study period and for each day in the reliability reporting period. This process is also referred in the literature as the scenario generation procedure.
2. The HCM methodology predicts the travel times on the specified corridor, given the predetermined traffic, weather, and incident conditions from the reliability methodology, for each of the analysis periods within the study period and for each day in the reliability reporting period. Note that this methodology includes procedures for estimating travel times during work zones and special events.

The flow chart shown in Figure 7.13 illustrates how these two methodologies interact in order to perform a reliability assessment.

To further elaborate on the STREETVAL reliability procedure from a software analyst perspective, use of the tool has been broken down into five main actions: Action 1. selection of project purpose, location, and scope; Action 2. HCM input data file creation; Action 3. scenario generation; Action 4. scenario evaluation; and Action 5. result interpretation.

### 7.7.1 Step 1: Project Purpose

Before beginning an analysis, it is recommended that the user has a clear idea of what is to be gained in doing such an analysis, namely what is the project purpose. There are many possible motivations for using STREETVAL, which are discussed in the literature. These include the following:

- Evaluating potential improvements (e.g., signal retiming, infrastructure improvements, etc.);
- Determining key sources of travel time unreliability; and
- Quantifying problems.

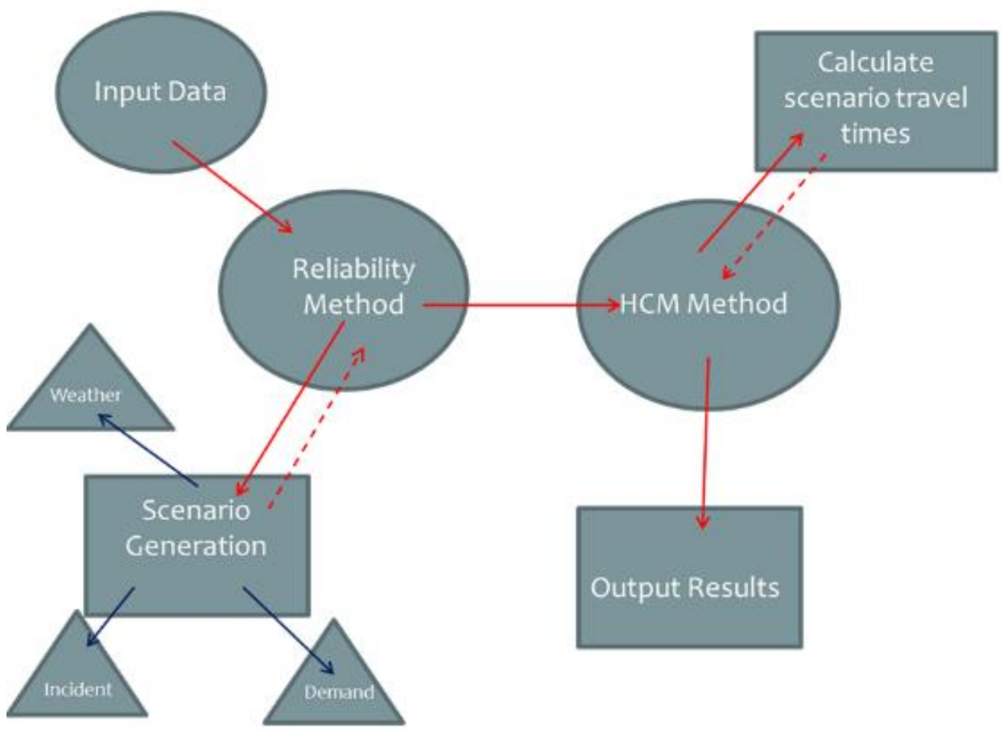



**Figure 7.13. STREETVAL methodology flowchart.**

A manageable project scope must be selected that consists of the project study site and the temporal scope. In selecting the study location the user is constrained on the length of roadway that can be evaluated. The study location must contain no more than nine signalized intersections (eight analysis segments). For the temporal scope, the user must specify three parameters: analysis period, study period, and reliability reporting period. These parameters are briefly defined below.

#### *7.7.1.1 Study Period*

It is recommended that the study period for a given project be a maximum of 6 hours, and no less than 1 full hour. The study period should be selected such that the first analysis period within the study period is uncongested.

#### *7.7.1.2 Analysis Period*

The analysis period essentially defines the resolution analysis that will be performed by the software. This period can range anywhere from 15 minutes to 1 hour. It is, however, recommended for operational analyzes, that a 15-minute period be selected. The selection of a longer period may cause incident and weather events lasting only a short period of time (such as a brief hard hailstorm) to be ignored.

#### *7.7.1.3 Reliability Reporting Period*

The reliability reporting period should be relatively long (not less than 200 days). The analyst may choose which days of the week to be included (e.g., exclude weekends, or all Mondays, etc.).

### 7.7.2 Step 2: HCM Input Data File Creation

This step requires the user to input the required input data into the USCE program (see screen shot in Figure 7.14), which is an Excel macro, in order to create an input file of type .txt that can be read by the Urban Streets Reliability Engine (USRE). The necessary input data required includes the following:

- Demand data for each intersection and access point located;
- Study section roadway geometric data; and
- Signal timing data for each intersection.

These sources of data will be further discussed in the following section. The USCE divides the study location into analysis segments, bounded on either end by a signalized intersection, and allocates an Excel sheet for each analysis segment as well as one sheet for the first segment intersection (as shown in Figure 7.15). The three previously listed types of data must be entered for each individual segment along the study section.

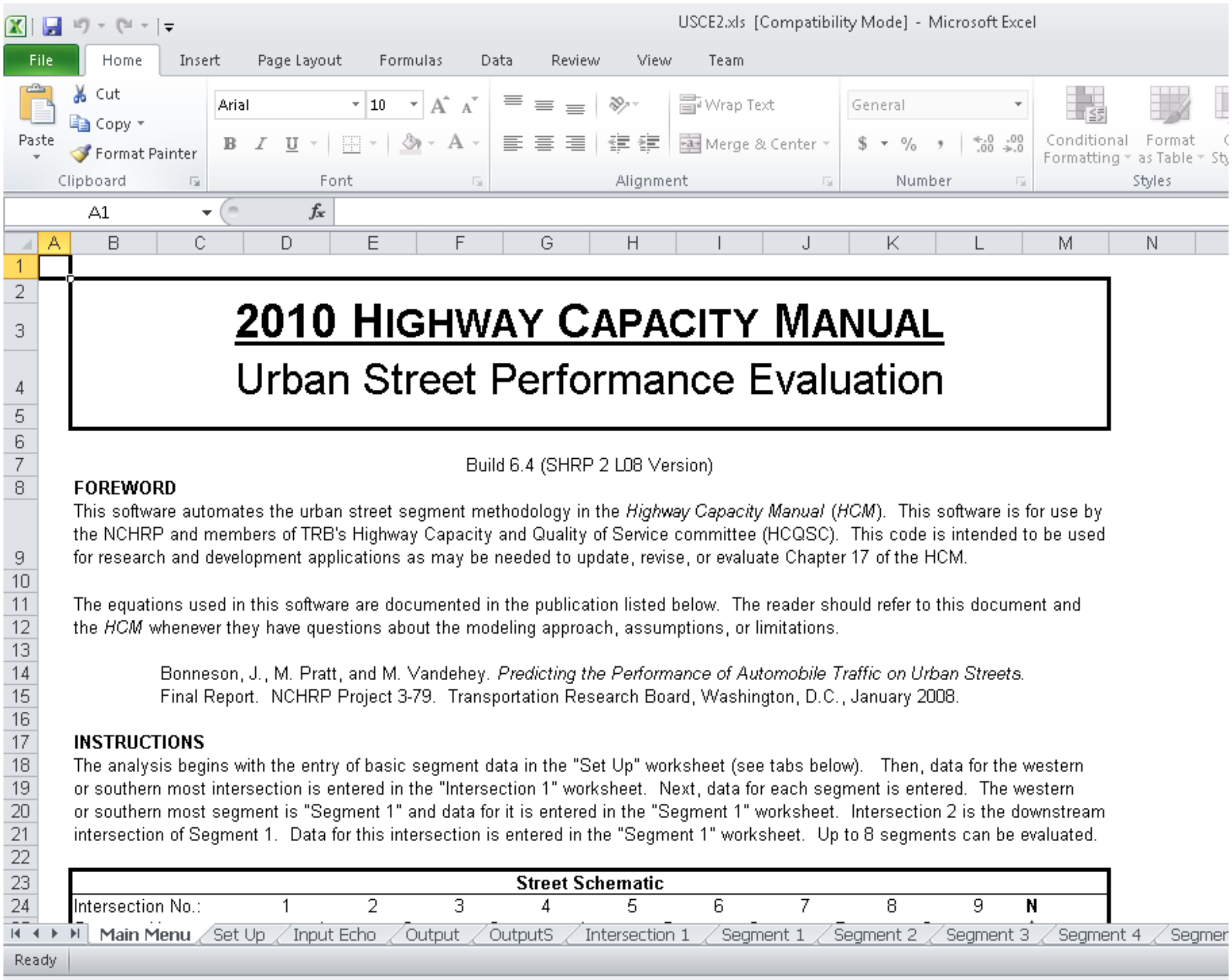



**Figure 7.14. Urban Streets Computational Engine (USCE).**

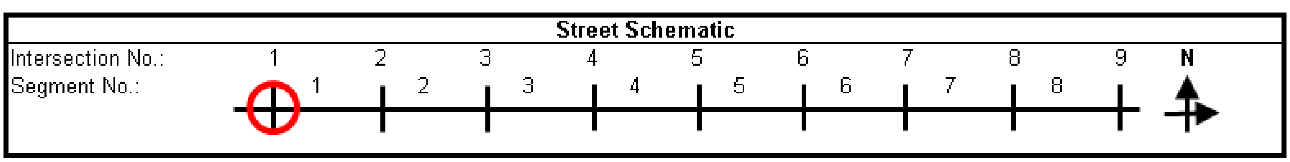



**Figure 7.15. STREETVAL segment schematic.**

After entering all the necessary data, the user writes the data to a file, which is saved to a user-specified directory. He or she is then prepared for the next step.

### 7.7.3 Step 3: Scenario Generation

The scenario generation step is carried out using the USRE, which is also an Excel macro program.

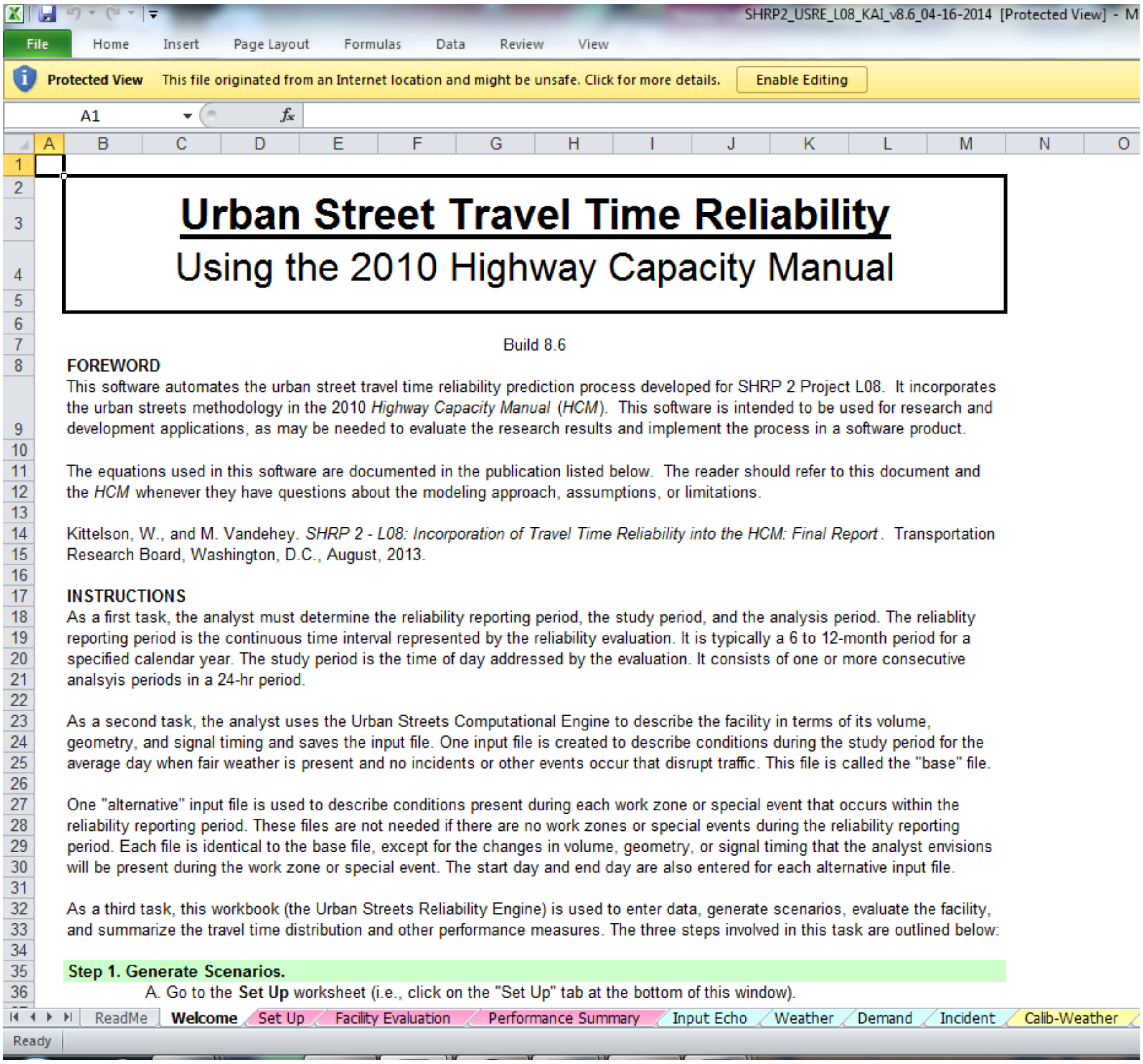



**Figure 7.16. USRE 2010 HCM.**

The user must first upload the HCM input file created in Step 2, specify the time and date of the seed demand data specified in the input file (1 hour of collected volume data), and enter the three temporal scope variables for the project. These values are entered in the “Set Up” layer of the tool. In addition to these values, crash data, peak hour factors (PHF) for traffic (if using 15 analysis periods and wish to randomize demand within 15-minute periods), and work zones and special event input files if they are deemed necessary and relevant. As previously mentioned, the scenario generation is a stochastic process, and it relies on the selection of user defined seed values. Three random seed values must be defined for each of the three stochastic variables: weather, incident, and demand. It is the combination of the weather, demand, and incidents occurring during a given analysis period that make up a given scenario.

After coding in the necessary inputs, the scenarios are generated by clicking the "Start Calculations" button. The generation process will take several minutes to complete and will vary depending the number of scenarios being evaluated. This process generates one scenario per analysis period in the reliability reporting period. For example, given a 0.25-hour analysis period, 3-hour study period, and 365-day reliability reporting period, there will be 3/0.25x365 = 1460 scenarios. For each scenario generated, one 8kb .txt file is created and saved to the directory. It should be noted that these files can quickly become a nuisance as a user may want to run several trials for a given test with different random seeds; these files quickly add up as well as take up precious hard-disk space (1460 files/test x 8kb/file ~14 Mb/test). An improvement would be to generate one output file for all the scenarios in a test. A screen shot of the tool illustrating the main input variables is shown in Figure 7.17. Figure 7.18 shows a supplemental input screen for random seed numbers and PHF.

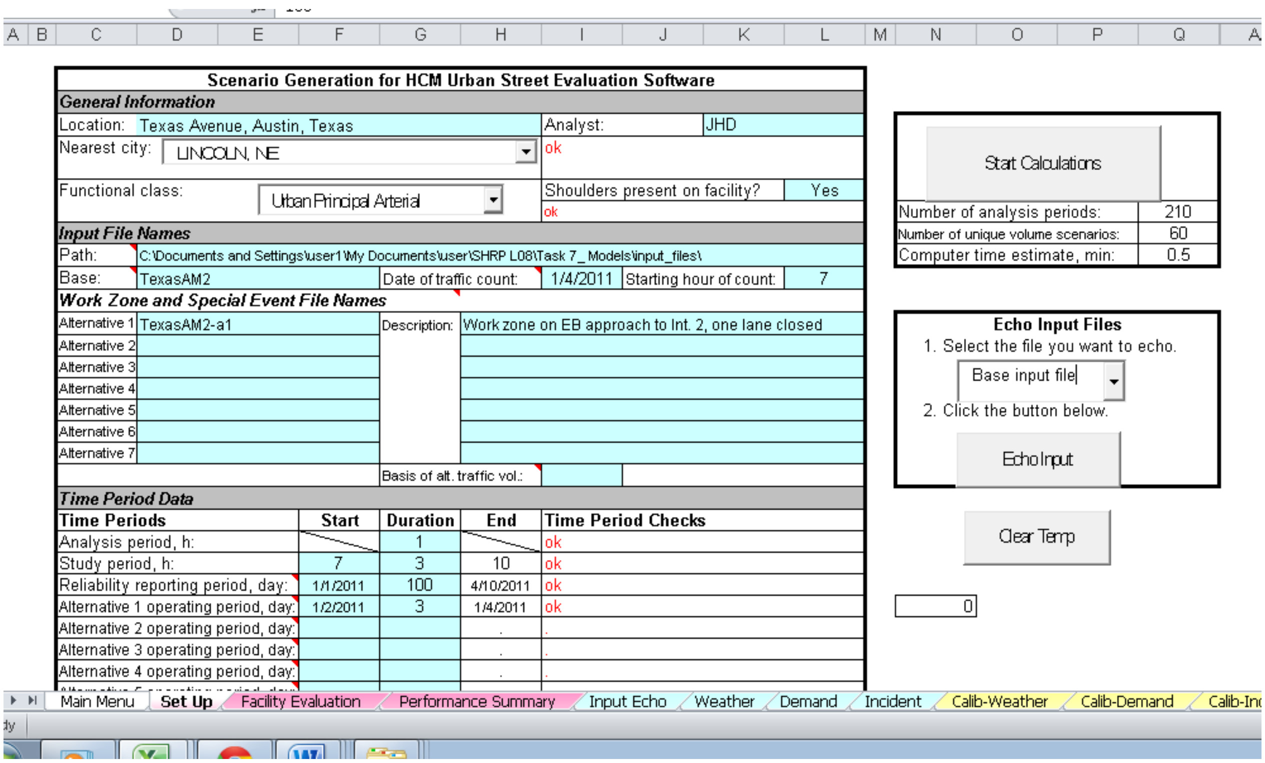


**Figure 7.17. Principal inputs for scenario generation.**

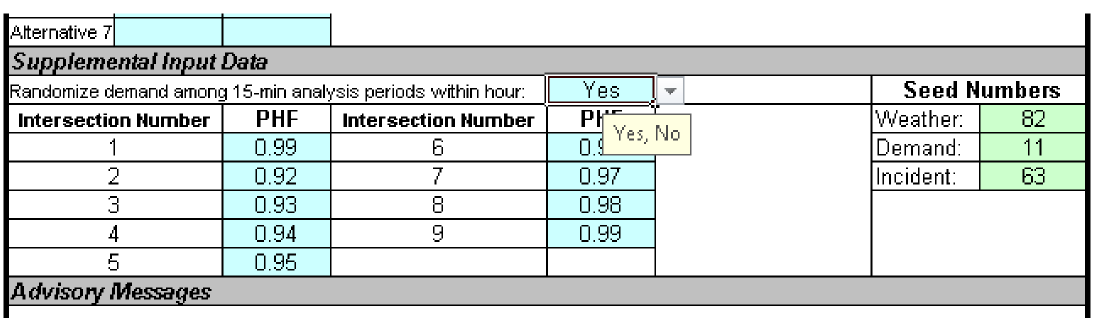


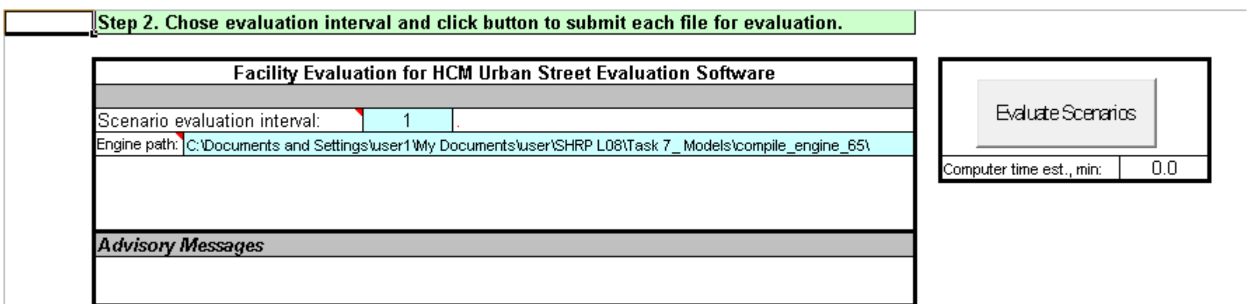
**Figure 7.18. Random seed numbers and PHF (peak hour factor).**

### 7.7.4 Step 4: Scenario Evaluation

This is the start of the HCM methodology, and it consists of evaluating the scenarios that were previously generated. In order to evaluate each scenario, the scenario engine is used. The scenario engine, which has not yet been mentioned in this report, is a .zip file that contains the operational procedures based on previously conducted research to estimate travel time performance measures for a given scenario. This step is the second most computationally intensive step after scenario generation and typically takes 3–6 minutes depending on the number of scenarios being evaluated.

An evaluation interval parameter gives the user the choice to evaluate either all of the generated scenarios or a subset of them. This can greatly reduce the required computation time however at the cost of an overall smaller sample size.

Figure 7.19 shows a screen shot of the scenario evaluation sheet of USRE. Two sources of data are entered in this sheet: engine path, which is the location of the scenario generator .zip file, and the evaluation interval that has just been discussed.




| Period Number | Day | Date | Month | Day of Week | Start Time (h) | Scenario File Name |
|---|---|---|---|---|---|---|
| 1 | 3 | 1/3/2011 | 1 | 2 | 7.00 | 20110103-0700_TexasAM2-a1 |
| 2 | 3 | 1/3/2011 | 1 | 2 | 8.00 | 20110103-0800_TexasAM2-a1 |
| 3 | 3 | 1/3/2011 | 1 | 2 | 9.00 | 20110103-0900_TexasAM2-a1 |
| 4 | 4 | 1/4/2011 | 1 | 3 | 7.00 | 20110104-0700_TexasAM2-a1 |
| 5 | 4 | 1/4/2011 | 1 | 3 | 8.00 | 20110104-0800_TexasAM2-a1 |
| 6 | 4 | 1/4/2011 | 1 | 3 | 9.00 | 20110104-0900_TexasAM2-a1 |
| 7 | 5 | 1/5/2011 | 1 | 4 | 7.00 | 20110105-0700_TexasAM2 |
| 8 | 5 | 1/5/2011 | 1 | 4 | 8.00 | 20110105-0800_TexasAM2 |
| 9 | 5 | 1/5/2011 | 1 | 4 | 9.00 | 20110105-0900_TexasAM2 |

**Figure 7.19. STREETVAL scenario generation.**

### 7.7.5 Step 5: Result Interpretation

In this step, the program outputs the findings of the scenario evaluation step in an easy and user-friendly fashion. The program allows the user to choose from a list of performance measures including:

- Travel time;
- Travel speed;
- Stopping rate;
- Through delay; and
- Total delay.

The user can also select if they would like to see results of the entire facility or only a particular segment. In Figure 7.20, a screen shot of the performance summary sheet of the software is shown. The user may select a different performance measure, direction of travel, or system component by clicking on the drop down menu and selecting the appropriate item.

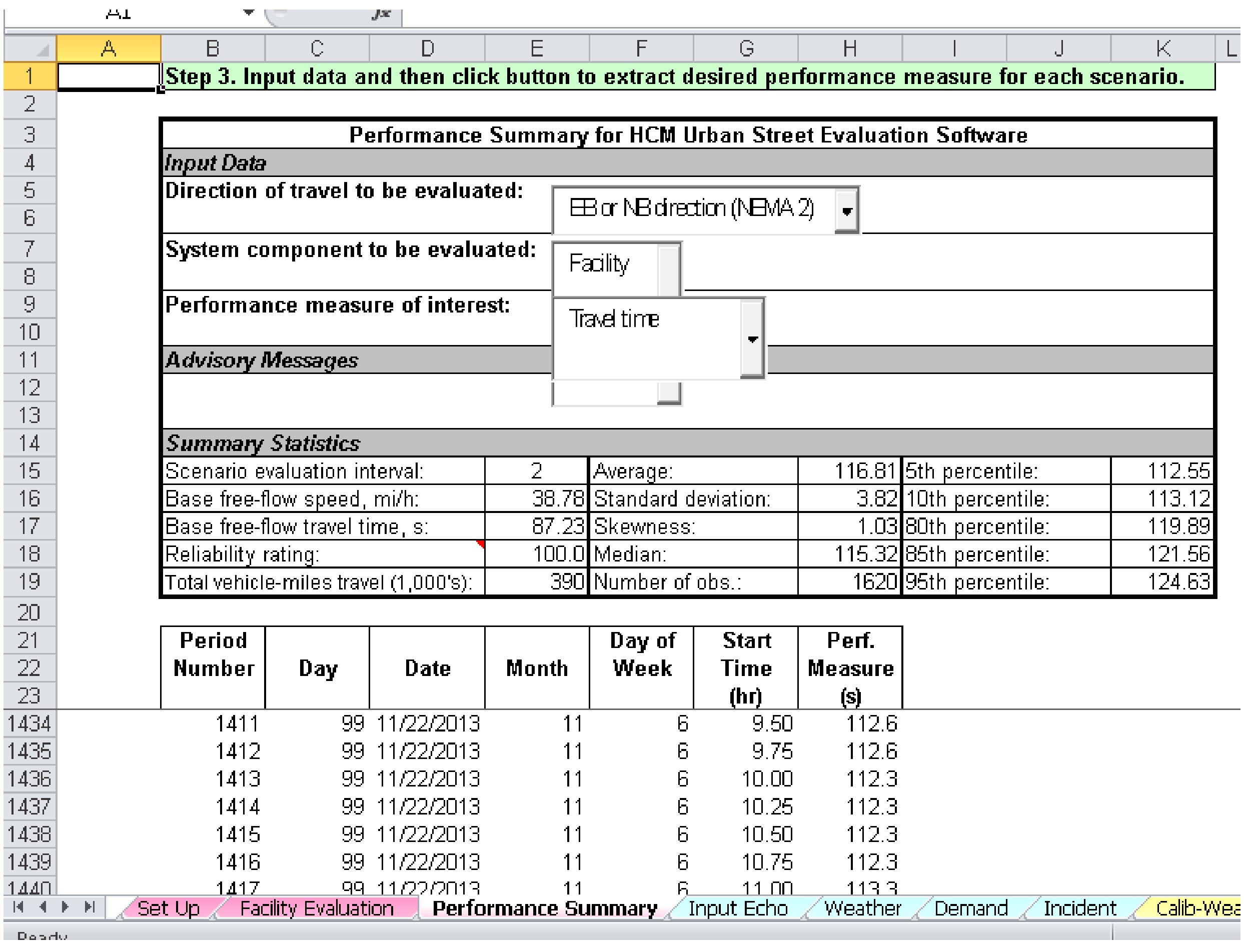



**Figure 7.20. Tool testing results.**

A histogram is created as a friendly visual illustration of the results, and a table summarizing the certain statistical properties of the histogram such as average, variance, and 80th, and 95th percentiles is also displayed. A list showing the incremental performance measures for each of the evaluated scenarios is also displayed and can be copied and pasted into another data file for additional analyses. Figure 7.21 shows the outputted list of each scenario, its date and time, and its corresponding performance measure.

| Period Number | Day | Date | Month | Day of Week | Start Time (hr) | Perf. Measure (s) |
|---|---|---|---|---|---|---|
| 1404 | 99 | 11/22/2013 | 11 | 6 | 7.75 | 119.4 |
| 1405 | 99 | 11/22/2013 | 11 | 6 | 8.00 | 115.4 |
| 1406 | 99 | 11/22/2013 | 11 | 6 | 8.25 | 115.4 |
| 1407 | 99 | 11/22/2013 | 11 | 6 | 8.50 | 115.4 |
| 1408 | 99 | 11/22/2013 | 11 | 6 | 8.75 | 115.4 |
| 1409 | 99 | 11/22/2013 | 11 | 6 | 9.00 | 112.6 |
| 1410 | 99 | 11/22/2013 | 11 | 6 | 9.25 | 112.6 |

**Figure 7.21. Tool results: List of performance measures for each evaluated scenario.**

## 7.8 Overall Evaluation of Tool Interface

It is worth noting that from an operator perspective, this tool is far from perfect. The interface is sloppy with many random numbers just floating in space on the spreadsheet (as shown in Figure 7.22). This is distracting from a user's point of view and undermines the integrity of the tool. Users may be unaware if they accidently entered these values or if the numbers are somehow part of the program. Although this may be a small flaw compared to the overall performance, further improvements to the aesthetics of this tool should definitely be considered.

Another distracting glitch of this tool was the buttons. The buttons on the tool would shrink every time they were pressed. Figure 7.23 shows a shrunken button from the USRE tool.

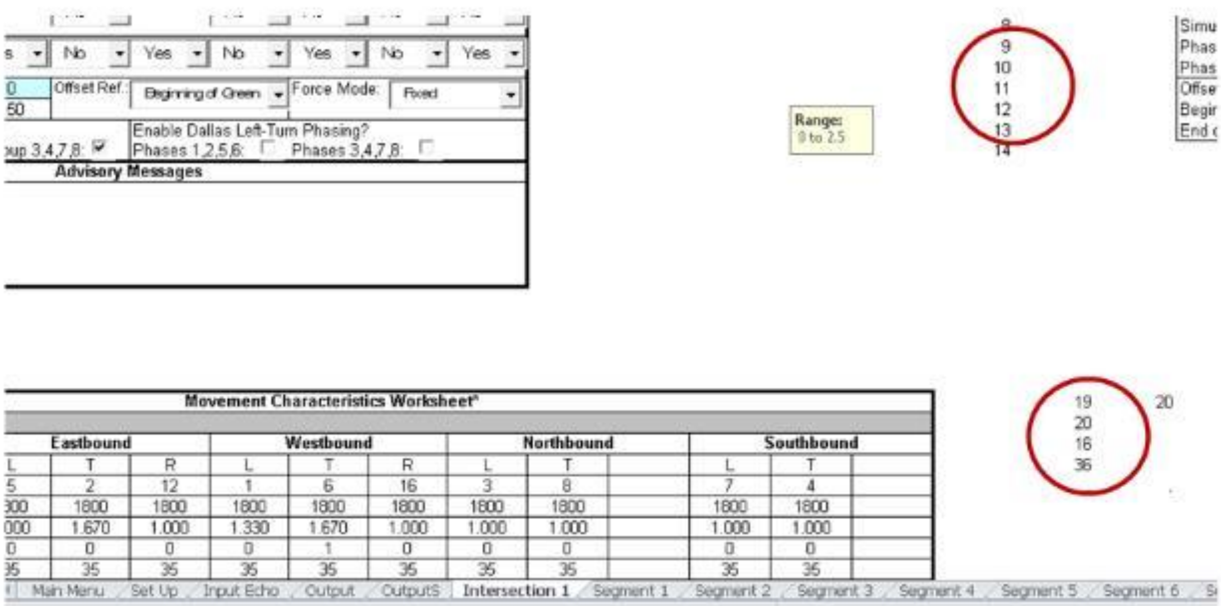



**Figure 7.22. Distracting floating numbers.**

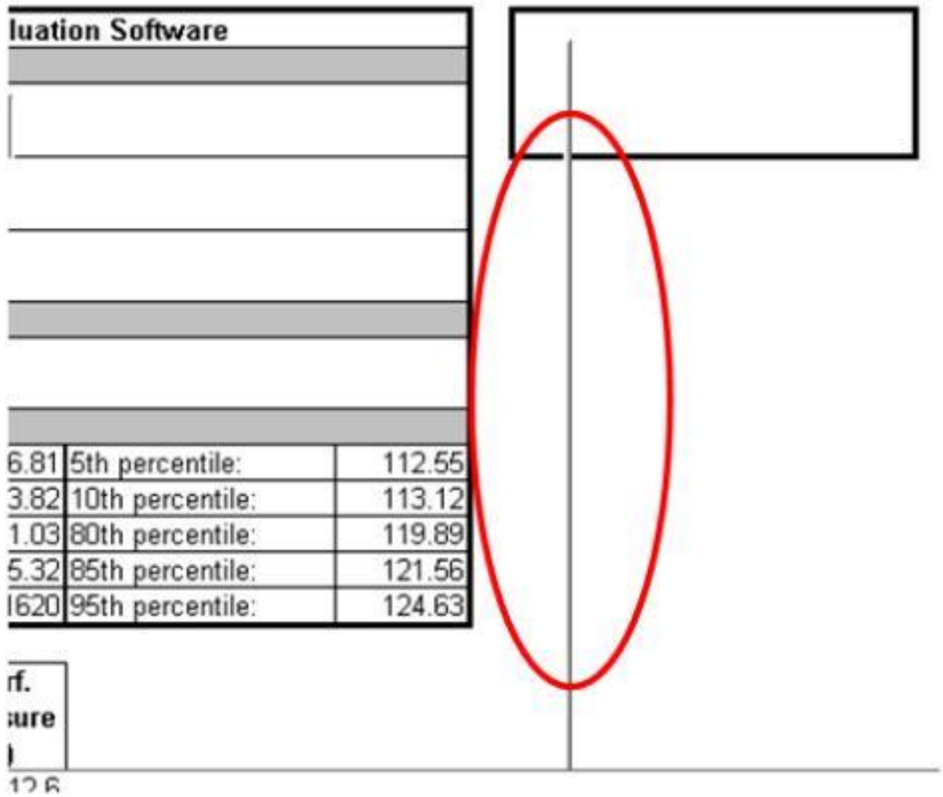



**Figure 7.23. Malfunctioning button circled in red.**

## 7.9 Input Data Requirements for STREETVAL

The data requirements for this tool are extensive and include demand data, incident data, signal timing data, roadway geometric data, and data from work zones and special events, if they are present during the period of time being analyzed (reliability reporting period).

For the demand data requirements, the user must enter the traffic volumes for each approach of each intersection located along the study segment. In many instances, however, such a thorough data set for a given corridor is non-existent. This makes any kind of retrospective analysis difficult. If no demand data for the segment exist, a traffic count study must be conducted along the corridor.

In addition to the demand requirements for intersections, demand data must also be collected for each access point along the study corridor. What exactly qualifies as an access point is, however, highly subjective and is based on the analyst’s opinion. According to the HCM 2010, an access point is any unsignalized entryway located along a corridor that receives enough traffic volume to influence travelers along the main arterial. This begs the question of what types of volumes would require an analyst to appropriately define an entryway as an access point for which demand data will need to be collected. If multiple smaller access points are located along the corridor, the tool recommends combining these access points into one single access point that is located at the average distance of each smaller access point from the upstream intersection and that receives the combined volumes of each of the smaller access. In most cases, where access point demand data are unavailable, a traffic count study is required, and this process is labor intensive and costly to an agency.

One improvement to the tool might be to provide a method to estimate access point data along an urban arterial based on a number of built-environmental factors that are likely to be of influence, such as land type, population density, parking lot size, time of day, and distance from a central business district.

For the incident data requirements, crash segment frequencies must be specified for each intersection and each segment. Crashes are considered to be intersection-related if they occur within the bounds of the intersection itself, if they occur as a result of a queue formed from the intersection bottleneck, or if they are caused by a traffic signal controller malfunction. If an incident cannot be classified as intersection-related, it is classified as segment-related. In most cases, the cause of the incident can be used to deduce the type of crash (intersection-related or segment-related).

The user manual suggests two methods to calculate the crash segment frequencies (expected number of crashes at given location (crashes/year)). The first method requires the user to have access to at least 3 years' worth of crash data. These data may then be used to calculate the crash frequencies, based on the average crash frequency during the 3 years of collected data. The second method involves using the 2010 *Highway Safety Manual* methodology, which is described in Chapter 12 of the manual.

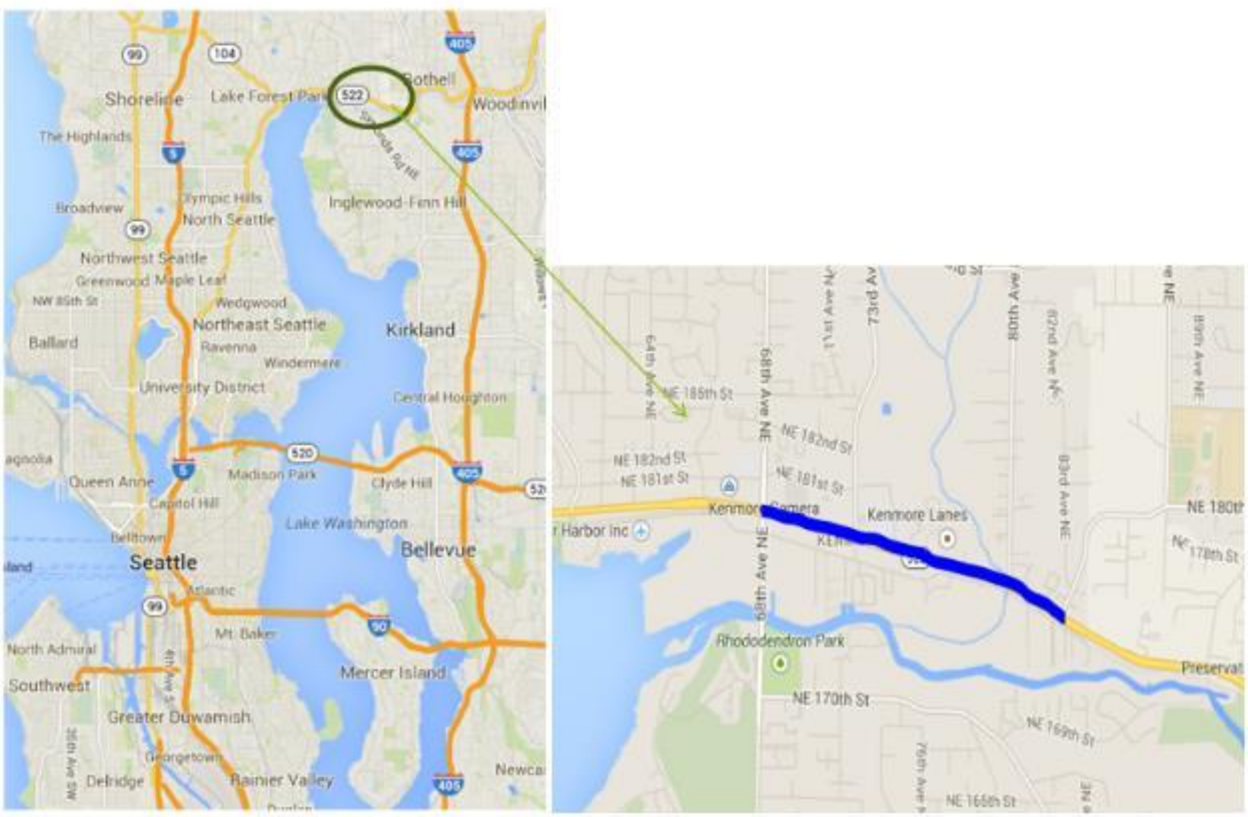
Signal timing data must be acquired from each of the traffic signals located along the study corridor and are crucial in the estimation of segment-level travel times. STREETVAL software is capable of accommodating both pretimed control and actuated/semi-actuated control operating under coordinated conditions, where several adjacent intersections are in sync and timed to a master controller or isolated control, where adjacent intersections have no communication with one another and act as independent entities.

In addition to the previously described data types, STREETVAL also requires weather data for the given study location including average monthly rainfall, days with rainfall greater than 0.01 inches, average monthly snowfall, and average monthly temperatures. The STREETVAL tool contains a large databank with 10 years of weather data for many prominent U.S. cities and towns. This eliminates the need to acquire adequate weather data and streamlines the overall reliability testing procedure.

Before collecting and gathering this data (signal timing, demand, crash, and weather data) from multiple various sources, the user must first determine when is the best time to collect or gather this data. The analyst must be certain that the demand data (collected for the 1-hour period during the study period) is collected at an appropriate time. Before this can be done, the analyst must appropriately define the temporal scope of the project. In STREETVAL, the temporal scope is defined equivalently as it was for FREEVAL. The user must choose the study period, analysis period, and reliability reporting period. These three parameters were defined previously.

## 7.10 Performance Test for STREETVAL

Test Site Location: In order to test the accuracy of this tool, a test was conducted on an urban arterial using real traffic data. The test location selected is a roughly 1-mile stretch of SR 522, an urban arterial located in Kenmore, Washington, just outside of Seattle. This site, shown in the map (Figure 7.24), provides travelers access to both I-5 and I-405 and serves as a major route around Lake Washington for those commuting into the city from the neighboring suburbs. This particular site location was selected because it acts as a major daily commute route for intercity travel and because of the abundance of sensor infrastructure that is currently installed along it, including ALPR cameras, which collect very accurate travel time data. The travel time data gathered from these cameras served as a ground truth base from which to assess the accuracy of STREETVAL.




Map data © 2014 Google

**Figure 7.24. Study site location along SR 522, Kenmore, Washington.**

As mentioned previously, testing the reliability of a corridor using the STREETVAL tool requires that a large amount of data first be gathered. Even though the research team currently has access to all of the loop detector data and live video feeds from several gantry-mounted video cameras along the study site, not to mention, a range of travel time data obtained from Bluetooth sensors and ALPR cameras, the demand data requirements of the tool could not be satisfied using data collected from the existing sensors. The reason for this was that the tool requires demand data for each movement of each intersection, and the rich sensor infrastructure installed along the study site gave the researchers complete demand data only for the main SR 522 arterial and not the side streets. When the research team became aware of this problem members had one of two choices: (1) try to find another urban arterial with more complete demand data, or (2) manually collect the missing demand data for SR 522. After some debate, it was decided that SR 522 would stay as the test sight and that the missing data for the other intersections approaches would be collected manually. There were two primary reasons for this decision. The first reason is that researchers were not able to find complete demand data for all signalized intersection approaches on an urban arterial. The second reason is that SR 522 was the only known arterial in Seattle that had accessible ground truth travel time data.

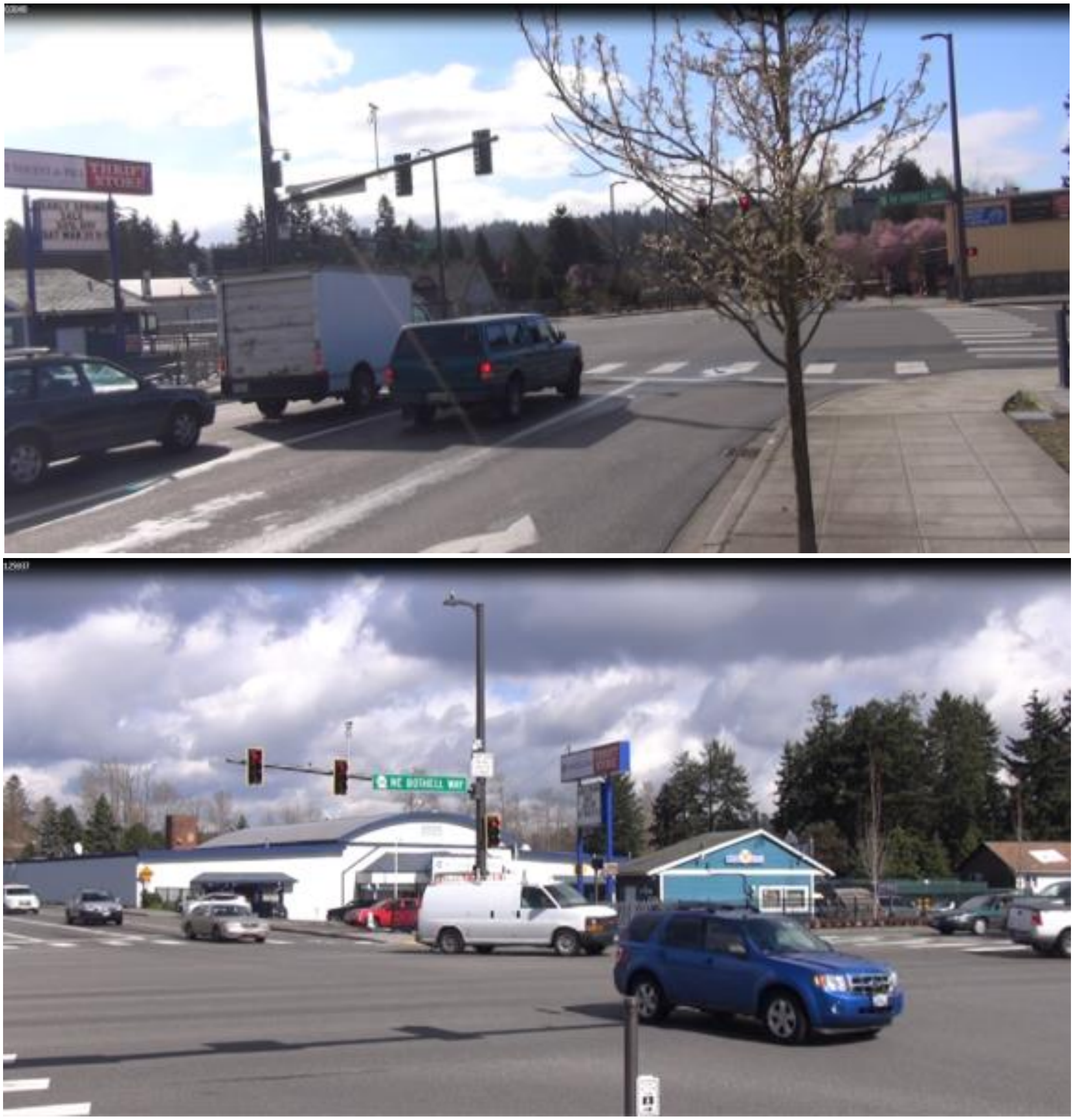
Volume Data Collection: Because of limited resources for the manual data collection, the originally proposed study site of roughly 4 miles in length was shrunk down to a manageable 1-mile section, stretching along SR 522 from 68th Avenue to 83rd Place (see Figure 7.25).


Map data © 2014 Google

**Figure 7.25. Study site location.**

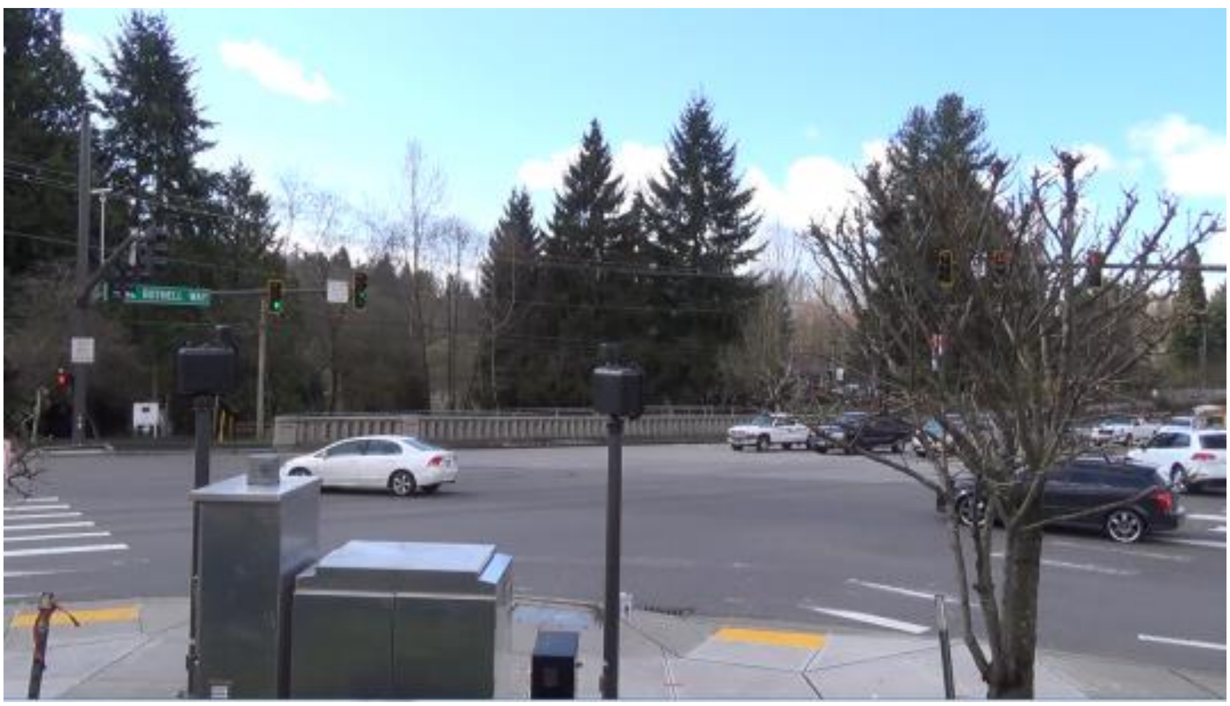
To satisfy the traffic volume data input requirements of the tool, 1-hour traffic volumes were simultaneously captured for all 5 intersections located along the study site using 7 tripod-mounted video cameras for two 1-hour periods. The complexity of the intersections and high rate of vehicle arrivals made it necessary to capture the volume data with a camera. These camera data were later viewed at a slower, more convenient pace, and the traffic volumes for each direction were obtained. Images captured from each of the 7 tripod-mounted cameras are shown directly in Figure 7.26. These cameras were situated so that all traffic from each individual approach could be observed.


(a)




(b)

(c)



(d)

(e)

**Figure 7.26 Camera-captured images of studied intersections: (a) 68th Avenue camera-captured images from video of four-way intersection EB/WB (upper figure) and NB/SB (lower figure) approaches; (b) 73rd Avenue camera-captured images of four-way intersection EB/WB (upper figure) and NB/SB (lower figure) approaches; (c) 77th Avenue camera-captured images of T-intersection; (d) 80th Avenue camera-captured images of T-intersection; and (e) 83rd Place camera-captured image of T-intersection.**

To further aid in the traffic counting process, a software program called Traffic Counter (shown in Figure 7.27) was developed by STAR Lab members; the program allows users to count traffic on the computer by pressing the appropriate key for a given direction. The advantage of this software is that users can touch-type the keys and thereby not have to take their eyes off the video and risk missing a count. This was crucial because traffic is often running at or near the saturation flow rate at the startup of the green phase, which requires a high level of visual attention to count.

Volume data were also collected via manual counting at all of the major access points along the study site. To aid with the data collection, a team of 10 volunteers was needed. Each volunteer was given a particular task: either manually counting cars at an access point or filming vehicles passing through an intersection using a tripod-mounted camcorder. In total, approximately 67 man hours were spent collecting data at the sight and counting vehicles from the videos that were recorded. This is worth mentioning because any agency that will in the future be using this tool will want to consider the potential costs of collecting the data to use it. The cost of 67 hours of labor is not trivial, and that's not considering the opportunity cost of sending 10 trained engineers from an agency or consulting firm to count cars.

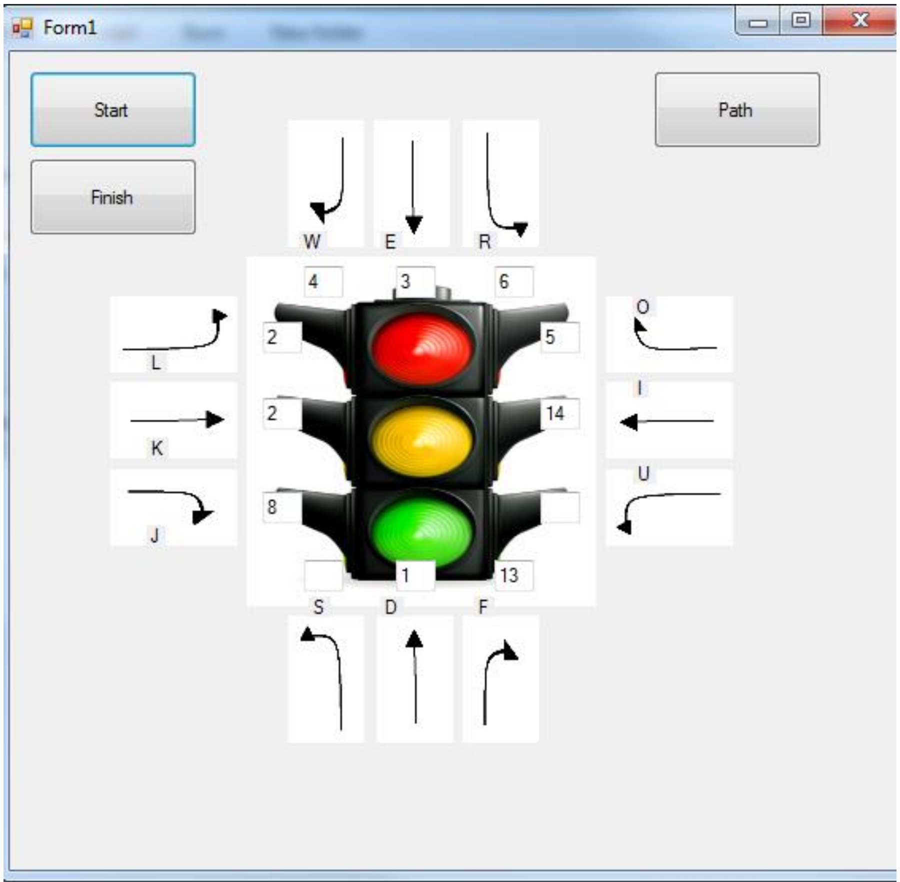



**Figure 7.27. Traffic Counter software user interface.**

### 7.10.1 Weather Data

As mentioned previously, it was not necessary to gather weather data along this corridor as the tool contains a built-in weather databank that contains 10 years of historical weather data for many prominent cities, including Seattle.

### 7.10.2 Incident Data

The incident data used in this study were obtained from the WITS database. Since the tool requires a minimum of only 3 years of incident data be collected, researchers more than met the data requirements. After querying the database, it was determined that zero incidents have been reported along the study section since 2002. This is not surprising, given that incidences are rare events, and the length of the study section was only 1 mile.

### 7.10.3 Traffic Signal Timing Data

Current traffic signal timing plans were obtained from WSDOT for each of the five intersections located along the study site. All of these five intersections are operating under coordinated actuated control, which is supported by STREETVAL, and the coordination plan selection is based on the time of day. It was crucial for the study, that the signal timing plans were current and that no signal retiming had occurred during the selected reliability reporting period, otherwise, the results of the test might be skewed. In this case, the plans had not been modified since July 2012, well before the first day in the reliability reporting period.

To summarize the previous section of this report, data were collected from a myriad of sources to suffice the requirements of STREETVAL. Complete demand data were unavailable, so a manual data collection was conducted at the test site. Despite the challenges of gathering all of the data, all of the necessary data requirements were successfully fulfilled.

### 7.10.4 Testing Results

Before running the software, it was first necessary to define the temporal scope of the test. The temporal scope parameters that were chosen are listed below:

- Analysis period, 0.25 hour;
- Study period, 7:00 a.m.–12:00 p.m.;
- Reliability reporting period, 228 days (8/16/13–3/31/14); and
- Days considered, Monday–Friday.

An analysis period of 0.25 hour was chosen because it is the shortest possible analysis period and will give the highest resolution test result possible. STREETVAL will ignore any incident or weather event that is shorter in duration than the selected period. The impetus for this was that it would minimize the chance of any intense but brief weather events, which might impact arterial travel times, from going unnoticed.

The study period was selected as a 5-hour period that overlaps the morning peak commute. There was no specific reason for selecting 5 hours other than it was a medium length of time, and not too short that it would fail to test the software's ability to predict reliability across many hours in a day, while not too long as to be excessive and irrelevant. The only constraint, described in the user guide, for selecting the study period is that it must include the hour of day of the specified seed volume. In this specific case, the seed volumes were manually collected for two different 1-hour time periods during the same day: from 10:00–11:00 a.m. and 13:00–14:00 p.m. Selecting 7:00–12:00 allowed the research team to satisfy this constraint.

In order to assess the accuracy of the STREETVAL software, the software reliability outputs were compared to the ground truth reliability of the corridor, which was calculated using real historical travel time data collected from ALPRs. For this analysis, ALPR travel time data were used to approximate the ground truth travel times on the corridor. Although no current studies have physically verified the accuracy of the travel times obtained from using ALPR technology, it is a widely accepted fact in the industry that these data are highly reliable. The technology has therefore been deemed to be a good estimator for the ground truth travel time data. The ALPR data were queried for a specific travel link corresponding to the travel link closest to the study, and researchers were interested only in the data within their previously defined temporal scope site. For this selected travel link, the travel time is measured from mileposts 7.21 to 8.18, which line up reasonably close to the origin and destination of the selected study site (mileposts 7.21 to 8.15). It should, however, be noted that because the destinations differ by 0.03 mile between the selected study site and the ALPR link the comparison is slightly biased.

Before using the ALPR travel time data, it was first cleaned to eliminate outliers and unreasonable data points using the recommended data quality control procedure discussed in Chapter 3 of this report. The ALPR data are aggregated in 5-minute periods, and for each 5-minute period, an average travel time value for a given travel link is given. This is not problematic; however, because STREETVAL produces 15-minute average travel time values, it was necessary to convert the cleaned ALPR average 5-minute travel time values into 15-minute average travel time values. This was a very important step for this test in order to provide reliable and sound test results because a histogram of 5-minute average travel times will have an inherently larger variance than a histogram of 15-minute average travel times. The distribution of 15-minute average travel times obtained from this data is shown in Figure 7.28.

Given that STREETVAL is simulation software, and it is sensitive to the selection of random seed values, three separate trial tests were conducted using three distinct sets of random seed values. Each trial test produced one travel time value for each generated scenario. The number of total scenarios evaluated in each trial, given the reliability reporting period of 228 days, a study period of 5 hours, an analysis period of 15 minutes, and an evaluation interval of 2 (generate scenarios for every other day) was 2,280 scenarios (5 hours/day * 4 analysis periods/day * 228days/2). Given the 15-minute analysis period, each scenario travel time value represents the average travel time for a specific 15-minute period. The test results from each of the three trial tests were combined into one large data file that amounted to 6,840 average travel time values. A histogram of these 6,840 average travel time values was then generated for comparison to the ground truth travel time distribution.

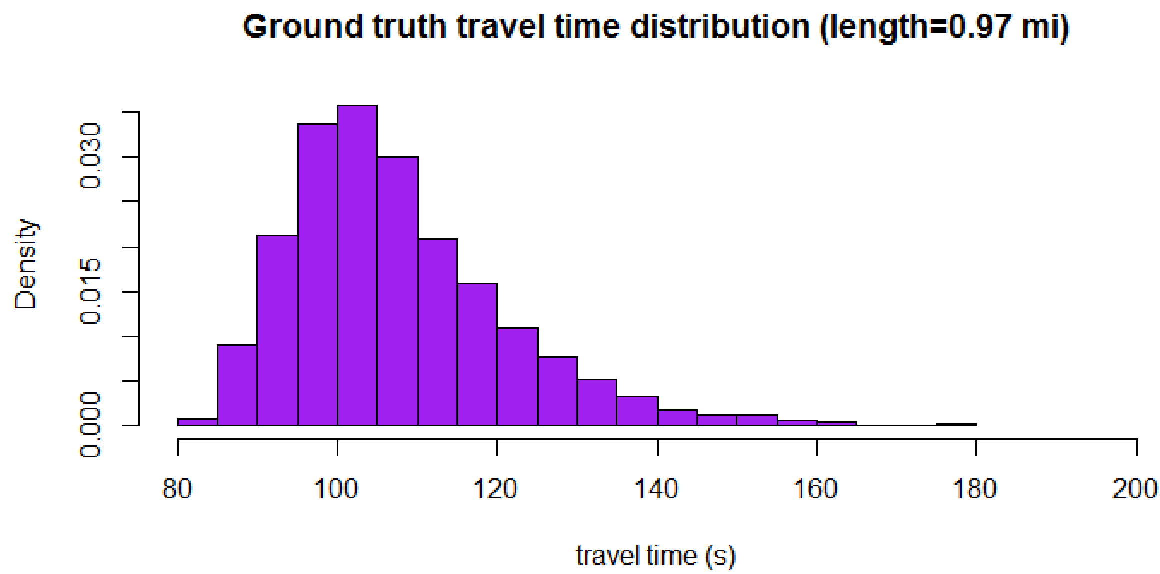



**Figure 7.28. Ground truth data distribution of travel times. (Note: This graph shows the distribution of 15-minute average travel times as calculated from the ALPR data.)**

The two histograms (Figure 7.29) illustrate the distribution of travel times of the test trial runs as compared to the ground truth ALPR travel time distribution. It should be noted that the histogram of the ground truth reliability is much more dispersed than that of the test results. However, despite the drastic difference in the widths of the distributions, the mean and median values of each distribution are quite similar as can be seen from the graphs.

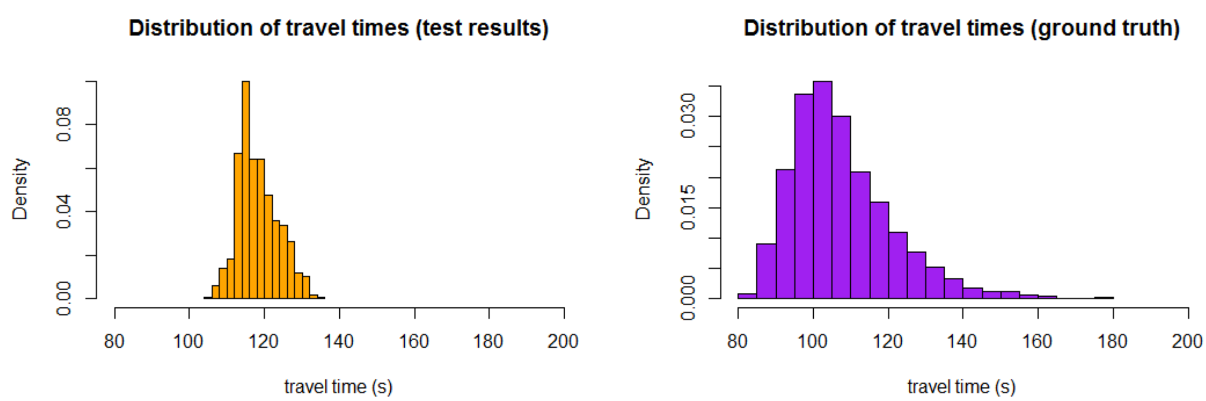



**Figure 7.29. Distribution of travel times from STREETVAL (gold) and ALPR (purple).**

To further illustrate these results, Figure 7.30 shows the cumulative distribution of travel times for the ground truth (shown in purple) compared to the test results (shown in gold). From this graph, it can clearly be seen the test results tend to overpredict the travel time for the lower probability range, and underpredict travel times for the higher probability range (0.9 and greater). In addition, the steepness of each curve is a good indicator of the travel time reliability. In this case, the slope of the ground truth curve (gold) is much steeper than the purple curve, which denotes a significantly greater reliability than the actual reliability (purple). These results indicate that STREETVAL provides an overoptimistic prediction of reliability.

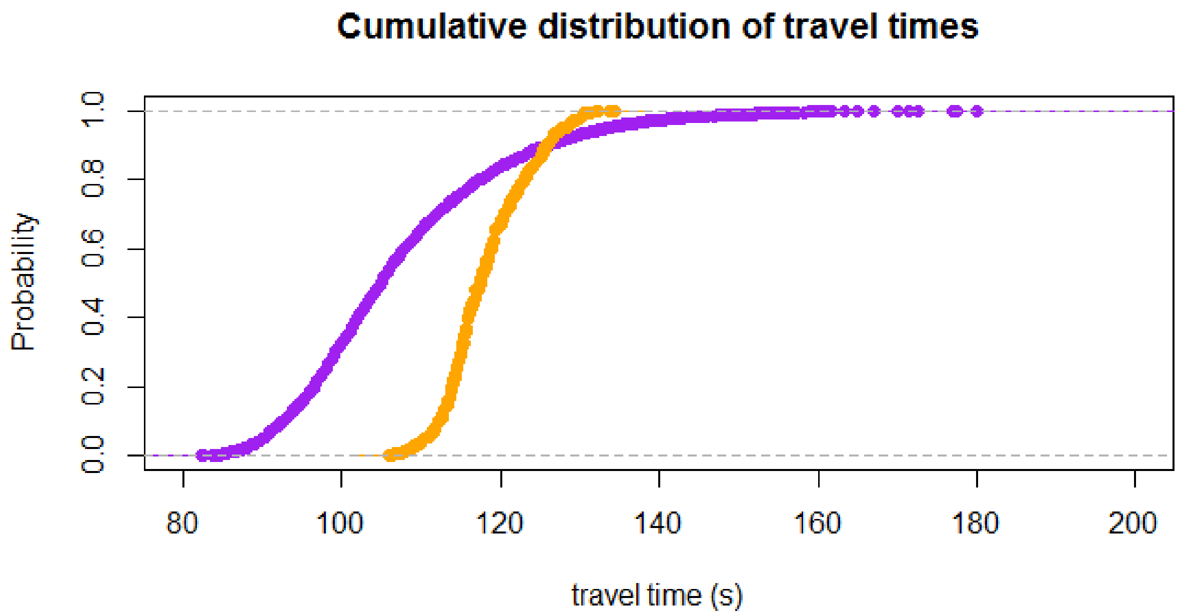



**Figure 7.30. Cumulative distribution of travel times from STREETVAL (gold) and ALPR (purple).**

Figure 7.31 compares several common reliability performance measures, derived from the travel time distributions for the ground truth travel time data and the predicted test results.

| Performance Measure | Ground Truth | Test Results |
|---|---|---|
| *5th percentile* | 90.3 | 110.8 |
| *10th percentile* | 93.0 | 112.2 |
| *80th percentile* | 117.7 | 123.0 |
| *85th percentile* | 121.3 | 124.4 |
| *95th percentile* | 133.7 | 127.6 |
| *mean* | 107.7 | 118.3 |
| *standard deviation* | 13.6 | 5.2 |
| *median* | 105.0 | 117.5 |

**Figure 7.31. Comparison of reliability performance measures between ground truth and test results.**

From the results presented, it is clear that there is a large disparity between the predicted reliability of STREETVAL and the actual reliability obtained from the ALPR data. There are many potential explanations for this disparity. However, the researchers believe that this error is most likely a result of a bias in the estimation of the travel demand for each scenario. In STREETVAL, the travel demand is estimated for each scenario using two main sources of information: (1) AADT volume factors for each month, day of week, and hour of day and (2) 1-hour seed volumes. It is possible that the demand from the seed day is not representative of the average demand on a given day, and this may introduce a small to very large bias in the software's prediction. Another possibility for the large discrepancy is that there is an additional factor that has not been accounted for, which, if included, would significantly decrease the prediction error. It is possible that better accounting of unpredictable driver behavior, accounting for variability in driver speed because of the presence of traffic lights or the glare caused by the reflection of the sun through the windshield, would improve the prediction accuracy. It is also worth noting that this software was originally tested and shown to work well for traffic in North Carolina, however, Seattle traffic and its drivers may be very different. Additional model calibration may be necessary to see if, for example, adjusting the average headway or driver acceleration will significantly improve results and help explain discrepancy.

## 7.11 Test Conclusion for STREETVAL

Based on test results, it was shown that STREETVAL was unable to provide a reasonable travel time reliability prediction for the urban arterial test site. The difference in variance and widths of the ground truth travel time distribution, and the predicted travel time distribution from STREETVAL is significant. Although the assessment of the software is biased because of a 0.03-mile difference in the lengths of travel time links between the ground truth data and STREETVAL results, an only 3% margin of error is not sufficient to explain this large of a discrepancy. This error is likely a result of both inaccurate demand prediction and not accounting for some principal factor influencing travel times. A redeeming quality of the software is that it was able to provide a reasonable prediction for the mean and median travel times, differing by less than 10%.

# CHAPTER 8
# Pilot Testing and Analysis on SHRP 2 C11 Product

## 8.1 Introduction

Most benefit–cost analysis tools incorporate recurring congestion impacts and exclude nonrecurring (resulting from incident/weather/work zone/demand fluctuation) congestion impacts. This is probably because of the difficulty of estimating nonrecurring congestion impacts. The SHRP 2 program developed the C11 Reliability tool to facilitate estimating both recurring and nonrecurring congestion delays and their associated costs. The tool was applied to analyze the I-5 facility through the Joint Base Lewis-McChord (JBLM), also known as JBLM project.

## 8.2 Description of the Test Site

The research team has selected I-5 facility through the JBLM located between SR 510 (Marvin Road NE) in Lacey and SR 512 in Lakewood for testing the travel time reliability tool. The test site is in Pierce County, Washington State, and is shown in Figure 8.1 (interchange locations are indicated by green circles).

This portion of I-5 experiences congestion in both directions of travel particularly during evening peak demand period. A congestion scan from INRIX is shown in Figure 8.2. INRIX data indicates peak period congestion in both directions of travel between Dupont-Steilacoom Road and Thorne Lane. Travel speed drops as low as 35 mph in the northbound direction during part of the evening peak period.

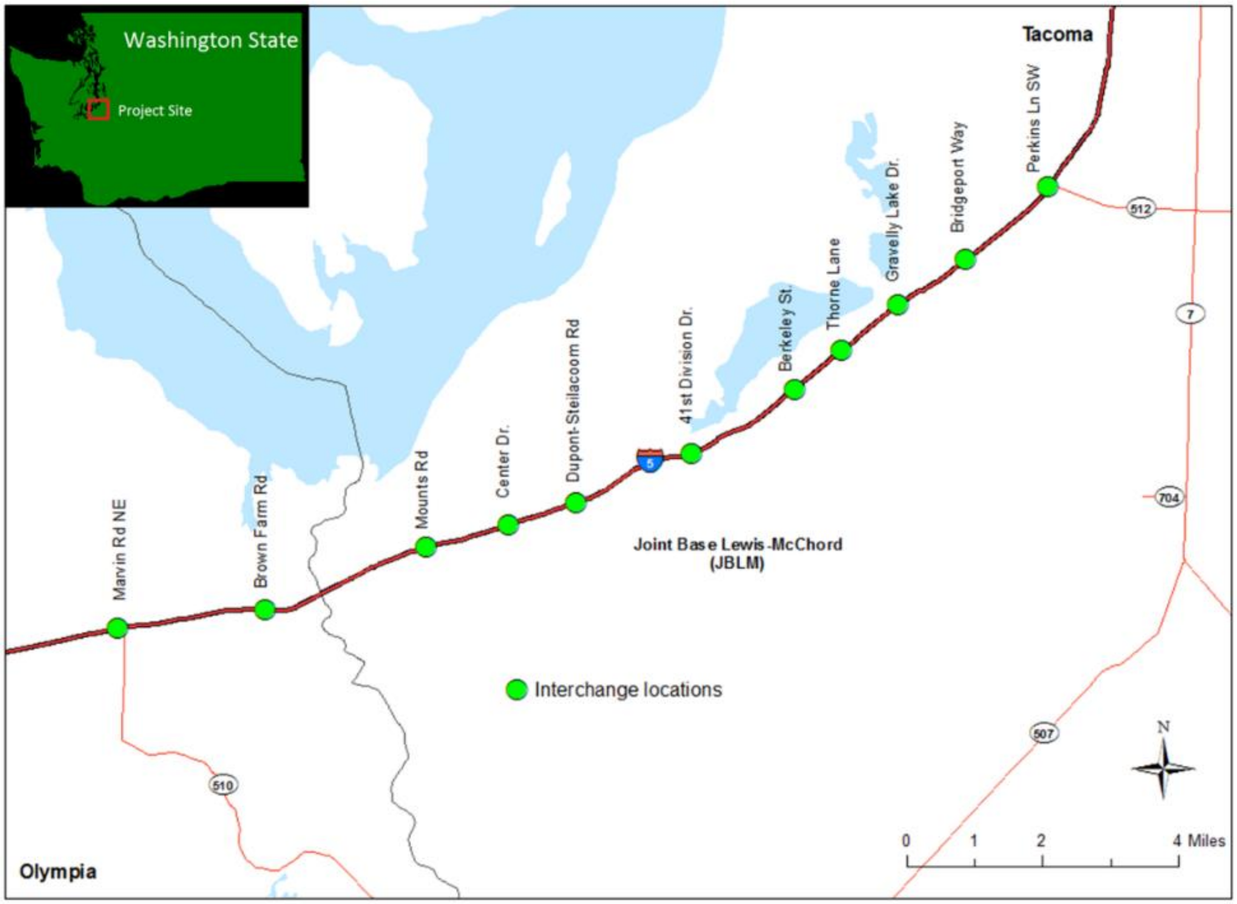



**Figure 8.1. Map of test site, I-5 through JBLM.**

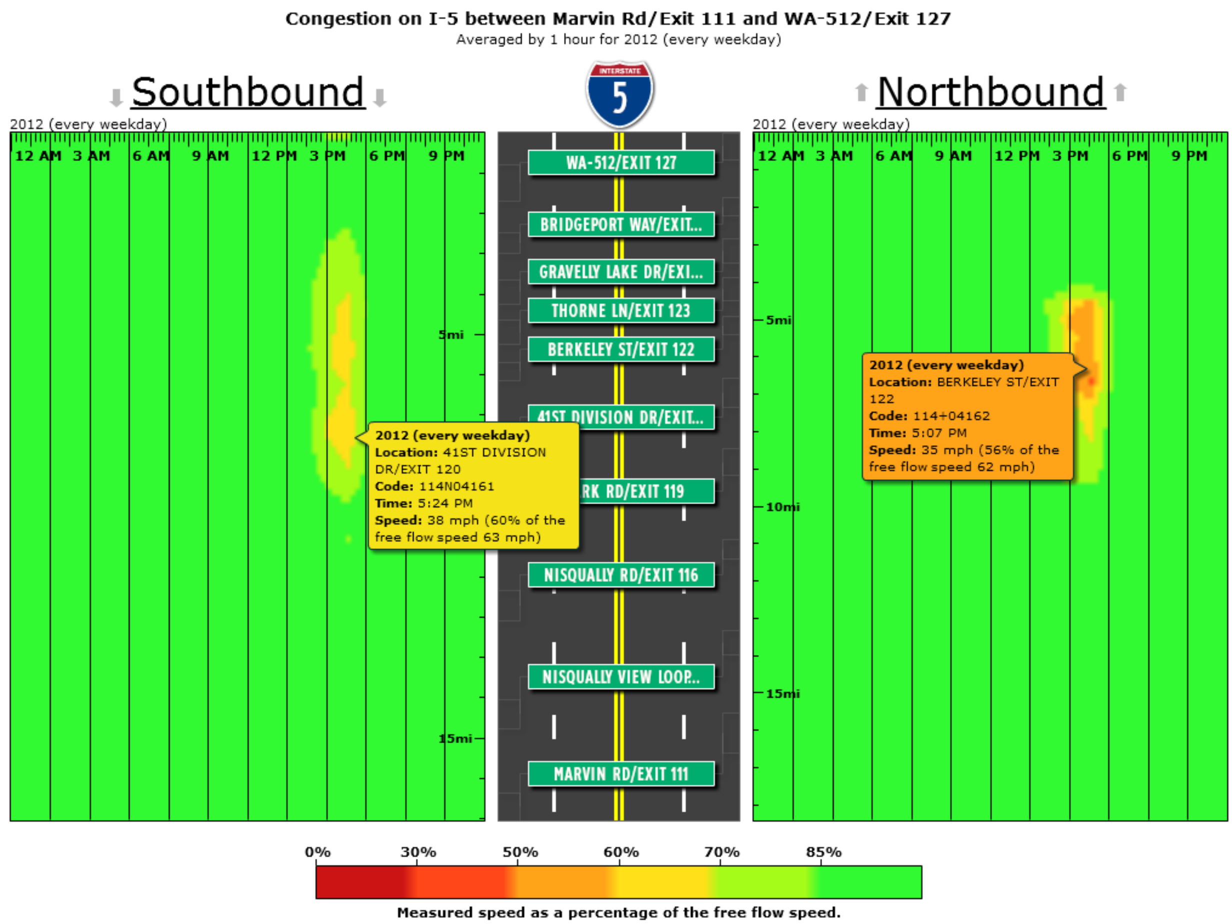



**Figure 8.2. INRIX congestion scan of I-5 JBLM area.**

## 8.3 Alternatives to Test

To test the travel time reliability tool, existing conditions (base case) and six conceptual alternative improvements (scenarios) have been evaluated. These scenarios are:

1. Hard shoulder running between 41st Division Drive and Thorne Lane, and ramp metering with HOV bypass at all interchanges between SR 510 and SR 512;
2. Extend 8 lanes from Berkeley Street interchange to Thorne Lane interchange and provide hard shoulder running between Mounts Road and Berkeley Street interchanges;
3. Add one lane each direction from Mounts Road to Thorne Lane;
4. Hard shoulder running from Mounts Road to Thorne Lane;
5. Ramp metering/increased incident response; and
6. Ramp metering/increased incident response in combination with Option 4.

## 8.4 Input Data

The travel time reliability tool helps perform estimates of travel time and reliability with minimal data. Data entry and scenario management have been made easier by providing a user-friendly interface (Figure 8.3). The tool comes with default data for some of the required data fields while providing options to replace them with project-specific data. Specifically the tool provides default data for the following variables:

- Travel time unit costs for personal and commercial travel;
- Effect of incident management strategies:
    - Reduction in incident frequency, and
    - Reduction in incident duration; and
- Reliability ratios (i.e., value of reliability over value of travel time) for personal and commercial travel.

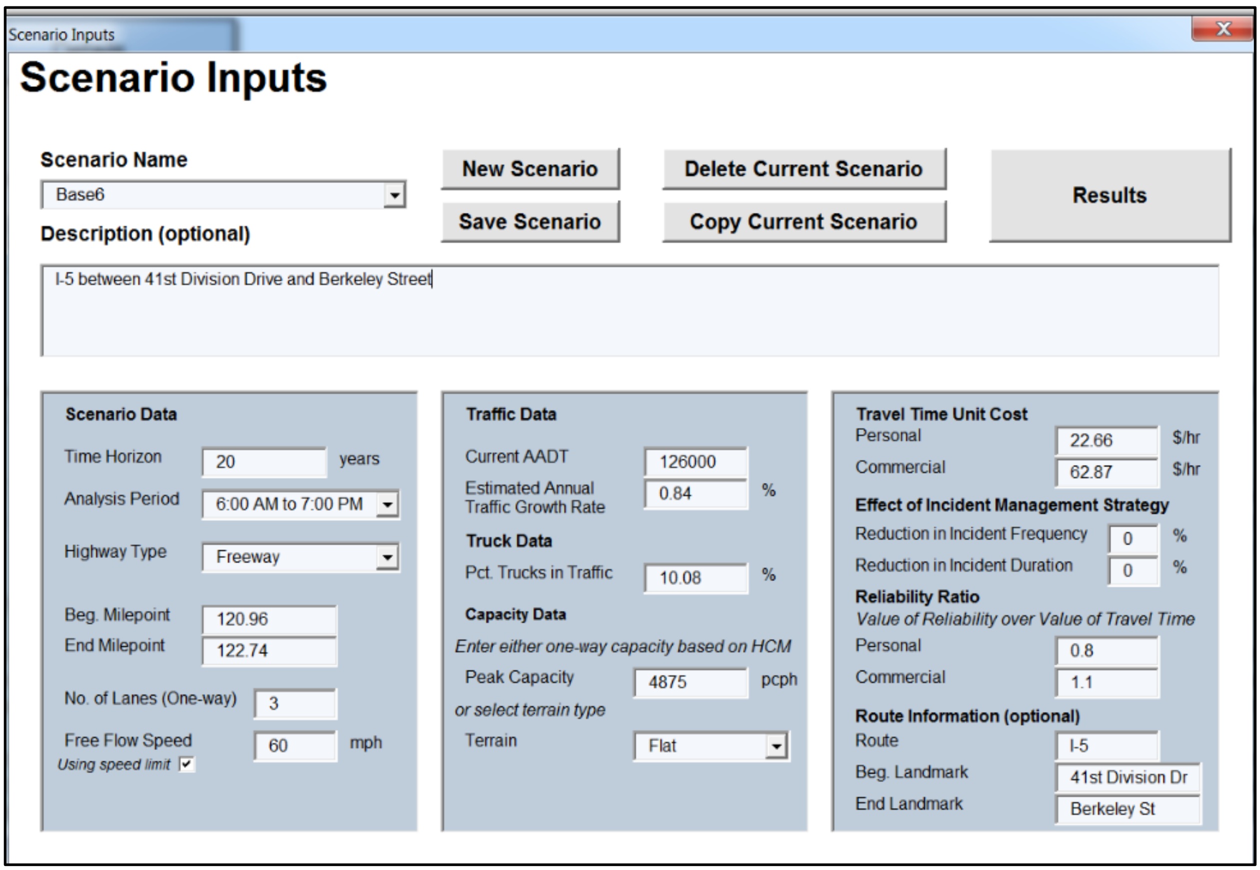



**Figure 8.3. Data input screen of the travel time reliability tool.**

The reliability tool allows evaluation of freeway mainline segments between interchanges. For this pilot study, I-5 through JBLM area has been divided into 10 segments (Figure 8.4). Necessary input data for these segments have been collected and/or generated using other tools. Reliability ratios for personal and commercial travel are the default values from the travel time reliability tool.

| Segment | ARM | | Length | Lanes | | Posted Speed | Base Year (2012) AADT | Annual Traffic Growth Rate | Truck | NB Capacity | SB Capacity | Terrain Type | Travel Cost | | Effect of Incident Mgt | | Reliability Ratio | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Begin | End | | NB | SB | | | | | | | | Personal Travel | Commercial Travel | Reduction in Incident Frequency | Reduction in Incident Duration | Personal Travel | Commercial Travel |
| | | | (mile) | | | (mph) | | (%) | (%) | (pcph) | (pcph) | | ($/hour) | ($/hour) | (%) | (%) | | |
| Marvin Rd NE (SR 510) to Brown Farm Rd NE | 112.01 | 114.18 | 2.17 | 3 | 3 | 60 | 99,000 | 1.21% | 12.06 | 4875 | 4875 | Level | $22.66 | $62.87 | 2.75 | 55 | 0.8 | 1.1 |
| Brown Farm Rd NE to Mounts Rd | 114.18 | 116.77 | 2.59 | 3 | 3 | 60 | 111,000 | 1.21% | 11.77 | 4875 | 4875 | Level | $22.66 | $62.87 | 2.75 | 55 | 0.8 | 1.1 |
| Mounts Rd to Center Dr | 116.77 | 118.02 | 1.25 | 3 | 3 | 60 | 120,000 | 1.21% | 11.77 | 4875 | 4875 | Level | $22.66 | $62.87 | 2.75 | 55 | 0.8 | 1.1 |
| Center Dr to Dupont-Steilacoom Rd | 118.02 | 119.07 | 1.05 | 3 | 3 | 60 | 121,000 | 0.84% | 11.77 | 4875 | 4875 | Level | $22.66 | $62.87 | 2.75 | 55 | 0.8 | 1.1 |
| Dupont-Steilacoom Rd to 41st Division Dr | 119.07 | 120.96 | 1.89 | 3 | 3 | 60 | 117,000 | 0.94% | 11.77 | 4875 | 4875 | Level | $22.66 | $62.87 | 2.75 | 55 | 0.8 | 1.1 |
| 41st Division Dr to Berkeley St | 120.96 | 122.74 | 1.78 | 3 | 3 | 60 | 126,000 | 0.84% | 10.08 | 4875 | 4875 | Level | $22.66 | $62.87 | 2.75 | 55 | 0.8 | 1.1 |
| Berkeley St to Thorne Lane | 122.74 | 123.64 | 0.90 | 3 | 3 | 60 | 134,000 | 0.94% | 10.08 | 4875 | 4875 | Level | $22.66 | $62.87 | 2.75 | 55 | 0.8 | 1.1 |
| Thorne Lane to Gravelly Lake Dr. | 123.64 | 124.71 | 1.07 | 4 | 4 | 60 | 143,000 | 0.94% | 10.08 | 6500 | 6500 | Level | $22.66 | $62.87 | 2.75 | 55 | 0.8 | 1.1 |
| Gravelly Lake Dr. to Bridgeport Way | 124.71 | 125.92 | 1.21 | 4 | 4 | 60 | 140,000 | 0.94% | 10.08 | 6500 | 6500 | Level | $22.66 | $62.87 | 2.75 | 55 | 0.8 | 1.1 |
| Bridgeport Way to SR 512 | 125.92 | 127.54 | 1.62 | 4 | 4 | 60 | 141,000 | 0.94% | 10.08 | 6500 | 6500 | Level | $22.66 | $62.87 | 2.75 | 55 | 0.8 | 1.1 |
| **Corridor - Marvin Rd to SR 512** | **112.01** | **127.54** | **15.53** | | | | | | | | | | | | | | | |

**Figure 8.4. Base year (2012) input data.**

## 8.5 Output Data

The travel time reliability tool provides different performance metrics in an easy-to-understand format, which aids the users in interpreting and communicating the results of analyses. For example, the tool generates an overall mean TTI, 95th percentile TTI, 80th percentile TTI, 50th percentile TTI, as well as a proportion of trips below 45 and 30 mph speed (an example of output is shown in Figure 8.5). Also performance measures are generated for the base year and a future year assuming an analysis period of 20 years.

In addition to performance metrics, the study team developed estimates of travel delay under each conceptual scenario (Figure 8.6). The tool helps estimate congestion delays separately for both personal and commercial travel. All improvement options show reduced congestion delays compared to the base case indicating the tool is sensitive to roadway improvements. “Hard shoulder running with ramp metering and increased incident response” provided most benefits in terms of congestion delay reduction.

| Scenario | Congestion Metrics | SR 510 to Brown Farm Rd | Brown Farm Rd to Mounts Rd | Mounts Rd to Center Dr | Center Dr to Dupont-Steilacooom Rd | Dupont-Steilacoom Rd to 41st Division Dr | 41st Division Dr to Berkeley St | Berkeley St to Thorne Lane | Thorne Lane to Gravelly Lake Dr | Gravelly Lake Dr to Bridgeport Way | Bridgeport Way to SR 512 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2012 Base Case | Overall mean TTI | 1.12 | 1.10 | 1.21 | 1.22 | 1.16 | 1.37 | 1.56 | 1.18 | 1.17 | 1.18 |
| | $TTI_{95}$ | 1.37 | 1.34 | 1.66 | 1.67 | 1.51 | 1.99 | 2.39 | 1.53 | 1.51 | 1.51 |
| | $TTI_{80}$ | 1.16 | 1.13 | 1.31 | 1.32 | 1.23 | 1.56 | 1.85 | 1.27 | 1.26 | 1.26 |
| | $TTI_{50}$ | 1.07 | 1.05 | 1.15 | 1.15 | 1.10 | 1.29 | 1.48 | 1.14 | 1.13 | 1.13 |
| | % trips less than 45 mph | 13.9% | 13.3% | 24.0% | 24.5% | 19.3% | 32.6% | 41.9% | 18.4% | 17.6% | 17.7% |
| | % trips less than 30 mph | 2.3% | 1.4% | 4.5% | 4.6% | 2.7% | 12.8% | 23.1% | 5.7% | 5.5% | 5.5% |
| | | | | | | | | | | | |
| 2012 Scenario 1 | Overall mean TTI | 1.07 | 1.08 | 1.13 | 1.13 | 1.10 | 1.04 | 1.06 | 1.10 | 1.10 | 1.10 |
| | $TTI_{95}$ | 1.25 | 1.29 | 1.42 | 1.43 | 1.34 | 1.14 | 1.21 | 1.32 | 1.31 | 1.31 |
| | $TTI_{80}$ | 1.10 | 1.11 | 1.18 | 1.18 | 1.13 | 1.05 | 1.08 | 1.14 | 1.13 | 1.13 |
| | $TTI_{50}$ | 1.04 | 1.04 | 1.07 | 1.08 | 1.05 | 1.02 | 1.03 | 1.06 | 1.06 | 1.06 |
| | % trips less than 45 mph | 9.7% | 11.3% | 16.3% | 16.5% | 13.3% | 5.4% | 8.1% | 12.2% | 11.8% | 12.0% |
| | % trips less than 30 mph | 1.2% | 1.2% | 1.8% | 1.8% | 1.4% | 0.8% | 1.0% | 1.8% | 1.7% | 1.7% |
| | | | | | | | | | | | |
| 2032 Base Case | Overall mean TTI | 1.37 | 1.64 | 1.87 | 1.65 | 1.64 | 1.77 | 2.06 | 1.35 | 1.33 | 1.34 |
| | $TTI_{95}$ | 1.99 | 2.58 | 3.06 | 2.60 | 2.58 | 2.86 | 3.42 | 1.96 | 1.92 | 1.93 |
| | $TTI_{80}$ | 1.56 | 1.98 | 2.33 | 1.99 | 1.97 | 2.18 | 2.60 | 1.53 | 1.51 | 1.51 |
| | $TTI_{50}$ | 1.29 | 1.55 | 1.77 | 1.56 | 1.55 | 1.68 | 1.94 | 1.28 | 1.26 | 1.27 |
| | % trips less than 45 mph | 32.6% | 47.6% | 58.6% | 48.0% | 47.6% | 54.1% | 67.1% | 31.9% | 30.5% | 30.9% |
| | % trips less than 30 mph | 12.7% | 24.8% | 33.5% | 25.0% | 24.8% | 29.7% | 37.0% | 12.9% | 12.5% | 12.6% |
| | | | | | | | | | | | |
| 2032 Scenario 1 | Overall mean TTI | 1.19 | 1.58 | 1.68 | 1.57 | 1.56 | 1.18 | 1.11 | 1.22 | 1.17 | 1.18 |
| | $TTI_{95}$ | 1.60 | 2.44 | 2.68 | 2.42 | 2.39 | 1.52 | 1.36 | 1.64 | 1.54 | 1.56 |
| | $TTI_{80}$ | 1.28 | 1.89 | 2.04 | 1.88 | 1.85 | 1.27 | 1.14 | 1.32 | 1.25 | 1.25 |
| | $TTI_{50}$ | 1.13 | 1.49 | 1.59 | 1.49 | 1.48 | 1.13 | 1.06 | 1.16 | 1.11 | 1.12 |
| | % trips less than 45 mph | 22.2% | 43.4% | 50.1% | 43.0% | 41.9% | 18.2% | 13.9% | 22.9% | 20.3% | 20.8% |
| | % trips less than 30 mph | 3.7% | 23.4% | 25.9% | 23.3% | 23.0% | 5.6% | 1.5% | 5.9% | 3.0% | 3.1% |

**Figure 8.5. Corridor performance indicators.**

| Scenario | Project Description | Annual Weekday Delay (vehicle-hours) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 2012 | | | | 2032 | | |
| | | Passenger Vehicles | Commercial Vehicles | Total Delay | | Passenger Vehicles | Commercial Vehicles | Total Delay |
| **Base Case** | Existing roadway as in 2012 | 991,000 | 138,000 | 1,129,000 | | 3,274,000 | 466,000 | 3,740,000 |
| **1** | Hard shoulder running between 41st Division Dr and Thorne Lane; and ramp metering with HOV bypass at all interchanges between SR 510 and SR 512 | 383,000 | 57,000 | 440,000 | | 1,982,000 | 294,000 | 2,276,000 |
| **2** | Extend 8 lanes from Thorne Lane to the Berkeley I/C; and provide hard shoulder running between Mounts Rd and Berkeley I/C | 481,000 | 68,000 | 549,000 | | 1,639,000 | 238,000 | 1,877,000 |
| **3** | Add one lane each direction from Mounts Rd to Thorne Lane | 508,000 | 71,000 | 579,000 | | 1,673,000 | 242,000 | 1,915,000 |
| **4** | Hard shoulder running from Mounts Rd to Thorne Lane | 499,000 | 70,000 | 569,000 | | 1,665,000 | 241,000 | 1,906,000 |
| **5** | Ramp metering and increased incident response | 151,000 | 22,000 | 173,000 | | 772,000 | 113,000 | 885,000 |
| **6** | Hard shoulder running with ramp metering and increased incident response | 110,000 | 17,000 | 127,000 | | 322,000 | 48,000 | 370,000 |

**Figure 8.6. Estimates of annual travel delay.**

Congestion cost was estimated using the travel time reliability tool. Congestion costs for base case and alternative options are shown in Figure 8.7. The cost of recurring congestion and the cost of unreliability (also known as the cost of nonrecurring congestion) were estimated. The hourly values of travel time for passenger and commercial vehicles were assumed to be $22.66 and $62.87, respectively. The total cost of congestion for 2012 base condition is estimated to be about $31 million (in 2012 dollar values).

| Scenario | Project Description | Annual Weekday Congestion Cost (in 2012$ values) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 2012 | | | | 2032 | | |
| | | Recurring Congestion | Unreliability | Total | | Recurring Congestion | Unreliability | Total |
| **Base Case** | Existing roadway as in 2012 | $25,109,000 | $6,026,000 | $31,135,000 | | $78,734,000 | $24,734,000 | $103,468,000 |
| **1** | Hard shoulder running between 41st Division Dr and Thorne Lane; and ramp metering with HOV bypass at all interchanges between SR 510 and SR 512 | $10,814,000 | $1,418,000 | $12,232,000 | | $49,287,000 | $14,092,000 | $63,379,000 |
| **2** | Extend 8 lanes from Thorne Lane to the Berkeley I/C; and provide hard shoulder running between Mounts Rd and Berkeley I/C | $12,722,000 | $2,459,000 | $15,181,000 | | $40,808,000 | $11,289,000 | $52,097,000 |
| **3** | Add one lane each direction from Mounts Rd to Thorne Lane | $13,420,000 | $2,587,000 | $16,007,000 | | $41,659,000 | $11,484,000 | $53,143,000 |
| **4** | Hard shoulder running from Mounts Rd to Thorne Lane | $13,142,000 | $2,561,000 | $15,703,000 | | $41,420,000 | $11,460,000 | $52,880,000 |
| **5** | Ramp metering and increased incident response | $4,453,000 | $374,000 | $4,827,000 | | $20,787,000 | $3,825,000 | $24,612,000 |
| **6** | Hard shoulder running with ramp metering and increased incident response | $3,235,000 | $296,000 | $3,531,000 | | $9,190,000 | $1,158,000 | $10,348,000 |

**Figure 8.7. Estimates of annual costs to travelers resulting from congestion.**

## 8.6 Cost of Alternatives

To perform economic analyses and compare project alternatives, it is necessary to estimate both benefits and costs of alternatives. The travel time reliability tool helps estimate travel time and reliability benefits. Cost estimation of alternatives has been performed using WSDOT's Planning Level Cost Estimation (PLCE) tool.

PLCE is a database tool to perform cost estimation for projects that are very conceptual, often with minimum or no design. The tool has been developed to estimate costs for varieties of projects namely widening existing roadways or bridges, building new roads or bridges, modifying existing interchanges or building new ones, improving intersections, and installing ITSs.

PLCE uses a unit price approach that accounts for regional differences as well as differences in land use types and development density within a region. Since unit prices vary by geographic area, separate unit prices are used in the estimate depending on where the project is located. Within each geographic area, unit prices are again a function of density of development such as rural, suburban, urban, and dense urban.

The tool comes with default quantities per lane-mile for common items such as grading, drainage, pavement, traffic control, etc. The underlying assumption of the methodology is that little or no geotechnical data are known at the time of planning-level estimate.

Furthermore, the tool comes with default unit costs obtained from historical data of WSDOT's past projects. Some unit prices were adjusted for differences in area prices, terrain (e.g., level, rolling, or mountainous), ground conditions, and design assumptions. These unit costs can be easily edited through user-friendly interfaces. An example of selecting project components to be included in the estimation is shown in Figure 8.8. (Additional information about the tool is available at http://www.wsdot.wa.gov/mapsdata/travel/pdf/PLCEManual_12-12-2012.pdf.)

A summary of estimated costs of alternatives is presented in Figure 8.9. Ramp metering and incident response (Scenario 5) would cost the least, while adding a lane in each direction between Mounts Road and Thorne Lane (Scenario 3) would cost the most. Scenario 3 requires the addition of two new lanes and reconstruction of a few interchanges and bridges, resulting in a much higher cost compared to other scenarios.

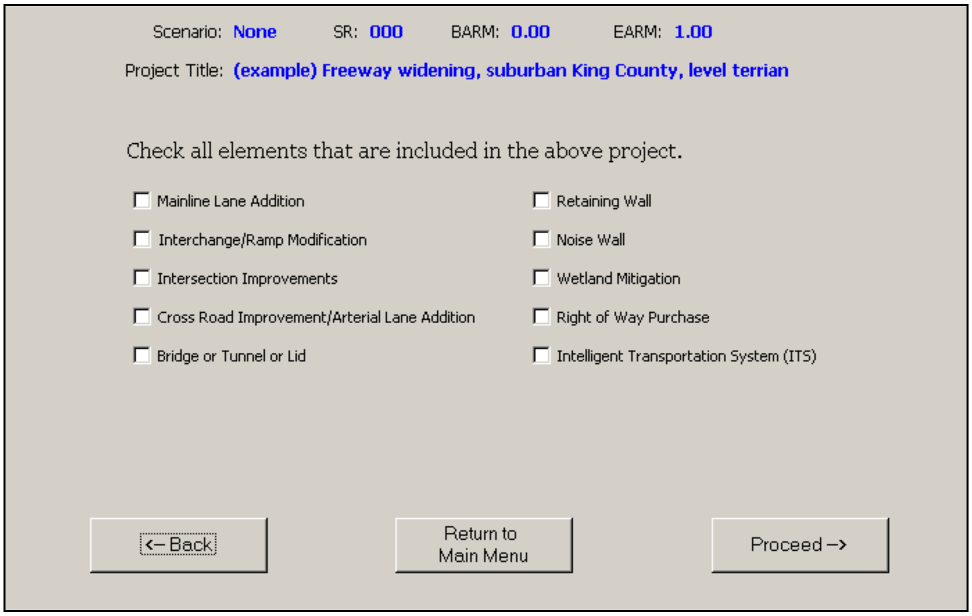



**Figure 8.8. Main menu of the PLCE tool.**

| Scenario | Project Description | Cost Range | Project Cost (2012$) | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | PE | ROW | Structures | Drainage & Grading | Others | Total Initial Capital Cost |
| 1 | Hard shoulder running between 41st Division Dr and Thorne Lane; and ramp metering with HOV bypass at all interchanges between SR 510 and SR 512 | Low | $900,000 | $26,370,000 | $1,350,000 | $0 | $0 | $28,620,000 |
| | | High | $1,200,000 | $35,160,000 | $1,800,000 | $0 | $0 | $38,160,000 |
| 2 | Extend 8 lanes from Thorne Lane to the Berkeley I/C; and provide hard shoulder running between Mounts Rd and Berkeley I/C | Low | $7,698,000 | $0 | $12,448,000 | $25,753,000 | $64,563,000 | $110,462,000 |
| | | High | $10,264,000 | $0 | $16,597,000 | $34,337,000 | $86,084,000 | $147,282,000 |
| 3 | Add one lane each direction from Mounts Rd to Thorne Lane | Low | $14,518,000 | $0 | $13,469,000 | $52,448,000 | $127,893,000 | $208,328,000 |
| | | High | $19,357,000 | $0 | $17,959,000 | $69,930,000 | $170,524,000 | $277,770,000 |
| 4 | Hard shoulder running from Mounts Rd to Thorne Lane | Low | $2,296,000 | $0 | $2,889,000 | $6,715,000 | $21,051,000 | $32,951,000 |
| | | High | $3,061,000 | $0 | $3,852,000 | $8,953,000 | $28,068,000 | $43,934,000 |
| 5 | Ramp metering and increased incident response | Low | $1,303,000 | $0 | $0 | $0 | $17,395,000 | $18,698,000 |
| | | High | $1,738,000 | $0 | $0 | $0 | $23,194,000 | $24,932,000 |
| 6 | Hard shoulder running with ramp metering and increased incident response | Low | $3,599,000 | $0 | $2,889,000 | $6,715,000 | $38,446,000 | $51,649,000 |
| | | High | $4,799,000 | $0 | $3,852,000 | $8,953,000 | $51,262,000 | $68,866,000 |

**Figure 8.9. Estimated costs of alternatives.**

## 8.7 Benefit–Cost Analysis

The travel time reliability tool performs an estimation of travel benefits. However, it does not facilitate performing benefit–cost analysis incorporating project costs and benefits. This analysis has been conducted outside the reliability tool using methodology in WSDOT's benefit–cost analysis tool (known as MP3B-C tool). This tool was found to be suitable for conducting benefit–cost analysis for the type of projects being analyzed and available data.

A summary of the benefit–cost analysis is shown in Figure 8.10. The analysis was performed with a set of assumptions that include the following:

- An analysis period of 20 years;
- Annual discount rate of 4% (used to convert future costs and benefits to present values);
- Benefits include travel time savings and reduction of unreliability;
- Personal and commercial travel time values are $22.66 and $62.87 per hour, respectively;
- Residual values were used to adjust the benefit–cost ratio to account for the value of the improvement remaining after 20 years (the residual value methodology is based on work done for AASHTO by the Texas Transportation Institute) and was done by applying the following factors to the project's estimated costs:
    - Right of way, 0.45,
    - Grading and drainage, 0.40,
    - Structures, 0.43, and
    - All other costs (including PE), 0.00;
- Annual roadway operations and maintenance cost is $16,500 (in 2012 dollar values) per lane-mile;
- Annual IRT cost is $7,000 (in 2012 dollar values) per lane-mile; and
- Annual signal/ramp meter operations and maintenance cost is $1,200 (in 2012 dollar values).

| Scenario | Project Description | Cost Range | During 20-Year Analysis Period | | | | B/C Ratio |
|---|---|---|---|---|---|---|---|
| | | | Capital Cost | O&M Cost | Total Project Cost | Travel Time & Reliability Benefit | |
| 1 | Hard shoulder running between 41st Division Dr and Thorne Lane; and ramp metering with HOV bypass at all interchanges between SR 510 and SR 512 | Low | $16,173,000 | $6,300,000 | $22,473,000 | $619,416,000 | 27.56 |
| | | High | $21,564,000 | $6,300,000 | $27,864,000 | $619,416,000 | 22.23 |
| 2 | Extend 8 lanes from Thorne Lane to the Berkeley I/C; and provide hard shoulder running between Mounts Rd and Berkeley I/C | Low | $94,808,000 | $4,770,000 | $99,578,000 | $706,912,500 | 7.10 |
| | | High | $126,410,000 | $4,770,000 | $131,180,000 | $706,912,500 | 5.39 |
| 3 | Add one lane each direction from Mounts Rd to Thorne Lane | Low | $181,557,000 | $4,770,000 | $186,327,000 | $687,256,500 | 3.69 |
| | | High | $242,076,000 | $4,770,000 | $246,846,000 | $687,256,500 | 2.78 |
| 4 | Hard shoulder running from Mounts Rd to Thorne Lane | Low | $29,023,000 | $4,770,000 | $33,793,000 | $693,210,000 | 20.51 |
| | | High | $38,696,000 | $4,770,000 | $43,466,000 | $693,210,000 | 15.95 |
| 5 | Ramp metering and increased incident response | Low | $18,698,000 | $2,570,000 | $21,268,000 | $1,104,222,000 | 51.92 |
| | | High | $24,932,000 | $2,570,000 | $27,502,000 | $1,104,222,000 | 40.15 |
| 6 | Hard shoulder running with ramp metering and increased incident response | Low | $47,721,000 | $7,340,000 | $55,061,000 | $1,267,602,000 | 23.02 |
| | | High | $63,628,000 | $7,340,000 | $70,968,000 | $1,267,602,000 | 17.86 |

**Figure 8.10. Summary of benefit–cost analysis.**

To prepare TIGER III Grant Application for I-5 JBLM project, WSDOT conducted an economic analysis using TREDIS software. The total project benefit–cost ratio, based on anticipated project design and construction costs, as well as on all monetized benefits, including travel time, vehicle operating costs, reliability, safety, freight, and environmental, was estimated to range from 5.67 to 8.38. Travel time and reliability benefits were estimated to amount to $123.8 million (undiscounted) for 24 years.

The travel time reliability tool provides estimates of benefits that include recurring congestion reduction and reliability improvements. When analyzed the same JBLM project using the travel time reliability tool with roadway capacity (2,190 pcphpl) from the HCM (as suggested by the tool), the benefit–cost ratio ranged from 1.96 to 2.43. Given this tool is considering only direct benefits from travel time and reliability improvements, the values are expected to be somewhat lower than those from analyses for TIGER III Grant Application (using TREDIS software). However, the benefit–cost ratios from the travel time reliability tool seem to be too low when compared with the values from TIGER III Grant Application.

When researchers analyzed the same JBLM project using the travel time reliability tool with reduced roadway capacity (1,625 pcphpl), the benefit–cost ratio ranged from 22.23 to 27.56. In this case, the benefit–-cost ratios from the travel time reliability tool are found to be much higher than the values from TIGER III Grant Application.

## 8.8 Validation of Outputs from the Travel Time Reliability Tool

Validation of outputs from the reliability tool was done by comparing the base year outputs, particularly total travel delay and delay cost, from this tool to the similar data from INRIX analytic tools (Figure 8.11). (More information about the INRIX Traffic Analytic Tools is available at http://www.itproportal.com/2013/09/21/a-closer-look-at-inrix-the-worlds-largest-traffic-intelligence-network/#ixzz2hubtfXAB.)

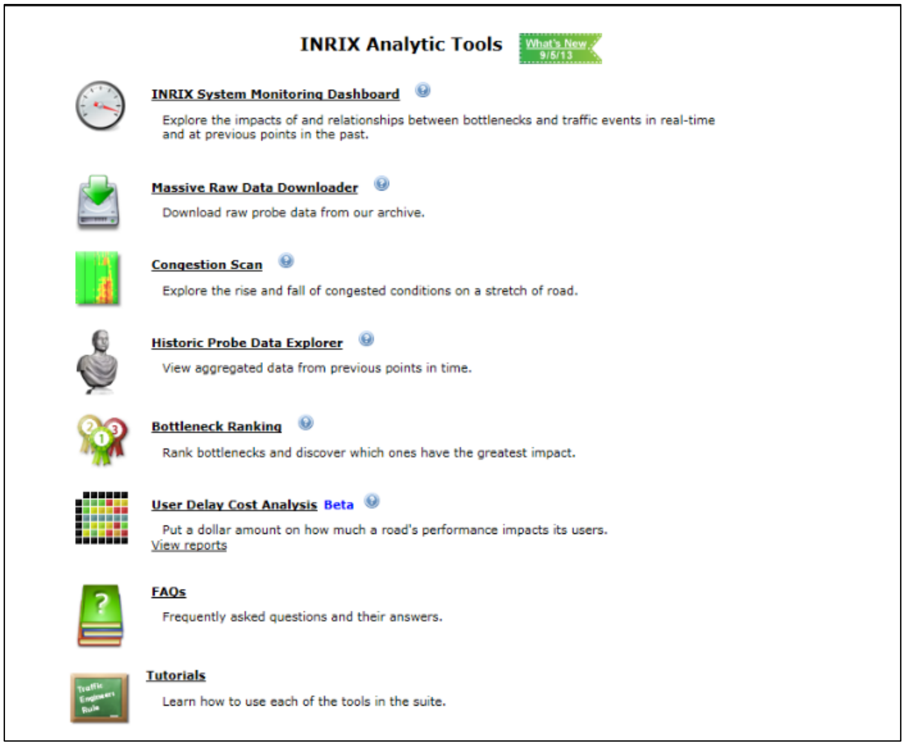



**Figure 8.11. Snapshot of INRIX Traffic Analytic Tools.**

INRIX recently added a new module called "User Delay Cost Analysis" to generate travel delay costs for each hour of a day for 365 days. For maintaining consistency of data, cost of congestion was estimated using INRIX analytic tools by applying the same hourly value of travel time for passenger and commercial vehicles as were assumed in the travel time reliability tool. The 2012 annual weekday cost of congestion from INRIX was $17,192,000 (in 2012 dollar values), while the travel time reliability tool showed a value of $1,720,000 when HCM capacity was used and a value of $31,135,000 when reduced capacity (1,625 pcphpl) was used. While using HCM capacity in the travel time reliability tool, INRIX data indicated about 10 times higher congestion cost than that from the travel time reliability tool. In contrast, INRIX data indicated about 45% lower congestion cost than that from the travel time reliability tool with reduced capacity.

For validation purposes TTI data from both the travel time reliability tool and INRIX were compared. The reliability tool with HCM capacity indicates less severe congestion than indicated by INRIX data. An example of TTI values between Berkeley Street and Thorne Lane is shown in Figure 8.12. It is also observed that TTI values from the reliability tool are more or less the same (close to 1 indicating not much of congestion) during both peak and off-peak periods.

Note that the reliability tool provides an overall TTI for both direction of travel instead of providing separate indices for each direction.

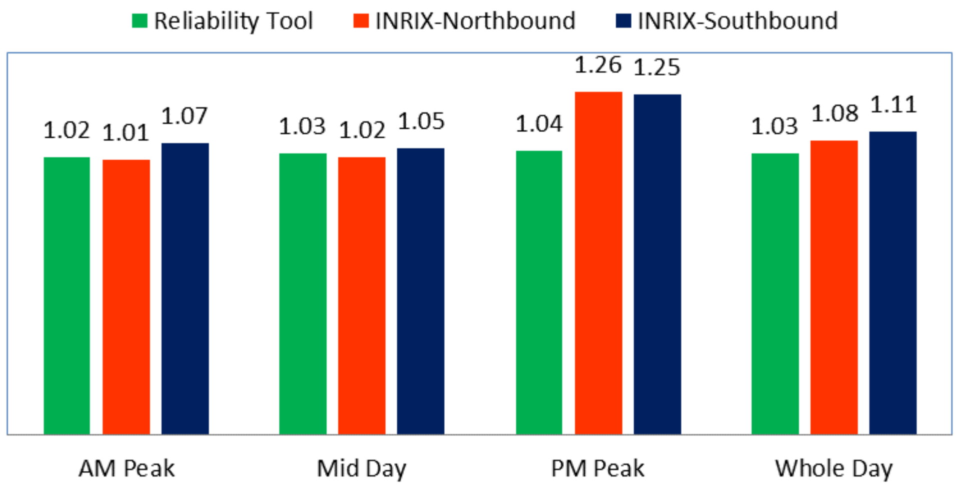



**Figure 8.12. TTI values for 2012 base case using HCM capacity.**

To further investigate if the tool underestimates congestion or it is because of inaccurate data entered into the tool, researchers rechecked the data used in the first round of analyses. No data issues were found. Then additional tests were conducted on I-405 between I-90 and 8th Street SE. These additional tests also indicated lower than expected congestion (i.e., TTI values).

In addition sensitivity analyses were performed by inputting lower capacity than that calculated using HCM methodologies. When reduced roadway capacity (e.g., congested capacity) is used, the reliability tool produces higher TTI values and indicates sensitivity to time of day. For example, a comparison of 2012 TTI values from INRIX and the reliability tool is presented in Figure 8.13 for the same I-5 segment between Berkeley Street and Thorne Lane.

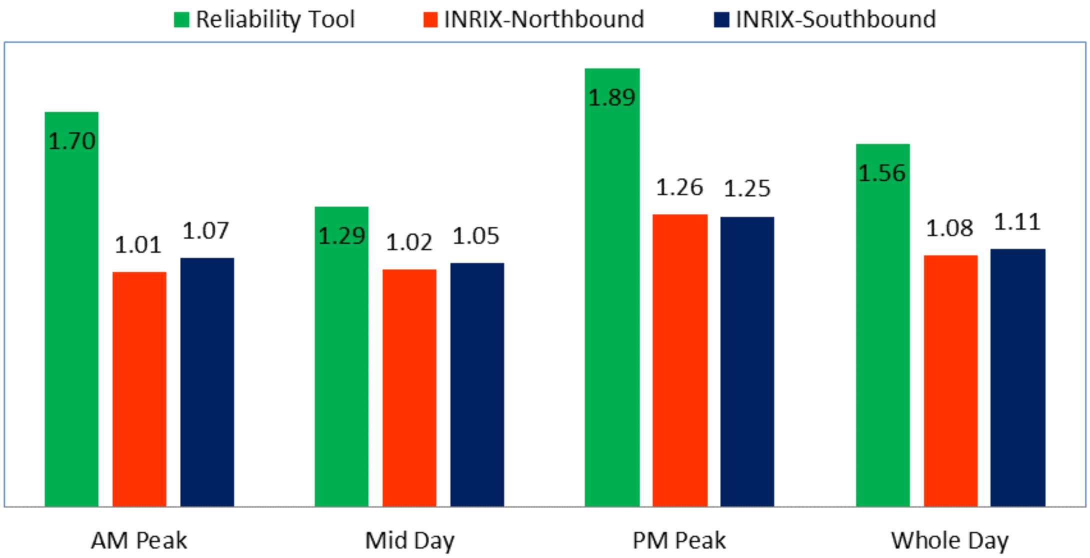



**Figure 8.13. TTI values for 2012 base case using congested capacity.**

If TTI values are generated by direction as well as by time of day, it becomes easier to understand which direction of travel experiences congestion effects at what time of the day. For example, INRIX data indicate relatively higher congestion in northbound direction during p.m. peak period (3:00 p.m. to 7:00 p.m.). The reliability tool does not show TTI values by direction, and therefore it is not possible to assess which direction of travel experiences what level of congestion at what time of the day.

## 8.9 Assessment of the Travel Time Reliability Tool

The research team conducted an assessment of the travel time reliability tool for its input requirements, ease of use, calculation algorithms, usefulness and organization of output data, scenario management, and reasonableness of the results produced by the tool. A summary of the assessment is provided below.

## 8.10 General Observations

The travel time reliability tool requires minimal data and appears to be easy to use. The tool has been designed to require data that can be easily collected or assembled by those conducting a sketch planning study. The required data can be acquired from widely used data sources.

The tool comes with simple and easy scenario management features. The tool facilitates analyses of multiple scenarios by allowing creating and saving new scenarios with relative ease. The tool displays results of the base and alternative scenarios side by side for ease of comparison.

This tool allows users to perform quick assessment of the effects of highway investments. It allows conducting assessment of transportation investment benefits in terms of reducing recurring delay as well as improving travel time reliability. Most of the existing economic analysis tools consider only recurring delay while excluding the effects of travel time reliability. Since this tool accounts for this additional benefit from travel time reliability, it is expected to show more positive effects of a highway investment on the economy than typical estimates using traditional tools and methodologies.

The tool was tested on a wide range of improvement options. A few observations regarding the analysis results are:

- The tool estimates travel delay that is about one-tenth of the values from INRIX traffic analysis tools. It seems like the tool underestimates travel impacts. This could be because of the fact that the tool does not account for impacts from traffic volume other than mainline volume, although ramp spacing and ramp traffic volume may have considerable effect on freeway operations. Particularly the I-5 ramp traffic volume along JBLM is thought to be the primary cause of congested condition along this stretch of the facility, but the tool does not analyze the freeway mainline and ramps together as a system.
- The travel time reliability tool uses three sets of hourly traffic distribution factors for peak travel direction of a roadway. The tool selects one of these three sets based on AADT/capacity ratio: less than 7.0, 7.1 to 11.0, and greater than 11.0. Base case and an improvement option could sometimes have different AADT/capacity ratio leading to usage of a different set of hourly distribution factors, and thus an improvement option might sometimes show worse traffic congestion than the base case.

  For example, the study included a 6-lane freeway segment with AADT of 111,000. The roadway capacity (in this case researchers used congested capacity) for the base case was 9,750 pcph (passenger cars per hour) and that of the improvement option was 10,285 pcph (assuming 5.5% increase of capacity because of ramp meters and HOV bypass lanes). This combination of AADT and capacity generates AADT/capacity ratios of 11.38 and 10.79 for the base case and the alternative. These ratios lead to use of different hourly distribution sets for the base case and alternative option resulting in higher TTI values for the alternative option (overall mean TTI values of 1.10 for the base case and 1.22 for the alternative option) even though the alternative option has higher capacity and expected to reduce congestion. In this case, the tool indicates congestion would increase even though traffic carrying capacity of the freeway is being increased.
- When roadway capacity based on HCM was used (as suggested by the tool), the nonrecurring congestion delay appeared to be much higher than that of recurring congestion for all improvement scenarios. However, when reduced roadway capacity was used, the tool produced nonrecurring congestion delay ranging from 8% to 19% for the scenarios, which is more in line with the expectation. Note that a 2003 report by Washington Transportation Center titled *Measurement of Recurring versus Nonrecurring Congestion: Technical Report* shows nonrecurring congestion ranging from 5% to 58%

depending on type of estimate (e.g., conservative or liberal). This report is found at http://www.wsdot.wa.gov/research/reports/fullreports/568.1.pdf.

## 8.11 Applicability

In assessing the tool, special attention was given to the applicability of the tool to evaluate various improvement scenarios. An overview of the assessment follows:

- The travel time reliability tool requires minimal data for performing assessment of impacts of highway investments. Most of the data the tool requires seem to be relatively easy to gather. So the tool can easily be used as a sketch planning tool for analysis of travel time and reliability effects of some of the conceptual improvements typically analyzed as part of planning studies.
- In assessing travel benefits, the travel time reliability tool accounts for impacts of reduced incident frequency and duration resulting from incident management strategies. However, it does not provide any default input values or any sources or references to get help in developing input data. The effects of incident management strategies have to be estimated outside this tool and then entered as input into this tool.
- The calculation methodology is directly applicable only to a roadway mainline (segments between interchanges/intersections), not to improvements at roadway intersections, interchanges, and freeway ramps. Therefore, it may not provide a comprehensive assessment of transportation options, because it does not perform analysis on a system of freeway mainline, ramps, and connecting roads accounting for vehicle interactions at the junctions.
- The tool has been designed to evaluate roadway capacity improvements (e.g., adding lanes). It does not come with a methodology to estimate benefits from varieties of transportation improvement types including ITS improvements, demand management strategies, etc. Therefore, this tool does not seem to be applicable to analysis of all sorts of transportation improvements typically considered by an agency.
- This tool does not perform any benefit–cost analysis; it just produces travel time and reliability benefits that can be used in a benefit–cost analysis. So for comparing alternatives, further economic analyses need to be performed using other appropriate tools.

# CHAPTER 9
# Conclusions and Potential Improvements

## 9.1 Summary and Conclusions

In sum, the research team has tested and evaluated the analytical products from the SHRP 2 projects. The major conclusions for each product are summarized as follows:

The L02 methodology builds a strong foundation for travel time reliability monitoring. In this project, travel time calculations and congestion data were acquired from single-loop detectors at 5-minute intervals. Nonrecurring condition data for incidents and weather were taken from the WITS and local weather stations. Plotting these data with cumulative distribution functions provided a clear diagnosis for each route by analyzing performance under congestion and nonrecurring conditions and provides a strong framework for comparison between routes. For example, comparing distributions for the alternative routes of I-5 and I-405 in the Seattle Metro Area clearly highlighted that I-405 was more reliable across various levels of congestion and nonrecurring conditions. The use of L02 to analyze reliability performance of roadway improvements was also tested and found to be quite effective. However, this analysis was found to be most effective at a smaller scale than at the route level since these improvements often affect a much smaller portion of roadway. For example, the I-405 Braided Ramps Project that was tested modified approximately 1 mile of roadway. Therefore, reliability performance measurement was scaled down to a 3-mile segment, where improvement in reliability across most conditions was clearly observed. Additionally, research revealed that the cumulative distribution charts provided primarily qualitative reliability information. The use of pie charts to show regime breakdown, and standard deviation of TTI to measure reliability improvements, were helpful in converting reliability information to quantitative results. The most practical application for the L02 methodology and results was to upload them to the DRIVE Net platform. DRIVE Net is an online tool where transportation agencies and everyday commuters can view travel time reliability information for any route or combination of routes. This accessible information can aid roadway improvement planning and evaluation and help drivers find the best commute routes.

For the pilot test of L07, various traffic data have been used, including WSDOT DRIVE Net Gray Notebook capacity analysis, single-loop detector data, traffic accident data, and WSDOT projects information. This study compared the measure of effectiveness, TTI curve, and the benefit–cost analysis with the results computed based on empirical data. The test results suggest that the tool tends to underestimate travel time under high traffic volumes and to generate overoptimistic measure of effectiveness and TTI curves. The major findings are (1) the classification of treatment types is trivial and inefficient, and the 15 types of very specific treatments are unable to address actual projects; (2) it is difficult to define some parameters for the treatment (e.g., the reduction of average accident clearance time) for the benefit–cost analysis; (3) travel time reliability improvement only takes up a small portion of the total treatment benefit; (4) the major benefits result from the reduction of number of accidents, and the accuracy in estimating the future accident number is the key factor influencing the benefit–cost analysis results; and (5) the detailed results and TTI curves are inaccessible, which limits further comparison.

For FREEVAL, tests were conducted to verify tool accuracy for two different study sites in Seattle, Washington: an urban section of I-5 with a high ramp density and a less urban section of I-405 with zero ramps. Ground truth travel times for each study site were calculated from spot speed data collected from dual-loop detectors. The Gray Notebook procedure was used to calculate segment-level travel times from spot speeds. The results obtained from this study by comparing the predicted travel time distribution outputted from FREEVAL to the ground truth travel times show that FREEVAL tends to be overoptimistic in its predictions of travel times. A second test comparing results between different seed days showed that the seed day does have an influence on the effect of the results. This suggests that multiple trial runs using several different seed days may be necessary in order to be confident in the test results. In sum, based on the testing results, FREEVAL does provide a decent ballpark estimation of the actual distribution on travel times and hints that the main sources and factors influencing travel time reliability have been accounted for by the tool.

In order to assess the accuracy of the STREETVAL software, a test was performed on an urban arterial in Seattle, Washington. Results from the test were obtained by comparing the predicted travel times for the study facility outputted by the tool, to the actual travel times obtained from ALPR data. The results show that the tool tends to underpredict the dispersion level of the travel time distribution. The predicted travel time distribution is less dispersed than the actual travel time distribution from the ALPR data, although the tool can reasonably predict the mean travel time. The discrepancy in travel times suggests that some other factors (not accounted for) are influencing the vehicle travel times. A few possible unaccounted factors are (1) vehicle speeds may be different than the posted speed limit and need to be properly calibrated for in the model; (2) vehicles slowing down or speeding up to catch traffic lights; and (3) vehicles may be blinded by the sun during the sunrise and sunset hours, and this could have an influence on the driver speed and segment travel times.

C11 accounts for travel time reliability as well as reoccurring congestion. It requires minimal data for performing assessment of impacts of highway investments, and thus allows users to perform quick assessment of the effects of highway investments. The tool comes with simple and easy scenario management features. It facilitates analyses of multiple scenarios by allowing, creating, and saving new scenarios with relative ease. The tool was tested to assess if it needs any further improvements for enhancing its potential for use by transportation agencies. After extensive testing on different improvement options, the project team developed a set of recommendations for further improvement of the tool.

Detailed suggestions and potential improvements for each tool can be found in Section 9.2.

## 9.2 Suggestions and Potential Improvements

### 9.2.1 Potential Improvements on SHRP 2 L02 Product

In general, the L02 is useful for outlining specifications for the data needed to create a TTRMS system, guiding how to organize different conditions for the CDF, helping understand how to read the CDF for impacts on delay, and identifying congestion sources for different corridors.

By testing the L02 procedure, the research team finds that there are limitations within the guide.

- The events classified in the guide are listed as either weather or incident. However, there is no category for "weather+incident" events. Because sometimes the cause of incidents can be attributed to and exacerbated by adverse weather conditions, the addition of a third "weather+incident" category is necessary. Guidance should also be provided for when an event should be considered a combined "weather+incident" and when these events should be considered separately.
- The unique impact of each incident and weather event on travel time is hard to show by grouping large amount of data into the CDF curves. It is certainly possible to make a large number of curves and more specific nonrecurring conditions, such as collisions versus disabled vehicles and light rain versus snow versus fog. However, the data can only provide meaningful curves if there are sufficient data points to plot for each regime. Thus, the guide should help provide guides on when and how to establish TTRMS for different weather/incident severities. The recommendations on the minimum sample size for drawing meaningful curves are also needed.
- The guide does not provide guides on the determination of route ends. For example, if traffic design treatments are implemented on a segment, how should engineers choose the length/boundary of the corridor for travel time reliability monitoring/analyzing relevant to the design treatments?
- The guide may consider including recommended methods to analyze the duration of the impact of incidents, weather events (especially winter storm events), and other nonrecurring conditions and recognize that their impacts on travel reliability can extend past the duration of the condition.
- The guide should recommend using additional charts beyond the CDF for evaluating reliability, especially where they can provide clearer quantitative information and help guide policy makers in planning future roadway improvements.
- The guide suggests analyzing for improvements at the route level; however, improvements are not generally implemented along the entire route, but rather in hot spots or bottlenecks. Therefore, it is also necessary to analyze segment CDFs in addition to route-level CDFs when considering roadway modifications to improve reliability. Recommended methods for TTRMS at the segment level would help identify areas contributing the most to unreliability so that improvements can be targeted more precisely.

As a final note, the guide assumes the existence of a highly intelligent data collection system to synthesize the data and make a TTRMS work effectively. For example, the I-5 facility could be much better analyzed with a more extensive network of weather stations, especially those closer to the roadway. Then this weather needs to be efficiently paired to each loop observation. Weather conditions, such as brief downpours, can be very local in nature, and investing in a higher resolution of weather data would make this system much more effective. Additionally, a system with traffic detector data and incident data temporally and spatially connected can make it much easier to analyze the true impact of incidents. The research team expects that regions having data collection systems with these (or similar) features will have the easiest time implementing the L02 methodology and derive the greatest benefit from its results. Nevertheless, the team has found it to be an effective guiding tool for examining the travel time reliability in a greater detail of a region's transportation network.

### 9.2.2 Potential Improvements on SHRP 2 L07 Product

The L07 tool has friendly interface and is easy to use. However, the software currently only considers less commonly used design treatments for roadway segments. Based on the testing results, the research team suggests the following potential tool/guide refinements for L07:

- Add a "Compute" button to allow the user to choose when to start the computation, so that the software does not need to spend time computing every time the user changes a single value.
- Make the interface fit different computer resolutions. For example, if an 800*600 resolution screen is used (for most projectors), only the rows on the right and in the middle can be shown.
- Be able to predict travel time during peak hours more precisely, as the tool tends to underestimate the effect of congestion.
- Enable software to save results to a separate file and include more details about the results.
- Consider the effect of combining multiple design treatments, because in some instances two or more treatments may be implemented on the same site.
- Present more detailed guidance for some default values such as event and work zone characteristics, treatment effects.
- Investigate further about the treatment effects, including potential effects, and make the coefficients in Figure 6.9 more open for modification.
- Further consider effects of ramp metering on mainline flow. Because of its definition of solutions, L07 may not be an ideal tool to estimate the effect of ramp metering. However, it is possible for L07 to provide MOEs for these situations:
    - Whether and how mid-interchange off-ramps will affect traffic.
    - How on-ramp design features will affect traffic flow. For example, different ramp

lengths and lane numbers will have different effects on mainline traffic condition.
  - Effects of ramp spacing and interchange type on mainline flow.

### 9.2.3 Potential Improvements on SHRP 2 L08 Product

In general, the FREEVAL tool is a powerful simulation tool for evaluating different reliability alternatives in association with various nonrecurrent traffic events. However, because the tool intends to cover as many aspects as possible, it requires multiple data sources, and the input procedure is complex. Below are potential improvements the research team found to be critical for improving the FREEVAL tool.

- Put all the tool guide information together for user reference. For now, users need to refer to multiple reference documents that L08 provided to make sure all the steps are correctly followed.
- Disable the unnecessary options for the selection of the number of HCM segments and disable the option of selecting nonbasic segment types for the beginning and ending segments.
- Show alerts when steps are missing. For example, the software will keep working if the user fails to choose the ramp metering method. Another alternative is to show data input summary, the model run will not be executed until the user has confirmed the data entry is complete.
- Allow more flexible data input. Though using “seed day demand + demand multiplier table” would save the user a lot of time inputting the data, it is time consuming for most engineers to get the demand multiplier table.
- Because the urban and rural defaults for the selection of demand ratios in the freeway scenario generator are based on data from I-40, it is not accurate to apply these values to other study locations because demand patterns are location-specific. Either this default data option should be removed, or it should be clearly noted that these values might not be valid because they are based on one particular study location.
- Most national holidays are on Mondays and Fridays. When we researchers calculated the demand multiplier they found a large travel demand variation on these days. The research team is not sure whether to use the holiday data to compute the multipliers or to consider these days as outliers and exclude them for the multiplier computing. Because of this issue, there is uncertainty about whether it will still be useful to include Mondays and Fridays. A potential improvement to the software would be allowing users to select which workdays are included in the analysis.

To make the tool easier to use, there are a few aspects that could be improved for STREETVAL.

- STREETVAL requires a large range of data input; researchers were unable to meet the necessary data requirements demanded from using multiple sources of loop and camera data. Even if a complete set of demand data is available (most likely provided by imbedded loop detectors) for each approach, and at each intersection along the study site, additional access point demand data are still required to complete an analysis, and this probably means collecting data manually, which is a time-consuming and costly procedure. To avoid this costly manual data collection procedure, the tool should offer a method to estimate access point demand data and seed demand data.

- Other improvements could be made to the procedure itself since this can be confusing for a first-time user. Providing the user with steps with clearly defined tasks would make this tool much easier and friendly to the user. The FREEVAL software is good in this respect; each task was a specific task that the user could follow consecutively in order to complete an analysis. Also, the aesthetics of the interface require some touch-ups, and there are a few glitches, such as the malfunctioning buttons and floating spreadsheet numbers.

### 9.2.4 Potential Improvements on SHRP 2 C11 Product

The travel time reliability estimation tool was tested to assess if the tool needs any further improvements for enhancing its potential for use by transportation agencies. After extensive testing on different improvement options, a set of recommendations has been developed for further improvement of the tool. These are:

- All three sub-tools—the travel time reliability, market access, and intermodal connectivity tools—could be designed as a coordinated suite with provisions to use them individually, if desired. This would allow easily combining the benefits from all these tools for use in further economic analyses. It would be more useful if the tool performs benefit–cost analysis by taking necessary information from a user about project's capital and operation and maintenance costs and other benefits calculated outside this tool.
- The tool is found to underestimate TTI values. Researchers recommend revisiting the calculation methodology and assumptions and modifying the tool to provide TTI and other performance metrics by direction of travel and time of day.
- The tool takes input for incident reduction frequency and duration, instead of helping estimate or suggesting values for these inputs. The tool does not suggest which tools/methodologies to use to estimate incident reduction frequency and duration. The study team recommends adding some suggestions about what tool can be used to generate these inputs or providing a set of default values to choose from depending on improvement types being analyzed.
- The input to the tool does not distinguish between types of trucks (e.g., light, medium, and heavy trucks). Instead of using proportion of different truck types, the tool uses an overall percentage of trucks in the vehicle mix. To capture travel impacts more accurately, the study team recommends performing analysis by taking truck classification into accounts. It is also recommended to use the values of time for light, medium, and

heavy trucks. These modifications would improve quality of assessment of travel time reliability and congestion costs.

- For all multilane and signalized highways, the tool derives two-way capacity from one-way capacity (input by users) by assuming symmetrical geometry on both directions of travel. Two directions of a highway segment are not always similar in terms of geometry and other characteristics affecting capacity. Therefore, it may not be always appropriate to derive two-way capacity from one-way data. The research team recommends modifying the tool to accommodate input for both directions of travel and perform calculations by directions.
- The study team recommends allowing input of hourly traffic volume in addition to AADT to facilitate calculation of travel delay and its economic impacts for any desired time of day (e.g., a.m. or p.m. peak hour). This will help assess travel impacts for any time period of a day.
- Hourly traffic volume plays an important role in calculating 24-hour delay and associated costs to travelers. The temporal distribution of traffic varies by corridor (and even by specific locations within a corridor) based on land use type, employment, etc. The study team suggests modifying the tool to allow making changes to the default hourly factors that comes with the tool. Thus, users would have two options: either use the default values or enter project-specific temporal distribution data (if available).
- The tool provides an option to select an analysis period (i.e., time of day) from four exclusive options (6:00 a.m. to 9:00 a.m., 9:00 a.m. to 3:00 p.m., 3:00 p.m. to 7:00 p.m., and 6:00 a.m. to 7:00 p.m.). It does not include night in the analysis. Also it does not allow selecting two or more time periods (for example both a.m. and p.m. peak periods) for analysis. To analyze peak demand periods, the tool needs to be run separately for each of the peak periods (e.g., a.m. peak or p.m. peak periods). The study team suggests expanding the list of analysis periods to include “Night” and “Daily” as options as well as allowing selecting multiple time periods for a single run.
- The tool provides options to either directly enter capacity calculated based on HCM methodology or simply selecting a terrain type (e.g., flat, rolling, or mountainous) representing the project. When terrain is selected, the algorithm in the tool estimates peak capacity assuming values for other parameters needed for calculations. This capacity calculation could be made more rigorous by taking lane width, shoulder width, and other necessary data from users.
- The tool comes with analysis capability of only a uniform segment of a roadway between two interchanges or signals. It would be more useful if the scope of the tool were expanded to include multiple segments containing interchanges/signals in-between or network of roadways with different geometric and traffic conditions.
- For a relatively long stretch of a roadway, the tool’s architecture requires dividing the roadway into a number of segments within the scope of a scenario, because the tool analyzes only segments between two adjacent interchanges and/or signal controls. In such

cases, the tool takes inputs and produces outputs for each segment separately. It would be helpful if the tool summarizes the outputs by combining the data from all the segments.

- The current version of the tool provides annual weekday delays and congestion costs. The project team recommends modifying the tool to provide annual output for weekdays and weekends. It is also recommended to produce output by hour of day. This will allow performing analyses by time of day (peak hour, peak period, daily, etc.), if necessary.
- The tool comes with default values of reliability ratios (i.e., value of reliability over value of travel time) for personal and commercial travel. These ratios may vary by geographic location (e.g., state, region, county, city, or a subarea) of the project. It is suggested to provide links to references (if any research materials are available) with a possible range of default values so that a user can choose values appropriate for the geographic location of the project to analyze.
- The tool does not take any input to specify which the base year is; instead the tool assumes the current year as the base year. This assumption may not hold for all cases. The study team recommends modifying the input screen to allow users to enter the base year of analysis.

## 9.3 Future Works

After completing this project, the research team has found that there are some opportunities for future testing and work on SHRP 2 reliability products. The future works are listed below.

- Evaluate alternative sources of travel time data such as INRIX and Bluetooth tracking. Other accurate sources of travel time data (e.g., INRIX and Bluetooth detection data) can be used as alternatives of the travel times generated from single-loop detectors, although these new travel time data are not as readily available for L02. INRIX provides travel time data collected from motorists that are using its navigation services. Bluetooth detection technology also has the ability to measure travel times by tracking cell phones and other devices. Although detectors are currently not widespread enough for network-level travel time calculation, this is an excellent emerging technology that can be applied for reliability research.
- Apply L02 methodology to signalized highways and arterials to evaluate travel time reliability. Travel time data from single-loop detectors does not transfer well from freeways to signalized highways and arterials, as it uses two point speeds and assumes an average speed to calculate segment travel times. This assumption is invalid for the signalized highways and arterials. However by using INRIX or Bluetooth data for travel time calculation, travel time reliability can easily be measured for roadways other than freeways.
- Expand access to travel time reliability information by advancing the DRIVE Net platform. Access to reliability information for transportation agencies and drivers can be expanded by increasing the quality and quantity of the data provided on online platforms

such as DRIVE Net. By acquiring travel time data from Bluetooth detectors and/or INRIX, the data might be more accurate, reliable, and available for many more roadways. This will enable much more personalized reliability data. Making this additional data available on DRIVE Net and expanding the reliability visualization tools available to users will help create a more reliable, efficient transportation network.

- The testing of L07 tool mainly focuses on freeways since the loop detector data are available for calculating travel time reliability. Many roadway treatments provided in the L07 tool are designed for highways, where the required traffic data are not available for this project. Thus, the findings and results generated from the analysis for freeway systems are not directly applicable to highways. By acquiring appropriate traffic data, the benefit–cost analysis of roadway treatments for highways can be conducted. Moreover, if L07 can provide more details about the tool results, the effectiveness of the algorithm can be also examined.
- For testing of FREEVAL, ground truth travel times were calculated from spot speed data generated from loop detector sensors. Travel times collected from ALPR cameras were used as the source of ground truth data for STREETVAL. For the future work, other sources of data might also be used for the same purpose, such as dedicated short-range communication device data like Wi-Fi and Bluetooth as well as a probe vehicle data source.

# References

ASTM E2665-08. *Standard Specification for Archiving ITS-Generated Traffic Monitoring Data*. ASTM International, West Conshohocken, Pa., 2008.

Athol, P. Interdependence of Certain Operational Characteristics within a Moving Traffic Stream. *Highway Research Record 72*, HRB, National Research Council, Washington, D.C., 1965, pp. 58–87.

Cambridge Systematics. *SHRP 2 Report S2-L05-RW-1: Incorporating Reliability Performance Measures into the Transportation Planning and Programming Processes*. Transportation Research Board of the National Academies, Washington, D.C., 2013.

Cambridge Systematics. *SHRP 2 Report S2-L03-RR-1: Analytical Procedures for Determining the Impacts of Reliability Mitigation Strategies*. Transportation Research Board of the National Academies, Washington, D.C., 2010.

Chen, C., J. Kwon, J. Rice, A. Skabardonis, and P. Varaiya. Detecting Errors and Imputing Missing Data for Single-Loop Surveillance Systems. *Transportation Research Record: Journal of the Transportation Research Board*, *No. 1855*. Transportation Research Board of the National Academies, Washington, D.C., 2003, pp. 160–167.

Corey, J., Y. Lao, J. Wu, and Y. Wang. Detection and Correction of Inductive Loop Detector Sensitivity Errors Using Gaussian Mixture Models. *Transportation Research Record: Journal of the Transportation Research Board*, *No. 2256*. Transportation Research Board of the National Academies, Washington, D.C., 2011, pp.120–129.

Economic Development Research Group. *SHRP 2 Report S2-C11-RW-1: Development of Tools for Assessing Wider Economic Benefits of Transportation*. Transportation Research Board of the National Academies, Washington, D.C., 2013.

INRIX. *INRIX Traffic Data Services: Tapping into Real-Time Traffic Flow*. http://cta.ornl.gov/TRBenergy/trb_documents/2012_presentations/192_%20T%20Trepanier%20-%20INRIX%20LeeSchipper%20Data%20Workshop%20TRB2012.pdf. Accessed Aug. 14, 2013.

Institute for Transportation Research and Education. *SHRP 2 Report S2-L02-RR-1: Establishing Monitoring Programs for Travel Time Reliability*. Transportation Research Board of the National Academies, Washington, D.C., 2013.

Ishimaru, J. M., and M. E. Hallenbeck. *FLOW Evaluation Design*. Technical Report. WA.RD 466.2, 1999.

Kimley-Horn and Associates, Inc. *SHRP 2 Report S2-L01-RR-1: Integrating Business Processes to Improve Travel Time Reliability*. Transportation Research Board of the National Academies, Washington, D.C., 2011.

Kittelson & Associates, Inc. *SHRP 2 Report S2-L08-RW-1: Incorporation of Travel Time Reliability into the* Highway Capacity Manual. Transportation Research Board of the National Academies, Washington, D.C., 2013.

Parsons Brinckerhoff & Delcan Corporation. *SHRP 2 Report S2-L06-RR-1: Institutional Architectures to Improve Systems Operations and Management*. Transportation Research Board of the National Academies, Washington, D.C., 2012.

Potts, I. B., D. W. Harwood, J. M. Hutton, C. A. Fees, K. M. Bauer, C. S. Kinzel, , and R. J. Frazier. *Identification and Evaluation of the Cost-Effectiveness of Highway Design Features to Reduce Nonrecurrent Congestion*. SHRP 2 Reliability Project L07. Transportation Research Board of the National Academies, Washington, D.C., 2013 (prepublication version).

Texas Transportation Institute. *Quality Control Procedures for Archived Operations Traffic Data: Synthesis of Practice and Recommendations*. Final Report. Prepared for Office of Highway Policy Information, FHWA, 2007.

Turner, S., R. Margiotta, and T. Lomax. *Monitoring Urban Freeways in 2003: Current Conditions and Trends from Archived Operations Data*. Report No. FHWA-HOP-05-018, December 2004.

Wang Y., M. Hallenbeck, and P. Cheevarunothai. *Quantifying Incident-Induced Travel Delays on Freeways Using Traffic Sensor Data*. Technical Report, Transportation Northwest, University of Washington, 2008.

Wang, Y., X. Ma, S. Xiao, Y. Malinovskiy, J. Corey, and K. Henrickson. *Digital Roadway Interactive Visualization and Evaluation Network Applications to WSDOT Operational Data Usage*. Technical Report. 2013.