2010-2011

Washington
State
Transportation
Center

TRAC

BIENNIAL REPORT

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(Photo by WSDOT)

As I reflect on the 2010–2011 biennium, I think about the economic challenges we faced and contemplate the role of research in such times. It is clear that over the years, TRAC research projects have resulted in many improvements in Washington's transportation system, including reduced costs, more durable infrastructure, wiser investment choices, fewer negative consequences on the communities and environment surrounding transportation infrastructure, and stronger support for the people and businesses in Washington state.

For example, materials research extends the life of our infrastructure through better understanding of the properties of materials, development of testing strategies to retrofit current infrastructure, development of new design standards, and evaluation of life-cycle costs so that we can make informed investment decisions. Although we have fewer resources and more travelers are using the transportation system, the state's transportation infrastructure is in very good condition, supported by knowledge we have gained through research

Another example is traffic research, which helps us understand the choices travelers make so that we can operate the existing transportation network more efficiently to improve travel times and reduce accidents. The information gathered through research also helps transportation system managers make better network investment choices that improve movement throughout the system. A focus on freight is helping us to understand the unique needs of freight transport and how to better support the efficient transportation of goods.

This biennial report provides examples of research projects that are changing transportation practices and policies within the state of Washington and, in some cases, beyond state borders. Despite the challenging economic times, it has never been more important to continue to invest in research. The projects we conduct are primarily applied research that is quickly adopted into practice. By filling the knowledge gaps and meeting the pressing needs that we target, we are successfully supporting the cost-effective management of our transportation system.

The research summarized here represents the work of the three institutions that compose TRAC, as well as other researchers and partner organizations. On behalf of all the TRAC Directors, a sincere thank you to our partners in federal and state agencies, local governments, tribes, businesses, and other universities for their contributions to our research program. Their participation strengthens the program and helps us achieve results that are useful to multiple organizations. I also congratulate the researchers, staff, and students who carried out TRAC's focused and solution-oriented research program and appreciate their contributions and commitment to improving transportation practice.

Sincerely,

Leni Oman
Executive Director
Washington State Transportation Center

Overview

Research at the Washington State Transportation Center (TRAC) addresses the issues of today's transportation systems and the needs of their users. The studies cover a wide variety of fields, and many require interdisciplinary contributions. These studies benefit from the collaborative work within and between research institutions and other organizations in Washington state and beyond. Through these partnerships TRAC is able to leverage not only funding but also knowledge and other research resources, conducting studies cost effectively and efficiently, to provide innovative solutions to transportation-related challenges.

Project Funding and Support

From July 1, 2009, to June 30, 2011, TRAC-UW researchers were involved in 65 research projects, for which the budgets totaled over $10.4 million. The 15 budgets for TRAC-WSU projects totaled nearly $1.2 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 and international support from

- European Commission
- Federal Highway Administration
- Maricopa County Association of Governments, Arizona
- National Cooperative Freight Research Program
- National Heart, Lung and Blood Institute
- National Institutes of Health
- Oregon Department of Transportation
- Strategic Highway Research Program
- Transportation Northwest (TransNow)
- Transportation Research Board
- Washington University School of Medicine
- Western Federal Lands Highway Division
- U.S. Congress
- 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, Indiana, Iowa, Kansas, Maryland, Michigan, Minnesota, Mississippi, Missouri, Montana, Nebraska, New Hampshire, New York, North Carolina, North Dakota, Ohio, Oregon, Pennsylvania, Tennessee, Texas, Utah, Virginia, Wisconsin, and Wyoming.

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

- Community Transit
- Seattle Children's Hospital and Medical Center
- Seattle Department of Transportation
- Sound Transit

TRAC received private support from or worked as a subcontractor for

- Cambridge Systematics
- Kittleson and Associates
- Post, Buckley, Schuh & Jernigan, Inc.
- The Bullitt Foundation

Faculty Representation

The breadth of TRAC research topics over the past two years involved 47 faculty and researchers from the following 18 UW and WSU departments:

- Aquatic and Fishery Sciences, UW
- Architecture, UW
- Atmospheric Sciences, UW
- Burke Museum, UW
- Civil and Environmental Engineering, UW
- Civil and Environmental Engineering, WSU
- Economic Sciences, WSU
- Electrical Engineering, UW
- Entomology, WSU
- Evans School of Public Affairs, UW
- Family Medicine, UW
- Geography, UW
- Human Centered Design and Engineering, UW
- Information School, UW
- Landscape Architecture, UW
- Mechanical Engineering, UW
- Office of Educational Assessment, UW
- Urban Design and Planning, UW

SR 539, Wiser Lake Road Roundabout near Lynden, Washington. (Photo by WSDOT)

Cooperation and Collaboration

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

Research Institutions

- Battelle Marine Sciences Laboratory
- Desert Research Institute
- Oregon Transportation Research and Education Consortium
- Royal Military College of Canada
- Stanford University
- University of California, Berkeley
- University of California, Davis
- University of California, San Diego
- University of South Florida
- University of Texas—El Paso
- Wayne State University
- Western Transportation Institute, Montana State University

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

Public Agencies

City of Des Moines
City of Federal Way
City of Goldendale
City of Morton
City of Mukilteo
City of Roslyn
City of SeaTac
City of Seattle
City of Sekin
City of Shoreline
King County Metro Transit
National Oceanic and Atmospheric Administration
Port of Seattle
Port of Tacoma
Puget Sound Regional Council
Sound Transit
Volpe National Transportation Systems Center
Yakima County Council of Governments

Private Companies

CH2M Hill
EBL Consulting
Urban Design 4 Health, Inc.

Associations

Northwest Regional Modeling Consortium
Washington Trucking Associations

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. During the 2010-2011 biennium, TRAC-UW and TRAC-WSU processed numerous proposals and produced nearly 30 reports and other publications.

In addition, over the past two years, researchers surveyed and assessed 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 continued 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://www.trac.washington.edu. Visitors can find information about TRAC, access research reports and project information, and obtain guidance on producing work through TRAC.

LED lights on a Smarter Highways sign. (Photo by WSDOT)

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. The office at WSDOT in Olympia serves as the central 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 conducts research.

Bridges and Structures

This past biennium, bridge research addressed seismic, design, construction, and maintenance issues. The two seismic projects involved the Aurora Avenue bridge, with its cruciform-shaped columns and hollow core piles that are not commonly used in Washington. Research was also conducted on the use of steel casings in shaft or pile construction to develop appropriate design guidelines. The problems of construction-related shrinkage cracking of bridge decks were reduced with research, and new guidelines are currently being implemented. Maintenance or preservation issues involved steel gusset plates (primarily in response to the Minnesota bridge collapse) and development of an in-house software program to evaluate bridge load and resistance factors.

Completed Projects

Design of Bridge Foundations with Steel Casings

Deep caisson bridge foundations are frequently required in bridge construction. These are typically large-diameter drilled foundations with a steel tube inserted into the drilled shaft. The steel tube is filled with reinforced concrete, and this caisson is then combined with the piers of the bridge substructure. Recent research on concrete-filled steel tubes (CFT) has shown significant benefits from their application. However, the current AASHTO Bridge Design Code for bridge piles and shafts does not adequately describe how to design a pile or shaft that uses a steel casing and reinforced concrete. Current design methods tend to be very conservative and neglect the benefits provided by composite action, and design parameters are needed to take advantage of the combined strength of the two materials. The objective of this research was to develop analytical equations or models that would allow engineers to rationally estimate the resistance, stiffness, and deformation of concrete filled steel tubes used as caissons for deep bridge foundations. The use of CFT elements may result in cost savings associated with a smaller drilled shaft, as well as less material and time required for caisson construction.

Principal Investigators: Roeder, C./Lehman, D., UW
Project Manager: Willoughby, K., WSDOT
Technical Monitor: Khaleghi, B., WSDOT
Sponsor: WSDOT

Evaluation of Gusset Plate Connections in Steel Truss Bridges

The 2007 failure of a steel truss bridge in Minnesota was attributed, in part, to overstressed and buckled gusset plates. This catastrophic event raised concerns about the potential for overstressing of gusset plates in similar bridges across the country. To help bridge engineers in evaluating gusset plates, the Federal Highway Administration released recommendations for load rating the gusset plates of steel truss bridges; however, the complex design methods make rapid assessment difficult. As a remedy, this study developed a new procedure for rapid and reliable evaluation of gusset plates. To develop the Triage Evaluation Procedure (TEP), the researchers analyzed specific gusset plate joints from Washington state bridges in detail. The TEP involves three primary checks: gusset plate yielding, gusset plate buckling, and fastener strength. Analysis showed that the TEP is conservative in relation to the FHWA recommendations for evaluating gusset plate strength. The TEP provides a streamlined initial assessment of gusset plates.. This new approach enables bridge engineers to more expediently evaluate the capacity of gusset plates, allowing those with critical demand-to-capacity ratios to be quickly identified for further, more refined analysis or retrofit.

Principal Investigators: Berman, J./ Roeder, C./Lehman, D., UW
Project Manager: Willoughby, K., WSDOT
Technical Monitor: Coffman, H., WSDOT
Sponsors: WSDOT/FHWA
WA-RD 757.1

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 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. In this study, researchers identified the main causes of early-age cracking in the decks and evaluated different concrete mix designs that could be used to prevent or minimize shrinkage cracking. They considered different sources (eastern and western Washington) and sizes of aggregates and evaluated the effects of paste content, materials (cement, fly ash, silica fume, slag), and shrinkage reducing admixture. They also performed a series of mechanical and shrinkage property tests for each concrete mix. The results should improve the durability and service performance of Washington bridge decks, decrease maintenance costs, and increase bridge safety and longevity.

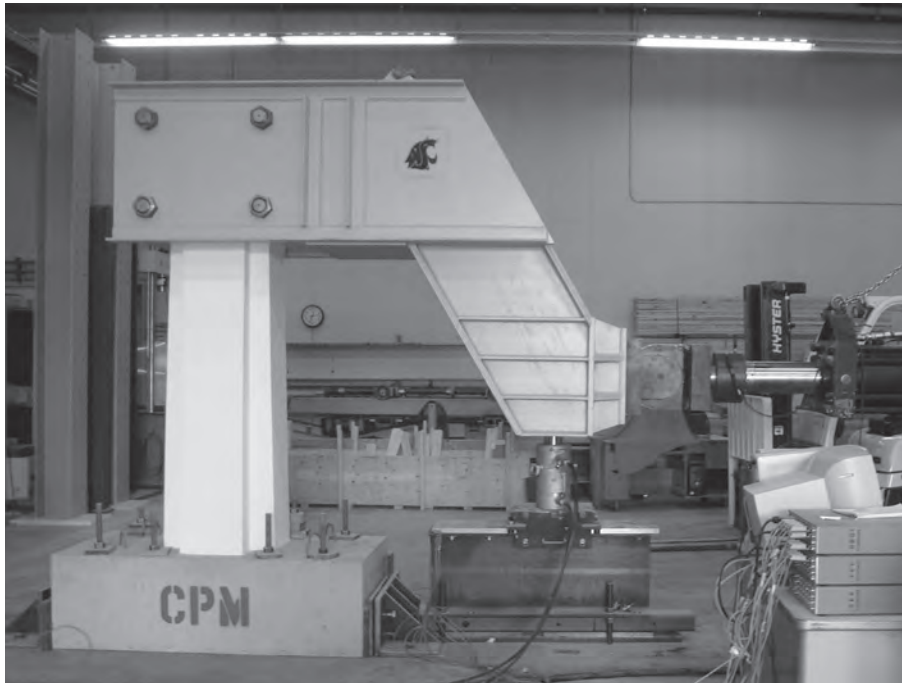
Principal Investigators: Qiao, P./McLean, D.I., WSU
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Sheikhizadeh, M., WSDOT
Sponsor: WSDOT
WA-RD 747.1

Seismic Assessment of WSDOT Bridges with Prestressed Hollow-Core Piles

There are 22 bridges with hollow-core pile foundations in Washington state. One of the major issues associated with prestressed hollow-core piles is that they do not provide sufficient ductility—the ability to deform without fracture—for use in regions subject to earthquakes. In tested piles, a typical cause of failure has been spalling of the concrete that covers the reinforcing steel and prestressing tendons. However, no effective retrofitting techniques exist to improve the ductility of hollow-core piles. To address this

issue, this project sought to (1) develop models that can accurately simulate the behavior of hollow-core prestressed reinforced concrete piles; (2) use the models to investigate the effects of soil confinement on pile behavior; and (3) develop an understanding of the connection between this type of pile and other bridge structural members. In all cases, analyses were conducted on the I-5 Ravenna Bridge in Seattle, Washington. The methods developed to quantify the seismic vulnerability of bridges founded on precast/prestressed hollow-core piles will allow WSDOT to make more cost-effective decisions about whether to replace or retrofit those bridges.

Principal Investigators: Cofer, W.F./ElGawady, M., WSU
Project Manager: Willoughby, K., WSDOT
Technical Monitor: Khaleghi, B., WSDOT
Sponsor: WSDOT
WA-RD 732.1 and 732.2



Columns from the Aurora Avenue Bridge are tested at Washington State University. (Photo provided by David McLean)

Seismic Retrofit of Cruciform-Shaped Columns in the Aurora Avenue Bridge Using FRP Wrapping

Experimental tests on specimens representing the cruciform-shaped columns of the 80-year-old Aurora Avenue Bridge in Seattle, Washington, showed that they have inadequate shear strength to withstand seismic loading during an earthquake. To correct that problem, researchers investigated measures to retrofit the columns and improve their seismic performance. Specifically, they evaluated the effectiveness of using fiber reinforced polymer (FRP) composite wrapping to enhance the seismic shear strength of the columns. Experimental tests were conducted on seven 1/3-scale column specimens. The results of this study showed that FRP jacketing, in combination with a particular corner anchorage and collar confinement, is effective at increasing the shear strength of the column to prevent brittle shear failure under seismic conditions. The researchers provided guidelines for designing the various components of the retrofit measure. WSDOT will use these results to retrofit state bridges with cruciform-shaped columns, making them safer in the event of an earthquake.

Principal Investigator: McLean, D.I., WSU
Project Manager: Willoughby, K., WSDOT
Technical Monitor: Boone, C., WSDOT
Sponsor: WSDOT
WA-RD 753.1

Active Projects

Update of the BRIDG Software Package for LRFD

Federal regulations require that departments of transportation continuously monitor and rate their steel and reinforced/pre-stressed concrete bridges and maintain records of those bridges' conditions. Washington engineers evaluate and rate state bridges by using WSDOT's in-house BRIDG software package. The software consists of a 2-D concrete module and a 3-D steel module. WSDOT also has a database of computer models for all of its steel and reinforced concrete bridge structures to work with these two software modules, which enables fast and efficient analyses when engineers need to update structural conditions or determine capacities for over-weight vehicles. However, although the existing software modules are fully functional and were carefully and extensively compared to alternative software packages, the techniques they employ for load generation and evaluation do not include modern Load and Resistance Factor Design (LRFD) standards. This project is adding those missing components to the existing software package while maintaining compatibility with the bridge computer models.

Principal Investigator: Mackenzie, P., UW
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Coffman, H., WSDOT
Sponsor: WSDOT

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. A research project that evaluated how WSDOT accepts materials was undertaken and produced a better system for materials purchase and acceptance.

Completed Projects

Infrared Thermal Integrity Testing: Quality Assurance Test Method to Detect Drilled Shaft Defects

Thermal integrity profiling measures the temperature generated in curing concrete to assess the quality of cast-in-place concrete foundations or drilled shafts. In concept, the absence of intact, competent concrete (necks or inclusions) is registered by regions that are cooler than the shaft average; the presence of additional concrete (over-poured concrete bulging into soft soil or voids) is registered by warmer regions. Thermal testing provides various details about shaft integrity, including effective shaft size (diameter and length), anomaly detection inside and outside the reinforcement cage, cage alignment, and proper hydration of the concrete. The ability to detect concrete volumes outside the reinforcing cage is perhaps its most important feature. In this study, no anomalies within the reinforcing cage were encountered, but various forms of external section changes were identified, as well as several cases of off-center cages. WSDOT plans to use the experience from this research to implement thermal testing for drilled shafts as a new quality assurance method.

Principal Investigator: Mullins, G., University of South Florida
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Sheikhizadeh, M., WSDOT
Sponsor: WSDOT
WA-RD 770.1

Crews drill a shaft for a bridge column in Tacoma, Washington. (Photo by WSDOT)

Materials Risk Analysis

State DOTs routinely examine the quality of the materials used in highway construction projects. These materials may range from concrete and steel for bridges to bark mulch for roadsides. While some materials are tested, others are accepted through a manufacturer's certification of quality, some are physically inspected during fabrication, and still others are accepted through visual inspection. Although WSDOT relied on professional logic to determine how to test various materials, a documented system for categorizing materials for different testing did not exist. This project sought to formalize such a system by conducting a materials risk analysis. Through a Delphi process, WSDOT subject matter experts (materials, construction, structures, maintenance, and traffic professionals) rated materials in relation to two risks: the risk of a material failing to meet specification and the consequences of that material failing to meet specification. As a result of the risk analysis, materials were classified into four categories for either more or less intensive examination. Future materials risk analyses may be performed at periodic intervals, and this ongoing process will help WSDOT purchase and utilize materials with more confidence in their safety and cost effectiveness.

Principal Investigators: Baker, T.E./Molohon, R.J./McIntyre, R.W., WSDOT
Project Manager: Willoughby, K., WSDOT
Technical Monitor: Willoughby, K., WSDOT
Sponsor: WSDOT
WA-RD 745.1

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 reducing collisions between wildlife and vehicles.

Completed Projects

An Assessment of Urban Form and Pedestrian and Transit Improvements as an Integrated GHG Reduction Strategy

Because transportation is one of the state's largest sources of greenhouse gas (GHG) emissions, WSDOT is seeking ways to reduce vehicle miles traveled (VMT) statewide. To serve that goal, this study tested the effects of sidewalk availability on travel patterns and sought to statistically relate sidewalk availability with VMT and GHG emissions. Taking advantage of recently collected local sidewalk data in King County, Washington, the researchers modeled the association of urban form, pedestrian infrastructure, transit service, and travel costs with VMT and carbon dioxide (CO_2). The researchers also developed and tested a simple spreadsheet tool for estimating the potential reduction in CO_2 and VMT due to urban form, sidewalk coverage, transit service, and travel cost changes. The study provided early evidence of the potential effectiveness of providing sidewalks in helping to reduce CO_2 and VMT. It is an important step toward better understanding how pedestrian investment and other factors can help meet the state's goals for reducing VMT.

Principal Investigators: Frank, L.D./Greenwald, M.J./Kavage, S./ Devlin, A., Urban Design 4 Health, Inc.
Project Manager: Lindquist, K., WSDOT
Technical Monitor: Reeves, P., WSDOT
Sponsors: WSDOT/Seattle Department of Transportation
WA-RD 765.1

Columbia River Crossing Fish Data Analysis

Major roadway infrastructure development in and around the Columbia River can have a significant environmental impact on river and estuary inhabitants. To mitigate the impacts of infrastructure development on threatened and endangered fish species, information about their presence, activities, and transit times is needed. While information on threatened and endangered species in the Columbia estuary has been scarce, more data about the activities of Pacific salmon below Bonneville Dam are now available from the Adult Anadromous Fish Radiotelemetry Project hosted by the UW's School of Aquatic and Fishery Sciences Columbia River DART project. With permission from the National Oceanic and Atmospheric Administration, researchers analyzed the data set to provide information on salmon migration rates, migration timing, and other aspects of migrant behavior. This information is helping WSDOT more efficiently and effectively mitigate the impacts of roadway construction on the environment.

Principal Investigator: van Holmes, C., UW
Research Manager: Brooks, R., WSDOT
Technical Monitor: Ficco, D., WSDOT
Sponsor: WSDOT

Eastern Washington Steep Slope Research for Management of Highway Stormwater

Highway embankments are an ideal location for integrating low impact development stormwater best management practices (BMPs) into a highway setting. Two such BMPs are use of vegetated filter strips (VFS) and dispersion. An issue limiting their application in Washington state is that although WSDOT highway embankments may be constructed on slopes as steep as 33 percent, the design criterion for these stormwater BMPs prohibits their use on embankment slopes steeper than 15 percent. When VFS or dispersion is required for slopes steeper than 15 percent, the embankment must be flattened and the roadway footprint expanded, which can require right-of-way acquisition, as well as additional construction and ecological costs. To better understand this issue, researchers inventoried 45 sites in Eastern Washington to determine the specific site characteristics that contribute to concentration of highway runoff on slopes steeper than 15 percent. Low vegetation coverage and a high percentage of sand were found to have the strongest correlation to erosion severity. The researchers recommended modified design criteria that will allow VFS and dispersion methods to be used on slopes of up to 33 percent. Such methods will help WSDOT to both save money and better manage stormwater runoff.

Principal Investigator: Navickis-Brasch, A.S., WSU
Research Manager: Brooks, R., WSDOT
Technical Monitor: Mauer, M., WSDOT
Sponsor: WSDOT
WA-RD 771.1

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. These make identifying high-risk locations for animal-vehicle collisions (AVCs) and appropriately allocating limited resources to improve safety important tasks for WSDOT. To help in identifying AVC locations, researchers first developed a data mapping algorithm to create a more complete AVC data set from the commonly reported state Collision Report and Carcass Removal databases. This combined data set was then used to develop and calibrate two models able to analyze drivers' behaviors and the spatial

distributions of animal populations, as well as the impacts of road and environmental factors on AVCs. Variables that were shown to be significant included number of lanes, locations of animal habitat areas, speed limit, percentage of trucks among all vehicles, and median width. The study also identified high-risk roadway segments along ten study routes. With a better understanding of AVCs on Washington highways and a list of locations at higher risk for AVCs, WSDOT will be better able to develop countermeasures to prevent these collisions.

Principal Investigator: Wang, Y., UW
Research Manager: Brooks, R., WSDOT
Technical Monitor: McAllister, K., WSDOT
Sponsors: WSDOT/TransNow
WA-RD 752.1

Impact of Drilled Shaft Synthetic Slurries on Groundwater Quality

WSDOT annually drills about 150 large diameter—2- to 10-ft—shafts to support bridge foundations and retaining walls. Shafts are generally uncased and 30 to 200 feet deep. Construction of uncased drilled shafts requires the use of thousands of gallons of synthetic slurry for stability. During this process, some loss of synthetic slurry always occurs in the surrounding soil under the groundwater table. However, the impact of the loss of WSDOT-approved synthetic slurry on groundwater quality is not known. This phase one project was the first step in evaluating the effects of synthetic slurries on groundwater quality. Researchers conducted a comprehensive literature survey to evaluate the composition of the WSDOT-approved synthetic slurries. Further work on the constituents of the slurries will help WSDOT minimize their impact on groundwater quality.

Principal Investigators: Hossain, M.A./Cofer, W.F./Yonge, D.R., WSU
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Sheikhizadeh, M., WSDOT
Sponsor: WSDOT
WA-RD 773.1

Workers inspect a washout on SR 206. Researchers are developing a baseline assessment of climate change impacts on transportation condition and serviceability in the Pacific Northwest and Alaska. (Photo by WSDOT)

Juvenile Salmon Behavioral Response to Ferry Terminal Light Mitigation Treatments

Studies have found that shadows caused by over-water structures such as ferry docks may alter the behavior of juvenile salmon migratory behavior as they migrate along the shoreline. This study evaluated the use of a commercially available fiber-optic light system to increase light beneath docks and reduce or eliminate dark shadow edges cast by terminal structures. UW researchers collaborated with Battelle Marine Sciences Laboratory to evaluate the system's efficacy: its area of coverage, its optimal placement and configuration to decrease shadow edges, and the responses of migrating juvenile salmon. The tests included visual observations, snorkel surveys, and video filming surveys to quantify fish behavior under different lighting treatments. The researchers observed dock avoidance behavior that suggests that ferry terminals likely delay some juvenile salmon migration by several hours per dock encounter. The results also indicated that light transmitted or installed under terminals could mitigate dock shading impacts on juvenile salmon, but the lighting systems would have to meet more robust structural and operational guidelines than those tested. Although the results were not sufficient to determine whether artificial light could completely mitigate the effects of the dock, the study concluded that the use of artificial light is promising.

Principal Investigator: Simenstad, C.A., UW
Research Manager: Brooks, R., WSDOT
Technical Monitors: Carey, M,/Rainsberry, S., WSDOT
Sponsor: WSDOT
WA-RD 755.1

Tse-Whit-Zen Faunal Research Project

WSDOT uncovered Tse-whit-zen in August 2003 while building a dry dock on the Port Angeles waterfront. After spending about $60 million—and uncovering thousands of artifacts—the state moved the drydock project to avoid further impact to the largest ancient Indian village ever unearthed in Washington state. The Burke Museum at the University of Washington curates the archaeological collection from Tse-whit-zen on behalf of WSDOT. This project supported the Burke Museum in the administratively complex task of removing and preparing numerous shellfish and fish and bird bone samples from the collection for temporary transfer to Portland State University, the University of Rhode Island, and Western Washington University. Researchers at those locations will analyze the samples to better understand the interplay between people, food resources, and the environment.

Principal Investigator: Lape, P., UW
Research Manager: Brooks, R., WSDOT
Technical Monitor: Williams, S., WSDOT
Sponsor: WSDOT

Washington State Scenic and Recreational Areas Resource Planning Index

Washington state's Scenic and Recreational Highway (SRH) system was established in the 1960s. WSDOT requested the creation of a Resource Planning Index for use in benchmarking and tracking the protection, preservation, and enhancement of the scenic, cultural, and historic resources associated with Washington's SRHs. The intent of the Index is to provide a rough measure of the potential for locations along the SRH system to benefit from stewardship projects. Researchers conducted a geographic information systems analysis to develop a unique Index value for each 1,000 feet of roadway. The Index value is based on the proximity of features of interest associated with specific opportunities for protecting, preserving, or enhancing resources, such as known habitat corridors or places of historic significance. This Index may be used in preliminary assessments to determine whether a site addresses one or desired combinations of these features. Local analysis must then determine those exact opportunities and whether a proposed project would actually provide the desired benefit or impact. Such analysis will help WSDOT make more cost-effective and context-sensitive stewardship investments.

Principal Investigator: Ramsey, K./Nyerges, T., UW
Research Manager: Lindquist, K., WSDOT
Technical Monitor: Reeves, P., WSDOT
Sponsor: WSDOT
WA-RD 740.1

Active Projects

Climate Change Impact Assessment of the Pacific Northwest and Alaska

The states in the Pacific Northwest and Alaska share interconnected travel networks for people, goods, and services. Regional climate change continues to affect the physical condition and serviceability of those networks, yet the nature of those changes and their potential impacts on the regional transportation system and its use are not well understood. The rising costs of building and maintaining reliable transportation infrastructure place pressure on transportation planners, engineers, researchers, and policy makers to deliver resilient transportation systems and to maximize return on investment. To aid them in that endeavor, this project is developing a baseline assessment of climate change impacts and issues affecting transportation in the Pacific Northwest and Alaska that will support the development of economical and resilient adaptation strategies. The project includes development of a preliminary risk characterization and vulnerability assessment, including a survey of study partners in the Alaska, Idaho, Oregon, and Washington departments of transportation, plus other stakeholders, to determine the perceived risks to infrastructure. The Oregon Transportation Research and Education Consortium and Alaska University Transportation Center are conducting the research.

Principal Investigator: MacArthur, J., Oregon Transportation Research and Education Consortium
Research Manager: Lindquist, K., WSDOT
Technical Monitor: Roalkvam, C.L, WSDOT
Sponsor: WSDOT

Determining Changes in Greenhouse Gas Emissions Due to Pavement Technology

Pavement design, management, materials, and construction have an impact on the overall emission of greenhouse gases (GHG) associated with WSDOT's roadway network and the vehicles that use it. This impact is potentially significant but has not been meaningfully quantified. For this project, researchers will work to quantify changes in GHG emissions from 1990 to 2010 that can be attributed to pavement condition, design, management, materials, and construction. They will also develop a calculator that can be used to quantify GHG, energy, and other emissions associated with a pavement construction project. A better understanding of the influences of pavement technology on GHG emissions over time will allow WSDOT to target specific areas of improvement that will have the largest impact on GHG emissions. It may also allow WSDOT to regularly estimate energy use, emissions, waste, or other factors associated with an entire pavement program or to tailor pavement construction materials and methods in ways that will reduce GHG for specific locations and projects.

Principal Investigator: Muench, S., UW
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Baker, T., WSDOT
Sponsor: WSDOT

Population and Flight Path Studies for Assessing Mitigation Measures to Minimize Impacts on Alkali Bees within the US 12 Phase 7 Project

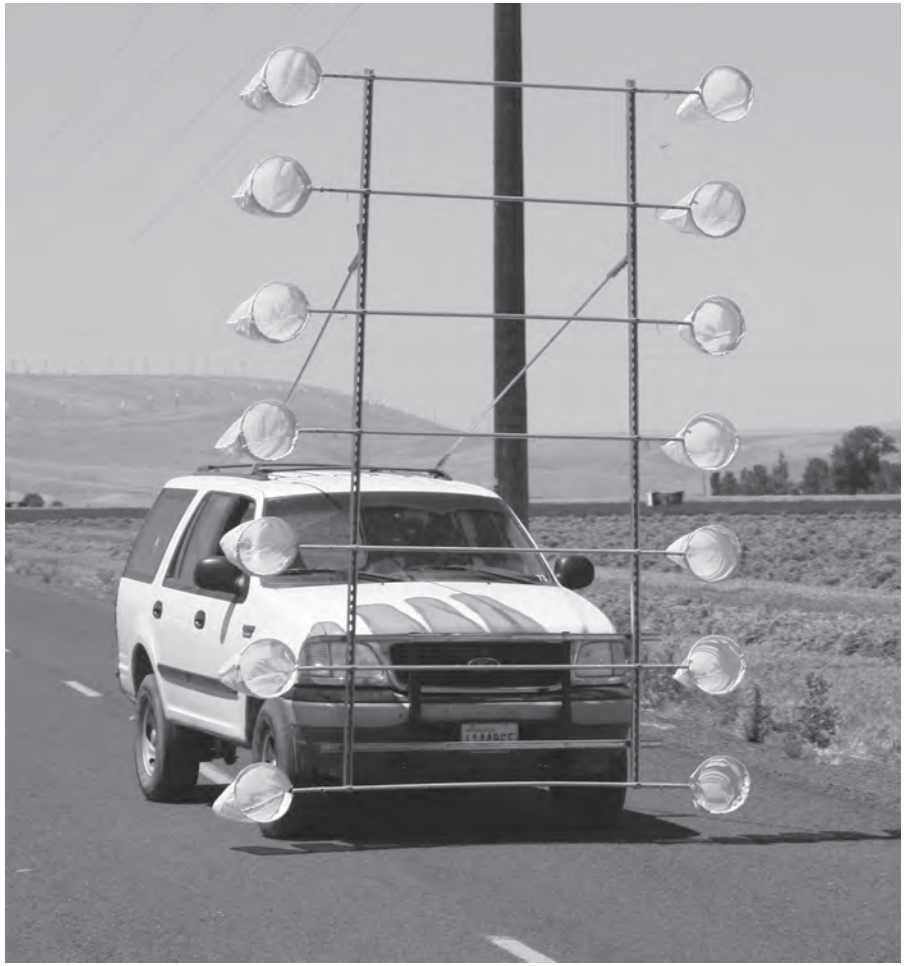
Phase 7 of WSDOT's long-term US 12 project will widen the highway from Nine Mile Hill, Washington, through the Touchet-Lowden agricultural district. Farmers in that area use native alkali bees to help produce alfalfa seed. Alkali bees need established bee beds, two to ten acres, where a surface crust of salt or alkali helps preserve moisture in the below-ground nests. These bees are subject to habitat loss, as cultivation, grazing, or even disturbance by off-road vehicles can damage bee beds. To minimize the impacts of US 12 construction on the native bees, researchers are surveying alkali bee population density in beds that would potentially be affected by the highway project. They are also determining bee flight-paths from bee beds to the alfalfa fields and back in relation to the footprint of the proposed project, and they are assessing the potential for barriers to effectively alter bee flight-paths both vertically and horizontally. Congress made native bee preservation a priority in the 2008 Farm Bill. This project will decrease the impacts of WSDOT highway construction on both farmers and their important bee resource.

Principal Investigator: Walsh, D., WSU
Research Manager: Brooks, R., WSDOT
Technical Monitor: Broadhead, C., 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, documentation of fish kills at several pile driving sites, including 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 decibels, 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. The modified TNAP was tested in the fall of 2009 at the Vashon ferry terminal dolphin replacement project. If the modified TNAP is successful, it will benefit WSDOT by allowing the agency to conduct pile driving operations year round. The researchers are also measuring and modeling 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 and making such projects more time- and cost-effective.

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



The vehicular bee sweeper collected bees to determine their numbers at various heights above the road bed. (Photo provided by Doug Walsh)

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. 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, 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. With an eye toward the future, the state is exploring new congestion-reducing innovations that are making 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.

Completed Projects

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 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 Puget Sound area freeways. This project continued to provide technical support for WSDOT's operational, planning, and policy activities in the form of ongoing freeway performance monitoring analyses, specific focused technical analyses, and software development and technical support. This included conducting analyses, including yearly analyses of the HOV lane network, for annually updated editions of the WSDOT and other departmental performance reports. The information provided 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., UW
Project Manager: Brodin, D., WSDOT
Technical Monitor: Neeley, M., WSDOT
Sponsor: WSDOT

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. However, WSDOT did not have the data collection, analysis, and archiving system—called a data mart—necessary to support these tasks. In response, this project developed the functional specifications for a WSDOT operations data mart, assessed the capabilities of data archive systems that WSDOT regions currently use, and identified the additional sources needed to provide data for the data mart. With the 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 program in Washington state is responsible for clearing roadways as quickly and as safely as possible to restore the normal flow of traffic. The objective of this project was to evaluate the current state of Washington's program, investigating the basic relationship between incidents and delay on Puget Sound area freeways. The study showed that incidents, including crashes, do not, by themselves, cause measurable delay. Instead, the delay related to any incident is a function of where and when it happens, as well as background congestion levels when it occurs. For the 2006 study year, a conservative estimate is that crashes and other traffic incidents cost Washington travelers 5,300,000 vehicle-hours of delay, in addition to typical congestion delay. That is roughly 30 percent of the total delay from all causes. The average incident that did not involve a lane closure was calculated to cause 576 vehicle-minutes of delay per minute that the incident was present. If that incident closed a lane, the effect of that lane closure added 814 vehicle-minutes of delay per minute of closure. Researchers determined that incident response saves between $244 and $345 for every minute that response reduces an incident in the Puget Sound region. With a better understanding of the impacts of incidents and incident response on congestion, WSDOT should be able to fine-tune the program's deployment strategies, helping to provide the highest level of service at the lowest cost.

Principal Investigator: Hallenbeck, M.E., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Legg, B., WSDOT
Sponsor: WSDOT
WA-RD 761.1

Congestion on I-5 approaching the Columbia River bridge. (Photo by WSDOT)

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

This project identified and evaluated 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 envisioned the future to create a long-term view of how new operational approaches might improve travel reliability. The project involved 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 their reliability needs, and establishing goals and desired performance targets for travel time reliability. The researchers also envisioned how new technologies and approaches to transportation system operations could improve the reliability of highway trips. In addition, they identified trends likely to affect travel time reliability and developed a Concept of Operations for three alternative futures through 2030, to help identify topics for future research and development.

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

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 evaluated the performance of Seattle-area HOV lanes, focusing on congestion on I-5 in the initial phase. Researchers identified segments where congestion routinely occurs, determined the potential causes of those bottlenecks, and developed a range of potential short-term (0- to 5-year) enhancements to increase HOV traffic flow at those bottlenecks. The results from this project have the potential to improve HOV system performance by increasing person throughput, improving transit efficiency, and enhancing incentives to commute via HOV modes of travel. The results 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

WA-RD 769.1

HOV Lane Evaluation and Monitoring Phase 10

Surveys have shown considerable support for the construction of HOV lanes in the Puget Sound region. In this ongoing study researchers conducted a multi-faceted evaluation of the effectiveness of HOV lanes. The evaluation included 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://www.washington.edu/hov/. The resulting information helps 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., UW
Project Manager: Brodin, D., WSDOT
Technical Monitor: Trepanier, T., WSDOT
Sponsor: WSDOT

Performance Measurement Framework and Congestion Management Update

In order to improve its planning process and be more accountable to taxpayers about how transportation funds are spent, the Maricopa County Association of Governments (MAG) in Phoenix, Arizona, required a more effective transportation performance monitoring system. As a subcontractor, TRAC provided technical assistance to Post, Buckley, Schuh & Jernigan, Inc., in developing and revising the performance evaluation tools and procedures available to MAG. TRAC's efforts included providing technical assistance on 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, 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 (IID) on Puget Sound freeways, researchers in Phase I of this study developed an algorithm for quantifying IID that uses freeway traffic sensor data and created a computer system to automate the algorithm's delay calculations. In this phase researchers worked to improve the accuracy of the algorithm. A remarkable advantage of this new approach over most other methods is that because it uses only volume data from traffic detectors to compute IID, it is easy to apply. Verification with data extracted from video also determined that the new approach is fairly accurate. The approach was implemented on a regional, map-based computer platform to enable quick, convenient, and reliable freeway IID estimates in the Puget Sound region. Better quantifying incident-induced delay will help transportation agencies make appropriate investment decisions about congestion mitigation measures and allocate limited resources in ways that will maximize the benefit-to-cost ratio of such investments.

Principal Investigator: Wang, Y., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Legg, B., WSDOT
Sponsors: WSDOT/TransNow
WA-RD 758.1

SR 167 HOT Lanes: Usage and Compliance Metrics

The high occupancy toll (HOT) lanes on SR 167 south of Seattle, Washington, are separated from their respective general purpose lanes by a double white line. Legal access to the 10-mile stretch of HOT lanes is limited to four locations southbound and six locations northbound. This study examined the frequency with which motorists illegally cross the double white line, rather than waiting for one of the legal access points. By using video footage from WSDOT surveillance cameras, the study determined the locations and operating conditions under which violations most commonly occur. The study showed that during most times and in most places, the number of illegal entries and exits is negligible. However, at a small number of locations and under specific congestion conditions, violation rates can exceed 1 per minute. The report detailed reasons for those increased violation rates. The information resulting from this study will help WSDOT formulate future HOT lane design decisions intended to make freeway HOT lanes less prone to violation, safer, and more efficient.

Principal Investigator: Hallenbeck, M.E., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Patterson, T., WSDOT
Sponsor: WSDOT
WA-RD 766.1

Active Projects

Congestion Survey

Adding to an already extensive freeway information system, WSDOT is installing traffic data collection devices on sections of major freeways in the Puget Sound region that have not yet been able to provide traveler information to roadway users. TRAC researchers are investigating motorists' responses to the newly available information. Motorists will be surveyed to determine whether they have noticed that new information is available on the WSDOT website, 511, or freeway variable message signs; whether the information is useful and accurate; whether they make any changes in route, time of travel, or mode on the basis of the information; and whether they think WSDOT should continue to collect and disseminate this type of travel information. This survey will give WSDOT a better understanding of the type of information that motorists desire, how they obtain it, and whether they change their behavior as a result of it. WSDOT will be able to use the results to assess its methods of traveler information delivery and make feasible modifications.

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

A revised vehicle-length truck classification scheme will be used to update computer chips in traffic counters and to establish calibration standards for truck measurements. (Photo by WSDOT)

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 established 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 previously collected and reported are approximately equal to the final classification scheme resulting from this study. State DOTs will use the results of this study to update computer chips in traffic counters and to establish calibration standards for vehicle length-based measurements.

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

FHWA Policy Support 2007—Traffic Monitoring Guide Update

Since the mid-1980s the Federal Highway Administration has published four editions of its Traffic Monitoring Guide. In this project, TRAC is working as a subcontractor to Cambridge Systematics, Inc., to produce the next edition of the Traffic Monitoring Guide. TRAC's staff will contribute sections dealing with equipment selection, data collection, data processing, and reporting.

Principal Investigator: Hallenbeck, M.E., UW
Technical Monitor: Vandervalk-Ostrander, A.P., Cambridge Systematics
Sponsors: FHWA/Cambridge Systematics Inc.

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 approximately one-third of all state gross business. 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; continued development of a state freight model; improved freight mobility for economic vitality; and reducing congestion at ports and borders.

Completed 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, and more. Although these events obviously have economic impacts, the relationship between infrastructure and economic activity is not well understood. For this project, researchers developed a GIS-based statewide freight transportation network model. They also collected detailed distribution data about two important industries in Washington state, potatoes and diesel fuel, and analyzed the responses of those industries to specific disruptions to the state transportation network. The researchers recommended improvements and additions to the GIS model that will allow it to capture additional system complexity. These models will help WSDOT minimize the economic consequences of transportation disruptions to the freight transportation system.

Principal Investigators: Goodchild, A., UW/Jessup, E.L., WSU
Research Manager: Brodin, D., WSDOT
Technical Monitor: Ivanov, B., WSDOT
Sponsors: WSDOT/FHWA/TransNow
WA-RD 730.1

The Economic Impact of Truck Congestion on Washington State Highways

Congestion delay has steadily increased not only in Washington's larger cities, but throughout the state, particularly affecting the freight transportation system. The efficiency and effectiveness of the overall transportation system and supply chains of goods are becoming compromised. Not only are drivers and trucking firms affected, but so are businesses tangential to the trucking industry, as well as those affected by the higher rates charged as a result of increasing congestion costs. The focus of this study was identifying these direct and "downstream" impacts to the overall economy and specifically to differing industries and supply chains. The researchers developed a survey and sample frame that will allow analysts to determine specific costs of congestion to trucks or freight-dependent industries. They also conducted an input-output analysis that allowed them to identify the total costs of congestion, by industry and geographical region, as those costs spread throughout the economy. By having a better understanding of the forms, sources, and overall impacts of congestion, WSDOT will be able to more effectively prioritize infrastructure investments and policy alternatives.

Principal Investigator: Casavant, K., WSU
Research Manager: Brodin, D., WSDOT
Technical Monitor: Ivanov, B., WSDOT
Sponsor: WSDOT

Improving Statewide Freight Routing Capabilities for Sub-National Commodity Flows

The National Cooperative Freight Research Program is working to increase the availability of freight flow data at the corridor and regional levels. To build upon this national effort, this research worked in parallel with the national study by developing and testing truck routing rules and logic that will be incorporated into the Washington state freight model. This effort gathered information on how truck freight routing decisions are made by cataloguing how routing decisions vary by truck freight services type, commodity shipped, and industry sector served. It included an assessment of how route choices are affected by factors such as urban congestion, travel time and route reliability, highway grade/elevation and curvature characteristics, and business and product-specific supply chain characteristics. WSDOT will use the results to better manage resources for the highest possible return on investment, deliver cost-effective solutions to improve the performance of the freight transportation system, and be environmentally responsible.

Principal Investigators: Jessup, E.L., WSU/Goodchild, A., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Ivanov, B., WSDOT
Sponsor: WSDOT

Mapping Freight Highway Routes and Identifying Connectors to Production and Receiving Centers

To update its Highway System Plan, WSDOT asked for help in mapping features of the state's freight system. The Washington State Highway System Plan is the state highway component of the Washington State Multimodal Transportation Plan (SMTP). The SMTP is the state's overall transportation plan that includes an analysis of facilities the state owns and those in which the state has an interest. For this project, researchers produced a geographic information system-based map of the primary freight highway routes and connectors to statewide production and receiving centers, including destinations such as port container terminals and rail yards. The resulting map added valuable information to the Highway System Plan, which is updated every two years and serves as the basis for the six-year highway program and the biennial budget request to the state's legislature.

Principal Investigator: Goodchild, A., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Ivanov, B., WSDOT
Sponsor: WSDOT

Researchers identified the direct and subsequent impacts of congestion on industries and supply chains related to the freight transportation system. (Photo by WSDOT)

Truck Performance Measure Research Project

Although trucks move the largest volume and value of goods in urban areas, relatively little is known about their travel patterns and how the roadway network performs for trucks. 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. In response, and in cooperation with the Washington Trucking Association, this project gathered GPS data from existing trucking fleet management systems and evaluated their feasibility to support a state truck freight network performance monitoring program. The researchers reviewed truck freight performance measures that could be extracted from the data and that focused on travel times and speeds, which, analyzed over time, determine a roadway system's reliability. The utility of spot speeds was evaluated in a case study of a three-week construction project on the Interstate-90 bridge. 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/TransNow
WA-RD 748.1

Active Projects

Defining the Washington State Truck-Intermodal Network

WSDOT does not currently have a definition of the state's freight truck-intermodal network. To help in defining that network, this project is reviewing methods used by other states, identifying the facilities in Washington included in the National Highway System, and comparing those facilities to others identified by regional planning organizations. The National Highway System is a nationally defined interconnected system of principal arterial routes that, among other goals, serves major population centers, international border crossings, ports, airports, other intermodal transportation facilities, and more. This project will produce a list of identified facilities within Washington and recommendations for criteria that WSDOT can use to define the truck-intermodal network for Washington. Those results will serve as input to the Washington State Freight Mobility Plan, which is intended to develop freight transportation strategies and recommendations to support sustainable economic growth, the environment, and social needs in the state.

Principal Investigator: Goodchild, A., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Ivanov, B., WSDOT
Sponsor: WSDOT

Development of a Freight Benefit/Cost Methodology for Project Planning

Although WSDOT has a well developed methodology for calculating the benefits and costs of highway projects within long-standing programs that support the state legislature's policy goals for safety, preservation, environmental issues, and mobility, at this time there is no framework for analyzing the freight-related benefits and costs of transportation projects. This is due in large part to the complexity and range of the economic, environmental, and social benefits related to freight movement. The benefits of freight-related projects are therefore undervalued and cannot be communicated well to either decision makers or the public. And decision makers cannot determine funding on the basis of a defensible benefit analysis. To address this issue, researchers are developing an improved methodology for calculating the value of freight and intermodal infrastructure projects. This freight methodology will be designed to be integrated into WSDOT's current benefit/cost analysis process, allowing it to more accurately consider the consequences of funding decisions and spend limited program dollars more wisely.

Principal Investigators: Goodchild, A., UW; Casavant, K./Jessup, E.L., WSU
Research Manager: Brodin, D., WSDOT
Technical Monitor: Ivanov, B., WSDOT
Sponsors: WSDOT/TransNow

Impact of Smart Growth on Metropolitan Goods Movement

State and regional planning organizations have begun to develop transportation plans that more effectively consider freight activities and their economic, social, and environmental impacts. However, although urban goods movement is being given more attention, the ways in which freight activities will be affected by smart growth and growth management are still not well understood. To improve that understanding, researchers from the Puget Sound Regional Council and UW are studying the relationship between goods movement and land-use policy, analyzing specific urban goods movement case studies, evaluating the efficacy of current transportation planning tools in modeling the impacts of smart growth on freight activities, conducting an urban goods movement modeling exercise, and devising a process that planners can use to engage with freight and other stakeholders regarding goods movement issues. The results will help metropolitan planning organizations and other public agencies more effectively consider both the benefits and costs of land-use decisions that may affect urban goods movement.

Principal Investigators: Bassok, A., PSRC; Goodchild, A./Carlson, D./McCormack, E.D., UW
Research Manager: Rogers, B., NCFRP
Sponsor: National Cooperative Freight Research Program

To help metropolitan planning organizations and other agencies, researchers are studying how land-use decisions such as smart growth and growth management will affect urban goods movement. (Photo by Mary Marrah)

Geotechnical Engineering

Dealing effectively with marginal soils that contribute to slides, erosion and liquefaction is a key focus of 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 evaluation of liquefaction and seismic hazards. In addition, work has continued on mechanically stabilized earth walls with marginal quality backfill.

Completed Projects

Earthquake Ground Motions Selection

Recent changes to federal seismic design standards, the availability of new ground motion databases, and new methods for developing design ground motions have resulted in more complex and time-consuming requirements for engineers designing transportation structures. In addition, the relatively unique seismic environment of Washington state leads to difficulties in identifying and processing ground motions suitable for use in local seismic design. Given these issues, researchers worked to identify tools that WSDOT engineers can use to efficiently and appropriately identify and apply recorded earthquake ground motions in the seismic design of structures. This project also identified suites of ground motions for special cases in Washington state, including large magnitude, long-duration motions and near-fault motions. The results will allow WSDOT engineers to more efficiently analyze structures and to use state-of-the-art procedures to better design transportation structures to withstand earthquakes.

Principal Investigators: Kramer, S.L./Arduino, P., UW
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Allen, T., WSDOT
Sponsor: WSDOT

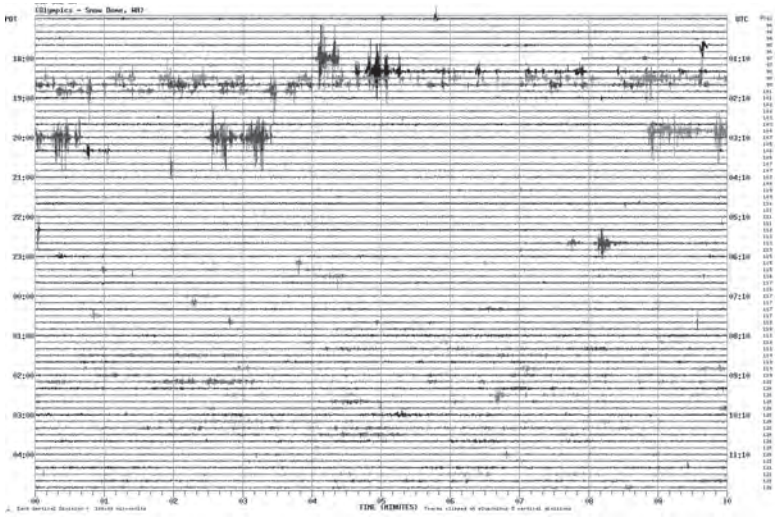
Experimental Evaluation of P-Y Curves Considering Liquefaction Development

During earth movements that cause soil liquefaction, the strength and stiffness of the surrounding soil dramatically decrease, including the strength and stiffness provided to a laterally loaded pile foundation. This resistance is conventionally modeled with non-linear p-y curves. The reduced p-y curve has typically been back-calculated from pile load tests conducted in stable ground (not liquefied) and modified with a scalar factor. However, it is unclear how the shape and amplitude of the reduced p-y curve develop during various levels of excess pore pressure. For this project, researchers sought to experimentally determine nonlinear p-y curves at various levels of liquefaction. They conducted a series of tests on a single pile embedded in homogeneous saturated Nevada sand subjected to dynamic shaking and lateral loading. The resulting experimentally developed curves will support the modeling of soil-pile systems, including modeling needed for the design of the Columbia River Crossing in Washington state.

Principal Investigators: Chang, B./Hutchinson, T.C., University of California, San Diego
Project Manager: Willoughby, K., WSDOT
Technical Monitors: Columbia River Crossing team/Allen, T., WSDOT
Sponsor: WSDOT
WA-RD 762.1

LRFD Procedures for Geotechnical Seismic Design

The design of bridge foundations, approach embankments, and other geotechnical elements of transportation infrastructure must take into account the potential effects of earthquakes in seismically active areas. Unfortunately, although biases and uncertainties in geotechnical seismic analysis and design procedures are known to exist, they are not accounted for in a coherent, consistent manner in practice. As a result, the designs of structures in seismically active areas frequently have different actual probabilities of acceptable performance. This situation results in the inefficient use of available design and construction funds, and of unintentionally different levels of public safety. This research sought to develop a framework for computing load and resistance factors for the seismic design of geotechnical elements of transportation infrastructure, and to implement that framework for pile foundations. The framework will allow engineers to determine load and resistance factors that will produce designs with reliabilities



More than one project looked at the design of bridge foundations, approach embankments, and other geotechnical elements in relation to the potential for seismic activity in the Pacific Northwest.

(This graph is used with permission from the Pacific Northwest Seismic Network, www.ess.washington.edu/SEIS/PNSN/.)

consistent with those achieved by Load and Resistance Factor Design (LRFD) procedures. Development of reliability-based design procedures will allow structures in all seismic environments to be designed for consistent reliability.

Principal Investigators: Kramer, S.L., UW/Baker, J., Stanford University
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Allen, T., WSDOT
Sponsor: WSDOT

Active Projects

Design Guidelines for Horizontal Drains Used for Slope Stabilization

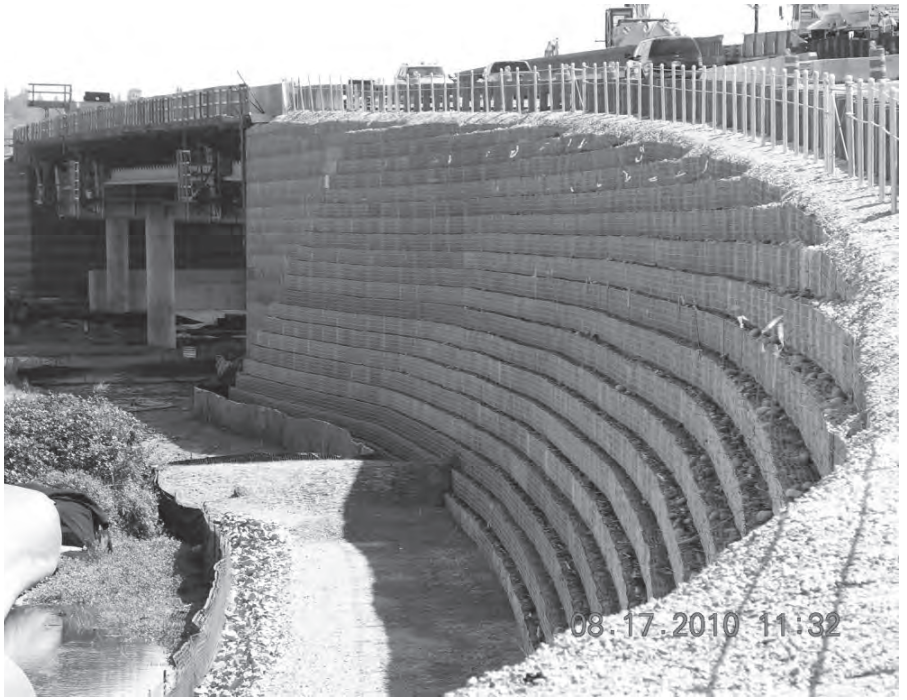
The objectives of this pooled-fund study are to (1) develop a standard protocol that uses accepted methodologies to characterize hydrogeologic sites, (2) select design guidelines that utilize both analytic and numerical models to cover a wide range of validated field conditions, and (3) develop a design manual that includes charts, equations, and useful numerical models for the optimal design of a subsurface drainage system. Ultimately, training for interested geotechnical engineers and hydrogeologists on the use of the selected design methodologies will occur as well. WSDOT's partners on this project are the California, Maryland, Mississippi, Montana, New Hampshire, Ohio, Pennsylvania, Texas, and Wyoming departments of transportation.

Principal Investigators: Pohll, G., Desert Research Institute/Muhunthan, B., WSU
Research Manager: Willoughby, K., WSDOT
Technical Monitors: Lowell, S./Badger, T., WSDOT
Sponsors: WSDOT and State Partners

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. However, 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



Completed retaining wall for a new bridge on SR 532 in western Washington. (Photo by WSDOT)

Health and Transportation

Transportation professionals are increasingly interested in better understanding the intersection of health and transportation, and health advocates are beginning to recognize the importance of participating in transportation planning and policy to ensure that they more fully consider the health implications of transportation decisions. To provide better information for policy proposals and transportation decision-making, TRAC researchers participated in three studies over the last biennium that explored the characteristics of neighborhood built environments, including transportation infrastructure, and their effects on people's physical activity levels.

Active Projects

Childhood Obesity Treatment: A Maintenance Approach

The National Institutes of Health is sponsoring research to explore the characteristics of neighborhood environments in which children live and to analyze the potential influence of these neighborhood built-environment characteristics on children's physical activity and eating habits. This project is conducting a multi-site, randomized controlled trial to test different models of weight maintenance within family-based behavioral treatments for overweight children. In this subcontract to the Washington University School of Medicine, St. Louis, UW researchers are geocoding children's home locations in King County, Washington, providing environmental variables to characterize the children's neighborhood environments, and advising the Washington University team on the development of environmental data for the St. Louis region. The data will help scientists analyze the neighborhood environments of children in the multi-site project, which may eventually aid planners in constructing built environments that better encourage healthy living behaviors.

Principal Investigator: Vernez Moudon, A., UW
Technical Monitor: Wilfley, D.E., Washington University School of Medicine
Sponsor: National Institutes of Health

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, Washington, 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. Changes in the neighborhood built environment, as well as changes in other transportation modes, are also being evaluated. 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 to 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., Children's Hospital and Regional Medical Center
Sponsor: National Institutes of Health

Rural Town Walkability: Measuring the Effect of the Built Environment

The prevalence of physical inactivity and obesity is significantly higher among rural residents, persons with low socioeconomic status, and Latinos. Modification of the built environment to increase physical activity, and walking in particular, holds the potential to reduce obesity and chronic illness among residents of rural towns. By studying rural towns from three distinct geographic regions—New England, Texas, and Washington state—with a varying range of socio-economic and ethnic characteristics, this study is measuring characteristics of the built environmental that correlate with walking among small town residents and evaluating the degree to which those correlations are influenced by household income, educational attainment, and Latino ethnicity. They will validate those correlations by using accelerometer and global positioning system measures. By helping researchers to draw some conclusions about how socioeconomic status and Latino ethnicity interact with the built environment to affect the physical activity of rural residents, this project may aid planners in making rural towns healthier environments for their citizens.

Principal Investigator: Doescher, M./Vernez Moudon, A., UW
Sponsor: National Heart, Lung and Blood Institute

Cooperating institutions are exploring the characteristics of neighborhood built environments and analyzing their potential influence on children's physical activity. (Photo by WSDOT)

Highway Design and Safety

Washington's highways are some of the safest in the nation as a result of continued research and investment to improve safety performance. Highway design research continues to evaluate the driver's experience, develop and test new roadside features, and improve overall highway operations to reduce the number and severity of accidents. As sustainability becomes more important for both limited operating budgets and the environment, other design-related research has investigated ways to make roadway and roadside design and construction more sustainable and cost effective.

Completed Projects

Assessment of Alternatives in Vegetation Management at the Edge of Pavement

The traditional WSDOT practice of maintaining a bare-ground strip at the pavement edge is being re-evaluated because of concerns about the potential effects of herbicide applications and other agencies have achieved satisfactory results without herbicides. This study documented the costs, outcomes, and recommendations resulting from 43 individual case studies on Washington state highways. In those case studies, the researchers either established and maintained vegetation up to the pavement edge or maintained a bare ground strip through non-chemical methods. In Eastern Washington, particularly in the more arid areas, the study found that desirable grasses could be established up to the edge of pavement. In wetter Western Washington, more maintenance was required for traffic safety and stormwater management. In the long-term, WSDOT will continue to develop more cost-effective ways to construct pavement edges and vegetated shoulders to reduce ongoing maintenance requirements and to improve stormwater management and pollution control.

Principal Investigators: Willard, R.G./Morin, J.R./Tang, O.K., WSDOT
Project Manager: Willoughby, K., WSDOT
Technical Monitor: Willard, R.G., WSDOT
Sponsor: WSDOT
WA-RD 736.1

Barriers to Implementing Low Impact Development Approaches on Washington State Roadways and Highways

Low impact development (LID) is an approach to stormwater management that seeks to mimic natural hydrologic processes. In general, LID techniques emphasize soil infiltration, air evaporation, and plant transpiration to remove pollutants and attenuate flows from urban runoff, as opposed to more conventional detention ponds, sewer stormwater systems, and treatment facilities. As the largest land developer in Washington state, WSDOT is interested in better understanding the challenges of applying LID techniques along highways. This project identified physical, technical, and institutional barriers to implementing LID approaches along state roadways. The researchers also recommended ways that WSDOT can address those barriers. As urban growth and land development increase the amount of impervious surface in our state, the importance of managing stormwater runoff will continue to grow. Applying LID techniques may help WSDOT not only meet regulatory requirements but also meet broader environmental protection goals that will improve air and water quality.

Principal Investigator: Miccio, C.E., UW
Project Manager: Brooks, R., WSDOT
Technical Monitor: Schaffner, L., WSDOT
Sponsor: WSDOT
WA-RD 756.1

GIS Data Coding

University of Washington researchers aided WSDOT in assigning geographic information system (GIS) coordinates to collision data. The data included fatal and disabling injury collisions on county roads and city streets within Washington state for 2009. This project, a continuation of previous work, was intended to complement ongoing WSDOT efforts to assemble a complete geospatial database on collisions. This helps WSDOT identify groupings of high severity crashes across jurisdictional boundaries (city, county, state), providing another way to identify areas of need. This gives WSDOT an additional means of prioritizing safety projects, helping it to spend limited state dollars more effectively.

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

Greenroads

Greenroads (www.greenroads.us) is an award-based, flexible rating system (sometimes called a "performance metric") that can be used to score, rank, and compare different road projects on the basis of their overall sustainability. Developed as a collaboration between UW researchers and CH2M HILL, Greenroads is the first such rating system for roadway projects and has been tested on over 40 projects throughout the U.S. and Canada. The ultimate goal is to encourage more sustainable roads by quantifying and communicating sustainability in a straightforward and meaningful way. Fundamentally, Greenroads can be used to (1) define what project features contribute to sustainability; (2) quantify sustainability, allowing it to be measured, managed, and improved; and (3) encourage innovation and promote competition. The Greenroads rating system consists of both required and voluntary best practices. Certification involves the completion of all eleven required best practices and the achievement of specified minimum point totals through the completion of any number of voluntary best practices. In 2010, the Greenroads

Foundation, a private non-profit company charged with the stewardship of this rating system, was formed and is now conducting project ratings in the U.S.

Principal Investigator: Muench, S.T., UW
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Uhlmeyer, J., WSDOT
Sponsors: WSDOT/TransNow/State Pavement Technology Consortium
WA-RD 725.1

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 worked with selected local agencies to evaluate projects that installed landscaped medians containing small trees and compare them to other roadway treatments that did not. This project continued a long-term evaluation of the safety effects of medians and sidewalks with trees, and summarized data on the cost of maintaining these types of landscaping and the effects these treatments had on vehicle speed and pedestrian activity levels. WSDOT and other jurisdictions can 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

Centerline rumble strips (here being placed on a shoulder of US 2) were found to be an effective, low-cost, low-maintenance countermeasure that reduces the frequency of collisions. (Photo by WSDOT)

Performance Analysis of Centerline Rumble Strips in Washington State

To reduce collisions, WSDOT implemented a policy in 2006 for installing centerline rumble strips on undivided highways. Most studies up to that time had focused on the prevention of centerline crossovers. Other collision types, such as run-off-the-road-to-the-right, had not been adequately explored to determine whether the use of rumble strips changed their frequencies. Another question was whether any site characteristics influenced the effectiveness of rumble strips. This study evaluated the effectiveness of centerline rumble strips under different traffic and geometric conditions. The researchers concluded that they are an effective, low-cost, low-maintenance countermeasure that significantly reduces the frequency of collisions, regardless of lane/shoulder width, speed limit, or any of the other geometric conditions examined. The resulting recommendations will allow WSDOT to install rumble strips with better confidence in their effects on safety and lives

Principal Investigators: Olson, D./Manchas, B./Glad, R.W./Sujka, M., WSDOT
Project Manager: Brooks, R., WSDOT
Technical Monitor: Olson, D., WSDOT
Sponsor: WSDOT
WA-RD 768.1

Preliminary Investigation of Luminaire and Traffic Signal Pole Lifespan

WSDOT has installed thousands of luminaires and traffic signals, each with several poles, around the state. Because over half of those steel poles have reached their 25-year design life, this research sought to help WSDOT prioritize the inspection and replacement of luminaire support structures throughout the state. The project included experimental fatigue testing of two in-service luminaire poles and a finite element analysis of the pole base. The researchers also developed a framework for estimating remaining life and made recommendations for luminaire inspection. This research will help improve public safety by 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: WSDOTWA-RD 735.1

Sustainable Roadside Design and Management for Urban Freeways in Western Washington

Restoration of roadside vegetation during construction and ongoing roadside vegetation maintenance practices significantly affect public perception of the overall quality of the highway system and the services WSDOT delivers. In this project researchers sought to provide recommendations for roadside design, construction, and maintenance that will allow WSDOT to achieve its goal of roadside sustainability at the lowest life-cycle cost. Approximately 20 urban freeway sites in Western Washington served as case studies for evaluation. The report includes recommendations for improving the design, construction, and management practices to create aesthetically, economically, and ecologically effective roadside landscapes in urban freeway settings. WSDOT will use the recommendations to more effectively achieve sustainable and functional roadsides, resulting in improvements in the public perception, aesthetics, and environmental quality of urban freeway roadsides, as well as a reduction in the costs of design, construction, maintenance, and operation.

Principal Investigator: Robertson, I., UW
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Willard, R., WSDOT
Sponsor: WSDOT
WA-RD 774.1

Through, Over, or Under Guardrail Penetration by Guardrail Height

Guardrail collisions are categorized by WSDOT into three collision types. These are dependent on whether the vehicle strikes the guardrail face; leading edge; or through, over or under (TOU) the guardrail. The TOU category is of particular interest, as this collision type indicates a penetration of the rail's safety feature. This project investigated whether a clear correlation between guardrail height and penetration of the guardrail could be found. The researchers looked at Washington state collision data from 1999 through 2009. They found no clear trends or indicators that guardrail height between 27 and 31 inches reduced or increased the number of TOU collisions. The data also indicated that the percentages of TOU collisions were consistent between heights of 26 to 31 inches. The researchers also found no clear relationship between guardrail height and the percentage of serious and fatal collisions. These results will be used in the design criteria for future guardrail installations.

Principal Investigators: Manchas, B./Olson, D., WSDOT
Project Manager: Brooks, R., WSDOT
Technical Monitor: Olson, D., WSDOT
Sponsor: WSDOT
WA-RD 742.1

Active Projects

Sustainability Best Practices for the Office of Federal Lands Highway

The use of sustainable practices by the Federal Lands Highway Program in design and construction can be difficult because those practices may not be part of the existing design/construction process, or because no effective, broad-based means of comparison or quantitative assessment exists. As a result, sustainable roadway design and construction practices may be overlooked or implemented piecemeal, without full consideration of their life-cycle impacts and interrelationships. To address this issue, this project is examining the strategic values of the Office of Federal Lands Highway (FLH) and partner agencies. It will also describe the state-of-the-practice in project-level roadway sustainability rating systems and will suggest how FLH might use them. Finally, it is reviewing seven FLH projects as state-of-the-practice sustainability case studies, including project scoring using the Greenroads Rating System and the FHWA Sustainable Highways Self-Evaluation Tool Pilot Version. A compilation of existing and potential techniques, along with a system capable of quantifying their features, will support more informed decisions regarding roadway design and construction sustainability, better dissemination of ideas, and more straightforward communication about their use and benefits.

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

Greenroads Development and Assessment

Oregon has been among the national leaders in adopting more sustainable practices related to business and development. The Greenroads Rating System (www.greenroads.us), a sustainability rating system for roadway design and construction, is a potentially helpful tool that ODOT could use in its pursuit of more sustainable practices. However, Greenroads must work well with existing and proposed ODOT standards and sustainable practices, and means to integrate it into a sustainability program must be explored and evaluated. This project is conducting such an evaluation at both the programmatic and technical levels, is applying Greenroads to three ODOT projects to determine its compatibility and costs, and will subsequently implement any desired changes. Should ODOT decide to incorporate some or all of Greenroads into its sustainability approach, its use could encourage more sustainable practices in roadway design and construction and support better informed decisions and trade-offs regarding roadway sustainability.

Principal Investigator: Muench, S.T., UW
Research Manager: Cornell, L., ODOT
Technical Monitor: Lifsey, M., ODOT
Sponsor: Oregon State Department of Transportation

Information Management

Employees gather and share large amounts of data and information necessary for accomplishing an organization's daily work and business goals through both formally developed and informal networks. Research in this area helped WSDOT understand how these networks function and the success of the interaction

Completed Projects

Identification Needs in Developing, Documenting and Indexing WSDOT Photographs

WSDOT has many thousands of photos and digital images, collected by various departments, representing all aspects of its work and the transportation system. The collection includes both current and historical images. However, because of many separate archives with multiple, incompatible access methods, the images 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. With the long-term goal of creating an agency-wide image indexing system, this study surveyed and assessed existing agency image collections, how they are currently indexed, who uses them, and for what purposes. In addition, the study evaluated the capabilities of potential systems for photo indexing, storage, and retrieval, identified missing components, and made recommendations for interim steps to improve image accessibility. The long-term benefits of the project will include savings in staff effort, 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
WA-RD 731.1

Knowledge Profile Interviews

Retirements, downsizing, and reorganization within WSDOT have resulted in significant staff turnover and loss of institutional knowledge. WSDOT initiated a pilot project to conduct knowledge profile interviews with subject matter experts before they left their positions. Each interview lasted two to seven hours and focused on operational detail not captured in available documentation. Two UW Communications doctoral students and one WSU Civil and Environmental Engineering student reviewed the audio files and prepared summaries of 15 interviews. This information was shared with program managers to assist in supporting new staff.

Research Manager: Lindquist, K., WSDOT
Technical Monitor: Oman, L., WSDOT
Sponsor: WSDOT

WSDOT funded organizational network analysis for two internal groups to analyze how employees share work-related information and to ultimately increase its efficiency, productivity, and cost management. (Photo by Mary Marrah)

Organizational Network Analysis for Two Networks in WSDOT

Organizational network analysis (ONA) consists of gathering data on information sharing and connectivity within a group, calculating measures of network effectiveness, creating network maps, and using this information to analyze how employees share work-related information and to improve the functionality of the group. ONA was conducted for two groups within WSDOT. The overall organizational health of these networks, as defined by network indicators, was positive, with a large percentage of individuals indicating that others in their network were effective at providing information necessary to accomplish their work. The researcher made recommendations for further improving information sharing and network effectiveness. The results of this project will help WSDOT improve intra-agency information sharing and thus increase its efficiency, productivity, and cost management.

Principal Investigator: Brown, S., WSU
Project Manager: Lindquist, K., WSDOT
Technical Monitor: Oman, L., WSDOT
Sponsor: WSDOT
WA-RD 754.1

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. With these data, traffic operators are better able 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

ITS Evaluation Framework: Phase III

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 such an evaluation is to give planners a better understanding of 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, 17 of those new projects were evaluated within the adopted framework. This Phase III project continued evaluation of the final 15 projects, covering everything from ITS planning to safety improvements.

Principal Investigator: Hallenbeck, M.E., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Vessey, R., WSDOT
Sponsors: WSDOT/FHWA
WA-RD 672.2, 672.3

Puget Sound In-Vehicle Traffic Map Demonstration

Congress requested and funded this project to gain a better understanding of the benefits of providing in-vehicle congestion information and to determine whether detectable changes in congestion levels result from providing that information. The researchers surveyed 2,215 drivers in the Puget Sound region who used an in-vehicle traffic map device for six months. The benefits reported by participants were mixed. About 20 percent thoroughly liked the device and would purchase it, but the rest either found no or occasional value from it and would not purchase it. However, 59 percent of participants indicated that receiving the information reduced their stress level. The project also analyzed a roadway corridor to determine how travelers' behavior affected congestion on alternative roadways. The researchers found that even without arterial performance information, some travelers seek alternative routes when the freeway becomes congested. And even the modest levels of diversion observed in this study increased arterial congestion. They concluded that, with increasing amounts of traffic congestion information available to motorists, roadway agencies will need to place higher priority on traffic management of ramps and arterial segments that connect to alternative routes.

Principal Investigators: Hallenbeck, M.E./Briglia, P.M./Wang, Y./Rutherford, G.S., UW
Research Manager: Brodin, D., WSDOT
Technical Monitor: Trepanier, T., WSDOT
Sponsors: WSDOT/U.S. Congress
WA-RD 737.1

Weather Information Resources for the WSDOT, Phase V

Researchers at the UW have developed innovative, Web-based applications to provide current and forecast weather conditions to WSDOT personnel and the traveling public for cross-state travel on state highways (http://i90.atmos.washington.edu/roadview/i90/) and ferry routes (http://i90.atmos.washington.edu/ferry/Ferryjs/mainframe1.htm). 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 are extensively used and have received strong positive feedback. This project continued work to make a wide range of weather and roadway information available. Such information is 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, Bluetooth 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, and evaluating the accuracy of the method. 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
Sponsors: WSDOT/TransNow

Information from Web-based applications to provide current and forecast weather conditions is helping WSDOT to more cost-effectively maintain state highways. (Photo by Guy Gill)

Maintenance

With funding for new roadways decreasing, the focus of transportation programs has been shifting from new construction to operations and maintenance. Maintenance is considered key to not only protecting the state's highway investments but also continuing to provide a safe, efficient transportation system. Maintenance professionals face important challenges in meeting the demands of an aging infrastructure, as well as meeting growing public and legislative demands for accountability and managing the rapid pace of technological change. In Washington state, an important aspect of state highway maintenance involves keeping winter roads operational. Two studies over the past biennium looked at best practices for the use of deicers and their effects on the environment and DOT vehicles and equipment.

Completed Projects

Investigating the Longevity of Corrosion Inhibitors and Performance of Deicer Products under Storage or after Pavement Application

This study evaluated the longevity of corrosion inhibitors and the performance of deicer products in storage or after pavement application. Three inhibitors were studied: GLT, FreezGard, and CCB. No significant degradation of corrosion inhibitor or loss of chlorides was seen during several months of field storage. No significant difference in anti-icing performance was observed among the three liquid deicers during two storm events, and all three worked effectively for anti-icing applications under the investigated conditions. Without dilution by precipitation, the percentage of chloride recovered from the pavement by the fourth day was between 20 and 50 percent. While such residuals could be washed away by precipitation, their presence on the pavement could potentially be measured and considered when chemicals are re-applied for snow and ice control. This study was a part of the Pacific Northwest Snowfighters pooled fund, which includes the Colorado, Idaho, Indiana, Iowa, Minnesota, Montana, North Dakota, Oregon, Utah, Virginia and Washington departments of transportation, as well as America West, Redmond Materials, and Tetra Technologies.

Principal Investigator: Shi, X., Western Transportation Institute
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Mills, M., WSDOT
Sponsors: WSDOT and Study Partners
WA-RD 759.1

Active Projects

Best Practices and Guidelines for Protecting DOT Equipment from the Corrosive Effect of Chemical Deicers

The objective of this project is to identify, evaluate, and synthesize best practices—such as design improvements, maintenance practices, and the use of coatings and corrosion inhibitors—that can be implemented to minimize the effects of deicer corrosion on DOT winter vehicles and equipment, The research includes a survey of current practice and the state of the art from DOTs and the airline, automobile/trucking, waterborne transportation, defense, and other industries. This will be followed by phone interviews and laboratory evaluation of select products and practices. The culmination will be a cost/benefit analysis of selected practices and products that will help departments of transportation more cost effectively maintain their winter roadway equipment.

Principal Investigator: Shi, X., Western Transportation Institute
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Mills, M., WSDOT
Sponsors: WSDOT and Study Partners

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 a priority for government and other providers of the facilities and services that make up the transportation system. Recent research has focused on 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

BE-LOGIC

Funded by the European Commission, BE-LOGIC was intended to improve the quality and efficiency of the flow of goods and services within and across different modes of transport in Europe. TRAC researchers supported this effort by inventorying U.S. transportation logistics policies for comparison to European policies. Project staff analyzed transport and logistics policy documents from U.S. federal and state agencies and compared them to European policies. They determined that, in comparison to Europe, the U.S. government's role in formulating intermodal logistics policy is limited. The level of regulation is also minimal, as a laissez-faire approach is common. In addition, the U.S. Department of Transportation does not give equal priority to different modes of transport. Most regulation therefore occurs at the state and local levels.

Principal Investigator: McCormack, E.D., UW
Technical Monitor: Zavgoli, D., Research Centre of the Athens University of Economics and Business
Sponsor: European Commission

A Comparison of Operational Performance: Washington State Ferries to Ferry Operators Worldwide

Washington State Ferries (WSF) is responsible for safely moving people, goods, and services around the Puget Sound. In 2009, the 22.4 million passengers and 9.9 million vehicles WSF carried made it the nation's most ridden ferry system. This study used eight measures of transit service quality and cost efficiency to compare WSF with 23 ferry systems around the world. Among many results, the researchers found that WSF completed 99.6 percent of its scheduled trips in 2009, exceeding the average of 98.1 percent; WSF averaged a cost per passenger of $10.08, less than half the $20.51 average of those with data on the statistic; and WSF received an average of $3.49 per passenger in taxpayer subsidies, significantly less than its peers in British Columbia ($5.86), Alaska ($300), North Carolina ($15.62), and Sydney ($4.52). The matrix of data collected through this research can serve as a template for creating further measures of performance that reflect state and agency priorities. These measures will help policymakers and state officials improve WSF performance and increase accountability.

Principal Investigator: Bennion, M.D., UW
Project Manager: Brooks, R., WSDOT
Technical Monitor: Johnson, M., WSDOT
Sponsor: WSDOT
WA-RD 750.1

Incorporating Assumptions for TDM Impacts in a Regional Travel Demand Model

Faced with substantial funding shortfalls to meet transportation needs, WSDOT is increasing the use of transportation demand management (TDM) strategies to improve the efficiency of existing highways by decreasing single-occupancy vehicle rates. This requires an ability to forecast the magnitude and geographic distribution of changes in travel patterns likely to result from more aggressive TDM programs. It also requires an ability to estimate the impacts those changes will have on delay, speed, and travel time. To help, this project developed a four-step modeling process called TDM Assessment Procedure (TDMAP) to incorporate TDM into WSDOT's travel demand model. The study also developed a low cost method to help WSDOT plan TDM strategies as part of its overall transportation planning process. Although more work is needed to help WSDOT identify and choose the most cost-effective mix of program elements, the eventual result will be more efficient use of existing transportation facilities at lower cost to the state.

Principal Investigators: Winters, P.L./Hillsman, E.L./Lee, C./Georggi, N.L.. University of South Florida
Project Manager: Lindquist, K., WSDOT
Technical Monitor: Lagerberg, B., WSDOT
Sponsor: WSDOT
WA-RD 746.1

MyBus Interface to GE and PT Systems

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 helped to create an interface between the MyBus prediction system and 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

Safe Routes to School: Statewide Mobility Assessment Study

The majority of children traveling to and from school now do so by private car. Driving children to school increases traffic congestion and is linked with higher rates of children's chronic health conditions. WSDOT is the lead agency in a Safe Routes to School (SRTS) Pooled Research Project with Florida, Mississippi, Texas, and Wisconsin. The study had

three objectives: (1) establish benchmark rates of children walking and biking to school, (2) provide recommendations for future allocation of SRTS funds, and (3) identify tools for further evaluating the effectiveness of SRTS investments. In phase one of the project, researchers focused on the first objective. They found that rates of walking and biking to school varied considerably and concluded that the most reliable benchmarks come from individual schools. They recommended that SRTS funded schools applying for SRTS funding provide counts of students currently walking and biking to school. Guidance based on the results of this research will help state SRTS coordinators make better funding decisions for their programs. In this way, the findings will 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
WA-RD 743.1, 743.2

South King County TDM/GTEC

As part of its efforts to improve the efficiency of the transportation system, WSDOT has focused state travel demand management (TDM) activities on Growth and Transportation Efficiency Centers (GTEC). GTECs are state-designated areas that contain many of the features necessary to support TDM measures, with specific emphasis on commute trip reduction. This project was a response to an initial GTEC project selection process, the outcome of which was that the seven GTECs selected were all within the state's larger cities. WSDOT wanted to understand why growing suburban cities had not competed successfully and to look for ways to encourage the formation of suburban GTECs. The resulting report provides guidance to WSDOT in creating, operating, and enhancing GTECs, especially those within suburban cities. The report also presents ideas on ways WSDOT could modify the current approach to GTECs in response to different budgetary scenarios. Besides benefiting the travel and quality of life of those who live and work in the new GTECs, the results of this research will also inform policy changes in the state's Commute Trip Reduction and GTEC programs, leading to greater breadth and versatility in WSDOT's TDM efforts.

Researchers are enhancing traveler information system tools, including OneBusAway, that help people more effectively use the Puget Sound region's transit systems. (Photo by WSDOT)

Principal Investigators: Hallenbeck, M.E./Carlson, D., UW
Research Manager: Lindquist, K., WSDOT
Technical Monitor: Aiken, C., WSDOT
Sponsor: WSDOT
WA-RD 763.1

State Highways as Main Streets: A Study of Community Design and Visioning

The objectives of this project were to develop a measurable link between transportation goals and investments and to identify efficiencies when state highways also serve as community main streets. The project had two components: a GIS-based system analysis and a series of case studies. First the researchers analyzed WSDOT's state highway system data and determined that 500 miles currently serve as "main streets." They found that 47 percent of state transportation projects completed in the past 10 years on those main street highway segments included scope, schedule, or budget changes; in comparison such changes occurred on 38 percent of all state transportation projects. The researchers then conducted case studies in four communities, using "storefront studios" to review project plans and engage local residents in the design process. Through the case studies and system analysis, they concluded that by using a community design-type process for these main street highways, WSDOT could have avoided an average of $9 million or 30 percent in additional costs per project for at least 40 recently completed projects.

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

Vehicle Miles Traveled Reduction Impacts on Selected Areas and Groups

Washington state has established benchmarks for reducing vehicle miles traveled (VMT). The ambitious targets call for VMT reductions of 18 percent by the year 2020, 30 percent by the 2035, and 50 percent by mid-century. The purpose of this study was to identify and assess current information about potential VMT reduction strategies and their economic impacts on five geographic areas, populations, and business groups mandated by state legislation. The five groups and areas included small businesses whose employees cross

county lines to get to work, low-income residents, farm workers, distressed counties, and counties with more than half the land in federal or tribal ownership. The study defined these groups and areas, categorized VMT reduction strategies, and made informed assumptions about the behavior and trip lengths of group members. The researchers then estimated impacts on the selected groups and concluded that because the five areas and groups are not homogeneous, a variety of strategies could be used, at different levels of government and for different groups and individuals, to reach the state's VMT reduction benchmarks.

Principal Investigator: Carlson, D., UW
Research Manager: Lindquist, K., WSDOT
Technical Monitor: Criss, A., WSDOT
Sponsor: WSDOT
WA-RD 751.1

Active Projects

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. 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

Enhancements to OneBusAway Transit Traveler Information Systems

Researchers are enhancing a set of traveler information system tools, called OneBusAway, that help transit riders more effectively use the Puget Sound Region's transit systems. OneBusAway, launched in summer 2008, integrates real-time information from transit agencies—including predicted arrivals and planned detours and cancellations—and delivers it in several intuitive ways—via the Web, a variety of smart phone applications, SMS text messages, and automated voice messaging—to give riders a clearer picture of the status of their trip (http://onebusaway.org). Its usage has increased steadily, and preliminary surveys of OneBusAway users show increased overall satisfaction with public transit, decreased wait times, increased transit trips per week, increased feelings of safety, and even increased distance walked among transit users. In this project, researchers are developing a real-time alert system that will help transit agencies internally capture real-time changes in service (for example, a temporary bus route change caused by an unexpected road closure), and pass along that information to transit riders in timely and informative ways.

Principal Investigator: Hallenbeck, M.E., UW
Research Manager: Shah, N., The Bullitt Foundation
Sponsor: The Bullitt Foundation

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, is being used to estimate changes in trip generation and mode split between home and workplace. The project will result in 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

Sustainable Design Guidelines to Support the Washington State Ferries Terminal Design Manual

Washington State Ferries is developing a new ferry terminal design manual. WSDOT is also currently challenged with two major initiatives that could potentially affect terminal design: an executive order from the governor for WSDOT to develop a sustainable transportation plan and growing use of Low Impact Development (LID) technologies to control storm water. These initiatives address facilities' energy and water use. To assist the developers of the terminal design manual in potentially incorporating sustainable design elements, researchers at WSU are producing sustainable design guidelines that will address the unique needs and requirements of ferry terminals. Specifically, the researchers are reviewing applicable sustainable design guidelines and rating systems, assessing the needs of WSF staff, investigating ways to address storm water quality and quantity with LID methods, and providing recommendations on the use of composite materials. This project is expected to be the first in a three-part effort.

Principal Investigator: Wolcott, M./Haselbach, L./Poor, C., WSU
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Bertucci, T., WSDOT
Sponsor: WSDOT

Pavements

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

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

WSDOT is responsible for over 2,300 lane-miles of portland cement concrete pavement (PCCP). Current PCCP conditions in key state transportation corridors will soon require large-scale reconstruction and rehabilitation. Before embarking on that effort, WSDOT is considering how the next generation of concrete pavements will be evaluated, designed, constructed, and maintained. For this project, researchers undertook a review of past and current PCC pavements, including design, construction and performance. They evaluated the effects, extent, and severity of studded tire wear on the WSDOT PCC pavement network and proposed and tested an approach for PCC pavement life-cycle assessment. They also analyzed the effects of loop detector installation on PCC pavement life. The results from this project will help WSDOT form a comprehensive strategy for designing, constructing, and maintaining the next generation of PCC pavements that will provide for the most efficient and effective use of public funds.

Principal Investigator: Muench, S.T., UW
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Uhlmeyer, J., WSDOT
Sponsors: WSDOT/FHWA
WA-RD 744.1–744.5

Effect of Chloride-Based Deicers on Reinforced Concrete Structures

When highways are likely to become slippery with ice, WSDOT may use deicing chemicals to prevent accidents. However, little has been known about the effects that corrosion inhibitors (and other additives) in deicers have on the highway infrastructure. Specifically, research was needed to determine whether corrosion-inhibited deicers are beneficial in preventing the corrosion of rebar or dowel bars in concrete. To this end, researchers performed laboratory tests that exposed concrete samples to four common chloride-based deicers for one year or less. Under the experimental conditions, the corrosion inhibitors in the deicers helped to preserve the strength of concrete undergoing temperature and wet/dry cycles. However, while they also slowed the initiation of steel corrosion in the concrete, those benefits seemed to diminish once active corrosion of the rebar began. The researchers concluded that WSDOT could better preserve its infrastructure—thereby saving scarce maintenance funds—by using less costly sodium chloride-based deicers and focusing efforts on creating concrete mix designs with less permeability, rather than procuring the more costly corrosion-inhibiting deicers.

Principal Investigator: Shi, X., Montana State University. Western Transportation Institute
Project Manager: Willoughby, K., WSDOT
Technical Monitors: Mills, M./Uhlmeyer, J./Wilson, D., WSDOT
Sponsor: WSDOT
WA-RD 741.

Crews install steel rebar on a bridge in Washington. Deicers may corrode rebar. Research concluded that the best prevention may be less permeable concrete, rather than more expensive, corrosion-inhibiting deicers. (Photo by WSDOT)

Hot in-place recycling successfully rehabilitated the pavement on SR 542 while using less new material than the traditional hot mix asphalt process. (Photo by WSDOT)

Evaluation of Hot In-Place Recycle

The traditional method of recycling hot mix asphalt (HMA) pavement in Washington state is to grind the top layer of the existing pavement, truck it back to the asphalt plant, stockpile it, and then incorporate it into new HMA. Hot in-place recycling (HIPR) is a technology that eliminates the trucking and handling of the recycled HMA and performs the complete process on-site. This project investigated the potential of HIPR to reduce energy consumption and lower the cost of HMA rehabilitation by documenting the construction of an HIPR pavement on SR 542. Although final results will not be known until after completion of the pavement evaluation in five years, preliminary results were positive. The HIPR process successfully rehabilitated the pavement on SR 542 while using less new material than the traditional HMA process. HIPR was found to reduce the initial project cost, and traffic was less disrupted that it would have been with HMA paving. If it proves successful, the HIPR process will give WSDOT a better ability to save money and conserve resources.

Principal Investigators: Russell, M./Uhlmeyer, J.S./DeVol, J./Johnson, C./Weston, J., WSDOT
Project Manager: Willoughby, K., WSDOT
Technical Monitor: Uhlmeyer, J., WSDOT
Sponsor: WSDOT
WA-RD 738.1

Evaluation of Long-Term Pavement Performance and Noise Characteristics of the Next Generation Concrete Surface

This project was part of a continuing effort by WSDOT to test new methods of decreasing the noise generated from highway facilities. For this project, WSDOT constructed its first Next Generation Concrete Surface (NGCS). NGCS is a new method of diamond grinding that produces the quietest concrete pavement surface tested to date. The researchers installed a 1,500-foot test section on the eastbound lanes of I-82 near Sunnyside, Washington, in October 2010. They took baseline measurements of noise, friction, wear, and smoothness. The sound intensity levels for the outside and inside lanes were within the range reported for other NGCS projects. To evaluate the NGCS, the test section will be monitored for at least five years, with noise, wear, roughness, and friction data gathered twice a year in April and October to bracket the legal studded tire season.

Principal Investigators: Anderson, K.W./Uhlmeyer, J.S./Russell, M./Weston, J., WSDOT
Project Manager: Willoughby, K., WSDOT
Technical Monitors: Uhlmeyer, J./Sexton, T., WSDOT
Sponsor: WSDOT
WA-RD 767.1

Evaluation of Long-Term Pavement Performance and Noise Characteristics of Open-Graded Friction Courses—Project 3

This was the last in a series of three experimental feature projects involving the construction of open-graded friction course pavements to decrease tire/pavement noise. The first was constructed in 2006 on I-5 near the city of Lynnwood, and the second was built on SR 520 between Lake Washington and I-405 in 2007. This project was built on northbound I-405 where it crosses I-90. All three projects used asphalt rubber and styrene butadiene styrene (SBS) modified asphalt binders combined with open-graded aggregate structures to produce a quieter pavement surface, but the underlying pavement for the I-405 section was portland cement concrete pavement, whereas on I-5 and SR 520 it was dense graded hot mix asphalt (HMA). Sound intensity measurements taken after construction in December 2009 indicated that the asphalt rubber and SBS modified sections were 3.5 to 2.0 decibels quieter than an HMA control section. In its effort to produce both quieter and cost-effective pavements, WSDOT will continue this experimental evaluation for the useful life of the pavement or a minimum of five years.

Principal Investigators: Russell, M./Uhlmeyer,J.S./Sexton, T./Weston, J./Baker, T., WSDOT
Project Manager: Willoughby, K., WSDOT
Technical Monitors: Uhlmeyer, J./Sexton, T., WSDOT
Sponsor: WSDOT
WA-RD 749.1

Open-Graded Friction Courses in the Pacific Northwest

Open-graded wearing courses are pavement layers constructed of open-graded hot mix asphalt (HMA). The main benefits of their use are better drainage from the pavement surface and potential reduction in tire-pavement noise. The Oregon Department of Transportation (ODOT) has been placing ¾-inch nominal maximum aggregate size open-graded wearing courses in structural layers of two inches or more for about 30 years. Despite this experience, open-graded wearing course performance in the Pacific Northwest is not well understood. This study determined the use and performance of ODOT open-graded wearing courses, with special attention given to ¾-inch open-graded HMA, and recommended guidelines for their future use. The results will help ODOT determine how to best construct open-graded wearing 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 Department of Transportation

Sharing and Evaluation of CalME Flexible Pavement Design Software

Under the direction of University of California Pavement Research Center (UCPRC) staff over a two-year period, personnel from WSDOT, the Texas Department of Transportation, and the Minnesota Department of Transportation examined models from a software program called CalME, a tool for designing flexible pavements and overlays, and identified areas in which those models might be modified or enhanced. Case studies were conducted by UCPRC with data provided by the individual DOTs. The participating states found many CalMEfeatures helpful and may adopt a selected set of models or approaches in their respective efforts to implement mechanistic-empirical pavement design. This project was funded by the State Pavement Technology Consortium (California, Minnesota, Texas, and Washington departments of transportation) through a pooled-fund study.

Principal Investigator: Harvey, J.T., University of California, Davis
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Uhlmeyer, J., WSDOT
Sponsors: WSDOT and Study Partners

Use of a Double Chip Seal to Correct a Flushing Hot Mix Asphalt Pavement in Washington State

Surface flushing on an aggregate roadway occurs when excess binder, if not properly accounted for during design and construction, migrates to the surface and fills the aggregate void spaces. When a chip seal is constructed on an existing flushed roadway, bleeding or flushing of the new chip seal can potentially result. WSDOT uses single chip seals almost exclusively to preserve low volume highways. However, if a double chip seal could successfully address flushing, it would provide an economical method of addressing this problem on chip seal roadways. For testing, WSDOT constructed a double chip seal on a section of pavement on SR 20. The double chip seal will be monitored for up to five years, after which conclusions will be drawn regarding its success or failure.

Principal Investigators: Russell, M./Littleton, K./Weston, J./Uhlmeyer, J.S./Johnson, B. Dunham, S./ Van De Bogert, S.A., WSDOT
Project Manager: Willoughby, K., WSDOT
Technical Monitors: Uhlmeyer, J./Sexton, T., WSDOT
Sponsor: WSDOT
WA-RD 760.1

Verification, Refinement, and Applicability of the LTPP Classification Scheme

Truck attributes vary from state to state because of differences among the states' truck size and weight laws. As a consequence, the algorithms used by different states to classify trucks often differ from one another, even though all states collect and submit classification data to USDOT using FHWA's 13-category system. The Long Term Pavement Performance (LTPP) project has developed another classification algorithm for weigh-in-motion (WIM) equipment with the intent of using that algorithm to uniformly classify trucks throughout the nation. As a subcontractor to Applied Research Associates, TRAC researchers examined how accurately that algorithm worked at sites across the country and whether truck volume counts produced with that algorithm differed significantly from counts produced with state-specific classification algorithms. They also looked at whether the use of the LTPP classification algorithm to produce load spectra data in combination with traffic volumes from state classification counts would produce significant errors in the pavement analysis research that LTPP performs.

Principal Investigator: Hallenbeck, M.E., UW
Research Manager: Selezneva, O., Applied Research Associates
Technical Monitor: Walker, D., FHWA
Sponsor: FHWA

Active Projects

Concrete Performance Using Low Degradation Rock

Marine basalt aggregates are commonly used in Washington, but their degradation is pronounced and can lead to concrete deterioration. Although the degradation of marine basalt aggregates is well understood, and specifications exist to restrict the use of low degradation aggregates to 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 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

Construction Analysis for Pavement Rehabilitation Strategies (CA4PRS)

In rehabilitating freeways with large traffic volumes, it is desirable to design and construct a pavement section that will last at least 50 years and cause minimal traffic delays during future maintenance and rehabilitation activities. However, on heavily trafficked freeways, limitations are often placed on construction closures because of traffic delay concerns. The challenge becomes how to design, analyze, and construct long-lived pavements while minimizing traffic delays. The CA4PRS software has been developed to address this issue. It is currently being upgraded to deal with different roadway scenarios, and training is available online and in person. Study partners include the California, Minnesota, and Texas departments of transportation.

Principal Investigators: Lee, E.B., University of California, Berkeley and EBL Consulting/
White, G., Pavia Systems
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Uhlmeyer, J., WSDOT
Sponsors: WSDOT and Study Partners

Evaluation of Warm Mix Asphalt in the State of Washington

Warm mix asphalt (WMA) refers to a technology that reduces mixing and compaction temperatures in creating asphalt in order to decrease energy consumption and the emission of greenhouse or other toxic gases. Other benefits of WMA include its applicability for cold season paving and long-hauling. With the growing emphasis on sustainability, more frequent use of WMA may be beneficial. However, past evaluations of WMA have shown mixed performance results. Unfortunately, most of those previous studies have been based on lab-produced mixes, which may have significantly different properties from those of field mixes and could lead to different findings about the performance of WMA. WSDOT built eight WMA trial projects in 2008 and 2009. To more accurately evaluate the field performance of WMA, this study is taking cores from those trial projects and comparing their fatigue, rutting, thermal cracking, and moisture susceptibility to control HMA from the same site. If WMA is found to perform well, this project could result in more sustainable and economical paving projects.

Principal Investigator: Wen, H., WSU
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Williams, K., WSDOT
Sponsor: WSDOT

Optimal Timing and Design for Bituminous Surface Treatments

In a recent change, WSDOT will resurface all its roads with an average daily traffic (ADT) of 5,000 or less with bituminous surface treatments (BST) in lieu of hot mix asphalt (HMA). Half of the state's 19,000 lane miles carry less than 5,000 ADT and are therefore candidates for BSTs. Given life-cycle costs, construction costs for BSTs are one-fourth those of an HMA overlay, making a BST an attractive preservation option. However, not enough is known about the optimal timing of BST placement onto an HMA wearing course to maximize the life of the overlay. Another issue involves the application rates for both the pavement binder and aggregate. By conducting a survey of state departments of transportation and analysis of WSDOT's pavement databases, researchers are addressing these issues, developing guidelines for the optimal timing for BST placement. In addition, the researchers are investigating how high ADT levels can be for application of BSTs and will recommend a BST design method. The findings of this research will improve the cost effectiveness of BST pavement surfaces, resulting in better pavement performance and more efficient investment of scarce paving dollars.

Principal Investigator: Mahoney, J.P., UW
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Uhlmeyer, J., WSDOT
Sponsor: WSDOT

Optimum HMA Density Based on Pavement Performance

WSDOT spends substantial funds on hot mix asphalt (HMA) pavement, and it is critical that the HMA be of high quality to maximize pavement performance. Both the literature and field experience have shown that lower than desirable HMA densities result in shorter pavement lives. On the other hand, densities higher than necessary waste limited dollars. Therefore, researchers are seeking to determine the optimal density for WSDOT HMA mixtures and how to best achieve that target. They are evaluating current HMA density criteria by reviewing performance information taken largely from WSDOT's Pavement Management System and the QA Specification/Statistical Analysis of Materials Database. On some projects, they will take core samples and compare the in-place density to the constructed density. On the basis of these evaluations, they will reassess the current statistically based HMA specification and propose appropriate changes to enhance HMA performance. By optimizing the density of its HMA, WSDOT will be able to ensure longer service life for this critical paving material, thus spending construction and maintenance funding more efficiently.

Principal Investigators: Mahoney, J.P./Muench, S.T., UW
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Uhlmeyer, J., WSDOT
Sponsor: WSDOT

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. www.pavementinteractive.org

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

On busy SR 520 in Seattle, pavement repair that closes the freeway must occur at night. Researchers are upgrading the CA4PRS software, designed to help engineers better design, analyze, and construct long-lived pavements while minimizing traffic delays. (Photo by WSDOT)

State Pavement Technology Consortium (SPTC)

The SPTC is a consortium of four state departments of transportation—California, Minnesota, Texas and Washington—that supports collaboration among the states in all aspects of pavement and construction. Various research projects have been performed within the SPTC pooled fund program, and semi-annual meetings are held. http://www.pooledfund.org/Details/Study144

Principal Investigators: Various, depending on research topic.
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Baker, T., WSDOT
Sponsors: WSDOT and Study Partners

Tire/Pavement Noise Research Consortium

This pooled-fund program was created to provide a forum for discussions of tire/pavement noise issues and development of research topics of national interest. Multiple ambassador tours of the various partner states have been conducted to collect tire/pavement noise measurements and investigate other research topics. This pooled fund is scheduled to continue, with the goal of developing a database of tire/pavement noise from multiple states. Study partners comprise the California, Colorado, Kansas, Minnesota, Montana, North Carolina, Ohio, Texas, and Washington departments of transportation and the FHWA. http://www.pavementinteractive.org/

Principal Investigator: Donovan, P., Illingworth & Rodkin
Research Manager: Willoughby, K., WSDOT
Technical Monitor: Sexton, T., WSDOT
Sponsors: WSDOT and Study Partners, FHWA

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.

Completed 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 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 was 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 was 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

A two-year research project for the Department of Homeland Security sought to increase understanding of and facilitate the development of better border-security processes. (Photo by Amy O'Brien)

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 technology 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

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) was through a pooled-fund arrangement managed by WSDOT. The research has helped 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 Transportation Pooled Fund-5(108)

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: Wilson, N., WSDOT
Sponsors: WSDOT/TransNow

Active Projects

Transportation Synthesis Reports.

Transportation practices continue to evolve. To ensure that WSDOT is employing current and cost-effective strategies, the Office of Research and Library Services prepares brief summaries of currently available information on topics of interest to WSDOT subject matter experts. Online and print sources may include newspaper and periodical articles and research project reports, as well as information about the practices of other state DOTs, countries, and regional organizations. State of the practice information may include quick surveys of all other DOTs or phone interviews with select states. In the past biennium, 25 synthesis reports were prepared. Published summaries can be found at http://www.wsdot.wa.gov/Research/Synthesis/.

Principal Investigators: Lindquist, K. and Wendt, M., WSDOT
Technical Monitor: Varies by request
Sponsor: WSDOT

Students interned at WSDOT's Traffic Systems Management Center. (Photo by WSDOT)

Bridges and Structures

Berman, J.W., Wang, B.S., Roeder, C.W., Olson, A.W., and Lehman, D.E. *Interim Report: Triage Evaluation of Gusset Plates in Steel Truss Bridges*. Seattle, WA, TRAC/University of Washington, December 2010, WA-RD 757.1. http://www.washington.edu/trac/bulkdisk/pdf/757.1.pdf

Cofer, W.F., ElGawady, M., and Greenwood, S.M. *Seismic Assessment of WSDOT Bridges with Prestressed Hollow Core Piles—Part I*. Pullman, WA, TRAC/Washington State University, August 2009, WA-RD 732.1. http://www.wsdot.wa.gov/Research/Reports/default.htm

ElGawady, M., Cofer, W.F., and Shafiei-Tehrany, R. *Seismic Assessment of WSDOT Bridges with Prestressed Hollow Core Piles—Part II*. Pullman, WA, TRAC/Washington State University, December 2009, WA-RD 732.2. http://www.wsdot.wa.gov/Research/Reports/default.htm

McLean, D.I., and Walkenhauer, B.J. *Seismic Retrofit of Cruciform-Shaped Columns in the Aurora Avenue Bridge Using FRP Wrapping*. Pullman, WA, TRAC/Washington State University, September 2010, WA-RD 753.1. http://www.wsdot.wa.gov/Research/Reports/default.htm

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Construction Management

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