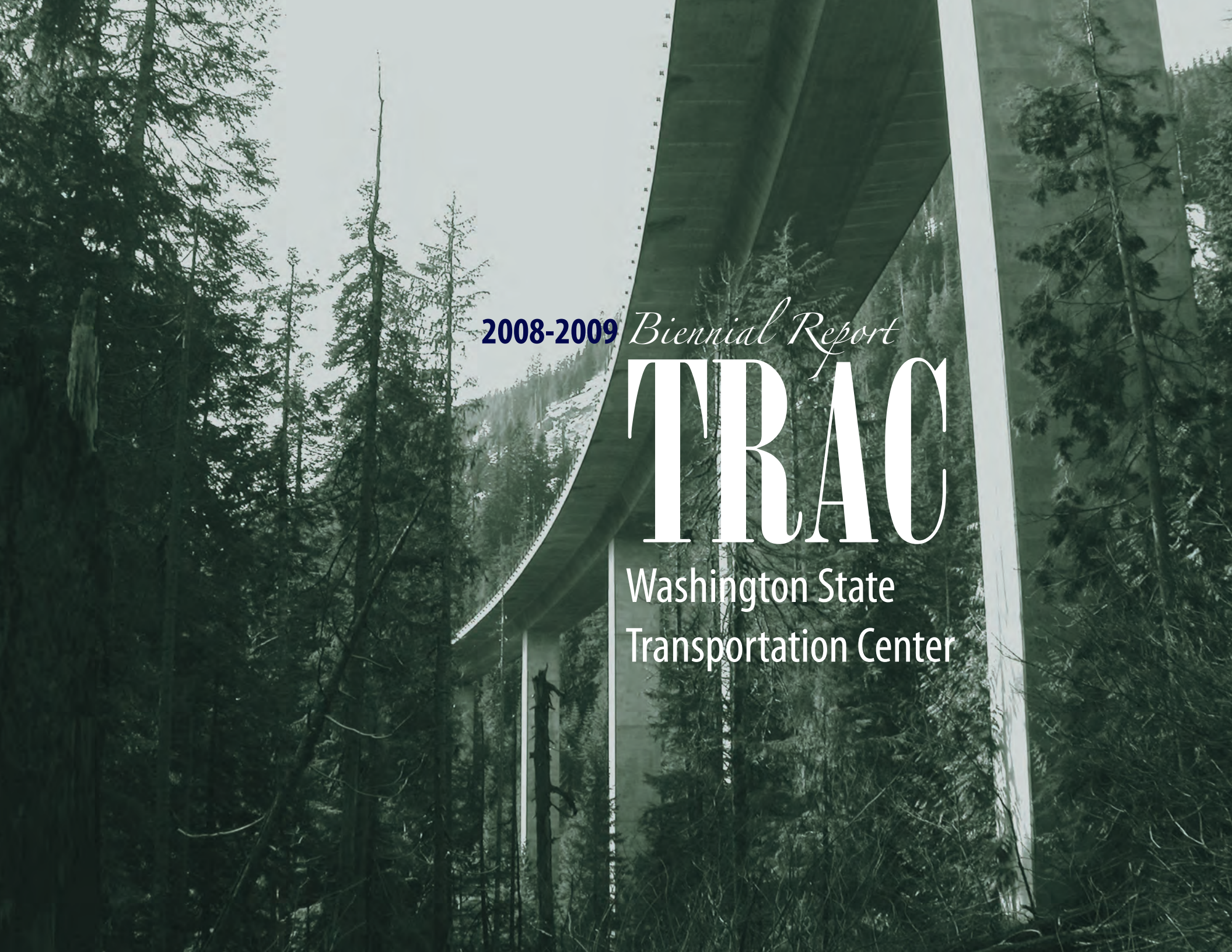

2008-2009 *Biennial Report*

TRAC

Washington State Transportation Center

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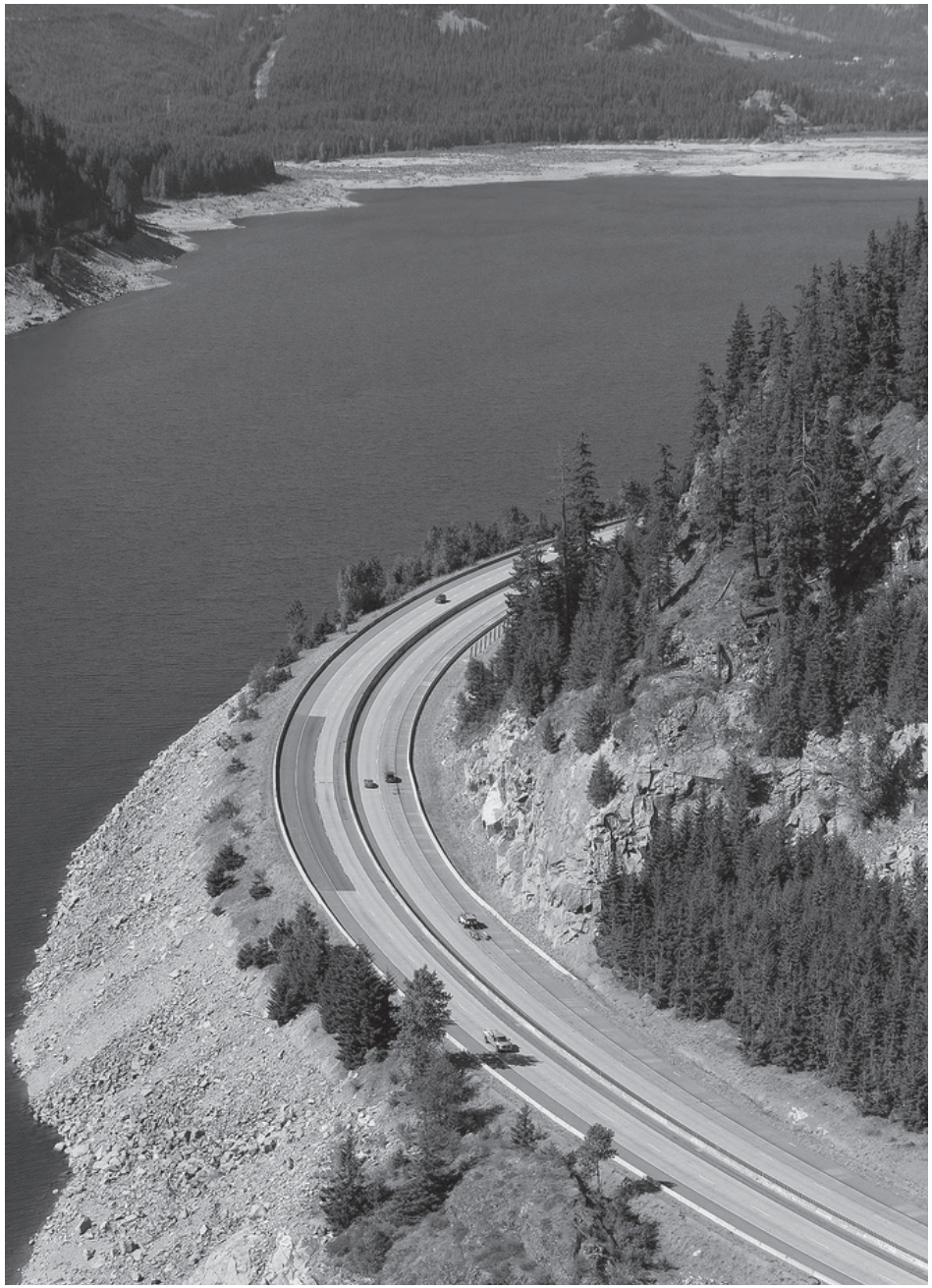

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MESSAGE FROM THE EXECUTIVE DIRECTOR

As I write, Washington and the transportation community are in the midst of some tough economic challenges. Now, more than ever, it's important to ensure that our research funding is spent wisely to address critical knowledge gaps. The research summarized in this report is doing just that. The results of these projects are helping the Washington State Department of Transportation (WSDOT) and other transportation providers do more with less, increase the life span of our transportation infrastructure, and proactively address change so that we can provide a safe and reliable transportation system for the traveling public. Within this report, you'll find projects that seek knowledge, methods, and strategies to

- retrofit, rather than rebuild, existing bridges and structures so that they are able to better withstand earthquakes
- speed the delivery of our construction processes
- maximize the movement of people and freight more reliably on our existing infrastructure
- minimize the impact of the transportation system on Washington's natural resources
- improve the durability of highway pavements and steel structures.

Recently, the WSDOT State Materials Engineer reviewed the contribution that research has made to pavement condition in the state. His analysis of changes in practice resulting from 11 research projects revealed an estimated savings of $106.7 million annually. Through these improvements in practice, pavement condition in Washington remains in fair or better condition on 93 percent of the roadways, despite a decreased budget and increases in population, lane miles, and vehicle miles traveled.

Similar outcomes are true for other areas of study. Over the last 20 years, investment in research has resulted in knowledge and tools that lead the nation in passenger and freight mobility. Safety research has helped reduce fatal and injury accidents. Research has also helped WSDOT target transportation project needs, improve project design and delivery, and maintain the transportation system. Through our partnership, we conduct practical research with useful results.

In addition to the knowledge gained through research, research helps provide a knowledgeable work force for the future. Students involved in the research projects gain valuable experience and knowledge about transportation practices, laying a strong foundation for their future employment. This is especially important as the baby boomer generation begins to retire.

The Washington State Transportation Center (TRAC), a partnership of WSDOT, the University of Washington, and Washington State University, was created in 1981. We remain committed to the conduct of research in support of informed decisions and improved practices within Washington and the transportation community. We thank the researchers, students, and industry professionals in both the public and private sectors who make our transportation research program so successful.

We also welcome your feedback on this report and our research program, and encourage you to stay in touch through our website at http://www.trac.washington.edu.

Leni Oman
Executive Director, TRAC
Director, Office of Research & Library Services, WSDOT

OVERVIEW

Steel Truss Bridge at Deception Pass

Research at the Washington State Transportation Center (TRAC) addresses the needs of today's transportation systems. The studies cover a variety of fields, and many require interdisciplinary contributions. These studies benefit from the collaborative work within and between research institutions in Washington, as well as other organizations. Through these partnerships TRAC is able to leverage knowledge, funding, and other research resources to provide cost-effective and innovative solutions to transportation-related challenges.

Project Funding and Support

From July 1, 2007, to June 30, 2009, TRAC-UW researchers were involved in over 60 research projects, for which the budgets totaled nearly $8.5 million. Budgets for TRAC-WSU's 16 projects totaled over $4.75 million. These figures do not include TRAC's administrative budgets.

Research support came from a variety of sources. In the past two years, TRAC received national support from

- Federal Highway Administration
- Maricopa County Association of Governments, Arizona
- National Institutes of Health
- Oregon State Department of Transportation
- Transportation Northwest
- Transportation Research Board
- Western Federal Lands Highway Division
- U.S. Congress
- U.S. Customs and Border Protection
- U.S. Department of Homeland Security
- U.S. Department of Transportation

A number of TRAC/WSDOT projects were supported by consortia or pooled funds in which the departments of transportation from other states were involved, including those of Alaska, Arizona, California, Colorado, Connecticut, Florida, Idaho, Illinois, Kansas, Maryland, Michigan, Minnesota, Missouri, Nebraska, New York, North Dakota, Ohio, Oregon, Pennsylvania, Tennessee, Texas, Washington, and Wyoming.

In addition to WSDOT, in-state public supporters for TRAC projects included

- Community Transit
- Seattle Children's Hospital Research Institute
- Sound Transit
- Western Washington University

TRAC received private support from or worked as a subcontractor with

- Cambridge Systematics
- Honda R&D Americas, Inc.
- Kittleson and Associates
- Post, Buckley, Schuh & Jernigan, Inc.

Cooperation and Collaboration

The breadth of TRAC research topics over the past two years involved 45 faculty and researchers from the following 16 UW and WSU departments:

- Applied Physics Lab, UW
- Aquatic and Fishery Sciences, UW
- Architecture, UW
- Atmospheric Sciences, UW
- Civil and Environmental Engineering, UW
- Civil and Environmental Engineering, WSU
- Construction Management, UW
- Economic Sciences, WSU
- Electrical Engineering, UW
- Evans School of Public Affairs, UW
- Forest Resources, UW
- Human Centered Design and Engineering, UW
- Information School, UW
- Mechanical Engineering, UW
- Office of Educational Assessment, UW
- Social and Economic Sciences Research Center, WSU
- Urban Design and Planning, UW

Through these research projects, TRAC researchers worked with numerous partners including private consulting firms, product manufacturers, other universities and research facilities, cooperative associations, and public agencies. Most research would not have been possible without the cooperation of these partners, and the collaborations have resulted in more successful and valuable results. Over the biennium, TRAC collaborated with the numerous research partners listed below.

OVERVIEW

Universities and Research Institutes

Arizona State University
Battelle Marine Sciences Laboratory
Battelle Memorial Institute
Foundation for Scientific and Industrial Research, Trondheim, Norway
Pacific Northwest National Laboratory
Royal Military College of Canada
Eastern Washington University
Texas Transportation Institute
University of South Florida
University of Texas—El Paso
Wayne State University

Through our partner organizations, TRAC also participated in the Region X Transportation Consortium that is working to strengthen the network between University Transportation Centers and state DOTs in the Northwest.

Public Agencies

British Columbia Ministry of Transportation
Canada Border Services Agency
City of Des Moines
City of Federal Way
City of Mukilteo
City of SeaTac
City of Shoreline
Confederated Tribes of Colville Reservation
Federal Aviation Administration
King County Metro Transit
Port of Seattle
Port of Tacoma
Seattle Public Schools
Sound Transit
Washington Department of Fish and Wildlife
U.S. Department of Agriculture
U.S. Fish and Wildlife Service
U.S. Maritime Administration
Volpe National Transportation Systems Center

Private Companies

American Presidents Line
Central PreMix Prestress Co
General Technologies Inc.
IBI Group
Maersk Line
Matson
MLB Company
Nichols Consulting Engineers
Telematics Wireless
TrafficGauge
TransCore
Yamaha

Associations

Northwest Regional Modeling Consortium
Washington Trucking Associations

Student Involvement

A new way that the universities and WSDOT partnered was through the Student Studies Program. The WSDOT Research Executive Committee established the Student Studies Program to supplement the department's capabilities to perform small and quick research tasks and to provide students at the University of Washington and Washington State University educational opportunities to explore transportation subjects. TRAC coordinated the effort, led by Mark Hallenbeck (UW) and David McLean (WSU), and provided oversight. Student work within this program, sponsored by different departments within WSDOT (Rhonda Brooks, Research Manager), includes the following:

- collection of data for GIS mapping on the migratory patterns of radio collared cougars to identify their key highway crossing locations
- identification of critical sulfate concentrations in soils and groundwater sources in Washington that may be detrimental to concrete structures and foundations
- analysis of media coverage of significant events in the Olympic Region to evaluate agency successes and identify areas for improving public communications
- evaluation of the current and future uses of "social media" to assess how WSDOT might use them to further customer outreach
- evaluation of the WSDOT website to ascertain whether the pages are effective in giving people the information they need
- collection of information on key components of the capital, operating, and institutional arrangements of ferry systems in other states and countries
- examination of the Whatcom County Smart Trip and other neighborhood Smart Trip programs so that other metropolitan planning organizations in Washington can be informed if they decide to set up similar programs
- a survey of people at selected senior centers to characterize some of the issues that transit agencies will face with the increase in retiring baby boomers
- assistance to small communities whose main street is a state highway in developing architectural and landscaping guidelines to

OVERVIEW

define and maintain the character of their towns

- researching and writing articles for the Pavement Interactive website on topics including construction, materials, pavements, and more
- analysis of various strengths of hot mix asphalt to provide data for the Mechanistic Empirical Pavement Design (MEPG) Guide.

Technology Transfer

Research dollars are wasted if clients are unaware of research results, unable to understand research findings, or unable to implement them. That's why TRAC emphasizes technology transfer as part of its operations. TRAC makes a special effort to ensure that research reports are understandable by developing project summaries and providing guidance to writers.

WSDOT also prepares synthesis reports that summarize currently available information to assist decision makers. This past biennium WSDOT and WSU staff developed 22 reports on a variety of topics. WSDOT staff also prepared Research Notes for nine studies. These short, nontechnical documents are distributed to all state DOTs and other interested parties. In addition, WSDOT developed a list serve to distribute Research Notes and reports.

As examples of recent technology transfer endeavors, over the past two years researchers began to survey and assess WSDOT photo collections to improve the management of photo resources for both public and private use. They participated in a Pavement Tools Consortium that fosters the continued development and implementation of computer-based paving tools, and they established a consortium to develop and implement a variety of computer-based tools for sharing and integrating geo-spatial transportation data. TRAC researchers also continued to support a traffic management center intern program at WSDOT to the mutual benefit of University of Washington civil engineering students and WSDOT Traffic Management.

TRAC also continued to maintain and improve its website, http://trac.washington.edu to inform visitors about TRAC work, provide access to research reports and project information, and guide researchers in producing work through TRAC.

TRAC Mission

Research at the Washington State Transportation Center (TRAC) is interdisciplinary, collaborative, and diverse.

TRAC is a cooperative transportation research agency. Its members, the University of Washington (UW), Washington State University (WSU), and the Washington State Department of Transportation (WSDOT), support TRAC to coordinate both public and commercial transportation research efforts and to develop research opportunities nationally and locally.

TRAC's most important function is to provide a link among the state and other research clients, university researchers, and the private sector. TRAC acts as a liaison, connecting those who need applied research at WSDOT or other agencies and those best suited to conduct it at the universities, as well as connecting researchers to data and other resources.

From its offices at the University of Washington in Seattle and Washington State University in Pullman, TRAC coordinates resources for research, serves as a focal point for student involvement in transportation research, and provides services such as report editing, production, and graphics. In fact, over the past two years, research at TRAC has been conducted by 44 faculty and researchers in 16 UW and WSU departments for over 20 sponsors and with over 40 public and private partners. The office at WSDOT in Olympia serves as the central control point of contact for agency managers interested in working with university researchers and students through a variety of programs. The WSDOT provides research funding and contracts and connects researchers to technical resources.

Intercity transit, Lacey, Washington.

PROJECTS: Bridges and Structures

Washington is *in an active seismic zone, and because of that, much of the bridge research has focused on seismic-related issues. The focus of the bridge research over the past biennium has continued to be on seismic retrofitting, rapid construction techniques for active seismic zones, and improving the design and construction of bridges.*

On the design side, reducing bridge deck shrinkage cracking was a major focus, and the research conducted will improve the performance of bridge decks. The seismic retrofit program, which is scheduled to conduct retrofits by bridge type and risk, will continue, as will further research to evaluate the next bridge type that is scheduled for retrofit. Rapid construction in seismic zones is in the implementation phase and will reduce on-site bridge construction time, thereby causing less traffic disruption and fewer construction hazards while ensuring that bridges are able to withstand an earthquake.

Completed Projects

Composite Material Alternatives to Timber in the Construction of Wing Walls

The wing wall system of a ferry terminal positions the vessel bow and dissipates energy through impact during the ship's approach for berthing. The material of choice for ferry terminal wing walls has traditionally been timber treated with preservative chemicals, which has the desirable properties of stiffness, wear, friction, and low cost. However, with the listing of salmon as an endangered species in Puget Sound, the continued installation of biocide-treated wood products in existing or new harbor facilities has become problematic. In response, this project explored the use of two wood-plastic composite (WPC) materials to replace current timber elements for the wear surfaces of wing walls. The researchers found that the materials' structural capacity and ability for development into large wing wall sections varied, but they concluded that if the positive environmental attributes of the WPCs are judged to offset their higher initial costs, WPCs appear to be a viable substitute for treated timber in ferry terminal wing walls.

Principal Investigators: Bender, D./Wolcott, M.P., WSU
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Bertucci, T., WSDOT
Sponsors: WSDOT/FHWA

Detection of Voids in Prestressed Concrete Bridges Using Thermal Imaging and Ground-Penetrating Radar

In the nondestructive inspection method of thermography, thermal imaging cameras detect infrared energy emitted from an object and then convert this energy reading into a display of the material surface temperature. Ground-penetrating radar (GPR) is a nondestructive inspection method that uses radar pulses to image subsurface structures. This project investigated the usefulness of these two structural inspection methods for detecting air voids in the prestressing strand ducts of concrete bridges. Key questions included what internal defects can and cannot be detected? What heating applications produce the best inspection results from infrared imaging? What concrete thicknesses can be inspected with GPR? The study included both laboratory tests on concrete simulated bridge walls and field inspections on four bridges in western Washington. The findings from this study will help WSDOT engineers more effectively utilize these nondestructive inspection methods to find air voids and other internal structural defects that require repair to maintain the safety of the state's bridges.

Principal Investigator: Pollock, D.G., WSU
Project Manager: Willoughby, K., WSDOT
Technical Monitor: Khaleghi, B., WSDOT
Sponsor: WSDOT/FHWA
WA-RD 717.1

Researchers are exploring the use of wood-plastic composite materials to replace biocide-treated wood in ferry terminal wing walls.

PROJECTS: Bridges and Structures

Dynamic Response of Bridges to Near-Fault, Forward Directivity Ground Motions

Research has shown that a special type of earthquake ground motion that occurs in the form of pulses near a fault can cause significant damage to structures. In addition, traditional simplified analysis methods for seismic design have been shown to be insufficient to capture the full effects of this type of ground motion on bridges. The objective of this project was to take advantage of a recent increase in ground motion data to improve the understanding of the response of typical reinforced concrete and precast concrete bridges to these pulse-type forward directivity ground motions. The results from detailed structural analyses of three post-1990 bridges in Washington showed that significant seismic damage may occur if the structural response is in tune with the period of the ground motion pulses. The researchers developed a methodology for seismic analysis that accounts for the additional hazard resulting from pulse-type ground motions. This work should help WSDOT design safer bridges by more accurately analyzing and predicting their seismic response at sites near faults.

Principal Investigators: Rodriguez-Marek, A/Cofer, W., WSU
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Willoughby, K., WSDOT
Sponsors: WSDOT/FHWA
WA-RD 689.1

Effect of Intermediate Diaphragms on Prestressed Concrete Bridge Girders in Over-Height Truck Impacts

Bridges struck from beneath by over-height trucks can be damaged enough to interrupt service. The use of intermediate diaphragms in concrete girders may improve the impact resistance and thus the survivability of bridges, but to date only limited research has been conducted. This study sought to develop and validate dynamic numerical finite element models to simulate the response of prestressed concrete bridge girders with intermediate diaphragms. The researchers also perform a numerical parametric study to evaluate the effects of critical factors on the design of the diaphragms. The results of this study will assist in the development of standards of practice for the design of prestressed concrete bridge girders with intermediate diaphragms, and the recommendations and proposed guidelines will help bridge engineers make better design decisions for prestressed concrete bridges.

Principal Investigators: Qiao, P./McLean, D.I., WSU and Yang, M., UTSA
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Khaleghi, B., WSDOT
Sponsors: WSDOT/FHWA
WA-RD 696.1

Rapid Construction of Bridge Bents with Precast Concrete

Bridge construction can dramatically increase traffic delays and congestion, particularly in areas with heavy traffic volumes. Traffic disruption can be reduced if reinforced concrete columns and cross-beams can be precast off-site and then assembled together at the bridge site. To take advantage of the benefits of using precast bridge components in Washington state, precast concrete systems must be developed that not only can be constructed quickly but that also perform well under earthquake loading. A previous phase of this program addressed some of these issues. The goal of this Phase 2 work was to develop methods of designing and constructing precast concrete bridge bents that can be built quickly and that will perform well under earthquake loading. With the use of reliable precast bridge components, WSDOT will be better able to reduce on-site bridge construction time, thereby causing less traffic disruption and fewer construction hazards.

Principal Investigators: Stanton, J.F./Eberhard, M.O., UW
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Kapur, J., WSDOT
Sponsors: WSDOT/FHWA/TransNow
WA-RD 684.1, 684.2, 684.3

New models will help engineers determine the effectiveness of intermediate diaphragms in improving the resistance of bridges to damage from overheight trucks (here on I-90 near Easton, Washington).

PROJECTS: Bridges and Structures

Seismic Assessment of WSDOT Bridges with Prestressed Hollow-Core Piles

Hollow prestressed reinforced concrete piles were used as foundations for many bridges in Washington state during the 1960s.

Tests have shown that when piles of this type are loaded to failure, they fail in a sudden, brittle manner that is highly undesirable in seismic regions. However, because full-size tests are impractical, those tests were performed on specimens of a much smaller scale, and the test results cannot be extrapolated with confidence to actual piles in place. To address this and other questions, a detailed computer model to accurately simulate the behavior of prestressed hollow-core piles was developed and verified through comparison with experimental tests. The computer model was then expanded to represent the configuration of actual piles, both in the ground with the effect of the confining soil and at the connection with the bridge superstructure. Given this information, a typical bridge built on such piles was evaluated for seismic loading. The resulting knowledge about the failure mechanisms for bridges of this type, the forces required for various levels of failure, and a definition of the earthquake magnitude that will cause failure will allow WSDOT bridge engineers to design safer retrofits and new bridges.

Principal Investigators: Cofer, W./ElGawady, M., WSU
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Khaleghi, B., WSDOT
Sponsors: WSDOT/FHWA
WA-RD 732.1

Seismic Retrofit of Rectangular Bridge Columns

Engineers continue to develop and implement retrofit strategies to upgrade the seismic performance of existing bridges. This study investigated retrofitting measures to improve the seismic performance of rectangular columns in existing bridges. Experimental tests were conducted on 0.4-scale column specimens with details that were selected to represent deficiencies present in older bridges in Washington state. Five columns were retrofitted with carbon fiber reinforced polymer (CFRP) composite wrapping and one specimen was retrofitted with a steel jacket. The specimens were subjected to increasing levels of cycled lateral displacements under constant axial load. On the basis of the results, the researchers recommended that oval-shaped jackets be used whenever possible to retrofit rectangular columns. Column specimens with oval-shaped jackets of steel and CFRP composite material performed similarly, both producing ductile column performance. With practical and effective guidelines for the seismic retrofit of rectangular columns, WSDOT engineers will be able to more cost-effectively maintain safer bridges.

Principal Investigators: McLean, D.I./Sack, R./ElGawady, M., WSU
Project Manager: Willoughby, K., WSDOT
Technical Monitor: Wilson, D., WSDOT
Sponsors: WSDOT/FHWA
WA-RD 716.1

A new procedure will aid engineers in evaluating the status of gusset plates on steel truss bridges (such as this one over the Nooksack River on SR 539, Washington).

Active Projects

Evaluation of Gusset Plate Connections in Steel Truss Bridges

The recent failure of a large steel truss bridge in Minnesota has been, in part, attributed to overstressed and buckled gusset plates. This catastrophic event signaled concerns about the potential for similar overstressing of gusset plates in steel truss bridges across the country. To help bridge engineers in evaluating gusset plates, the Federal Highway Administration released FHWA Bridge Design Guidance No. 1; however, the complex design methods make rapid assessment difficult. To remedy this, a study is under way to develop a new procedure for rapid and reliable evaluation of the state of gusset plates, including their maximum stresses, likelihood of gusset buckling, and critical connection configurations. The new approach should enable bridge engineers to more expediently evaluate the capacity of gusset plates, allowing the gusset plates with near critical demand-to-capacity ratios to be identified for further, more refined analysis or retrofit.

Principal Investigators: Berman, J./Lehman, D./Roeder, C., UW
Project Manager: Willoughby, K., WSDOT
Technical Monitor: Coffman, H., WSDOT
Sponsors: WSDOT/FHWA

Researchers are investigating the primary causes of transverse shrinkage cracking in WSDOT concrete bridge decks (above, restrained shrinkage cracking from an AASHTO ring test).

Mitigation Strategies for Early-Age Shrinkage Cracking in Bridge Decks

Early-age shrinkage cracking has been found in bridge decks across the U.S., including in Washington state. Such cracks in a bridge deck allow water, de-icing chemicals, sulfates, and other corrosive agents to penetrate into the concrete and substantially diminish the deck's service life. Because concrete deck repair is expensive and can cause traffic delays, the extent of this cracking needs to be reduced to prevent premature deterioration. This project is addressing that issue by working to determine the primary causes of the transverse shrinkage cracking occurring in newly constructed WSDOT concrete bridge decks and to develop appropriate mitigation strategies to reduce or eliminate early-age shrinkage cracking. The results should improve the durability and service performance of Washington bridge decks, decrease maintenance costs, and increase bridge safety and longevity.

Principal Investigators: Qiao, P./McLean, D.I., WSU
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Sheikhizadeh, M., WSDOT
Sponsor: WSDOT

PROJECTS: Construction Management

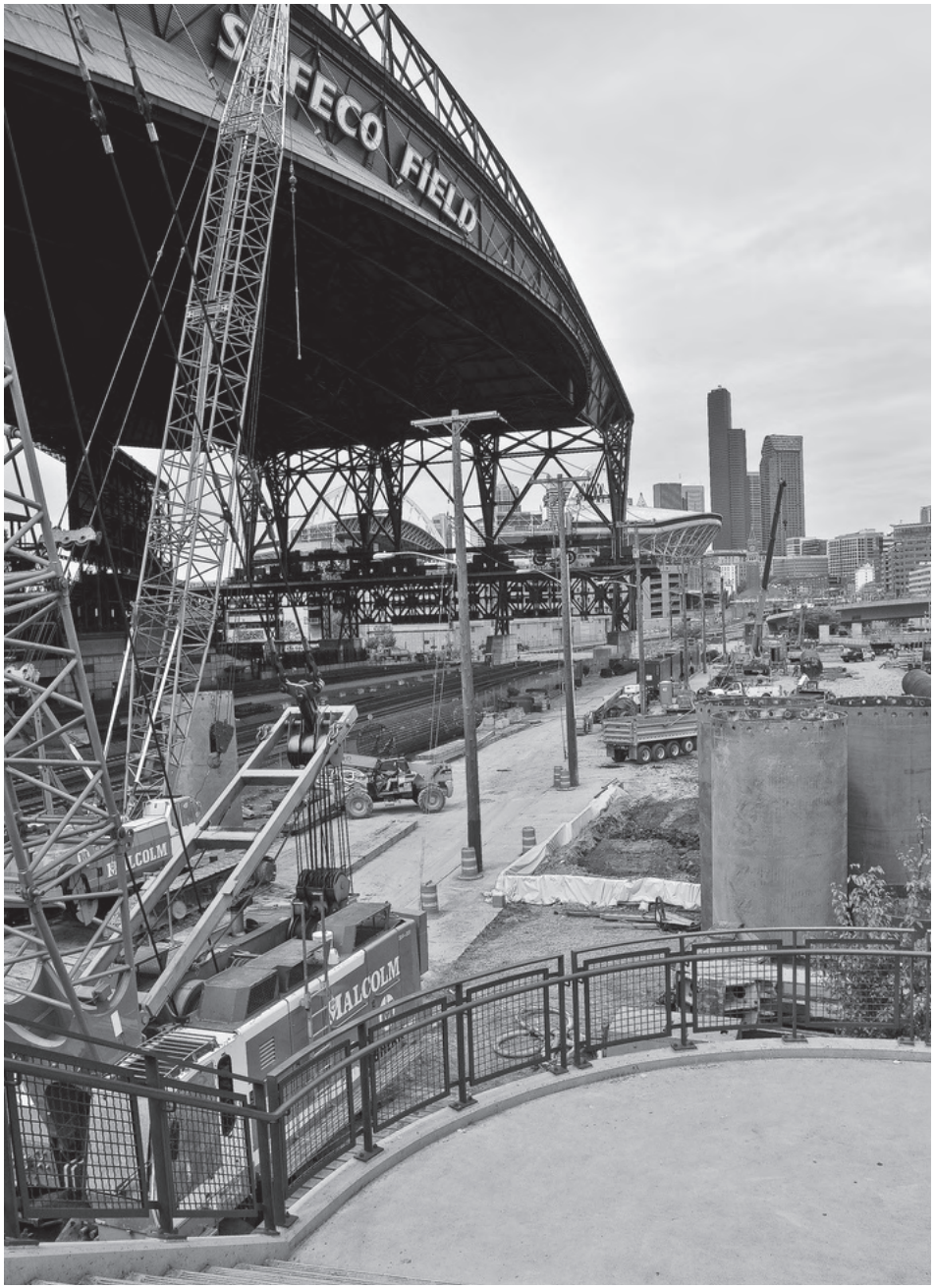
***Research to improve** project scoping, budgeting, and management is critical for improving the success of and accountability for the hundreds of major transportation projects that are constructed every year. Project scope, time, and cost estimates for these projects are critical in making decisions about planning, monitoring, and budgeting and for maintaining accurate accountability to the taxpayers for effective project delivery.*

Completed Projects

Performance Analysis and Forecasting for WSDOT Highway Projects

The time and cost of highway projects are important for highway agencies to control. The objectives of this research were to develop tools to monitor the contractor's performance during construction in order to detect unsatisfactory progress and to improve the prediction of time and cost for highway projects to reduce overruns. The researcher developed minimum and average performance bounds by using regression analysis and a set of successfully completed projects clustered in categories based on quantities of asphalt, contract value, project duration, and project miles. The researcher also developed time and cost prediction models based on a number of major variables in pavement projects. These new tools better enable WSDOT construction managers to more carefully monitor the performance of projects during construction, as well as to more accurately estimate construction duration and cost before projects are bid.

Principal Investigator: Abdel Aziz, A.M., UW
Research Manager: Lindquist, K., WSDOT
Technical Monitor: McDaniel, C., WSDOT
Sponsor: WSDOT
WA-RD 675.1



Researchers are developing tools to monitor contractors' peformance during construction to improve the prediction of time and cost and reduce overruns (construction of I-90 off-ramp at Atlantic Street, Seattle).

PROJECTS: Environment

Transportation environmental *research seeks to find ways to reduce impacts to Washington's valuable resources, such as reducing the demand for transportation to improve air quality and energy resources, and to build on opportunities to improve the natural environment through better transportation project development and construction. While reducing the impacts of transportation on the environment, such research may also improve safety, for example, by examining ways to reduce wildlife and vehicle collisions.*

Completed Projects

Analysis of Deer and Elk-Vehicle Collision Sites along State Highways in Washington State

WSDOT personnel remove approximately 3,000 deer and 85 elk, killed by collisions with vehicles, from Washington state highways annually. To reduce these numbers, this project developed models to assess the influences of road characteristics, habitat features, deer densities, and deer behavior on the frequency of ungulate-vehicle collisions (UVCs). A key factor found to influence the potential for UVCs on state highways was the number of deer in the surrounding area. The modeling also indicated that parameters related to better deer habitat were associated with higher collision counts. These results suggest that providing passageways for deer to cross over or under highways, constructing barriers that prohibit entry onto roadways, and discouraging deer presence near highways by reducing the quality of adjacent habitats may decrease UVC rates, thereby reducing accident costs to motorists and improving safety for both humans and the animals.

Principal Investigator: Myers, W.L., Washington Department of Fish and Wildlife
Research Manager: Brooks, R., WSDOT
Technical Monitor: Carey, M., WSDOT
Sponsor: WSDOT
WA-RD 701.1

Determination of Hydraulic Conditions and Eddy-Like Motions in the Culvert Test Bed and Their Effects on Upstream Juvenile Salmon Passage

Road culverts on federal, state, and private lands currently block upstream passage of juvenile salmon to thousands of miles of suitable rearing habitat. The WSDOT is leading a cooperative program to study juvenile salmon passage through culverts by conducting experiments in a full-scale culvert system at a state hatchery. The overall goal of the culvert test bed program is to identify culvert configurations and associated hydraulic conditions that facilitate successful upstream passage of juvenile salmon. This study sought to determine whether the culvert retrofits recommended by the Washington Department of Fish and Wildlife, sloped-weir baffles, limit juvenile salmon passage. Culvert slope, baffle spacing, and baffle height were varied, and velocity was measured. A separate, concurrent biological study was conducted by Battelle Memorial Institute. The study results will provide professionals with guidance for retrofitting culverts.

Principal Investigator: Horner-Devine, A., UW
Research Manager: Brooks, R., WSDOT
Technical Monitor: Petersen, J., WSDOT
Sponsors: WSDOT/FHWA
WA-RD 687.1

Eelgrass Restoration in the Pacific Northwest: Recommendations to Improve Project Success

Eelgrass (*Zostera marina L.*) is the most widespread of nearly 65 seagrass species and plays an important role in nearshore ecosystems. Because of their continued losses, seagrasses are a focus of conservation and restoration efforts. This project surveyed eelgrass restoration and mitigation project results and recommendations in the Pacific Northwest since 1990. The report concluded that, under favorable site conditions, and if the reason for the initial loss of eelgrass is understood and corrected, eelgrass can be restored to match the structure and function of natural eelgrass meadows. However, eelgrass restoration science is hampered by knowledge gaps. Recommendations included the development of standard monitoring protocols and a clearinghouse of eelgrass restoration and monitoring results that will provide summaries and data from eelgrass enhancement efforts.

Principal Investigator: Thom, R., Pacific Northwest National Laboratory
Research Manager: Brooks, R., WSDOT
Technical Monitor: Carey, M., WSDOT
Sponsor: WSDOT
WA-RD 706.1

Environmental Investigation of Heavy Metals in Highway Runoff

Stormwater runoff from highways is a growing concern across the country. The Federal Highway Administration currently identifies cadmium, chromium, copper, iron, lead, nickel, and zinc as the heavy metals typically associated with highway runoff. The U.S. Environmental Protection Agency states that the primary sources of these metals are wear and tear of various vehicle components such as tires, engine parts, and brake pads; auto body rusting; lubricants; and fuel combustion. Although attempts have been made to relate stormwater runoff quality to average daily traffic (ADT) loads, the relationship between metals in stormwater runoff and levels of traffic has proved to be complex, and simply treating highway runoff from

roads with high ADT is not the answer. To help WSDOT find both short- and long-term solutions to cost-effectively address concerns about highway runoff, this research suggests that a robust, scientifically defensible methodology be developed for predicting the timing and location of enhanced metals treatment in highway runoff.

Principal Investigators: Barber, M.E./Yonge, D.R., WSU
Research Manager: Brooks, R., WSDOT
Technical Monitor: Schaffner, L., WSDOT
Sponsor: WSDOT

Movement and Habitat Use of Chinook Salmon Smolts, Northern Pikeminnow, and Smallmouth Bass Near the SR 520 Bridge, 2007 Acoustic Tracking Study

Many Chinook salmon in Lake Washington must pass beneath the four-lane SR 520 bridge on their way to Puget Sound. This study undertook to evaluate the movement and habitat use of Chinook salmon smolts and two kinds of their predators near the SR 520 bridge. The researchers tracked tagged fish near the west end of the bridge, which is within a major migratory corridor for the salmon. They found that most actively migrating salmon appeared to be delayed by the bridge. Conversely, many fish that were holding in the area rather than migrating chose to reside in areas near the bridge for prolonged periods. For the northern pikeminnow, the bridge did not seem to be a major foraging site, but larger smallmouth bass were often found near bridge columns. WSDOT will use the results of this and future studies to help minimize impacts on fish in Lake Washington as it designs a new bridge for the site.

Principal Investigator: Celedonia, M.T., U.S. Fish and Wildlife Service
Research Manager: Brooks, R., WSDOT
Technical Monitor: Bloch, P., WSDOT
Sponsor: WSDOT
WA-RD 694.1

In rebuilding the SR 520 bridge across Lake Washington, WSDOT will consider new information about the behavior of fish, including migrating salmon, near the bridge and its columns.

Plain Talk

Several government agencies have been requesting that writers improve the quality of environmental policy documents by applying principles taken from Plain Language (PL), a movement to make communications with the public easier to read, understand, and use. This project sought to determine whether implementing some specific PL guidelines would influence readers' perceptions and comprehension of environmental policy documents. After a literature review and survey, the researchers examined the effects of heading phrasing and personal pronouns. Results revealed that headings in question form can make documents seem more familiar but less reliable than when headings are in statement form. Use of personal pronouns can make information seem easier to find and more friendly. These findings showed that PL precepts can affect readers of environmental policy documents, but more work is needed to further understand the impacts of PL guidelines on the public.

Principal Investigator: Spyridakis, J., UW
Research Manager: Brooks, R., WSDOT
Technical Monitor: Roalkvam, C., WSDOT
Sponsor: WSDOT

Active Projects

Identifying High Risk Locations of Animal-Vehicle Collisions for Washington

In Washington State, more than 3,000 collisions occur yearly with deer and elk on state highways. Therefore, identifying high-risk locations for animal-vehicle collisions (AVCs) and appropriately allocating limited resources to improve safety are important tasks for WSDOT. The objectives of this study are to build a relational database that stores data on

PROJECTS: Environment

AVC occurrences, highway geometry, traffic variables, and animal habitats; to develop a new modeling approach that can quantify the relationships between AVC risk and roadway and/or environmental variables; and to identify locations on selected Washington state highways that are at high risk for AVCs. The benefits from this research will be a better understanding of AVCs on Washington highways and a list of locations at high risk for AVCs that are a priority for investigation. In addition, the findings of this study may establish a solid foundation for developing a statewide animal habitat connectivity plan, a necessary tool for minimizing AVCs with the construction of future highways.

Principal Investigator: Wang, Y., UW
Research Manager: Brooks, R., WSDOT
Technical Monitor: McAllister, K., WSDOT
Sponsor: WSDOT

Juvenile Salmon Behavioral Response to Ferry Terminal Light Mitigation Treatments

Studies have found that shading caused by over water structures such as ferry docks may affect juvenile salmon migratory behavior. To facilitate fish passage beneath ferry terminals, scientists experimented with increasing light beneath the docks and reducing or eliminating dark shadow edges cast by terminal structures. Toward that end, this study is evaluating the use of fiber-optic technologies to minimize shading under existing structures. UW researchers are collaborating with Battelle Marine Sciences Laboratory to complete feasibility testing of a commercially available fiber-optic system, looking at its area of coverage, its optimum placement and configuration to decrease shadow edges, and the responses of migrating juvenile salmon to the light mitigation. The tests include in situ sampling of fish behavior under different experimental lighting treatments. If the lights prove effective and cost efficient, they will enhance the migratory movement of these endangered fish.

Principal Investigator: Simenstad, S., UW
Research Manager: Brooks, R., WSDOT
Technical Monitors: Huey, R./Carey, M,, WSDOT
Sponsor: WSDOT

Reduction of Underwater Sound Levels from Pile Driving Operations

The sound generated by driving large-diameter steel piles underwater may have adverse effects on marine animals. In fact, the documentation of fish kills at several pile driving sites, including Washington state ferry terminals, has led to increased regulatory concern and tighter permit restrictions. Researchers are proposing to reduce the noise from pile driving by at least 35 dB 10 meters from the pile by modifying a previously developed device called a Temporary Noise Attenuation Pile (TNAP), which surrounds the pile as it is driven into the soil. This modified TNAP will be tested in the fall of 2009 at the Vashon ferry terminal dolphin replacement project. The researchers will also measure and model shallow water sound propagation to enable engineers to predict sound levels at distances of up to 500 meters from the pile. The modeling effort will help improve the prediction of noise levels from pile driving during the planning stages of future projects, thereby streamlining associated regulatory processes.

Principal Investigators: Reinhall, P./Dahl, P.H., UW
Research Manager: Brooks, R., WSDOT
Technical Monitors: Carey, M./Laughlin J./Huey R., WSDOT
Sponsor: WSDOT

A new device may reduce the noise of underwater pile driving and its effects on aquatic animals, allowing WSDOT to conduct pile driving operations year round (Sauk River, Washington, stabilization project).

PROJECTS: Freeway and Arterial Management

The free flow *of people and goods is vital to Washington and the families that live here. That's why traffic congestion is one of the state's top transportation priorities. In 2003 the annual estimated cost of delays caused by traffic congestion was $486 million. In 2007, the congestion price tag rose to $617 million, an increase of 27 percent.*

For years Washington has worked to manage highway congestion with tools such as high-occupancy vehicle (HOV) lanes, metered on-ramps, variable-direction express lanes, traffic cameras, variable message signs and traffic centers, Incident Response Teams, and signal optimization. Now the state is taking the challenge to a new level. By studying the most cutting-edge and successful traffic management advances in the world, Washington is developing smarter highway systems that will make our highways more efficient, less congested, and safer for all.

Research in the state is developing measurements and benchmarks to present a clear, more accurate picture of congestion on the state's most affected freeways. The research is focusing on developing ways of measuring efficiency and reliability and on producing improvements that people can see and experience.

Researchers are developing a method of monitoring arterial performance that will complement existing freeway monitoring techniques.

Completed Projects

Arterial FLOW Methodology

Through its research program, WSDOT has developed and deployed a performance monitoring methodology that uses the WSDOT's FLOW system of loop detectors and data archiving processes to monitor Puget Sound freeways. Because most trips involve at least some use of the regional arterial network as well, a method of monitoring arterial performance that complements the existing freeway monitoring techniques would enable performance of an entire trip to be analyzed, not just the freeway component. To develop such a method at low cost to any transportation agency, this study investigated the general relationship between the data from loop sensors at signalized intersections and the overall level of congestion on the arterial. The project also developed a prototype analytical method to utilize such data and explored issues that would make deployment of a traffic signal sensor-based arterial monitoring system feasible. If successfully developed, such a method for monitoring arterial performance will aid in planning and operational analyses, as well as in potential real-time monitoring applications such as on-line traffic maps.

Principal Investigators: Hallenbeck, M.E./Ishimaru, J.M./Kang, J., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Trepanier, T., WSDOT
Sponsor: WSDOT

Congestion Analysis and WSDOT Support

As part of WSDOT's continuing efforts to manage the central Puget Sound region's transportation network and enhance traveler mobility, WSDOT's Northwest Region has an ongoing need for timely, detailed technical information on traffic conditions, historical trends, and emerging transportation issues associated with the area's roadways. Since 1995, TRAC has developed data collection tools and analyses to provide this information for Seattle area freeways. This project continued to update those freeway monitoring analyses, enhance evaluation tools, and provide technical support to WSDOT. This included conducting analyses for the seventh and eighth editions of the WSDOT Central Puget Sound Freeway Usage and Performance Report, now published as interactive graphics on-line at http://depts.washington.edu/hov, as well as yearly

analyses of the HOV lane network. The project also developed Seattle freeway performance and congestion analyses to support the WSDOT's Gray Notebook performance monitoring program. The information provided by these analyses helps WSDOT improve freeway operations, conduct planning studies, and analyze alternative strategies to improve the Puget Sound transportation network.

Principal Investigators: Hallenbeck, M.E./Ishimaru, J.M./Kang, J., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Neeley, M., WSDOT
Sponsor: WSDOT

Construction Traffic Driver Behavioral Study

During major highway closures in the Seattle area, a significant percentage of drivers temporarily change their travel behavior, dramatically reducing the number of vehicles on routes where construction occurs and notably increasing traffic on alternative routes. Traffic and transit data analysis have determined that some drivers shift their travel schedules, routes, and modes, but complete data have been unavailable to understand the actions of the majority of drivers during closures. This study conducted a survey of residents in the greater Seattle area to determine driver behavior during major highway construction closures in the urban area. The information from this survey research will be helpful to decision makers in understanding what actions the majority of drivers take during construction closures, why they take them, and whether these actions are sustainable in providing long-term congestion relief.

Principal Investigator: Moore, D.L., WSU
Research Manager: Lindquist, K., WSDOT
Technical Monitors: Suchan, S./Helmann, J., WSDOT
Sponsor: WSDOT

HOV Lane Evaluation and Monitoring Phase IX

Surveys have shown considerable support for the construction of HOV lanes in the Puget Sound region.

The work of HOV traffic counters is helping planners evaluate the impact and adequacy of the Puget Sound HOV lane system.

In this ongoing study researchers are conducting a multi-faceted evaluation of the effectiveness of HOV lanes. The evaluation includes yearly analyses of data collected to describe the number of people and vehicles that use the HOV lanes, the reliability of the HOV lanes, travel time savings in comparison to general purpose lanes, violation rates, and public perceptions. These statistics are available at http://depts.washington.edu/hov/. The resulting information is intended to help transportation decision makers and planners evaluate the impact and adequacy of the existing Puget Sound HOV lane system and plan for other HOV facilities.

Principal Investigators: Hallenbeck, M.E./Ishimaru, J.M./Kang, J., UW
Project Manager: Brodin, D., WSDOT
Technical Monitor: Trepanier, T., WSDOT
Sponsor: WSDOT

Quantifying Incident-Induced Travel Delays on Freeways Using Traffic Sensor Data, Phase I

It is generally believed that more than 50 percent of congestion on freeways is non-recurrent and that a large portion of that congestion is the result of incidents. Particular attention should be paid to travel delays caused by non-recurring congestion because it may be effectively alleviated through traffic management, control, and incident response. To better understand non-recurring congestion on Puget Sound freeways, researchers developed a database of loop detector and incident data to support delay estimation studies and decision making, developed an algorithm for quantifying incident-induced travel delay on freeways that uses traffic sensor data, and created a computer system, the Advanced Roadway Incident Analyzer (ARIA), that automates the algorithm's delay calculations. The result should be a better understanding of incident delays that helps WSDOT in choosing the most effective incident response strategies and congestion countermeasures.

Principal Investigator: Wang, Y., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Trepanier, T., WSDOT
Sponsors: WSDOT/TransNow/FHWA
WA-RD 700.1

Statewide Operations Data Archive

To improve the performance of the state's roadways, WSDOT requires a robust and flexible system to collect, store, summarize, and make available roadway data. A number of efforts have been undertaken within the WSDOT to collect, archive, and distribute data. The primary objective of this research effort was to recommend cost-effective ways to make existing WSDOT data more readily available. The intent was

to allow previously collected data to be easily located by users throughout WSDOT, who could then quickly understand, obtain, and integrate them with data from other sources. Work on this project produced valuable information about how people access the data and how to combine dissimilar but related data sets. Two data prototypes were developed. The first was designed to test user interfaces for identifying available data, and it also provided WSDOT analysts with better access to WSDOT's FLOW performance statistics. That site has been refined as part of the Statewide Traffic Data Mart project. The second prototype was used to test mechanisms for combining dissimilar types of traffic data in order to provide more analytically useful data combinations. This prototype is available at http://140.142.198.49/.

Principal Investigators: Hallenbeck, M.E./Sanderson, A., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Trepanier, T., WSDOT
Sponsors: WSDOT/FHWA

Washington Incident Response Tracking System

The Washington Incident Tracking System (WITS) database was written in a database language that prevented it from being readily accessed by other computerized WSDOT applications. This project rewrote the WITS database with Microsoft SQL Server to make the data more accessible within WSDOT. At the same time, the project team updated the functional capabilities of the WITS. This included developing a better user interface, additional reporting capabilities, improved incident location referencing systems, and the ability to enter data directly into the WITS database from remote devices. With these changes, WSDOT is better able to access WITS data, combine those data with other datasets to better manage roadway operations, and develop more integrated decision support tools.

Improvements to WSDOT's Incident Tracking System, used by its Incident Response Team, will make the data more accessible and allow WSDOT to better manage roadway operations.

Principal Investigators: Hallenbeck, M.E./Sanderson, A., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Bremmer, D., WSDOT
Sponsor: WSDOT

Active Projects

Development of a Statewide Traffic Data Mart

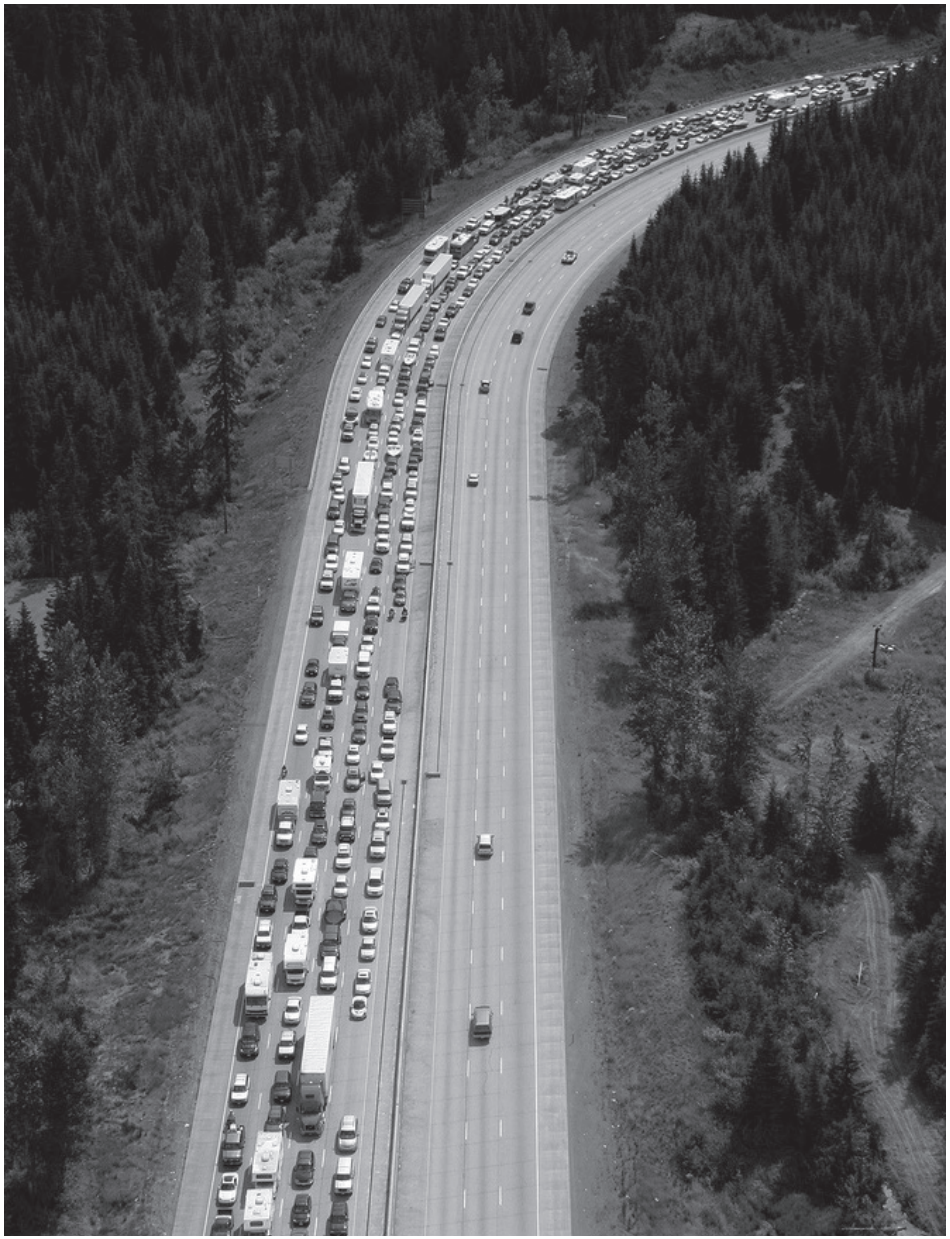
The limited funding available to expand roadway capacity means that WSDOT needs to optimize the performance of its existing roadway system. To do this, WSDOT needs to monitor the performance of current roadways, track the effectiveness of its operations strategies, and plan for operational improvements. Currently, WSDOT does not have the data collection, analysis, and archiving system—called a data mart—necessary to support these tasks. In response, this project is developing the functional specifications for a WSDOT operations data mart, assessing the capabilities of data archive systems that WSDOT regions currently use, and identifying the additional data sources needed to provide input to the data mart. This material has been delivered in technical working reports to WSDOT. In the near-term, these recommendations are being used to enhance WSDOT's current data systems (see http://trac29.trac.washington.edu/flowdata/maps/ ; passwords can be obtained from TRAC-UW). With the eventually resulting data mart, WSDOT will be better able to monitor the effectiveness of its operations efforts, which will enable it to more cost effectively improve the efficiency of its roadway system.

Principal Investigator: Hallenbeck, M.E., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Neeley, M., WSDOT
Sponsor: WSDOT

Efficient Incident Response Program Operations

The Incident Response (IR) program in Washington state is respon-

PROJECTS: Freeway and Arterial Management



Researchers are evaluating near- and long-term strategies for meeting roadway users' needs for travel time reliability.

sible for clearing roadways as quickly and as safely as possible to restore the normal flow of traffic. The program first started in Seattle in 1990. It now consists of a partnership among WSDOT, the Washington State Patrol, contracted registered tow truck operators, and contracted private media assistance vans across the state. The objective of this project is to evaluate the current state of Washington IR program. This evaluation includes an inventory and comparative analysis of the different program elements, as well as an analysis of deployment statistics and service levels to determine how incidents affect congestion on the roadway. Identifying the strengths and weaknesses of the various program elements will give decision makers objective data on which to base decisions for IR program modifications. In addition, analyzing the impacts of incidents and incident response on congestion should provide guidelines for deployment strategies, helping the program provide the highest level of service at the most efficient cost.

Principal Investigator: Hallenbeck, M.E., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Legg, B., WSDOT
Sponsor: WSDOT

Evaluating Alternative Operations Strategies to Improve Travel Time Reliability (SHRP II L11)

This project is intended to identify and evaluate both near- and long-term strategies for satisfying roadway users' requirements for travel time reliability. As members of a team led by Kittelson & Associates, TRAC researchers are envisioning the future to create a longer view of how new operational approaches might improve travel reliability. The project involves developing a profile of current and future highway users and describing their individual and collective needs for travel time reliability, assessing the effectiveness of transportation agencies in meeting the reliability needs of those highway users, and establishing goals and desired performance targets for travel time reliability. The researchers are also identifying trends likely to affect travel time reliability and its importance over the next 20 years, and developing a Concept of Operations for three alternative futures for the year 2030.

Principal Investigator: Hallenbeck, M.E., UW
Research Manager: Zegeer, J., Kittelson & Associates
Technical Monitor: Hyman, W., TRB
Sponsor: Strategic Highway Research Program, Transportation Research Board

PROJECTS: Freeway and Arterial Management

Feasibility of Creating a Vehicle Length Classification Scheme

Many states collect length-based vehicle classification data, but few states use the same criteria for classifying length. Agencies need to understand the variability in their data collection programs in order to better use their limited resources for collecting vehicle classification data. The final product of this pooled-fund study will be a nationally approved, length-based classification scheme and the establishment of calibration standards for vehicle length-based measurements. About ten years ago, WSDOT created a vehicle classification scheme based on vehicle length. That scheme places vehicles into thirteen distinct categories. WSDOT's intent for participating in this pooled fund study is to update its current length classification scheme and to verify that the traffic data it has collected and reported to date are approximately equal to the final classification scheme resulting from this study. State DOT's will use the results of this study to update computer chips in traffic counters and for other data collection applications.

Research Manager: Lindquist, K., WSDOT
Technical Monitor: Rosen, J., WSDOT
Sponsors: Minnesota (Lead), Alaska, Connecticut, Florida, Idaho, Illinois, Michigan, New York, Ohio, Pennsylvania, Texas, Washington, and Wyoming

HOV Action Plan

Performance data have indicated that travel speed and reliability in the high-occupancy vehicle (HOV) lanes of the central Puget Sound freeway network are not meeting the adopted state performance standard on an increasing number of segments. Furthermore, trends suggest that HOV travel demand will increase. This effort is evaluating the performance of Seattle-area HOV lanes, focusing on congestion on I-5 in the initial phase. Researchers have identified segments where congestion routinely occurs, determined the potential causes of those bottlenecks, and developed a range of potential short-term (0 to 5 years) enhancements to improve HOV traffic flow at those bottlenecks. The results from this project have the potential to increase person throughput, improve transit efficiency, and more effectively maintain desired incentives to commute via HOV modes of travel. They will also inform WSDOT plans and studies that require assumptions about HOV operating policy.

Principal Investigator: Hallenbeck, M.E., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Prestrud, C., WSDOT
Sponsor: WSDOT

Performance Measurement Framework and Congestion Management Update

In an effort to improve its planning process and be more accountable to taxpayers about how transportation funds are spent, the Maricopa County Association of Governments in Phoenix, Arizona, is developing a more effective system for monitoring and reporting transportation performance. As a subcontractor, TRAC is providing technical assistance to Post, Buckley, Schuh & Jernigan, Inc in developing and revising the performance evaluation tools for use in that measurement system. TRAC's efforts include providing documentation on the performance measures and congestion management systems and practices currently used in the Puget Sound metropolitan region, as well as providing technical assistance in recommending which transportation measures to produce, how to calculate and report those measures, and how to apply the measures to evaluate the performance of the system in relation to the county's transportation policies.

Principal Investigator: Hallenbeck, M.E., UW
Research Manager: Ciccarelli, A., Post, Buckley, Schuh & Jernigan, Inc
Sponsor: Maricopa County Association of Governments, Arizona

Quantifying Incident-Induced Travel Delays on Freeways Using Traffic Sensor Data, Phase II

To develop more effective ways to alleviate non-recurrent congestion, a better understanding of the impacts of incidents on congestion is essential. To better understand incident-induced delay on Puget Sound freeways, researchers in Phase I of this study developed a database of loop detector and incident data, developed an algorithm for quantifying incident-induced travel delay on freeways that uses traffic sensor data, and created a computer system that automates the algorithm's delay calculations. However, the performance of the algorithm, based on Deterministic Queuing Theory (DQT), was not stable. So in this phase researchers will try to improve the accuracy of the algorithm. Better quantifying incident-induced delay will allow transportation agencies to make appropriate investment decisions in congestion mitigation measures and to allocate limited monetary and labor resources to maximize the benefit-to-cost ratio of such investments.

Principal Investigator: Wang, Y., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Legg, B., WSDOT
Sponsor: WSDOT

PROJECTS: Freight Transportation

The value and volume *of goods moving in the Washington State freight system are large and growing. This system consists of three components. The first is international and national trade through Washington ports, airports, and other gateways. About 70 percent of international goods entering Washington's gateways continue on to the larger U.S. market. The second component consists of the state's own producers and manufacturers. Hundreds of thousands of jobs in regional manufacturing, agriculture, construction, and forestry depend on Washington's freight system; these industries accounted for $145.7 billion or 36 percent of all state gross business in 2005. The third component is the retail and wholesale distribution system that produces up to 80 percent of all truck trips in the state's metropolitan areas.*

The state's freight policy goal is to ensure reliable freight movement and transportation investments that support Washington's strategic freight advantage. Current areas of freight research include quantifying changes in freight mobility resulting from roadway improvements; development of a Washington State Freight Data System; improved freight mobility for economic vitality; and reducing congestion at ports and borders.

Completed Projects

Cross-Border Transportation Patterns at the Western Cascade Gateway and Trade Corridor: Implications for Mitigating the Impact of Delay on Regional Supply Chains

The Pacific Highway border crossing in Blaine, Washington, is the fourth busiest commercial crossing on the northern U.S. border and the most significant commercial crossing for Western Canada and the U.S. The primary commodities that flow across this border are agricultural/food, wood, and paper products. Nevertheless, research on the northern U.S. border has typically focused on trade along the eastern portion of the border between Ontario, Canada, and Michigan and New York. In response, this study developed a commercial vehicle profile of transportation patterns and commodities for the Pacific Highway border crossing, filling the western border data gap with descriptions of both regional trade and current transportation delay patterns, consequences of delay, and causes of delay. This increased understanding of cross-border commercial travel can aid in the development of solutions to mitigate border delay and its impacts.

Principal Investigator: Goodchild, A.V., UW
Technical Monitor: Davidson, D., WWU
Sponsor: Western Washington University

Freight Scanning Tour

Within Washington state, freight mobility is a major concern because of this state's dependence on freight for economic growth. Unfortunately, Washington's freight system is stressed. The Norwegian and other European governments have also recognized that their freight systems are facing challenges and have funded several large projects to apply technology to increase the effectiveness of their goods transportation systems. For this project, the researcher visited and worked with the Foundation for Scientific and Industrial Research (SINTEF) in Trondheim, Norway, which is the lead agency for several of these projects. This cooperation provided an opportunity to identify advanced technologies that might be used to improve freight mobility in Washington state. Application of new technologies offers the potential to better track, monitor, control, and plan freight movements, which could result in increased freight system efficiency.

Principal Investigator: McCormack, E.D., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Legg, B., WSDOT
Sponsor: WSDOT

Strategic Freight Transportation Analysis—Phase 2

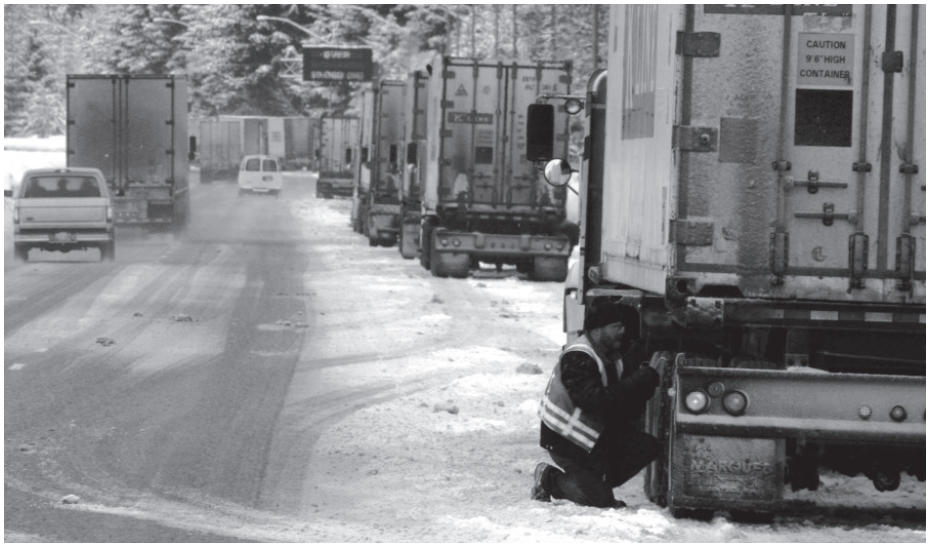
A need exists to accurately determine how changes in intermodal technologies, energy prices, air quality concerns, and environmental efforts will affect the state's multimodal transportation system, infrastructure, and economic development. As a follow-up to Phase 1, the objectives of this study were to identify past, present, and prospective freight corridors by vehicle volume, type and commodity; and to assess the operation of selected modes of the current transportation system, evaluate infrastructure adequacy, and identify deficiencies and investment needs. The study also conducted analyses of mode cost structure and competitive mode shares as ownership and government policies change; assessed the potential for economic development opportunities to support the overall multimodal transportation system; examined case studies to establish a baseline of private and public contributions to individual modes; and researched opportunities for public/private partnership investments in infrastructure to stimulate and support rural economic development. The results will aid decision makers in formulating strategic, coordinated investment decisions for the multimodal system. For more information and reports, see

PROJECTS: Freight Transportation

the project website at http://www.sfta.wsu.edu/.
Principal Investigator: Casavant, K.L., WSU
Research Manager: Brodin, D., WSDOT
Technical Monitor: Lenzi, J., WSDOT
Sponsor: WSDOT

Storm-Related Closures of I-5 and I-90: Freight Transportation Economic Impact Assessment Report

In the winter of 2007-2008, severe weather forced closure of portions of I-5 through Washington for four days in December and portions of I-90 for four days in January. To evaluate the resulting economic impacts, WSDOT contracted with WSU's Social and Economic Sciences Research Center to conduct a survey and develop a new economic assessment methodology that would provide a comprehensive analysis of the effects of the closures on the state's freight-dependent industries and the economy as a whole. The researchers found that the total economic loss from the freight delay caused by the closures was over $75 million. In addition, about 460 jobs, over $3 million in tax revenues, and over $23 million in personal income were lost. WSDOT will use the study results to improve its response to similar disruptions. The report's recommendations include providing more investment for maintenance, better defining detour routes to I-5, and improving communications with the freight industry.
Principal Investigator: Moore, D.L., WSU
Research Manager: Brodin, D., WSDOT
Technical Monitor: Ivanov, B., WSDOT
Sponsor: WSDOT
WA-RD 708.1



A new assessment methodology will help in analyzing the effects of roadway closures on freight delay and the resulting economic losses.

Active Projects

Development and Analysis of a GIS-Based Statewide Data Flow Network

The ability of the transportation system to provide service to freight carriers is subject to disruption from natural disasters, weather, work stoppages , terrorist acts, and more. Although these events obviously have some economic impacts, the relationship between infrastructure and economic activity is not well understood. Additional work is required to understand the flow of goods through the system, the dynamics of that flow in response to disruption, and the economic impacts to the industries supported by that flow. This project will deliver a statewide, GIS-based intermodal freight flow map with infrastructure usage by industry. The resulting tool will allow more efficient system-wide management and prioritization of resources in response to disruptive events.
Principal Investigator: Goodchild, A., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Ivanov, B., WSDOT
Sponsors: WSDOT/FHWA

Truck Performance Measure Research Project

Although freight bottlenecks cause millions of truck hours of delay annually on highways, limited truck data are available to monitor any type of performance measures. Therefore, it is difficult to identify which segments of the transportation system contribute to freight delays and to identify specific locations of freight bottlenecks. As a result, it is also difficult to determine the correct operational, roadway, or other infrastructure investments necessary to improve freight movements and to assess whether the investments that have been made have been effective. In response, this project is gathering GPS data from existing trucking fleet management systems. These data will be used to demonstrate the feasibility of a truck-based freight performance monitoring system. The resulting performance monitoring program may result in more effective use of funding for projects intended to reduce truck delays and in better estimates of freight project benefits.
Principal Investigators: McCormack, E.D./Nihan, N.L., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Ivanov, B., WSDOT
Sponsors: WSDOT/FHWA

PROJECTS: Geotechnical Engineering

Dealing effectively *with marginal soils that contribute to slides, erosion, and liquefaction is a key focus of current research.*

The construction of pavements and bridges on or around marginal soils has been an important area of recent geotechnical research. Projects have looked at the use of marginal soils for fill and marginal soils underneath a structure, as well as the evaluation of liquefaction hazards. In addition, work has continued on mechanically stabilized earth walls with marginal quality backfill.

Completed Projects

Evaluation of Liquefaction Hazards in Washington State, Phase III

Soil liquefaction, caused by earthquakes, commonly occurs in saturated, cohesionless soils, those often encountered in and adjacent to rivers and bodies of water. It is hazardous to many existing transportation structures such as bridges and can add cost to the design and construction of new structures. This project, continuing the work of two previous phases, developed improved procedures for evaluating liquefaction hazards specific to Washington state. The study's products included a manual of practice describing those procedures and a computer program that produces a map of liquefaction hazards across the state. This information will help bridge designers more cost effectively build and retrofit state bridges, tunnels, and roadways, such as the Alaskan Way Viaduct, by taking into account seismic features that more accurately reflect the liquefaction hazards of the soils in which they are constructed.

Principal Investigator: Kramer, S. L., UW
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Allen, T., WSDOT
Sponsors: WSDOT/FHWA
WA-RD 668.1

Interpretation of Geotechnical Properties of Cement Treated Soils

One of the most pressing geotechnical issues is the use of marginal soils (such as silts and soft rock) as fill and backfill material for walls and bridge abutments. The lack of availability of higher quality materials and the added costs for these materials will eventually force engineers to replace materials of better quality with marginal soils. Often however, the high water content and low workability of these soils pose difficulties for construction projects. Frequently, additives such as cement are used to improve their engineering properties. The choice and effectiveness of an additive depends on the type of soil and its field conditions, and knowledge of the mechanistic behavior of the treated soil is as important as selecting the stabilizer.

Researchers are evaluating the use of cement additives to improve backfilled soils for walls and bridge abutments.

This study quantified improvements in mechanical behavior attributable to cement treatment and highlighted the fact that higher percentages of cement can turn stabilization from a beneficial to an extremely dangerous practice.

Principal Investigator: Muhunthan, B., WSU
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Allen, T., WSDOT
Sponsors: WSDOT/FHWA
WA-RD 715.1

Stephen L. Kramer received the American Society of Civil Engineers' 2009 Norman Medal for a paper based on this work. The Norman Medal is the highest honor granted by the ASCE for a technical paper that "makes a definitive contribution to engineering science."

PROJECTS: Geotechnical Engineering

Richard J. Bathurst and co-author Yoshihisa Miyata received the 2007 R.M. Quigley Award from the Canadian Geotechnical Society for their paper "Development of the K-stiffness method for geosynthetic reinforced soil walls constructed with c-Ø soils" (Canadian Geotechnical Journal vol. 44). The R.M. Quigley Award is given annually to those whose paper has been judged to be the best published during the preceding year in the Canadian Geotechnical Journal. This is the second time that Bathurst has won this prestigious award for a paper based on his work for WSDOT on mechanically stabilized earth walls.

In addition, the Canadian Society for Civil Engineering granted the Casimir Gzowski Medal for 2008 to the paper entitled "Calibration concepts for load and resistance factor design (LRFD) of reinforced soil walls" (Canadian Geotechnical Journal Volume 45, No. 10), co-authored by Bathurst, Tony M. Allen, and Andrzej S. Nowak. The medal is awarded annually for the best paper on a civil engineering subject in the areas of surveying, structural engineering, and heavy construction.

The K-Stiffness method, successfully developed for designing the internal stability of mechanically stabilized retaining walls, is being evaluated for application to marginal soils and full-scale walls.

Active Projects

Strength and Deformation Analysis of MSE Walls at Working Loads

This pooled fund study has developed an improved method, called the K-Stiffness method, for designing the internal stability of mechanically stabilized earth (MSE) retaining walls. This method appears to produce designs for MSE walls that are more cost-effective than those produced by the AASHTO Simplified Method.

The K-Stiffness method has been developed and validated only for high quality, sandy backfill soils. The next two phases of the study will extend the applicability of the K-Stiffness method to marginal quality backfill materials and full-scale field walls, which will be monitored for validation. Such validation is necessary to incorporate the K-Stiffness method into the AASHTO Load and Resistance Factor Design (LRFD) specifications. WSDOT's partners on this project are the Alaska, Arizona, California, Colorado, Idaho, Minnesota, Missouri, New York, North Dakota, Oregon, and Wyoming departments of transportation.

Principal Investigator: Bathurst, R., Royal Military College of Canada
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Allen, T., WSDOT
Sponsors: WSDOT and State Partners

PROJECTS: Highway Design and Safety

"Target Zero" *is a statewide highway safety program that provides a framework within which agencies can coordinate and prioritize safety improvements. A key component of the Target Zero program is conducting safety research to support efforts to reduce and eliminate highway collisions and injuries.*

Several projects over the past biennium have looked at ways to make highways safer for both pedestrians and motorists, collecting more useful data and implementing safety improvements. Research on highway design has also investigated ways to make roadway design and construction more sustainable and cost effective.

Completed Projects

Analysis of Pedestrian Safety Treatments by Functional Class

Transportation issues have historically focused on the mobility and safety of motor vehicles, not pedestrians. Pedestrian safety treatments and countermeasures have not been thoroughly monitored, tested, and analyzed for effectiveness on various types of roadways. This study evaluated motorist and pedestrian behaviors at seven arterial locations in Washington where pedestrian safety treatments such as medians, signage, and lighting had been implemented. Data on motorist and pedestrian movements were collected with a digital video recorder. These data were analyzed to compare the impacts of the treatments on pedestrian and motorist behaviors. A better understanding of the effectiveness of pedestrian treatments on various roadway types will help ensure the best investment of limited safety resources and will aid WSDOT in providing appropriate guidance to cities and counties.

Principal Investigators: Hallenbeck, M.E./Davis, K., UW
Research Manager: Lindquist, K., WSDOT
Technical Monitor: Reeves, P., WSDOT
Sponsors: WSDOT/FHWA
WA-RD 707.1

Cost Effective Safety Improvements on Two-Lane Rural State Roads in Washington State

From 1999 to 2005, 42.8 percent of the fatal collisions on Washington state's highways occurred on two-lane rural highways. To help WSDOT increase the safety of its roadways, this project developed a decision-matrix for selecting collision mitigation strategies on two-lane rural highways. The decision matrix consists of three parts: (1) identification of features and segments (such as proximity to rural town centers) with characteristics associated with higher rates of collision and worse severities, (2) a list of all major collision types identified during the study that includes reference to relevant mitigation types, and (3) a summary of countermeasures, with focus on lower cost mitigation. The resulting decision matrix should help WSDOT more effectively design safer two-lane highways in rural areas.

Principal Investigator: van Schalkwyk, I., Arizona State University
Research Manager: Brooks, R., WSDOT
Technical Monitor: Olson, D., WSDOT
Sponsor: WSDOT
WA-RD 695.1

GIS Data Coding

University of Washington researchers aided WSDOT in assigning geographic information system (GIS) coordinates for collision data. The data included fatal and disabling injury collisions on county roads and city streets within Washington state from 2002 through 2007. The purpose of the project was to complement ongoing WSDOT efforts to assemble a complete geospatial database on collisions. This will help WSDOT to identify groupings of high severity crashes across jurisdictional boundaries (city, county, state). This capability will provide WSDOT with another way to identify areas of need and could provide an additional way to prioritize safety projects.

Principal Investigator: Vernez Moudon, A./Hallenbeck, M.E., UW
Research Manager: Lindquist, K., WSDOT
Technical Monitor: Enders, M., WSDOT
Sponsor: WSDOT

A long-term project is evaluating the safety effects of landscaped medians and sidewalks.

PROJECTS: Highway Design and Safety

Active Projects

Federal Lands Highway Sustainability Best Practices and Integration with Greenroads Rating System

Although the application of sustainable practices to transportation infrastructure can be challenging, Federal Lands Highway Program (FLHP) partner agencies all have sustainability-related goals that they strive to achieve. This project will develop a user's guide of FLHP sustainability best practices and will contribute to the development of a sustainability performance rating system for roadways—broadly termed "Greenroads"—that can be used to holistically assess the sustainability of FLHP projects. The user's guide will be formally assembled as a fully searchable and interactive Web document hosted on the Greenroads website. Making these resources available to FLHP design and construction engineers will allow them to make more informed decisions about roadway sustainability and to better incorporate such features to more closely align projects with partner agency sustainability goals.

Principal Investigator: Muench, S.T., UW
Research Manager: Armstrong, A., FHWA
Sponsor: Western Federal Lands Highway Division

Greenroads

Greenroads is a sustainability performance rating system for roadway design and construction. It comprises a collection of roadway sustainability best practices that are divided into two types: required and voluntary. Required best practices are the minimum that must be completed for a roadway to be considered a Greenroad. Voluntary best practices, called Voluntary Credits, are those that may optionally be included in a roadway project. Each Voluntary Credit is assigned a point value on the basis of its impact on sustainability. Agencies and organizations can use Greenroads in a variety of ways, including as a performance metric for roadway design and construction sustainability, as a means to define basic roadway sustainability attributes, as a means of conferring market recognition on more sustainable roadway projects, and as a voluntary or required baseline standard to which roadways are design and constructed. Greenroads will likely be an important tool in assisting organizations in implementing and assessing the overall sustainability of their strategic decisions.

Principal Investigator: Muench, S.T., UW
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Uhlmeyer, J., WSDOT
Sponsors: State Pavement Technology Consortium (California, Minnesota, Texas, Washington)

In-Service Evaluation of Major Arterials with Landscaped Medians

Interest in landscaping medians along urban roadways with speed limits of 35 to 45 mph has been growing as cities work to enhance safety and improve the aesthetic characteristics of their major arterials. The WSDOT is working with selected local agencies to evaluate projects that installed landscaped medians containing small trees and compare them to other roadway treatments that do not. This project is continuing a long-term evaluation of the safety effects of medians and sidewalks with trees, as well as summarizing data on the cost of maintaining these types of landscaping and the effects these treatments have on vehicle speed and pedestrian activity levels. WSDOT and other jurisdictions can then use the results to make informed decisions about whether to allow (or plan for) such improvements in future years.

Principal Investigator: Briglia, P., UW
Research Manager: Brooks, R., WSDOT
Technical Monitor: Briggs, B., WSDOT
Sponsor: WSDOT
WA-RD 636.2

Preliminary Investigation of Luminaire and Traffic Signal Pole Lifespan

WSDOT has installed thousands of luminaires and over 1,000 traffic signals, each with several poles, around the state. Those steel poles were projected to have a 25-year design life, and because over half of them are approaching that milestone, this research is developing a methodology for determining replacement priorities for in-service WSDOT luminaire and traffic signal poles. The project is also identifying critical WSDOT details for which experimental data are not available in the literature and will begin developing a methodology for estimating the remaining life of such structures. This research will help improve public safety by preliminarily identifying the traffic and luminaire poles in Washington state that are most susceptible to fatigue failure. In addition, by allowing WSDOT to replace the poles that are at highest risk of failure and leave in service those that are deemed safer, the research will also help WSDOT to most efficiently focus its limited resources.

Principal Investigator: Berman, J., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Neeley, M., WSDOT
Sponsor: WSDOT

PROJECTS: Intelligent Transportation Systems

Transportation professionals *agree that congestion problems cannot be simply built away; additional, innovative solutions are needed. Intelligent transportation systems, or ITS, provide technologies that enable people to make smarter travel choices.*

Intelligent transportation systems encompass a broad range of wireless and traditional communications-based information, control, and electronics technologies. They provide transportation professionals with tools to collect, analyze, and archive data about the performance of the system. Having these data enhances traffic operators' ability to respond to incidents, adverse weather, or other capacity constricting events.

When ITS are integrated into the transportation system infrastructure, and in vehicles themselves, these technologies help monitor and manage traffic flow; reduce congestion; provide alternative routes to travelers; enhance productivity; and save lives, time, and money.

Completed Projects

Interface MyBus Prediction System to Sounder, Bus Rapid Transit Devices, and the Internet

Sound Transit, King County Metro, and the University of Washington have collaborated on the development of various applications associated with the successful MyBus and BusView real-time transit information systems. A number of these applications were moved from the UW to King County Metro computer servers for day-to-day operation. For this project, the UW researchers helped Sound Transit personnel interface the MyBus prediction system with the Sounder scheduling software and signage, as well as to Seattle's Bus Rapid Transit system. This will enable real-time Sounder commuter train scheduling to be available on both variable signs and the Sounder website.

Principal Investigator: Dailey, D. J., UW
Technical Monitor: Marquardt, N., Sound Transit
Sponsor: Sound Transit

ITS Evaluation Framework: Phase II

The Phase I ATIS Evaluation Framework project developed a standard method for evaluating the conduct of a range of intelligent transportation systems (ITS) projects. The primary purpose of an evaluation is to give planners a better understanding of intelligent transportation system (ITS) deployments during various project stages. The framework focuses on identifying technical and institutional issues that arise, the measures or strategies taken by project partners to address and resolve those issues, and lessons learned that might be applicable to future ITS deployments. After the Phase I project, WSDOT identified 33 additional ITS projects that also required local evaluation. During Phase II, these new projects, covering everything from ITS planning to safety improvements, were evaluated within the adopted framework.

Principal Investigators: Briglia, P./Hallenbeck, M.E., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Vessey, R., WSDOT
Sponsors: WSDOT/FHWA
WA-RD 672.1, 672.2

South Snohomish Regional Transit Signal Priority Evaluation

By reducing the amount of time that transit vehicles are stopped at intersections, transit signal priority (TSP) can improve the speed and on-time reliability of transit. However, enthusiasm for TSP has been tempered with concerns that overall traffic performance may be compromised when signal timing plans intended to optimize traffic flow are overridden to provide a travel advantage to transit vehicles. To improve levels of Community Transit service, the South Snohomish Regional Transit Signal Priority (SS-RTSP) project implemented TSP at selected locations in Snohomish County. Researchers at the UW evaluated the impacts of the SS-RTSP project on both transit vehicles and automobiles that used the affected streets with both simulation models and field observations. The evaluation results showed that the SS-RTSP system provided remarkable benefits to transit vehicles, with insignificant negative impacts to local traffic on cross-streets. While WSDOT did not directly control the signals involved in the evaluation, the Department does operate a number of signal systems for which TSP is being considered. The results of this evaluation will help WSDOT determine the optimal TSP operating parameters for those locations.

Principal Investigator: Wang, Y., UW
Research Manager: Lindquist, K., WSDOT
Technical Monitor: Senn, L., WSDOT
Sponsors: WSDOT/TransNow/Community Transit
WA-RD 699.1

Technical Assistance to Advanced Safety Systems Honda R&D Americas, Inc.

Honda would like to better understand which intelligent transportation systems (ITS) applications are considered priorities by transportation agencies and are, therefore, most likely to be deployed. Honda would also like an assessment of how the deployment of these ITS applications will alter individuals' driving experience. TRAC engineers who have been involved with the deployment and evaluation of ITS since its national inception were asked to provide an independent assessment

of the state of ITS deployment by the year 2020. Topics of the resulting paper included the current state of ITS deployment in terms of drivers' and transportation agencies' priorities and the potential roles of automobile manufacturers in meeting those priorities; technologies likely to be implemented between now and 2020 and how they will affect the driving experience as well as vehicle safety, mobility, and the environment; and the relationship between transportation agencies and car companies.

Principal Investigator: Hallenbeck, M.E., UW
Technical Monitor: Schaffnit, T., Honda
Sponsor: Honda R&D Americas, Inc.

Transportation Applications of an Unmanned Aerial Vehicle

Unmanned aerial vehicles (UAVs) are small enough to be launched from a truck but still large enough to be equipped with cameras and sensors. They hold considerable promise for WSDOT, since a UAV could be used for low-cost data collection and aerial surveillance where the locations of potential transportation-related problems are only crudely known. Potential transportation applications include avalanche control, search and rescue, accident scene photography, land-use mapping, surveying, security inspections, hazardous material monitoring, construction inspections, and roadway condition and congestion monitoring. For this project, researchers conducted a series of tests to evaluate the general capabilities of UAVs while also exploring institutional issues. The tests focused on the use of UAVs as an avalanche control tool on mountain slopes above state highways. The UAVs also captured aerial images suitable for traffic surveillance and data collection. The limited tests will help WSDOT better understand the issues involved in employing UAVs, such as Federal Aviation Administration requirements and liability, and will guide its policies on their future use.

Principal Investigator: McCormack, E.D., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Trepanier, T., WSDOT
Sponsors: WSDOT/FHWA
WA-RD 703.1

Innovative websites combining meteorological and roadway data are helping WSDOT to more cost-effectively maintain state highways, particularly during the winter.

Weather Information System for Washington State Transportation Needs, Phase IV

Researchers at the UW have developed innovative, Web-based applications to provide current and forecast weather conditions for state highway routes to WSDOT personnel and the traveling public. The resulting websites combine complex meteorological and roadway data from a number of sources and present them through user-friendly, intuitive Web interfaces. These websites have received strong positive feedback. This project continued work to make a wide range of weather and roadway information available. It included maintenance of current WSDOT weather-related software and hardware, management of data resources, and inclusion of new data resources when available. Such information is already helping WSDOT to more cost-effectively maintain state highways, particularly during the winter months, and enabling the public to plan their routes for safer travel.

Principal Investigator: Mass, C., UW
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Neeley, M., WSDOT
Sponsor: WSDOT

Active Projects

Error Modeling Analysis for Travel Time Data Obtained from Bluetooth MAC Address Matching

Travel time is one of the variables that travelers and transportation agencies most want to track and understand. However, collecting travel time data is challenging because most existing traffic sensors cannot measure travel time directly. Recently, Blue-

tooth Media Access Control (MAC) address-based travel time estimation methods have been gaining attention from traffic researchers and practitioners because they are relatively low cost and are not difficult to install, susceptible to weather conditions, or subject to privacy concerns. For this study, researchers are developing a Bluetooth MAC address detection (MACAD) system, extracting travel time data for a highway section by using Bluetooth MAC address matching, evaluating the travel time data errors produced by the Bluetooth-based method, and investigating the error sources. The study will produce guidelines for using the developed system for travel time data collection, and if it is successful, such a system may give WSDOT an accurate and cost-effective alternative for travel time data collection.

Principal Investigator: Wang, Y., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Neeley, M., WSDOT
Sponsor: WSDOT

MyBus Interface to GE and PT

Sound Transit, King County Metro, and the University of Washington have collaborated on the development of various applications associated with the successful MyBus and BusView real-time transit information systems and a pilot for sign applications. In this project, UW researchers are helping to interface the MyBus prediction system to the Sounder schedule and signage management systems in order to have both real-time field displays and a Web presence through SoundTransit.org.

Principal Investigator: Dailey, D. J., UW
Technical Monitor: Marquardt, N., Sound Transit
Sponsor: Sound Transit

Real-time transit information systems have been developed at the UW for King County Metro and Sound Transit to provide more frequent and reliable information to riders.

Puget Sound In-Vehicle Traffic Map Demonstration

Traveler information has long been expected to have significant benefit to both travelers and public transportation agencies. However, current studies have shown that available travel information does not result in actual time savings during most commute trips; that significant route diversion can result in congestion on alternative routes and that fewer than expected travelers have proved willing to pay for traffic data. To investigate this issue in detail, Congress requested and funded a test of the effects of in-vehicle traffic information and measurement of its benefits. With the help of subcontractors Battelle Memorial Institute and Volpe National Transportation Systems Center, this project is examining the benefits that can be gained from using in-vehicle traffic information devices. Two sets of analyses are being conducted. One analysis focuses on the benefits perceived by travelers who use the devices, and the other is determining changes in roadway performance that occur as travelers use the devices.

Principal Investigators: Hallenbeck, M.E./Wang, Y./Rutherford, G.S., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Trepanier, T., WSDOT
Sponsors: WSDOT/U.S. Congress

PROJECTS: Multimodal Transportation Planning

***Transportation is key** in the daily lives of people and supports our quality of life. Delivery of an appropriate and efficient transportation system is an important priority for government and other providers of the facilities and services that make up the transportation system.*

The issues on which recent research has focused include quality of life, community livability and cohesion, environmental quality, land use and transportation, and economic, social and cultural values and trends. Collaboration at all levels to better coordinate planning of land use, transportation, and the environment is ongoing. The coordination of transportation and the needs of special groups—such as students—is an important new focus.

Completed Projects

Forest Products' Use of Roadways and Transload Facilities in Washington

Washington's forest products sector has changed dramatically over the past several decades, as well as the movement of timber and forest products over the state's roadways. In fact, the movement of raw material resources and products will likely continue to adjust as timber resources change, and milling and processing facility investments respond to those changes. By combining information from recent studies on the future of Washington forests with data on roadways and transload facilities, researchers estimated the current and future use of roadways and transload facilities by Washington's forest products sector. Such estimates will allow WSDOT to better plan its infrastructural needs to move goods across the state efficiently.

Principal Investigator: Perez-Garcia, J., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Ivanov, B., WSDOT
Sponsor: WSDOT

Impacts of Tolling on Low-Income Populations in the Puget Sound Region

The Washington State Legislature recently approved tolling on the SR 520 floating bridge to help pay for its replacement. However, to implement tolls in compliance with federal law, the state needs to report on how tolling is likely to affect the state's low-income populations. To understand the socio-economic impacts of both flat-rate and time-varied tolling, WSDOT needs to know who will pay the tolls, how residents will change their behavior in response to tolls, and what the impacts of those changes will be. To help answer these questions, this study assessed the usefulness of currently available Washington and Puget Sound data for estimating the impacts of tolling on low-income populations in the area, developed a preliminary estimate of the impacts of tolling on those populations, and suggested data collection and methodological strategies for future research. The results will benefit WSDOT by helping to improve environmental justice analyses for Puget Sound transportation projects and thus help WSDOT comply with federal regulations. They will also provide a basis for addressing concerns raised by elected officials and the public.

Principal Investigator: Plotnick, R., UW
Research Manager: Lindquist, K., WSDOT
Technical Monitor: McKinney, K./Kruger, P.W., WSDOT
Sponsor: WSDOT
WA-RD 721.1

Indian Reservation Road GIS Layer Pilot on the Colville Reservation

Unlike public roads in any other jurisdiction of the state, Indian Reservation Roads (IRR), public roads that provide access to and within Indian reservations, Indian trust land, restricted Indian land, and other selected areas, have not been well inventoried and assessed, perhaps preventing them from receiving funding and improvements for which they would qualify. In a pilot project, IRRs on the Confederated Tribes of Colville Reservation were chosen for study. These roads are of interest not only to the tribes but also to WSDOT, the counties of Okanogan and Pend Oreilles, the U.S, Forest Service, the County Road Administration Board, the Transportation Improvement Board, the Bureau of Indian Affairs, and the National Park Service because they may lead to or intersect with lands or roads within the purview of these other jurisdictions. The project developed a geographic information system (GIS) map of all IRR roads within the boundaries of the Reservation. This GIS map is accessible to WSDOT, tribes, and others. An inventory of location, characteristics, and status information will be valuable for capacity planning and funding future improvements.

Principal Investigator: Winchell, D., Eastern Washington University
Research Manager: Lindquist, K., WSDOT
Technical Monitors: Jollie, C.,WSDOT/Kitchel, K., FHWA
Sponsors: WSDOT/FHWA

Traffic Management Center Design

WSDOT's Northwest Region has been operating a freeway management system in the Seattle metropolitan area since the early 1980s. The system has expanded beyond the original Traffic Management Center's (TMC) capability. Additional staff and associated workstations, video monitors, media viewing rooms, and other facilities are needed. In addition, the Region's Emergency Operations Center (EOC) needs to be upgraded and provided with a permanent facility,

probably one that is integrated with the TMC. In this project, researchers familiar with TMC operations requested proposals and supporting materials to enable WSDOT to hire a consultant to design a new Northwest Region TMC. The project also involved providing technical guidance during the consultant selection process. This project enabled the RFP and agency consultation process to begin immediately, allowing WSDOT to save time and money.
Principal Investigator: Briglia, P., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Balogh, M., WSDOT
Sponsor: WSDOT

Transportation Demand Strategies for Schools Phase II

This project, conducted in two phases, looked at the steps that Washington state can take to reduce traffic congestion and SOV use at and around schools. In the first phase, the researchers reviewed literature on commute trip reduction and transportation demand management (TDM), school siting criteria, and examples from other states and jurisdictions. This second phase study examined efforts at ten locations in urban, suburban, and rural areas of Washington to reduce auto use around schools. Elementary and middle school efforts emphasized walking school buses, website networking, school-based campaigns, and infrastructure improvements. High school and higher education programs provided pre-paid transit service and transportation education. The study concluded that auto congestion around schools can be reduced by state policies that set targets to reduce auto use and increase walking/bicycling, update school siting and performance standards, expand the Safe Routes to School approach and align it with TDM efforts, and require all colleges and universities to implement universal transit/unlimited access pass programs.
Principal Investigator: Carlson, D., UW
Research Manager: Lindquist, K., WSDOT
Technical Monitor: Cotton, K., WSDOT
Sponsor: WSDOT
WA-RD 719.1

Washington State Ferry Passenger Demand and Lost Revenue Analysis

Washington State Ferries (WSF) currently collects fares from walk-on passengers and car passengers (drivers pay both ways) only as they travel westbound for ferries going to Southworth, Bremerton, Bainbridge Island, and Kingston. This creates the opportunity for passengers to travel westbound free, then return to their origin by using a different mode, most likely as a car passenger driving through Tacoma. WSDOT and the state legislature had questions about the magnitude of the fare evasion and whether it would make economic sense to prevent it. This study analyzed data to answer those questions. Conclusions from the findings were that ferry ridership and passenger data did not support these concerns.
Principal Investigator: Rutherford, G.S., UW
Research Manager: Brooks, R., WSDOT
Technical Monitor: Johnson, M., WSDOT
Sponsor: WSDOT

Active Projects

Analytical Procedures for Determining the Impacts of Reliability Mitigation Strategies (SHRP L-03)

The objective of the SHRP L-03 project is to develop relationships between strategies for improving travel reliability and metrics for measuring roadway performance. To achieve that objective, the project is focusing on two primary questions: 1) What is the cause of congestion? 2) If operational improvements are made, how do they improve congestion, including their effect on travel reliability? Under subcontract to Cambridge Systematics, TRAC researchers are primarily focusing on the causes of congestion. They have also produced a series of case studies on the benefits of a variety of operational improvements in the Seattle area.
Principal Investigator: Hallenbeck, M., UW
Research Manager: Bill Hyman, TRB
Sponsor: Strategic Highway Research Program, Transportation Research Board

CTR Survey Processing

Washington state law requires that a commute trip reduction plan include an annual review of employee commuting and that it report progress toward meeting its single-occupant vehicle reduction goals to the appropriate county, city, or town consistent with the method established in the plan. The law also requires a survey of work sites to determine whether they are making progress toward or have met the law's reduction goals. This survey is an annual review of employee commuting at selected worksites and reporting of progress toward meeting single-occupant vehicle reduction goals. This information is critical for evaluating program progress.
Principal Investigator: Marks, M., UW
Research Manager: Lindquist, K., WSDOT
Technical Monitor: Cotton, K., WSDOT
Sponsor: WSDOT

Effect of Light Rail Transit on Physical Activity: a Natural Experiment

Growing interest in the environmental factors that affect adults' physical activity, such as neighborhood design and transportation infrastructure, has been hampered by study designs that limit the ability to draw causal inference. This project is taking advantage of the introduction of light rail transit (LRT) in south King County (Seattle area), and likely changes in the

neighborhood environment around LRT stations, to better study the causal effects of the built environment on walking and overall physical activity. The researchers are assessing 1,000 adults living either close to or far from an LRT station before and after the introduction of LRT service. In a subcontract to Seattle Children's Hospital Research Institute, UW researchers are evaluating changes in the neighborhood built environment, as well as changes in other transportation modes. If this study enables researchers to draw some conclusions about how the built environment affects adults' levels of physical activity, then perhaps planners will be able create neighborhoods that better encourage citizens to be more active and healthy.

Principal Investigators: Vernez Moudon, A./Rutherford, G.S., UW
Research Manager: Saelens, B., SCHRI
Sponsor: National Institutes of Health/Seattle Children's Hospital Research Institute

Architecture students are developing tools to help small communities whose main street through town is a state highway to communicate their planning and economic visions for their main street to WSDOT.

Measuring Employer-Based Transportation Demand Management Strategies

This research is developing a process to estimate how implementing a particular transportation demand management (TDM) strategy or mix of strategies will affect the travel time, delay, and speed within specific corridors. The research is using employer data and employee mode choice data from Washington's Commute Trip Reduction program to estimate the impacts of the TDM strategies. This information, combined with data on alternative modes collected by WSDOT, transit agencies, and Census data, will be used to estimate changes in trip generation and mode split between home and workplace. The end result will be a data format or interface that metropolitan and regional planning agencies can integrate with their transportation system planning models to help them estimate the impacts of various TDM strategies on travel time, delay, and speed in specific corridors.

Principal Investigator: White, P., University of South Florida
Research Manager: Lindquist, K., WSDOT
Technical Monitor: Lagerberg, B., WSDOT
Sponsor: WSDOT

Safe Routes to School: Statewide Mobility Assessment Study

Most children traveling to and from school now do so by private car. Driving children to school has contributed to increasing traffic congestion and has also been linked with increases in the rates of children's chronic health conditions. Unfortunately, there are no quality statewide data on children walking and biking to school, which makes planning and understanding the scope of the problem difficult. WSDOT is now the lead agency in a newly created Safe Routes to Schools (SRTS) Pooled Research Project with Texas and Florida. This project will provide information about the most cost effective ways to identify the number of children walking and biking to school at the state level; school/community characteristics that are most likely to result in children walking and biking to school; and implementation efforts that have been most successful. Guidance based on the results of this research will help state SRTS coordinators make better funding decisions for their SRTS programs. The findings should help improve the health and safety of children and decrease school-related traffic congestion and vehicle miles traveled.

Principal Investigator: Vernez Moudon, A., UW
Research Manager: Lindquist, K., WSDOT
Technical Monitor: Claybrook, C., WSDOT
Sponsors: WSDOT/FHWA

State Highways as Mainstreets: A Study of Community Design and Visioning

In many smaller communities, a state highway serves not only as the primary link to the world beyond but also as the community's main street through town. For this project, architecture students from the UW are providing technical assistance to communities attempting to foster economic growth by physically revitalizing their downtown transportation corridors and restoring them as integrated shopping and pedestrian districts. The students are documenting existing field conditions, illustrating the redesign or restoration of existing street facades and highway corridors by using digital imaging and modeling programs, and participating in consultant interviews and community open house processes. The primary outcome will be a set of community character design guidelines for state highway corridors, a tool intended to help smaller communities communicate a proactive vision of their main street/highway corridor to the state department of transportation.

Principal Investigator: Nicholls, J., UW
Research Manager: Lindquist, K., WSDOT
Technical Monitor: Reeves, P., WSDOT
Sponsor: WSDOT
WA-RD 733.1

PROJECTS: Pavement

***The goal** of pavement research is to produce longer lasting pavements and to manage them effectively.*

The focus over the past few years has been on improvements to pavement design, construction, portland cement concrete rehabilitation, and quieter pavements. Research focusing on pavement construction techniques has included dowel bar retrofitting, best practices for portland cement concrete pavements, and bituminous surface treatments. Quieter pavements has been a focus as well, with multiple test sections being placed on state highways to determine their long-term benefits in terms of noise, cost, and pavement life. The overriding goal of these research projects has been to produce longer lasting pavements through cost-effective decision-making.

Completed Projects

Bituminous Surface Treatment Protocol

A bituminous surface treatment (BST) is a thin surface treatment of liquid asphalt covered with aggregate. BSTs are normally applied to pavements with lower traffic volumes, but it is possible to successfully place them on high speed, high traffic roads when precautions are taken. Statistics from the past 12 years have shown that in Washington state, BST resurfacings cost about four times less than hot mix asphalt (HMA) resurfacings. This study tested the average annual daily traffic and equivalent single axle load levels as criteria for selecting the appropriate application of BSTs to WSDOT pavements. It verified the feasibility of using BSTs to maintain pavements with higher traffic levels. The study also determined the validity of alternating the application of BST resurfacings and 45-mm HMA overlays. In addition, it estimated the impacts that increased use of BST surfaces would have on the performance of the state-owned route system. Increased use of BSTs on higher traffic roads may result in significant savings for WSDOT.

Principal Investigator: Mahoney, J.P., UW
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Pierce, L.M., WSDOT
Sponsors: WSDOT/FHWA
WA-RD 652.1

Brief History of the Performance of Rubberized Pavements in Washington State

WSDOT has been experimenting with the use of recycled tire rubber in pavements since 1977. Besides the advantage of recycling rubber, the use of rubber in pavements is thought to provide benefits such as preventing reflection cracking and mitigating tire noise. This report traces the performance history of pavements built in Washington with recycled tire rubber, including applications such as chip seals, stress absorbing membrane interlayers, and open-graded pavements with rubber asphalt binders. Among the report's conclusions are that modified hot mix asphalts are more susceptible to raveling and wear from studded tires than densely graded pavements, and it is unclear whether pavements with asphalt binders modified with rubber will have service lives that will justify their added cost. The results of this investigation will help WSDOT make clearer and more cost-effective decisions in designing its pavements.

Principal Investigator: Anderson, K., WSDOT
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Uhlmeyer, J., WSDOT
Sponsor: WSDOT
WA-RD 693.1

Dynamic Modulus Test—Laboratory Evaluation and Future Implementation in the State of Washington

The dynamic modulus test is still in the implementation stages in many states. Before the test is implemented, it is important to evaluate local conditions in order to have first-hand information on the dynamic modulus of commonly used mixes. This project developed a database of dynamic modulus values for typical Superpave hot mix asphalt (HMA) mixes that are widely used in Washington. The database will be used to investigate the sensitivity of the dynamic modulus to HMA mix properties and its relationship to field performance. It will also be used to evaluate NCHRP's 2002 Guide for Mechanistic-Empirical of New and Rehabilitated Pavement Structures. The results will provide WSDOT with the necessary HMA input parameters for the Guide. In addition, this database will provide WSDOT with valuable information about the use of dynamic modulus in forensic studies and future research.

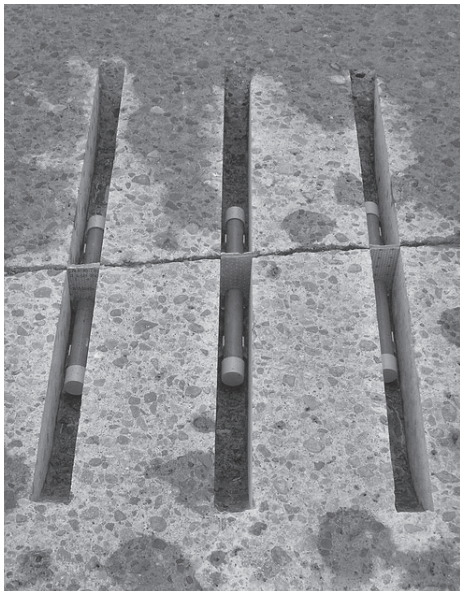
Principal Investigator: Tashman, L., WSU
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Pierce, L.M., WSDOT
Sponsors: WSDOT/FHWA
WA-RD 704.1

Evaluation of Dowel Bar Retrofitting (DBR) for Long-Term Life in Washington State

Since 1993, WSDOT has been rehabilitating its aged portland cement concrete pavements by retrofitting the transverse joints with dowel bars. WSDOT has found that this procedure is a cost effective rehabilitation option; however, questions remain about its situational appropriateness, long-term performance, and ultimate failure mechanism. WSDOT has some of the oldest significant stretches of DBR pavement in the U.S. Researchers took advantage of WSDOT's careful documentation of construction and performance to develop guidelines for dowel bar retrofit project selection and construction best practices,

create a summary of dowel bar retrofit performance in Washington state, and estimate dowel bar retrofit project costs. The research findings will likely become standard DBR practice in the state. And at current costs of nearly $350,000 per lane-mile for DBR and with perhaps 1,000 lane-miles in need of retrofitting, this work will have direct impact on over $350 million of work in the next two decades.

Principal Investigator: Muench, S.T., UW
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Baker, T., WSDOT
Sponsors: WSDOT/FHWA
WA-RD 727.1



New guidelines for dowel bar retrofit project selection and construction best practices will likely become standard practice in Washington state.

Evaluation of Long-Term Pavement Performance and Noise Characteristics of Open-Graded Friction Courses

WSDOT is working to produce pavements that reduce noise generated at the interface between tires and the pavement. This is especially important in areas where freeways abut neighborhoods. In this project, experimental sections of quieter open-graded friction courses were built with asphalt rubber and styrene-butadiene-styrene polymer modified asphalt binders on I-5 through Lynnwood. Sound intensity measurements were taken immediately after construction and monthly for a year. Data showed that both experimental sections were quieter than a hot mix asphalt control section. However, although open-graded pavements have additional benefits, the project also found that studded tire wear has a significant negative impact on the sound absorbing qualities of the open-graded mixes.

Principal Investigator: Anderson, K., WSDOT
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Uhlmeyer, J., WSDOT
Sponsor: WSDOT
WA-RD 683.1

Evaluation of Long-Term Pavement Performance and Noise Characteristics of Open-Graded Friction Courses—Project 2

Open-graded pavements have a higher volume of surface voids than densely graded pavements and thus produce less noise when tires drive over them. As citizens request quieter freeways, especially when they abut neighborhoods, WSDOT is exploring the use of open-graded pavements. This second study in a series of three experimental projects evaluated two kinds of open-graded pavements on two general purpose lanes of westbound SR 520 through Bellevue. The results showed that both open-graded pavements were more quiet than a hot mix asphalt test section, but the sound intensity levels of all three increased over time. WSDOT will have to continue to weigh the drawbacks of open-graded pavements—susceptibility to studded tire wear with resulting rutting—against the levels of reduced tire noise demonstrated in these experiments.

Principal Investigator: Anderson, K., WSDOT
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Uhlmeyer, J., WSDOT
Sponsor: WSDOT
WA-RD 691.1

Evaluation of Trinidad Lake Asphalt Overlay Performance

Construction of the new Tacoma Narrows Bridge included use of two transportation technologies new to Washington state. The first was a steel orthotropic bridge deck. This kind of bridge deck was chosen to reduce weight and lower costs, but its higher flexibility causes pavement placed upon it to fatigue and crack more quickly than pavement placed on a normal roadway. For this reason, the second new technology was a hot mix asphalt overlay placed over the bridge deck that incorporated Trinidad Lake Asphalt (TLA). The TLA overlay was intended to help resist the deck's stresses. This project is evaluating the short- and long-term performance of the overlay with the TLA binder. Long-term conclusions will be drawn over the next five years, at which point a report will summarize performance characteristics and recommendations for future use of the TLA overlay.

Principal Investigator: Russell, M., WSDOT
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Uhlmeyer, J., WSDOT
Sponsor: WSDOT
WA-RD 710.1

I-5 Seattle Corridor—Pavement Deterioration Study

The portland cement concrete pavements (PCCP) constructed on I-5 through Seattle are among a small group of pavements nationwide that were built as part of the original Interstate Highway System and that have never been rehabilitated, despite remaining in service. The first pavement reconstruction project within this corridor is scheduled to begin in 2013, but there is concern that pavement deterioration will require WSDOT to act well before then. To address such

concerns, this study assessed how much longer each segment within the 28-mile I-5 Seattle urban corridor will survive before rehabilitation/reconstruction is required. Researchers also developed improved PCCP performance analysis tools and procedures so that WSDOT can update the assessment and expand it to other sections of its highway system. In addition, the project created a visual means of conveying the current and future conditions of this corridor to decision makers and the general public. The information provided by this project will be crucial in helping WSDOT budget the funds needed for pavement rehabilitation. Additionally, WSDOT will receive updated analysis tools that will allow it to better identify future rehabilitation needs.

Principal Investigators: Mahoney, J.P./Turkiyyah, G.,UW
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Hunter, C., WSDOT
Sponsors: WSDOT/FHWA
WA-RD 682.1, 682.2. 683.3

NovaChip

In Eastern Washington, WSDOT has tried several types of road surface treatments through rural towns and small cities, including bituminous surface treatment (BST), open-graded friction course (hot mix asphalt (HMA) Class D), and finely graded dense asphalt (HMA Class G). Each presents drawbacks. Therefore, WSDOT is seeking a more cost effective, durable, and maintainable pavement surface for these locations. NovaChip is marketed as a pavement rehabilitation or surface treatment that has a durable surface with resistance to rutting and wear. WSDOT placed 26,000 square yards of NovaChip on a curbed portion of SR 17 through Soap Lake in August 2001. Evaluation five years later showed that NovaChip was effective at reducing both the frequency and severity of cracking. Ride quality remained constant through the evaluation period, and wear and rutting were minimal. Although the cost of NovaChip was not found to be competitive with that of HMA Class G, it was found to be comparable when the total project cost was compared.

Principal Investigator: Russell, M.A., WSDOT
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Uhlmeyer, J., WSDOT
Sponsor: WSDOT

Quieter Pavements Survey

WSDOT continues to search for pavements that reduce noise generated at the interface between tires and the pavement. This study evaluated the relative performance of quieter pavements in the U.S. and Europe by surveying 35 of 50 U.S. states about the performance of their open-graded and stone matrix asphalt mixes. The states reported that their open-graded mixes provided about 70 percent of the service lives of their dense graded mixes. Most states that continue to use open-graded friction course mixes are found in the southern U.S. and have different maintenance issues than states in the north, where snow plowing and studded tire use are common. The study concluded that because of these issues, WSDOT could probably expect shorter service lives than those demonstrated in southern states by comparable open-graded pavements. This survey will help WSDOT engineers make more cost-effective decisions about appropriate pavements for use in the state.

Principal Investigator: Jackson, N.C., Nichols Consulting Engineers
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Pierce, L., WSDOT
Sponsor: WSDOT
WA-RD 688.1

Statistical Comparison of Quality Assurance and Quality Control Data

As contractors have become more involved in the design, acceptance, and performance of hot mix asphalt (HMA) pavements, questions have arisen about whether the data from contractor process control tests, known as quality control (QC) tests, are biased or can be incorporated into the acceptance and pay factor processes that state highway agencies use. To examine this issue, researchers assessed the use of statistical F- and t-tests for comparing QC data to results from agency-conducted quality assurance (QA) tests. The project looked at data from four state DOTs and found that the statistical tests do provide adequate evaluation when differences are sought between data from QC and QA testing programs. The results suggest that state DOTs can have confidence in using QC data for quality assurance purposes, helping to produce higher quality HMA pavements with more cost-effective oversight procedures.

Principal Investigator: Mahoney, J.P., UW
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Willoughby, K., WSDOT
Sponsors: California, Minnesota, Texas, and Washington
WA-RD 686.1

WSDOT tested NovaChip on SR 17 in Eastern Washington to find a more cost effective, durable, and maintainable pavement surface for rural applications.

PROJECTS: Pavement

Active Projects

Best Practices for the Design and Construction of Portland Cement Concrete Pavements in Washington State

Current portland cement concrete pavement (PCCP) conditions in key Washington state transportation corridors require large-scale reconstruction and rehabilitation. This will be the state's largest PCCP rehabilitation/reconstruction effort ever, and if it is done well, it should last 50 years or more. Before embarking on this effort, WSDOT would like to identify and quantify design methods, materials, and construction practices that (1) provide for the most efficient and effective use of public funds and (2) provide long-lasting, high performance pavements. This research is helping WSDOT form a comprehensive rehabilitation and reconstruction plan that will address issues such as design details, costs, construction methods, and environmental footprinting.

Principal Investigator: Muench, S.T., UW
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Uhlmeyer, J., WSDOT
Sponsors: WSDOT/FHWA

Concrete Performance Using Low Degradation Rock

Marine basalt aggregates are commonly used in Washington, particularly as good quality gravel sources are becoming exhausted, but their degradation is pronounced. Although the degradation of marine basalt aggregates is well understood, and specifications exist to restrict the use of low degradation aggregates for hot mix asphalt and sub-base applications, the long-term performance of concrete made with low degradation aggregates has not been investigated, and aggregate degradation specifications are needed for their use in concrete. This study is developing plans for a testing program to evaluate the long-term performance of concrete with low degradation aggregates and, in collaboration with the WSDOT Materials Laboratory, is constructing test specimens and conducting preliminary tests to establish baseline data. The results of this work will include prevention of future problems in concrete pavements and structures, improvement in their construction and maintenance, and economic savings through improved access to and utilization of aggregates from lower quality sources.

Principal Investigators: Qiao, P./McLean, D.I., WSU
Research Manager: Willoughby, K., WSDOT
Technical Monitors: Williams, K./Polodna, M., WSDOT
Sponsor: WSDOT

Before embarking on the state's largest ever PCCP rehabilitation effort, WSDOT is seeking to ensure that it uses the most effective and cost-efficient design methods, materials, and construction practices.

Open Graded Friction Courses in the Pacific Northwest

Open graded friction courses are pavement layers constructed of open graded hot mix asphalt (HMA). The main benefits of their use are better drainage of water from the pavement surface, more resistance to permanent deformation, and potential reduction in tire-pavement noise. However, open graded wearing course performance in the Pacific Northwest is not well understood. This project is conducting a review of open graded mixtures used in the Pacific Northwest to determine which mixes are most appropriate for the area, the performance achieved by the mixes already used in Oregon and Washington, and the prospects for adoption of newer open graded friction courses. Researchers will specifically review the performance, advantages, and disadvantages of using 3/4-inch open graded mixes, as well as review and recommend other types of open graded mixes suitable for use in the Northwest. The results will help ODOT determine how to best construct open graded friction courses for long life and where to use them most effectively within the ODOT roadway network.

Principal Investigator: Muench, S.T., UW
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Hunt, E., ODOT
Sponsor: Oregon State Department of Transportation

PROJECTS: Security

The performance *of our transportation system during and after both natural disasters and human-originated hazards is a key element of our state's ability to respond to major emergencies. Considerable work is under way to determine how to cost effectively make the state's transportation system more resilient, both so that it operates effectively during emergencies and so that it will recover quickly from disruptions. A robust, resilient transportation system minimizes the impacts of disasters on the state's economy, while also increasing the safety and security of the population.*

Achieving transportation system resilience requires a combination of technical improvements in how we build and maintain our transportation infrastructure, as well as new approaches to operating it. Better transportation system operations require not just new technical improvements but also developing and implementing better working relationships with other local, state, and federal agencies. Therefore, TRAC's security research efforts cover both technical and institutional subjects and involve a variety of participating agencies.

Completed Projects

Effects of Blast Loading on Prestressed Girder Bridges

Since the events of September 11, 2001, more attention has been given to the effects of blasts on structures. Bridges are especially important because of their potentially critical role in the economy and emergency response. Prestressed girder highway bridges are very common, but little is known about how prestressed concrete bridges respond to blast loading. This study experimentally and analytically examined the vulnerability of prestressed girder bridges to explosive loadings with various orientations. A finite element model of a precast, prestressed girder was created and validated with two full-scale empirical tests. The girder model was then expanded to a four-girder, simple-span bridge model, and four different scenarios were examined with explosive events at several locations above and below the bridge. The tests allowed the researchers to draw conclusions about the level of damage and the integrity of the bridge after sustaining the various loads. The results of this research will be beneficial in retrofitting prestressed bridges to prevent damage that may result from acts of terrorism.

Principal Investigators: McLean, D.I./Cofer, W.F., WSU and Ray, J./Ertle, C., U.S. Army
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Lewis, R., WSDOT
Sponsors: WSDOT/FHWA

Electronic Container Seal Expansion Project

This was a Federal Highway Administration-sponsored Field Operational Test of a transponder-based container seal system, located on the doors of cargo containers, for ensuring the security of and providing processing improvements for containers transported by truck. The effort, which expanded on a previous field test, evaluated the efficacy of these seals as a tool for detecting unauthorized intrusions into containers, tracking shipping containers both in ports and along roadways, and reducing roadway congestion at ports and borders. The seal is one element in a larger WSDOT effort to facilitate the movement of commercial vehicles on the state's highways by providing enforcement agencies with regulatory and management information from transponder technology.

Principal Investigator: McCormack, E.D., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Legg, B., WSDOT
Sponsors: WSDOT/FHWA

Active Projects

Department of Homeland Security—National Center for Border Security and Immigration

The University of Washington, University of Texas–El Paso, and Wayne State University are engaged in a two-year research project as part of the new National Center for Border Security and Immigration (NCBSI) sponsored by the Department of Homeland Security. The goal of the project is to increase understanding of and facilitate the development of better border-security processes, including increased awareness, improved decision-making capabilities, and better coordination among stakeholders. The project's emphasis is on operational analysis, information resources, and coordinated response, including analysis to increase understanding of the impacts of security alternatives on international trade.

Principal Investigator: Haselkorn, M.P., UW
Technical Monitor: Gemelas T., DHS
Sponsor: Department of Homeland Security

PROJECTS: Technology Transfer

Technology transfer *is a core element of the TRAC mission. Research dollars are wasted if clients are unaware of research results, unable to understand research findings, or unable to implement them. For that reason, TRAC has always emphasized technology transfer as part of its operations.*

To enhance access to TRAC research, projects are entered into the national Research in Progress database managed by the Transportation Research Board. Short Research Notes are also produced to briefly describe the project need, findings, and planned implementation of the results. Specific transfer projects over the past two years included enhancing a computer-based pavement course and electronic tools to aid in communication and training about the design and construction of pavements; participating in a Pavement Tools Consortium that fosters the continued development and implementation of computer-based paving tools; and continuing to support a traffic management center intern program at WSDOT.

Completed Projects

Traffic Management Center Intern Program

This project allowed the University of Washington (UW) and WSDOT to cooperatively provide professional experience, training, and research opportunities at WSDOT's Traffic Management Center (TMC) to students from the UW's Department of Civil and Environmental Engineering. Under the supervision of WSDOT engineers, students learned about and helped to operate ramp meters, closed-circuit TV incident identification, variable message signs, highway advisory radio, and traffic condition update reports on regional phone lines. They also helped conduct research and analysis tasks. With this project, the WSDOT gained a reliable way to staff the TMC without increasing costs, and UW engineering students were able to acquire valuable experience in a real-world setting.

Principal Investigator: Rutherford, G.S., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Dang, V., WSDOT
Sponsor: WSDOT

Active Projects

Identification Needs in Developing, Documenting and Indexing WSDOT Photographs

WSDOT has tens of thousands of photos representing all aspects of its work, transportation system infrastructure, and the transportation system in use. The collection includes both current and historical images. However, they are not easy to find and retrieve, and requests for these photos from both the public and WSDOT staff confirm the need to index the collection and make it more easily accessible. This study is surveying and assessing existing agency photo (image) collections, how they are currently indexed, who uses them, and for what purposes. In addition, the study is evaluating the capabilities of the WSDOT Electronic Content Management system, as well as other systems, for photo indexing, storage, and retrieval and is identifying missing components and recommending solutions. The long-term benefits of the project will include savings in staff effort and frustration, reduced storage space needs, and improved management of photo resources for both public and private use.

Principal Investigator: Endicott-Popovsky, B., UW
Research Manager: Lindquist, K., WSDOT
Technical Monitor: Culp, J., WSDOT
Sponsor: WSDOT

With tens of thousands of archived photos, WSDOT has asked UW researchers to recommend better systems for image indexing, storage, and retrieval.

PROJECTS: Technology Transfer

Pavement Tools Consortium

The Pavement Tools Consortium fosters the continued development and implementation of computer-based paving tools, such as the Pavement Guide, Media Library, HMAView, Stockpile Blender, XPactor, and EverFE. The major focus of the pavement tools is to enhance pavement-related training and construction operations. WSDOT's partners are the California, Florida, Idaho, Illinois, Kansas, Maryland, Minnesota, and Texas departments of transportation, and the Federal Highway Administration.

Principal Investigator: Mahoney, J.P., UW
Research Manager: Willoughby, K., WSDOT
Sponsors: WSDOT and PTC Member States

Software Tools for Sharing and Integrating GIS Data

WSDOT established a consortium of public and private entities to develop, implement, and provide a variety of computer-based tools for sharing and integrating geo-spatial transportation data for a variety of purposes and uses. Funding for the Geo-spatial Integration and Sharing Data Consortium (GISDC) is through a pooled fund arrangement managed by WSDOT. The research will help to reduce costs and increase efficiency by enabling members of the consortium to collect and combine location referencing and GIS data from multiple agencies to create a complete transportation network and associated location referencing systems.

Research Manager: Lindquist, K., WSDOT
Technical Monitors: Griffin, T./Leierer, M., WSDOT
Sponsors: Washington (Lead), Nebraska, Ohio, Idaho, Oregon, and Tennessee

The main focus of the Pavement Tools Consortium is to enhance pavement-related training and construction operations through continued development and implementation of computer-based paving tools.

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