Contract No. SHRP L-38(D)

SHRP 2
L-38

Pilot Testing of SHRP 2 Reliability Data and Analytical Products

Research Plan

Washington State Department of Transportation

In association with:

University of Washington
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1. Introduction

1.1 General Background

Washington State Department of Transportation (WSDOT), in association with the University of Washington (UW), is pleased to carry out the research tasks for the Strategic Highway Research Program 2 (SHRP 2) Project L38: Pilot Testing of SHRP 2 Reliability Data and Analytical Products. The following five projects in the SHRP 2 Reliability area have produced guidelines and/or analytical tools to be tested in SHRP 2 L38 for travel time reliability measurement, monitoring, enhancement, and impact assessment:

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
C11: Development of Improved Economic Analysis Tools

Specifically, these projects aid in quantifying the reliability characteristics, identifying possible corrective solutions, and also analyzing the potential effects of implementing those solutions. The products from these five projects can be categorized into Data (L02), Analysis (L07, L08, and C11), and Project Prioritization (L05).

SHRP 2 L02 developed a Travel Time Reliability Measurement System (TTRMS) that is intended to show practitioners how to develop such systems in addition to the corridor queue prediction model (Lei et al., 2012). The analytical tool produced by SHRP 2 L07 project is used to evaluate the cost-effectiveness of geometric design treatments for reducing non-recurring congestion. The Excel spreadsheet-based analytical tool has incorporated SHRP 2 L03 methods, such as before/after analysis and a cross-sectional statistical model. This tool can assist in estimating operational effectiveness and economic benefits of a variety of design treatments for specific locations. SHRP 2 L08 developed a procedure to estimate travel time reliability and the impacts of non-recurrent congestion factors in the highway capacity context. Two Excel spreadsheet tools, FREEVAL and STREETVAL, are being developed to evaluate the change in travel time reliability associated with a variety of traffic characteristics utilizing a scenario generator for freeways and signalized roadways. 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 SHRP 2 C03 to enable broader economic analyses. The tool utilizes 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 guidebook 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.
These projects are either completed or near to their completion. To pilot test and identify improvement directions on these data integration and analytical tools, SHRP 2 L38 was initiated. WSDOT considers it a great opportunity for implementing these products into its practice because travel time reliability enhancement represents an important strategic direction at WSDOT.

Effective transportation is critical to maintaining Washington’s economy, environment, as well as the quality of life. Thus, WSDOT has long been promoting a reliable, responsible, and sustainable transportation system. WSDOT's economic vitality and renowned livability plan also targets the reliability improvement as the state’s transportation goal for planning, operating, and investing. Moving Washington, with key components shown in Figure 1-1, is our proven approach as well as investment principle for creating an integrated, 21st century transportation system. It is also our framework for making transparent, cost-effective decisions that keep people and goods moving and support a healthy economy, environment, and communities.

![Figure 1-1: Key Components of the Moving Washington initiative](image)

Washington State provides an excellent testing environment and opportunity for the SHRP 2 Reliability research products under the umbrella of Moving Washington. The Puget Sound area has several potential testing sites that allow for third party data to be used in evaluating the developed analytical tools. It offers the advantages of spanning future operational plans for a more comprehensive geographical coverage and evaluating reliability from a network-wide perspective. WSDOT also proposes to incorporate the analyses products into the business and decision-making process, to improve the capability of analyzing travel time reliability at facility, corridor, or even system levels, as well as to test the validity and usability of the economic models.

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. **It is our intention to use products from all these five projects in our proposed**
L38 testing activities. To better understand the available products, a thorough review has been made to identify the main features of the products in each project and relevant specifications. Findings of the review are summarized in the tables below for each project.

SHRP 2 L02: Establishing Monitoring Programs for Travel Time Reliability

SHRP 2 L02 focuses on reliability measurement, factors affecting systems’ reliability, and solutions for reliability enhancement. Products developed through this effort are summarized in Table 1-1.
### Table 1-1: SHRP 2 L02 Reliability Product Summary (for TTRMS)

<table>
<thead>
<tr>
<th>Products</th>
<th>Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. A guidebook and supporting methodologies</td>
<td>2. Travel time reliability monitoring system (TTRMS)</td>
</tr>
<tr>
<td>3. Approach on synthesizing route travel time distribution from segment travel time distributions</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Researcher</th>
<th>Researcher</th>
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</table>

<table>
<thead>
<tr>
<th>Input</th>
<th>Input</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <strong>Infrastructure-based sources</strong></td>
<td></td>
</tr>
<tr>
<td>• Loop detectors;</td>
<td></td>
</tr>
<tr>
<td>• Video image processors;</td>
<td></td>
</tr>
<tr>
<td>• Wireless magnetometer detectors; and</td>
<td></td>
</tr>
<tr>
<td>• Radar detectors</td>
<td></td>
</tr>
<tr>
<td>2. <strong>Vehicle-based sources</strong></td>
<td></td>
</tr>
<tr>
<td>• Vehicle-based detectors collect data about specific vehicles, either when they pass by a fixed point (AVI data) or as they travel along a path (AVL data).</td>
<td></td>
</tr>
<tr>
<td>• Automated Vehicle Identification (AVI) data collection includes Bluetooth readers and License Plate Readers (LPR), radio-frequency identification, vehicle signature matching data.</td>
<td></td>
</tr>
<tr>
<td>• Automated Vehicle Location (AVL) data include data from Global Positioning Systems, Connected Vehicles, Cellular telephone network.</td>
<td></td>
</tr>
<tr>
<td>3. <strong>Non-recurring event data</strong></td>
<td></td>
</tr>
<tr>
<td>Incident, Weather data, Work Zones, Special Events</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Output</th>
<th>Output</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Segment travel time including its distribution;</td>
<td></td>
</tr>
<tr>
<td>2. Route travel time including its distribution;</td>
<td></td>
</tr>
<tr>
<td>3. Sources of unreliability; and</td>
<td></td>
</tr>
<tr>
<td>4. The impact of the sources of unreliability.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>The project team conducted five case studies of sites with various data collection technologies to develop methods for assembling and visualizing travel time reliability information.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Memo</th>
<th>Memo</th>
</tr>
</thead>
<tbody>
<tr>
<td>This work builds on data generated by current traffic monitoring systems to provide a long-term picture of travel time reliability.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Test locations</th>
<th>Test locations</th>
</tr>
</thead>
<tbody>
<tr>
<td>San Diego, California; Northern Virginia; Sacramento–Lake Tahoe, California; Atlanta, Georgia; and New York–New Jersey.</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Accuracy</th>
<th>Accuracy</th>
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</thead>
<tbody>
<tr>
<td>N/A</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th>Strength</th>
<th>Strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>An agency that implements a TTRMS will understand much better the reliability performance of its systems and monitor how its reliability improves over time:</td>
<td></td>
</tr>
<tr>
<td>• What is the distribution of travel times in their system?</td>
<td></td>
</tr>
<tr>
<td>• How is the distribution affected by recurrent congestion and non-recurring events?</td>
<td></td>
</tr>
<tr>
<td>• How are freeways and arterials performing relative to performance targets set by the agency?</td>
<td></td>
</tr>
<tr>
<td>• Are capacity investments and other improvements really necessary given the current distribution of travel times?</td>
<td></td>
</tr>
<tr>
<td>• Are operational improvement actions and capacity investments improving the travel times and their reliability?</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Weakness</th>
<th>Weakness</th>
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</thead>
<tbody>
<tr>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>
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. Findings of the review for SHRP 2 L05 are summarized in Table 1-2.

Table 1-2: SHRP 2 L05 Reliability Product Summary (for Reference Guide)

| Products          | 1. The reference guide  
|-------------------| 2. The technical reference |
| Researcher        | Cambridge Systematics, Inc. |
| Input             | • Reliability measure that the leadership, staff, and stakeholders understand and that yields consistent results  
|                   | • Reliability benefits of each project in the project list  
|                   | • 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  
|                   | 2. Model post-processing tools: link-level data: more robust than 1, based on local data from the established regional model  
|                   | 3. Simulation or multi-resolution methods: provide most robust forecast of TTV, combining TDM provide most accurate assessment of long-short term impacts on reliability  
|                   | 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  
|                   | 2. Model post-processing tools: require a regional TDM, limited reliability metrics  
|                   | 3. Simulation or multi-resolution methods: requires regional TDM and simulation model be available; time and resource intensive  
|                   | 4. Monitoring and management tools: analysis capability limited by data availability and quality, cannot test future strategies to address congestion |
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, bus pull-offs, designated bus lanes, emergency pull-offs, etc., in reducing nonrecurrent congestion. Findings of the review for SHRP 2 L07 are summarized in Table 1-3.
Table 1-3: SHRP 2 L07 Reliability Product Summary

<table>
<thead>
<tr>
<th>Products</th>
<th>Spreadsheet-based analysis tool</th>
</tr>
</thead>
<tbody>
<tr>
<td>Researcher</td>
<td>Midwest Research Institute (MRI)</td>
</tr>
</tbody>
</table>

**Input**

1. **Treatments**

2. **Data:**
   1. Geometric data:
      - Number of lanes
      - Lane width
      - Right/ Left shoulder width
      - Number of interchanges per mile
   2. Traffic data:
      - Free-flow speed
      - Demand volume (by hour of day)
      - Peak hour factor (by hour of day)
      - % trucks (by hour of day)
      - % RVs (by hour of day)
   3. Crash statistics for roadway segment:
      - Total annual PDO crashes
      - Total annual minor-injury crashes
      - Total annual serious and fatal-injury crashes
   4. Information about typical crash duration (time until cleared):
      - Average crash duration (min) for PDO crashes
      - Average crash duration (min) for minor-injury crashes
      - Average crash duration (min) for serious- and fatal-injury crashes
   5. Other:
      - Information about special events (e.g., number, percent increase in volume)
      - Information about work zones

3. **Benefits and Costs**

**Output**

Evaluation results of cost-effectiveness for a treatment, such as Travel Time Index (TTI), reliability Measures of Effectiveness (MOEs).

**Description**

What does the tool do?
- Implements Project L03 models
- Computes cumulative Travel Time Index curve for untreated and treated conditions
- Estimates traffic operational effectiveness of design treatments at specific locations
- 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 the treatment’s effect on the three model variables can be ascertained. A custom treatment tab is available in the tool to input this information.

**Test locations**

N/A

**Accuracy**

N/A

**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**

N/A
SHRP 2 L08: Incorporation of the Non-Recurrent Congestion Factors into the Highway Capacity Manual Methods

SHRP 2 L08 develops methods and guidance on incorporating travel time reliability into Highway Capacity Manual (HCM) analyses. The main product of this project is a guidebook that describes travel time reliability concepts for the HCM audiences, provides step-by-step processes for predicting travel time reliability for freeway and urban street facilities, and illustrates example applications of the procedures. Findings of the review for SHRP 2 L08 are summarized in Table 1-4.

Table 1-4: L08 Reliability Product Summary

| Products                                                                 | 1. Guidebook 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.  
|                                                                         | 2. FREEVAL and STREETVAL Computational Engine |
| Researcher                                                             | Kittleson, 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 non-recurrent congestion. A further objective is to develop methodologies to predict travel time reliability on selected types of facilities and within corridors |
| Test locations                                                         | I-40, NC  
|                                                                         | Principal arterial at Lincoln, Nebraska  
|                                                                         | I-40 and US70 corridor, NC |
| Accuracy                                                               | N/A |
| Strength                                                               | N/A |
| Weakness                                                               | For freeway, weather event with marginal impact are excluded; assume incident occurrence and traffic demand are independent of weather condition  
|                                                                         | For urban streets, 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. |
SHRP 2 C11: Development of Improved Economic Analysis Tools Based on Recommendations from SHRP 2 C03

SHRP 2 C11 provides a sketch planning corridor spreadsheet tool based on SHRP 2 L03 research that estimates the benefits of improving travel time reliability for use in benefit/cost analysis. Findings of the review for SHRP 2 C11 are summarized in Table 1-5.

Table 1-5: C11 Reliability Product Summary

<table>
<thead>
<tr>
<th>Products</th>
<th>1. Analytical tools</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2. User Guide</td>
</tr>
<tr>
<td>Researcher</td>
<td>Economic Development Research Group</td>
</tr>
</tbody>
</table>

**Input**

- Simple inputs, default values:
  1. Scenario data
    - Highway type
    - Free flow speed
  2. Traffic data
    - AADT
    - Truck percentage
    - Terrain
  3. Time/travel cost
    - Value of time
    - Value of reliability

**Output**

- Result for base year and forecast year
  1. Congestion Metrics
    - Overall mean Travel Time Index (TTI), TTI$_{95}$, TTI$_{80}$
    - % trips less than 45 mph, % trips less than 30 mph
  2. Total annual weekday delay (veh-hrs)
    - Recurring delay
    - Incident delay
    - Total equivalent delay
  3. Total annual weekday congestion cost for passenger and commercial vehicles, respectively
    - Cost of recurring delay
    - Cost of unreliability
    - Total congestion cost

**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

<table>
<thead>
<tr>
<th>Accuracy</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strength</td>
<td>N/A</td>
</tr>
<tr>
<td>Weakness</td>
<td>N/A</td>
</tr>
</tbody>
</table>
1.3 WSDOT Application Needs and Selection of Products to Test

Moving Washington is WSDOT’s proven initiative for making responsible and sustainable decisions. It reflects the state’s transportation goals and objectives for planning, operating, and investing. The investment principles of Moving Washington are twofold; first, maintain existing facilities under safe and efficient operations and, second, integrate investments in cost-effective solutions. The WSDOT strives to give our highest priority to maintaining and preserving the safe and long-lasting performance of existing infrastructure, facilities, and services. In order to achieve and align the WSDOT’s objectives and those of our partners, we combine the following three essential transportation strategies:

- **Operate Efficiently** – This approach gets the most out of existing highways by using traffic-management tools to optimize the traffic movement and maximize available capacity. Strategies include utilizing traffic management technologies such as ramp metering, speed harmonization, and other control strategies to improve traffic flow and reduce collisions, deploying incident response teams to quickly clear capacity-reducing incidents, optimizing traffic signal timing to reduce delay, and implementing low-cost/high-value enhancements to address immediate needs.

- **Manage Demand** – Excess travel demands during peak hours are often the direct cause of congestion and system unreliability. Managing travel demand on overburdened routes allows our entire system to function better. In addition to commuter side actions, such as shifting departure times or using public transportation, WSDOT will actively manage demand through strategies such as real-time traveler information dissemination, high occupancy toll (HOT) lane operations, and dynamic tolling to reduce peak-hour traffic and optimize utilization of the existing facilities.

- **Add Capacity Strategically** – Targeting our worst traffic hotspots or filling critical system gaps to best serve an entire corridor, community or region means fixing bottlenecks that constrain the smooth movements of traffic flow. Upgrading a failing on-ramp merge or hard-shoulder running during peak periods can free up the flow of traffic through a busy corridor. From improving rail crossings and ferry service to working with transit agencies to connect communities, from building direct-access ramps for carpools and transit to including paths for pedestrians and bicyclists, capacity improvements require strong partnerships with a shared vision for the corridor.

Washington State law directs public investments in transportation to support economic vitality, preservation, safety, mobility, the environment and system stewardship. Coupled with Moving Washington’s investment principles, WSDOT is capable of providing an excellent platform for pilot testing the analytical products generated by the SHRP 2 Reliability program. This can be done by evaluating the solutions recommended through applications of the SHRP 2 methods and products and evaluations of the expected results versus observed results from previously implemented solutions.

Every investment decision needs to be facilitated and supported by a series of well-connected activities, from proof of concepts, data collection, to methodology formulation and analyses, to eventually a trade-off can be achieved. WSDOT proposes to test products from each of the five
projects listed in the pilot testing plan by using the available resources within the Moving Washington scope, and to enable such a decision-making process by incorporating reliability in activities described above. WSDOT has the advantage of including the analytical products into the business process, and would be able to provide feedback on how the tools function, focusing on particular aspects of implemented, ongoing, or upcoming projects. The projects WSDOT funds under the Moving Washington initiative can be categorized into three categories: capacity, operations and travel demand management (TDM), and capital investment projects. Projects that fall into operations and TDM are typically anticipated to improve the reliability of the transportation system, particularly to reduce the nonrecurrent delays. For example, for projects that aim at extending the Intelligent Transportation System (ITS) infrastructure by improving incident response management, applying hard shoulder running, adopting ramp metering control and variable speed limit, etc., the evaluation of travel time reliability is definitely an indispensable component in this decision-making process.

### 1.4 Research Approach Summary

This research project has two major objectives: (1) to assist agencies in moving reliability into their business practices through testing of the products developed by the five SHRP 2 Reliability projects; and (2) to provide feedback to SHRP 2 on the applicability and usefulness of the products tested. Through literature review and discussion, the research team identified three major challenges in this project as follows:

1. Test project selection, data collection, and quality control;
2. Experiment design for testing different products by SHRP 2; and
3. Test results evaluation and possible improvements.

To address these challenges, the research team has proposed an innovative systematic approach that comprises of the following key components:

- **A strong steering committee** with members from all relevant fields in WSDOT, including transportation planning, traffic operations, urban corridor management, performance measurement and economic impacts, and project prioritization. The steering committee will meet periodically to schedule and review research activities, and coordinate research efforts.

- **A complete test scope and procedure** that can be well integrated into WSDOT’s practice. The five SHRP 2 analytical products fit nicely into the investment principles of WSDOT’s Moving Washington initiative. The investment principles of the Moving Washington align very well with the objectives of SHRP 2 L38. The research team proposes to include analytical products from all the five SHRP 2 projects into test plan under the Moving Washington initiative so that these analytical products can be truly integrated into WSDOT’s business process for project prioritization, travel time reliability monitoring, and performance measurement.
- A wide range of urban freeway and arterial data collection including 1) mobile sensor data (GPS-based vehicle trajectory data, Bluetooth-device-based travel time data); 2) traditional static sensor data (loop, camera, radar, etc.); 3) roadway geometric profile data; 4) incident and crash data; 5) work zone data; 6) weather data; and 7) traffic operation and management data (such as ATM control). Data fusion and mining will be performed to integrate traffic data with weather, incidents, and work zone data on a regional map basis to investigate travel time reliability under recurring and non-recurring congestion conditions.

- A carefully designed implementation plan detailing the data collection, computation of measures of effectiveness (MOEs), interpretation of estimated MOEs, and application of analytical results. Over the past decades, WSDOT has completed a number of projects that offer opportunities for the before and after analysis on travel time reliability. Also, those projects selected for implementation on the agenda of Moving Washington can be used to test the project prioritization and decision support tools. Specifically, the following projects are chosen as study projects for SHRP 2 L38:
  
  o Corridors used for the WSDOT Gray Notebook production will be used to test SHRP 2 L02 products. WSDOT has already 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 both on a corridor and a statewide level. The Gray Notebook provides excellent information for testing and evaluating products of SHRP 2 L02.

  o Among the Moving Washington projects, the I-5 Joint Base Lewis-McChord (JBLM) and the State Route 522 are well suited for testing the methods and analytical tools from SHRP 2 L07 and L08.

  o WSDOT’s two *GPS based Freight Performance Measures* projects will be used to evaluate the usability of SHRP 2 C11 products for evaluating and forecasting cost of (non)recurrent delay and cost of unreliability.

  o I-5 JBLM is also chosen as a case study for testing the effectiveness of the five step procedure from SHRP 2 L05. A couple of projects in this region will be prioritized within the 10-year investment strategy.

### 1.5 Research Team Summary

The research team has a keen grasp on all the pertinent issues in travel time reliability and development and testing of performance measures, and is highly qualified for this project. The team members have a proven track record of conducting applied research in the areas that are related to this project. A sample list of these projects is as follows:
• SHRP 2 C18 – Pilot Test of the Collaborative Decision-Making Framework Including a Self-Assessment Methodology
• NCHRP 3-107: Work Zone Capacity Methods for Highway Capacity Manual
• NCHRP 3-96: Analysis of Managed Lanes on Freeway Facilities
• SHRP2 L11: Evaluating Alternative Operations Strategies to Improve Travel Time Reliability
• SHRP2 L03 Analytic Procedures for Determining the Impacts of Reliability Mitigation Strategies
• NCHRP 3-68: Guide to Effective Freeway Performance Measurement

2. Research Approach

This research project aims to pilot test the reliability data and analytical products from five SHRP 2 projects. As the lead institution, WSDOT will take the opportunity to integrate these analytical tools into our business processes to enhance the capability to analyze and improve travel time reliability on one or more facilities or corridors, or on a system. WSDOT will also summarize and report the validity and usability of the tested products to SHRP 2 to help improve these products. Our research approach is described following the work flow presented in the Request for Proposals document and the project contract.

2.1 Task 1: Attend a One-Day Briefing

The team has attended a one-day briefing in Washington, D.C. on March 21, 2013, with representatives of all other selected research teams and the research contractors of the products to be tested to refine understanding of the SHRP 2 products and establish a community of practice. The meeting was to ensure a wide geographical coverage of samples in testing the targeted SHRP 2 Reliability products and to avoid overlapping or duplicate efforts.

2.2 Task 2: Prepare a Revised Research Plan

Following the briefing, the proposed revised research plan tries to response to the insights gained from the briefing. Specifically, this revised plan will guide the following activities of this project:

• The data compilation and integration for the pilot testing;
• The analytical methods for reliability and improvement strategies;
• The integration of reliability into the decision supporting role; and
• The evaluation of relevant SHRP 2 products.

The SHRP 2 L38 Project Panel will review and comment on the revised research plan before work proceeds on Task 3.
2.3 Task 3: Compile and Integrate Data for the Test

Task 3 will concentrate on acquiring the data for the selected study sites. It involves data collection, data fusion, quality assurance, testing, and validation. The proposed research plans to use large amount of ITS-sensor data from roadway surveillance systems while retaining the data collection from other sources such as probe vehicle, ALPR, floating car, etc. The advantage of ITS-sensor data is that they supply continuous data at designated locations. However, the quality and completeness of archived data vary greatly from time to time and system to system. This makes it important to apply data quality assurance procedures to the ITS-sensor data. In this task, the research team will collect and process different types of data needed by the proposed tests. Specifically, traffic data, incident data, work zone data, weather data, geometric data, operating and improvement data will be needed and briefly described as follows:

2.3.1 Traffic Data: Delay, Speed, Queuing, and Travel Time

Our team will review available traffic data and collect new data to fill in any gaps that are identified during the course of the project. Data from three types of facilities will be analyzed: urban freeways, signalized arterials, and as available, rural highways or freeways.

**Urban Freeway Data** – Urban freeway data will be obtained from traffic management centers (TMCs) that, in the opinion of our team and our sponsors, are known for maintaining quality data. Other considerations will include availability of incident data from the TMCs, presence of before and after improvement sets of data, and a sizeable history of archived data.

**Signalized Arterial Data** – Signalized arterial data will be acquired from both public and private sources and will include data from several technologies (e.g., road sensors, radio frequency toll tag probe data, GPS probe data, and Bluetooth-device probe data). Potential private data sources include Inrix and SpeedInfo sourced data. These companies provide and sell data primarily for real-time traveler information to private and public entities, but also archive the data for other purposes. Inrix and WSDOT signed a contract earlier last year to provide WSDOT free access to Inrix probe vehicle data and the corresponding analytical tools for one year. So Inrix data will be an extra data resource for this study. Before their use, however, these data will be screened to ensure they contain a sufficient number of samples to adequately establish the reliability of the information.

**Rural Freeway Data** – Rural freeway travel-time data will also be obtained from sources such as Inrix and SpeedInfo. Data will be analyzed to ensure that a sufficient sample size exists for the available locations. Another option is to use the Bluetooth detector developed by the Smart Transportation Applications and Research Laboratory (STAR Lab) of the University of Washington (UW) to collect travel time data.

The START Lab Bluetooth sensor technology has been tested in several places, such as Tri-cities, WA and Montreal, Canada (Wang et al., 2011). These tests concluded that Bluetooth technique is a useful and cost-effective tool for travel-time data collection. Figure 2-1 illustrates one travel time collection study along a 3-mile-long SR 520 floating bridge corridor in Seattle, Washington on February 22, 2009. The speed limit on the bridge is 50 mph. The average speeds in free-flow conditions tend to be around 60 mph. A portable Automatic License Plate Recognition (ALPR)
system was borrowed from WSDOT to check the accuracy of the data obtained from Bluetooth device-based detection. Figure 2-2a shows the comparison between ALPR and the Bluetooth device-based travel time measurements. The error for the hour-long test ranged from 6 percent to nearly 20 percent, with a mean of 9.6 percent. After a mean shift of 17.5 seconds, the error rates decreased to a maximum of 9.4 percent and a minimum of -3.95 percent, well within the FHWA recommended values. Figure 2-2b shows the resulting error and Bluetooth-based travel times after adjustment. The sample travel time data collected by the Bluetooth device were within expectations and consistent with the ALPR-collected travel time data. The results confirmed the Bluetooth-based detection system’s ability to collect travel time data for freeways.

Figure 2-1: a) Selected Freeway Test Corridor on SR 520 b) Bluetooth Sensor (left) and Portable ALPR (right) Used to Collect Travel Time Data at the 24th Ave Location
Figure 2-2: SR 520 Freeway Test (Wang et al., 2011)

**Dataset Creation** – Dataset creation will involve obtaining, cleaning, and integrating data collected primarily by public agencies and to some extent private vendors (e.g., freeway speed information). There are several challenges with this approach. Among them are processing, reviewing, and reducing raw data into summaries suitable for analysis and matching different data types geographically. The research team will choose data quality assurance procedures with
success histories over the past years in addition to our existing data quality control methods to enhance the quality of data.

2.3.2 Incident and Work Zone Data

Data describing the basic characteristics of incidents are available from several sources. Traffic.com (other data sources such as SpeedInfo will also be sought as part of the project) provides incident data through its Traveler Information Management System (TIMS). TIMS data provide a standardized source of information for traffic incidents, events, scheduled and unscheduled construction, and other events that could affect traffic conditions (such as severe weather or transit delays). Incident data from Traffic.com have several unique attributes:

- All reported incidents are entered. However, Traffic.com does attempt to confirm reports and their system indicates when reported incidents have been confirmed.
- The incident data are collected by an independent entity that is not involved in the traffic or emergency management process. Therefore, Traffic.com staff can gather more complete and accurate data because information gathering and reporting is their sole focus (whereas public agency traffic managers typically must manage incidents and record relevant information at the same time).
- The data contain the sequence of events as an incident is reported, responded to, and cleared. For example, an incident record is updated and appended at any time in which the status or conditions of the incident change.
- Traffic.com incident data provide consistent data attributes in all of the cities under consideration by our team. Additionally, the data have unambiguous location referencing.

Potential incident attributes for utilization in this study are:

- Unique Traffic Item Identifier – Uniquely identifies each record.
- Unique Original Traffic Item Identifier – Uniquely identifies the original traffic incident. This identifier does not change as information about the same incident is updated.
- Metropolitan Area – Uniquely identifies the city.
- Roadway and Location Identifier – Unique combination of identifiers for the location.
- Type of Traffic Item – Entries can include:
  - Accident
  - Alert
  - Congestion
  - Disabled Vehicle
  - Mass Transit
  - Miscellaneous Incident
  - Other News-Induced Incident
  - Planned Event
  - Road Hazard
  - Scheduled Construction
  - Unscheduled Construction
  - Weather.
• Verification – Yes/no entry indicates whether the incident has been verified.
• Number of Lanes Blocked – Numeric entry for number of travel lanes blocked.
• Start and End Time – The combination of these attributes provides incident duration. The start time is the time when the lane or shoulder blockage begins; the end time is when the blockage is cleared. Data collected by TMC operators (entered into consoles at the TMC) or entered by freeway service patrols (FSP) are available for some cities. The types of data collected by these entities vary, but they mostly correspond to Traffic.com data. The key items of location, duration, and lane blockage are the same.

2.3.3 Weather Data

Overview – A potential source of weather data is the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA). NCDC produces climate publications and responds to data requests from all over the world. One of the surface climate products that NCDC offers is the Local Climatological Data. The Center also offers marine and upper air data. The Local Climatological Data product consists of hourly, daily, and monthly climatological summaries for approximately 1,600 U.S. locations. However, Daily Summary forms are not available for all stations. After January 2005, the Local Climatological Data have been processed through automated quality control processing.

Data Access – Similar to other NCDC products and services, the Local Climatological Data are available on a variety of media, including on-line access, CD-ROMs, DVDs, computer tabulations, maps, and publications. Free access to NCDC data is granted to certain users, such as academic and educational users, using reverse domain lookup. ASCII format download of these data for all stations are available at http://www5.ncdc.noaa.gov/ulcd for unlimited subscription customers and FREE domains. Final Data loads occur on a monthly basis, usually overnight. Data gaps may exist during the timeframe of previous and current final data loads.

Data Format and Description of Hourly Data – The basic weather elements of the available hourly data files are:

• Sky condition – Cloud height and amount (clear, scattered, broken, and overcast) up to 12,000 feet;
• Visibility (to at least 10 statute miles);
• Basic present weather information – Type and intensity for rain, snow, and freezing rain;
• Obstructions to vision – Fog, haze;
• Pressure – Sea-level pressure, altimeter setting;
• Ambient temperature and dew point temperature;
• Wind – Direction, speed and character (gusts, squalls);
• Precipitation accumulation; and
• Selected significant remarks, including variable visibility, precipitation beginning times, rapid pressure changes, pressure change tendency, wind shift, and peak wind.

Geometric, Operating, and Improvement Data

Geometric data will be obtained from WSDOT Traffic Data Office (TDO). TDO maintains a detailed roadway geometric log data as well as GIS shape files. Operating and roadway improvement data are also available at WSDOT TDO and Urban Corridors’ Office (UCO).
Critical data pieces in this category are those elements related to calculating capacity for each individual link.

2.3.4 Data Processing Procedure

**Urban Freeway Data Processing** – Data for all urban freeway sections will be centrally processed to ensure consistency. Considering that over 80% of loop detectors are subject to sensitivity problems (Zhang et al., 2003), the sensitivity problem detection and correction procedures developed by the UW STAR Lab (Cheevarunothai et al., 2006 and 2007, Lao et al., 2012) will be applied to the original dataset before processing them through the following procedures (Cambridge Systematics, 2010):

- Begin processing of data from the TMCs with quality control procedures developed for FHWA (Texas Transportation Institute, 2007).
- Apply Station-Level and Section-Level spatial aggregation on the five-minute interval data. Station Level aggregation is applied laterally over all lanes in a direction. Section Level aggregation is applied longitudinally for all stations on a study section.
- From the Section-Level data, estimate the start and end times of the peak hour and peak period. Analysts then review the start and end times, and make adjustments based on local knowledge.
- Section-Level statistics are computed for each time slice used in the analysis. The time slices include Peak Hour (weekdays only); Peak Period (weekdays only); Counter Peak Hour (the opposite time slice from the peak hour, weekdays only. For example, if the peak hour is in the morning, then the counter peak is in the afternoon); Mid-day; Week Day (all hours of the day); and Weekend/Holiday (all hours of the day).

**Signalized Arterial Data Processing** – Calculating travel-time and reliability statistics from toll tag-equipped probe vehicles should be straightforward. Since travel times are measured directly, there is no need for transformations. Data quality control is a different issue. Because of the opportunities for vehicles to make incomplete trips through a section of an arterial (such as stopping at adjacent land uses), some travel times will be detected as being excessively high. As a result, probe data quality controls have been focused on eliminating outliers. FHWA’s Mobility Monitoring/Urban Congestion Program (Turner et al, 2004) defines the quality control criterion for probe data as two consecutive travel times that cannot change by more than 40 percent. Another method proposed by researchers at the UW is that a travel time cannot be more than one standard deviation above or below the moving average of the 10 previous entries. These methods work well for freeway data where probe data coverage is high. However, probe data on arterials are sparser. Many of the outliers in arterial data will pass through this method undetected because there are not enough immediate adjacent observations. Instead of relying on continuous observations, arterial data quality control will focus more on the overall spread of the data. Examination of arterial data leads us to believe that we can apply the following QC processing rules to these data:

1. Visual inspection to remove any days that have extremely low or high travel times.
2. Ranking of all travel time for a section, and treating 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 as an outlier. This technique is robust because it uses the quartile values instead of variance to describe the spread of the data.

3. Not allowing two consecutive travel times to change more than 40 percent.

4. Not allowing a travel time to be more than one standard deviation above or below the moving average of the 10 previous entries. These 10 previous entries must be continuous and valid data.

**Rural Freeway Data Processing** – Rural freeway data are available from commercial sources, e.g., Inrix, SpeedInfo, etc. From a data processing standpoint, we treat these data in the same way as the traffic detector data. However, because the commercial data are representative of relatively short links and many links comprise the very long rural segments to be used in the research, a trajectory-based method is proposed to estimate travel times for the entire segment. The vehicle trajectory method traces the vehicle trip in time and applies the link travel time corresponding to the precise time in which a vehicle is expected to traverse the link. For example, a section travel time that begins at 7:00 a.m. will use a link travel time for 7:00 a.m. to 7:05 a.m. at the trip origin, but could use a link travel time from 7:05 a.m. to 7:10 a.m., or 7:10 a.m. to 7:15 a.m. at the trip destination. The vehicle trajectory method attempts to more closely model the actual link travel times experienced by motorists as they traverse the freeway system. In the trajectory method, the vehicle “stair steps” through a time/distance matrix (rows are time, columns are distance along the route as indicated by detector location). Thus, the travel time/speed at any given location depends on what time the vehicle is at that location. The snapshot method simply takes all the travel times/speeds for a time slice along the entire route, i.e., speeds are not considered to be time-dependent.

**Calculation of Free-Flow Speed** – The distribution statistics for the Travel Time Index (TTI) depend on measuring travel time relative to an ideal or free-flow speed. For urban freeways, the research team will utilize a constant value for all sections, for example 60 mph. This is a well-established threshold for measuring congestion on urban freeways. For signalized highways and rural freeways, the situation is more complex due to variation in speed limits and signal-influenced delay, even at very low volumes. For these sections, we will apply the 85th percentile speed as the free-flow speed. In all cases, if section speeds are greater than the free-flow speed, the TTI will be set to 1.0; no “credit” will be given for going faster than the free-flow speed.

2.3.5 **Final Dataset for Analysis**

As the preceding discussion demonstrates, a large array of datasets at various levels of spatial and temporal aggregation can be created. The end result of the processing and fusing will be a highly summarized dataset to be used in the analyses. This level of compilation and summary 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 dataset is for an individual section for an entire year for each of the daily time slices studied: peak hour, peak period, mid-day, weekday, and weekend/holiday. Dataset 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 Travel Time Index.
- Buffer indices (based on mean and median), Planning Time Index, Skew Statistic, and Misery Index.
- On-time percents for thresholds of: median plus 10 percent, median plus 25 percent; 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).
- TMC staff per mile covered.
- Number of ramp meters, DMSs, and CCTVs.

**Capacity and Volume Characteristics**
- Start and end times for the peak hour and the peak period.
- Calculated and imputed VMT.
- Demand-to-capacity and 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.
2.3.6 Data Archiving and Visualization Platform

The UW STAR Lab has produced a prototype web based analytical framework called the Digital Roadway Interactive Visualization and Evaluation Network (DRIVE Net). DRIVE Net has the potential of being an excellent online platform for transportation data sharing, visualization, modeling, and analysis. DRIVE Net allows easy access of real-time regional traffic information, facilitates data sharing and visualization, enables online data analysis for scientific discovery and decision support, and offers opportunities for early stage e-science of transportation investigations (Ma et al., 2011). The prototype DRIVE Net system can be accessed online at http://www.uwdrive.net/.

Data Description:

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. Figure 2-3 shows an interface snapshot of DRIVE Net Version 3.0.

Figure 2-3: DRIVE Net Interface with Color-Coded Traffic Flow Feed from WSDOT
A brief description of DRIVE Net data is as follows:

20-Second Freeway Loop Data

Data coverage: freeway single loop detectors in the Puget Sound area

Time resolution: 20 seconds

Data is archived by the passive data retrieval. There is a C# program periodically fetching remote data in a predefined interval via file transfer protocol (FTP). Data are retrieved every 20 seconds and stored in the DRIVE Net database.

The key attributes of this dataset include date/time, volume, occupancy, speed and flag indicating whether there the errors exist. There are a total of 8,551 loop detectors producing data for archival in the DRIVE Net system.

The 20 second loop data are archived from September 2009 to now in a real-time manner.

City of Bellevue Loop Data

The Bellevue loop detector data have been collected in a 20-second time interval, and fetched to store in the Arterial database every minute since August 2006. The key attributes include date/time, occupancy, cycle length, and volume. There are a total of 311 intersections and 698 links that form this arterial network.

GPS Truck Fleet Data

Trucking GPS data are collected from several commercial companies via in-vehicle GPS with a cellular connection. There are approximately 2500 trucks in the Puget Sound area. The GPS reading frequency ranges from 5 minutes to 15 minutes. Average total daily records are 94,000. The time range is from April 2009 to June 2012. The key data items include latitude and longitude, GPS spot speed, direction, date/time, and moving status.

Bluetooth Detection Data

The Bluetooth detection data are collected directly from Bluetooth signal readers. By matching the unique median access control address, travel time between any two points with Bluetooth readers can be calculated.

Washington Incident Tracking System (WITS)

The WITS database contains majority incidents occurred on Washington state highways and major freeways. The STAR lab stores WITS data from 2006 through present. In addition, incident data are disseminated in flat files, such as excel files. The key data attributes include notification date/time, patrol arrival time, incident clearance time, milepost, direction, primary lane closure type, and incident type.
**Freeway Traveler Information and Work Zone Data**

The statewide freeway traveler information includes work zone or lane closure alert, freeway cameras, and freeway travel time.

Freeway cameras information is only displayed as a static picture on the map every minute.

The above data are retrieved from the website: [http://www.wsdot.wa.gov/traffic/api](http://www.wsdot.wa.gov/traffic/api), and are presented in DRIVE Net in a real-time manner.

**Mountain Pass Condition Data**

Mountain pass condition information contains statewide temperature, humanity, and restriction conditions.

**Border Crossings Data**

Border crossings include the waiting time to crossing the U.S- and- Canada border. There are only six stations to collect such data in Washington State.

2.3.7 *Summary of Data Compilation and Integration for SHRP 2 Product Testing*

Field data collection is expensive. Candidate corridors must be carefully selected to best satisfy the product testing needs under the budget constraints. In order to test travel time (un)reliability products for SHRP 2 projects, candidate corridors should have relative traffic sensors to best measure nonrecurrent traffic event, traffic volume, and travel time. Depending on different project test objectives and product types, data amount various from 3 months to 2 years. The detailed corridor/platform selection plan is listed as table 2-1.
### Table 2-1 Corridor/Platform selected for SHRP 2 Product Testing

<table>
<thead>
<tr>
<th>Project to Test</th>
<th>Corridor/Platform to Test</th>
<th>Data Type</th>
<th>Data Amount</th>
<th>Parameters to Collect</th>
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<tbody>
<tr>
<td>L02</td>
<td>DRIVE Net platform</td>
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<td>1 year</td>
<td>N/A</td>
</tr>
<tr>
<td></td>
<td>I-5</td>
<td>Loop detector data</td>
<td>1 year</td>
<td>Traffic volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>INRIX data</td>
<td>1 year</td>
<td>Travel speed, travel time</td>
</tr>
<tr>
<td></td>
<td>SR-522</td>
<td>Loop detector data</td>
<td>1 year</td>
<td>Traffic volume</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Video data</td>
<td>3 months</td>
<td>Traffic volume, travel time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ALPR data</td>
<td>3 months</td>
<td>Travel time</td>
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<td></td>
<td>Bluetooth data</td>
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<td>Travel time</td>
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<td>I-5 JBLM</td>
<td>Nonrecurrent events</td>
<td>1 year</td>
<td>Nonrecurrent event types and rates</td>
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<td></td>
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<td>1 year</td>
<td>Traffic volume</td>
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<td></td>
<td></td>
<td>INRIX data</td>
<td>1 year</td>
<td>Travel speed, travel time</td>
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<td>Bluetooth data</td>
<td>3 months</td>
<td>Travel time</td>
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<td>Treatment and Costs</td>
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<td></td>
<td>INRIX data</td>
<td>2 years</td>
<td>Travel speed, travel time</td>
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<tr>
<td></td>
<td></td>
<td>Incident data</td>
<td>At least 2 years</td>
<td>Incident types and rates</td>
</tr>
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<td></td>
<td>SR-522</td>
<td>Loop detector data</td>
<td>2 years</td>
<td>Traffic volume</td>
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<tr>
<td></td>
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<td>ALPR data</td>
<td>2 years</td>
<td>Travel time</td>
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<tr>
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<td>Incident data</td>
<td>2 years</td>
<td>Incident types and rates</td>
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<td>Travel time, delay, cost</td>
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<td>L05</td>
<td>INRIX data</td>
<td>3-4 years</td>
<td>Travel speed, travel time</td>
</tr>
</tbody>
</table>

2.4 Task 4: Analyze Reliability and Improvement Strategies

As one of the most important complementary performance measures, travel time reliability has been studied and investigated for various traffic facilities to enhance trip consistency and predictability. Data compiled from Task 3 will be used to analyze the baseline reliability issues associated with the study sites as well as the alternative strategies for improving reliability. Using the analysis tools developed in the SHRP 2 projects, WSDOT would be able to pilot test on the Moving Washington projects, by either comparing with the observed results, or projecting on the next several years’ investment strategy. Below is a description of research approach of how we propose to fit each project’s products into the Moving Washington business process.

**SHRP 2 L02: Establishing Monitoring Programs for Travel Time Reliability**

With the SHRP 2 L02 TTRMS data, WSDOT can better allocate resources such as incident response vehicles to incidents on vulnerable road segments as quickly as possible. Following TTRMS development procedure, WSDOT can identify various sources of congestion and unreliability and better manage demand from the Active Traffic Information System (ATIS) side by showing predicted travel times in order to reroute traffic in case of congested conditions. The TTRMS data can further be utilized to select segments for tolling or other demand management.
techniques. Areas with chronic problems identified by the TTRMS may be suitable for capacity improvements.

WSDOT continuously monitors corridor travel times and uses them as a performance measure in the Gray Notebook (WSDOT, 2012). The Gray Notebook is the WSDOT’s quarterly accountability report, with the first report initiated back in May 2001. WSDOT has used the quarterly document to provide updates on system performance and project delivery. It also includes a complex, annual congestion report and quarterly Incident Responses analysis. The Gray Notebook documents a wide variety of detailed analysis of our highway system performance (utilizing loop measured volume data, speed data, and various economic indicators), both on a corridor and a statewide level. A broad range of congestion and reliability metrics have already been developed and applied to evaluate the delay, travel time, as well as travel time reliability improvements (before and after analysis) for various Moving Washington projects. It can thus provide a great platform for testing the SHRP 2 L02 pilot data and analytical tools, including the TTRMS and the corridor-level queuing prediction model, through comparisons with the field observed results. The vast amount of data that WSDOT possesses, e.g. loop detector data, Bluetooth data, Automatic License Plate Recognition (ALRP) data, as well as a systematic procedure for data cleaning and missing data imputation, provide a great environment for the implementation and testing of the SHRP 2 L02 products.

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

The spreadsheet-based analytical tool from L07 was developed to evaluate the cost-effectiveness of geometric design treatments for reducing nonrecurrent congestion. This tool has implemented SHRP 2 L03 methods, such as before/after analysis, cross-sectional statistical model. It can help to estimate traffic operational effectiveness and measure economic benefits of various design treatments.

This product can fit into the Moving Washington investment principle of *Integrate Investments for Cost-effective Solutions*. For example, by estimating traffic operational effectiveness, this analytical tool can help to optimize traffic signal timing to reduce delay and implement low-cost/high-value enhancements to address immediate needs. Meanwhile, the treatment tool offers the transportation agencies to choose traffic technologies such as ramp metering to smooth traffic flow and reduce crashes. The output of this spreadsheet-based analytical tool is a predicted cumulative Travel Time Index (TTI) curve for untreated and treated conditions. The predicted TTI can be used to estimate traffic operational effectiveness of design treatments at specific locations, such as appropriate median crossover, drivable shoulders, etc.

Among the Moving Washington projects, the I-5 Joint Base Lewis-McChord (JBLM) is well suited for testing the analysis tool from Project L07 (see Figure 2-4). As the single largest employer in Pierce County and the third largest in Washington State, JBLM plays an important role in our communities. I-5 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 ops, and the overall economy. Highway investment studies and growth coordination plans have thus concluded the needs for changing the existing interstate system, include reconstructing I-5 to add high-occupancy vehicle and general capacity travel lanes,
rebuilding various interchanges, and constructing the Cross Base Highway, in addition to many transportation projects on-base. Implicit in these recommendations is reconstructing the Burlington Northern Santa Fe mainline that crosses over I-5 immediately south of JBLM, and replacing the two bridges that cross the Nisqually River at the Thurston / Pierce County line. By applying the L07 product to this particular project as a decision supporting tool, it takes the reliability analyses to a regional/network level for estimating the potential improvement of a variety of design features.

![Figure 2-4: I-5 JBLM Area](image)

**Figure 2-4: I-5 JBLM Area**

**SHRP 2 L05: Incorporating Reliability Performance Measures into the Transportation Planning and Programming Process**

This research project produced a guidebook with five steps for incorporating reliability into planning and programming. The primary audience is managers and decision makers. It also includes a technical reference for practitioners that describes the tools and data needed (recipes) to calculate performance measures (Cambridge Systematics, 2012).

Through the development of this guidebook 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 level. It is without a doubt that WSDOT has already considered reliability as one of the top priorities in the strategic planning process. WSDOT plans to take the SHRP 2 L38 opportunity to improve the existing procedure and further showcase the value of SHRP 2 Reliability studies.
SHRP 2 L08: *Incorporation of Non-recurrent Congestion Factors into Highway Capacity Manual Methods*

SHRP 2 L08 develops methods on incorporating travel time reliability into the Highway Capacity Manual (HCM) analytical procedures. A guidebook 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 non-recurrent 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 will be generated and the impacts of variability on facility performance over the course of a year can be estimated. Excel-based HCM computational engines, i.e. 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 2-5 illustrates the flow chart of the methodology developed in SHRP 2 L08.

![Flow Chart of the Methodology Framework in Project L08](Kittleson & Associate, Inc., 2012)

It is noted not only does freeway or urban street facility can be used as application to evaluate the travel time reliability under the impact of a variety of nonrecurrent congestion sources, the methodology in L08 also gives guidance on conducting corridor level analysis, where freeway and urban street facilities can be considered jointly to study the network impact of the nonrecurrent congestions. The vast resources in the WSDOT's Moving Washington initiative enable the testing ability of these three methodologies (freeway, urban street, corridor). As mentioned earlier, I-5 JBLM can be a great project to test the freeway methodology.
The pioneer Integrated Corridor Management (ICM) site in Seattle at South of Downtown (SoDo) area is another candidate site for performing corridor-wide analysis. Figure 2-6 shows details of this area. In this area, I-5 is the major freeway running north-south. Because of the heavy freight volume, limited access facilities, as well as geographical constrains, this site would be quite vulnerable if an accident, a large spikes in demand or other nonrecurrent events happened on the freeway. However, in parallel to I-5, several alternate routes and modes are available within 1-mile width, such as Airport Way, 4th Ave South, 1st Ave South. The corridor-wide study will enable the local agencies to answer questions about possible traffic diversion strategies from congested I-5 during peak hour to fully utilize the unfilled capacities on local arterials.
Figure 2-6: Major Corridors in the South of Downtown Area in Seattle (Dang, 2008)

*SHRP 2 C11: Development of Improved Economic Analysis Tools*
The Excel spreadsheet-based tool from SHRP 2 C11 is a remedy for the SHRP 2 C03 tool to enable a wider economic analysis. Using this tool, WSDOT is able to evaluate the costs and benefits for multiple alternatives, and choose the most appropriate one for implementation. In addition, transportation agencies can also utilize this tool to predict the future economic impacts generated by a specific project. These concepts are extremely helpful to estimate whether a certain solution is cost effective. Based on these judgments, legislators can make a smarter investment strategy.

Freight performance measure could be a suitable test bed to compare with the result from T-PICS web-based tool plus the C11 spreadsheet-based tool. For freight transportation, reliability is a particularly crucial performance measure of the system. With the vast deployment of just-in-time delivery, the freight industry emphasizes most on how reliable the delivery would be, rather than the speed itself. To support the testing of the C11 product, WSDOT can leverage two projects being completed.

- The first project is using data collected from GPS devices in trucks to develop a Washington State freight performance measures program. This effort is locating roadway bottlenecks for truck and using GPS-derived speed distribution curves to quantify the reliability of these segments. The segment information is in the process of being aggregated into corridor metrics to measure the reliability of major, economically important truck flow in the state.

- The second project is improving WSDOT’s cost benefit analyses process by adding truck GPS data. This on-going effort is both measuring roadway reliability (using methods developed in the project above) and attempting to forecast reliability, but is also exploring the value of roadway reliability for the trucking community (Wang et al., 2013).

Both efforts are developing WSDOT agency level tools that quantify the impacts of reliability. The second project is attempting to measure the economic impact of (un)reliability. These two efforts will provide a framework to test the tools developed as a part of C11. For example, the spreadsheet tool created for C11 can potentially be using to test the inclusion of the mean TTI into both WSDOT’s corridor performance measures and cost benefit analysis process. This research would evaluate the integration of such C11 tools into these processes.

**2.5 Task 5: Prepare an Interim Report**

The research team will prepare an Interim Report for review by the SHRP 2 L38 Panel. The report will include:

- Data compilation and integration details; and
- The reliability analysis and improvement strategies on the basis of compiled data and the analytical tools from the five SHRP 2 Reliability projects.

The Panel will review and comment on the Interim Report before work proceeds on Task 6. The research team will also participate in an interim Expert Task Group (ETG) meeting in
Washington, D.C., with all of the pilot site contractors and representatives of FHWA and AASHTO for comments.

2.6 Task 6: Apply Analytical Results for Decision Making

Within the scope of WSDOT's Moving Washington initiative, analytical products from all the five listed SHRP 2 projects are proposed to be tested. Particularly for SHRP 2 L05, it provides an analysis procedure to support funding for mitigating strategies in the decision-making process.

To test the effectiveness of the five step procedure for incorporating reliability into planning process, the research team will continue using I-5 JBLM as a case study. Comparing with the recurring congestion due to high demand, travel time reliability is a more significant issue for travel in this area, negatively impacted by major incidents, work zones, and primarily by large spikes in demand caused by major troop and equipment movements in and out of the military base. In pilot testing the product from SHRP 2 L05, the research team will perform a reliability analysis, as guided by the technical reference from L05, to determine the appropriate tool to use on the basis of resource availability. With the performance measures identified, cost and benefit analysis will be performed by looking at the 10-year investment strategy in this region to provide project prioritization of the proposed projects. Table 2-2 provides a list of the projects to be prioritized within the 10-year investment strategy.
Table 2-2: First 5 years of a 10-year Investment Strategy in Tumwater to Lakewood Area

<table>
<thead>
<tr>
<th>First 5 years of a 10-year Investment Strategy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Both Directions I-5 / Tumwater to Marvin Rd. I/C - Mobility &amp; Safety</strong></td>
</tr>
<tr>
<td>I-5/Tumwater to Marvin Rd. - Ramp Meters: This project would extend Intelligent Transportation System (ITS) infrastructure from the Mounts Rd I/C through Olympia. Includes ramp meters through Olympia, additional cameras, and electronic signs. Also includes HSR SB approaching Martin Rd. This project will reduce mainline congestion, reduce congestion related collisions, and improve traveler information.</td>
</tr>
<tr>
<td><strong>Both Directions I-5 / Nisqually River Bridges - Preliminary Assessment</strong></td>
</tr>
<tr>
<td>Develop replacement strategy to identify near term alternatives (temporary alignments) that could add benefit now (ie: HSR), that would be necessary to accomplish end of service life replacement of the two bridges.</td>
</tr>
<tr>
<td><strong>Both Directions I-5: Berkeley St. to Thorne Ln./ Interchange Replacement &amp; Mainline Lanes - Mobility and Safety.</strong></td>
</tr>
<tr>
<td>Replace the Thorne Lane crossing structure and extend one additional lane in each direct to Berkeley St. This project removes one bottleneck, reduces mainline congestion, and provides construction staging alternatives for the future Berkeley interchange replacement project.</td>
</tr>
<tr>
<td><strong>Southbound I-5 / 84th to SR 512 - Auxiliary lane Extension - Mobility</strong></td>
</tr>
<tr>
<td>Provides an &quot;add lane&quot; from the 84th St. on-ramp to the existing auxiliary lane. Reduces mainline congestion.</td>
</tr>
<tr>
<td><strong>Southbound I-5, City Center to SR 101 / Lane Conversion and Hard Shoulder Running - Mobility</strong></td>
</tr>
<tr>
<td>Converts shoulders to extend the fourth lane from the City Center off ramp to the SR 101 exit. Implements HSR from the City Center on-ramp to SR 101 (vic. Crosby).</td>
</tr>
<tr>
<td><strong>Northbound I-5; Eastbound SR 512 / Auxiliary Ln Extension &amp; Hard Shoulder Running - Mobility</strong></td>
</tr>
<tr>
<td>Ramp widening and auxiliary lane extension to provide a second off-ramp lane from I-5 to SR 512 by time of day. Requires extension of the auxiliary lane to SR 7.</td>
</tr>
</tbody>
</table>

### 2.7 Task 7: Evaluate the Reliability Products

With the reliability analysis and evaluation of improvement strategies conducted for the relevant SHRP 2 products, this task will focus on the assessment of the applicability of the products as well as the results from the analytical tools. Figure 2-7 provides the general approach for pilot testing of the SHRP 2 travel time reliability products.

Generally, two kinds of products will be tested: 1) technical guidelines involving travel time reliability methodologies and implementation procedures, and 2) Excel spreadsheet based tools. For technical guidelines test, methodologies and procedures from technical reports and guidebooks will be re-experimented on test sites with non-recurrent traffic events such as I-5 JBML and State Route 522 in Washington State. Historical data will be utilized and comparison will be made amongst different study sites. Detailed testing methods will be applied in response
to different project objectives and testing targets. For Excel-based tool test, data obtained from potential test beds will be applied and the installation on various kinds of operating systems, the interface and usability, the algorithm and calculation correctness, and the methodology transferability will be tested. The consistency between the technical report/guidebook and the Excel-based tool will be studied as well. Results will be analyzed and concluded after the test and potential refinements are provided.

**Figure 2-7: General Approach on Pilot Testing of SHRP 2 Products**

The applicability assessment will emphasize on the following three aspects:

- **Functionality**
  A tool is useful if has desired functions. Functionality testing focuses on function evaluation and the effectiveness of each function. Compatibility with common operating systems will also be evaluated.

- **Usability**
  Guidelines or functions should address important issues and be easy to understand and apply. Experiments will be conducted to evaluate usability of the research products.

- **Credibility**
  Travel time reliability issues are complex and tools/guidelines are needed to assist decision making and infrastructure operations. Before applying the tools/guidelines, we
need to make sure that they are producing reasonably accurate results. Efforts will be made to evaluate the credibility of each test product.

Table 2-3 summarizes the proposed product testing approaches and procedures for SHRP 2 projects, respectively.
<table>
<thead>
<tr>
<th>Project</th>
<th>Products</th>
<th>Actions to take</th>
</tr>
</thead>
</table>
| **L02** | – Guidebook on Travel Time Reliability Monitoring System (TTRMS) | – Apply WSDOT data (at least three months, from I-5 and SR-522) to the TTRMS procedure  
– Use DRIVE Net as platform for data management and analysis  
– Evaluate the techniques to generate route-level travel time from segment-level travel time  
– Study the relationship between travel time and volume to identify the association of facility travel time reliability with volumes and other relevant factors  
– Compare with published reports such as the Gray Notebook and the annual congestion report, for product validation and potentially fine-tune the methods |
| **L07** | – Guidebook on costs and effectiveness of highway design features to improve travel time reliability  
– Spreadsheet-based tool on design guide | – Utilize I-5 JBLM data to estimate potential improvements of a variety of design treatments, such as rebuilding interchanges, constructing the cross base highway, etc.  
– Compare the tool result with literatures  
– Report effectiveness and usability of the tool |
| **L08** | – Technique report on incorporation of non-recurrent congestion factors into HCM methods  
– Spreadsheet-based tool FREEVAL and STREETVAL | – Apply FREEVAL to I-5 JBLM and STREETVAL to SR-522  
– Test the tools’ usability and effectiveness  
– Test the methods and guidance on incorporating travel time reliability into capacity estimates and performance measurements  
– Report effectiveness, usability, and reliability of the tool |
| **C11** | – Spreadsheet-based tool to evaluate benefit-to-cost ratios for multiple highway and freeway scenarios | – Use WSDOT freight performance measures based on GPS data to quantify roadway reliability  
– Measure economic impact of (un)reliability, including adding truck GPS data to improve WSDOT benefit-to-cost analysis, forecasting reliability, and exploring the value of roadway reliability for trucking  
– Compare with the ongoing projects for corridor performance measures and benefit-to-cost analysis  
– Report effectiveness, usability, and reliability of the tool |
2.8 Task 8: Prepare a Draft Final Report

A final report summarizing all the findings and methodologies developed through the research efforts of this project will be composed. All team members will work intensively on this task to ensure a high quality report to be delivered in time. The draft final report will document all tasks accomplished in this research effort and will submit to the SHRP 2 L38 Panel for review.

The tentative outline of the final report is as follows:

Chapter 1: Introduction
  1.1 Brief SHRP 2 research products introduction
  1.2 Applications of research products
  1.3 Testing principles
  1.4 Report Organization

Chapter 2: Literature Review
  2.1 Detailed SHRP2 research project overviews
  2.2 Review of material relevant to SHRP 2 research products
  2.3 Current state of the practice at WSDOT
  2.4 Review of material relevant to testing

Chapter 3: Data Collection and quality control
  3.1 Data collection site selection
  3.2 Data processing and quality control
  3.3 Data archiving

Chapter 4: Methodologies for Testing and Evaluation
  4.1 Testing methods
  4.2 Evaluation methods
  4.3 Integrating the Testing and Evaluations results into decision making process

Chapter 5: Testing Implementation
  5.1 L02 testing sites and testing results
     o Testing site description
     o Testing results
5.2 L05 testing sites and testing results
  - Testing site description
  - Testing results
  - Impact on decision making

5.3 L07 testing sites and testing results
  - Testing site description
  - Testing results
  - Impact on decision making

5.4 L08 testing sites and testing results
  - Testing site description
  - Testing results
  - Impact on decision making

5.5 C11 testing sites and testing results
  - Testing site description
  - Testing results
  - Impact on decision making

Chapter 6: Discussion
  6.1 Strengths and weaknesses for each product
  6.2 Suggested improvements of product design based on the investment principles of Moving Washington
  6.3 Suggested improvements for systematic integration

Chapter 7: Conclusions
  7.1 Summary of projects/products
  7.2 Summary of product testing
  7.3 Results summary
  7.4 Recommendations

2.9 Task 9: Finalize Research Report
Revisions on the draft final report based on the Panel’s comments will be made and the final version of the report will be submitted by the completion date of the project.

3. Anticipated Research Results
The products that will result from this research were described in each task description. All of these products will be provided in the final report. In summary, the project deliverables are listed below:

- Revised Research Plan
- Monthly and quarterly progress reports
- Interim Report following Task 4
- Participate in a midterm meeting in Washington, D.C., in Task 5, to present interim findings to SHRP 2, and selected invitees from FHWA and AASHTO
4. Implementation Issues

As the research team was assembled to prepare this proposal, several implementation issues were identified that will play an important role in the successful completion of this project. The research team will work in earnest to ensure that those issues to be resolved are on track in the course of this project. A summary of the implementation issues that the team found to be crucial to this project is listed below:

4.1 Research Schedule

The research team has consensus on the research deliverables identified in Section 3, and believes that the research objectives can be reached by successfully delivering these products in a timely and efficient manner. The research team is also aware of the schedule challenges of this project and knows it is interdependent with many other SHRP 2 reliability and capacity projects.

The preparation of the project began in January, 2013 and the project contracts starts from April 2013. The interim report will be submitted to the SHRP 2 L38 panel by August 2013. Assuming the approval from the SHRP 2 L38 Panel for proceeding on Task 6 will be received by mid-August 2013, Tasks 6 through 9 will be completed by the end of March 2014, with submittal of the draft final report in April 2014. Figure 4-1 presents an overview of the proposed project schedule.

<table>
<thead>
<tr>
<th>ID</th>
<th>Task Name</th>
<th>Start</th>
<th>Finish</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Task 1: Attend a One-Day Briefing</td>
<td>2/25/2013</td>
<td>3/29/2013</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Task 2: Prepare a Revised Research Plan</td>
<td>2/25/2013</td>
<td>4/30/2013</td>
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<tr>
<td>3</td>
<td>Task 3: Compile and Integrate Data for the Test</td>
<td>5/1/2013</td>
<td>7/31/2013</td>
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<td></td>
</tr>
<tr>
<td>4</td>
<td>Task 4: Analyze Reliability and Improvement Strategies</td>
<td>6/3/2013</td>
<td>10/2/2013</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Task 5: Prepare an Interim Report</td>
<td>9/2/2013</td>
<td>10/17/2013</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Task 6: Apply Analytical Results for Decision Making</td>
<td>10/16/2013</td>
<td>12/13/2013</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Task 7: Evaluate the Reliability Products</td>
<td>12/2/2013</td>
<td>3/3/2014</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4-1: Proposed Project Schedule

4.2 Management and Coordination

Good communication is essential to the successful completion of the project. The research team will ensure a timely delivery of monthly and quarterly progress reports, as well as the efficient responses to the Panel’s reviews and comments. Also, through various meetings in the forms of
teleconferences, webinars, and interim meetings, etc., the research team will discuss the progress and anticipated problems constantly with the Panel and all the other key stakeholders.

The research team is also aware that the internal communication among the team members is important to guarantee that the project is in progress with the schedule. A steering committee will be set up to include top experts of WSDOT in all the relevant fields. This committee will review the research plan and quarterly progress reports to ensure that products from the five SHRP 2 Reliability projects are sufficiently tested and properly integrated into the WSDOT Moving Washington business process if possible. Regular weekly team meetings will be held to ensure that the lead institution and the subcontractor work together collaboratively and every team member is connected and receives the task assignment that maximizes advantages of every team member’s capability and expertise.

4.3 Activities Necessary for Implementation

The research team is fully aware of the necessary concepts to be considered when attempting to implement new methodologies into practice. To this end, several activities are considered intrinsic for the implementation of this project as well as the research result.

- Take maximum advantage of the available data
- Generating sample problems to illustrate the computational procedure and validate the analytical products
- Explain the benefits of using the analyses methods and performance metrics

4.4 Audience or Market for the Research Product

It is clear that the research product of this project is rather practical than theoretical which will guide the design and planning professionals, and decision makers in using these analytical tools for evaluating of reliability benefits and make informed policy decisions. The testing results will also be beneficial to the transportation system operations and management professionals that would use travel time reliability as a performance measure to monitor roadway performance. Other audiences of the product include researchers who will use the models/methodologies evaluated in this project to facilitate their understanding of travel time reliability; and other SHRP 2 project contractors who will also incorporate the research findings to the reliability and capacity areas related topics.

4.5 Applicability of Results to SHRP 2 Objectives

Considering the increasing expectations by road users for reliable system performance and federal regulatory requirements for investments to result in improved system performance, it is imperative that the transportation agencies need to increase the organizational, technical, and decision-making capabilities to meet these expectations. Through pilot testing the SHRP 2 Reliability products, we are able to answer both big picture and detailed technical questions, such as how to incorporate travel time reliability into the policy making process, what types of performance measures are suited for reliability evaluation under a variety of resource availability and roadway conditions, and how reliable a traffic system is. By providing feedback to SHRP 2 on the applicability and usefulness of the products tested, the benefits and value of reliability can be identified. Meanwhile, by proposing potential refinement of the products, a more comprehensive understanding of the reliability concept can be achieved. It is expected that the
findings and results of this project will fulfill the SHRP 2 objectives and complement the reliability studies in multiple dimensions and scopes.
References


