



Human-centered technology to enhance safety and mobility



ITS INSTITUTE
Intelligent Transportation Systems

Annual Report 2006-2007



CENTER FOR TRANSPORTATION STUDIES

UNIVERSITY OF MINNESOTA

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2006–2007 Annual Report

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A report of research, education, and technology transfer activities of the Intelligent Transportation Systems Institute at the University of Minnesota for fiscal year 2006–2007

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Message from the Director



In a recent study by Farmers Insurance Group, more than a third of motorists surveyed admitted to driving through a red light in the past year—an alarming statistic, given the fact that roughly 800 people die every year as a result of red light running in the United States. Thousands more are injured. Roughly half of those killed are not the signal violators themselves, but pedestrians and occupants of other vehicles. In Minnesota, there were 9 deaths and 1,666 injuries—84 of which were life-changing—due to red light running incidents in 2006.

Automated traffic signal enforcement using cameras mounted at intersections may be the most promising tool to reduce red light running. Several studies carried out in cities around the country have shown that the presence of intersection cameras can dramatically reduce the number of red light violations. Drivers are much less likely to willfully run a red light if they know their actions will be recorded.

However, acceptance of such automated enforcement measures—by the driving public and by political leaders—is complicated by several issues. Here in Minnesota, for example, deployment of cameras at several Minneapolis intersections was halted in part by concerns over how the criminal liability for red light violations would be assigned to drivers based solely on the image of a vehicle (rather than an identifiable individual).

Pursuing our mission to develop “human-centered technology,” the ITS Institute is currently supporting research into the legal issues raised by automated enforcement. Leading this effort is the TechPlan research group, an interdisciplinary group of faculty and researchers whose work focuses on the use of ITS technologies in the fields of planning and policy.

TechPlan leader Frank Douma, a research fellow at

the University's Hubert H. Humphrey Institute of Public Affairs whose background includes degrees in public affairs and law, has formed a productive collaboration with professor Stephen Simon and associate professor William McGeeveran of the Law School. Their work is developing a clearer picture of the rapidly evolving relationship between privacy law and emerging technologies in transportation.

With this research and several other studies now in progress, TechPlan is building on the work begun by the Sustainable Technologies Applied Research (STAR) Initiative, led by Lee Munnich of the Humphrey Institute.

In the case of red light running, the central issue is vicarious criminal liability—whether criminal liability can be assigned to the owner of a vehicle that runs a red light without direct evidence that the vehicle's owner was operating it at the time the infraction was committed.

Without revisions to state law establishing vehicle owners' vicarious criminal liability for red light running, automated enforcement would require the ability to identify vehicle drivers. Though well within the capabilities of current camera technology, this type of enforcement raises even more thorny privacy issues with ramifications extending all the way to the Fourth Amendment of the U.S. Constitution.

Clearly, ITS technology and public policy are inextricably linked. Effective technological solutions cannot

be developed without considering the policy framework governing their implementation; nor is it possible to formulate sound transportation policy without understanding the technological tools being developed to manage and improve the transportation system.

The issues raised by red light cameras are just one example of the critical dialogue between technology and public policy—a dialogue that will continue to evolve as the public demands faster, safer, and more reliable transportation options.

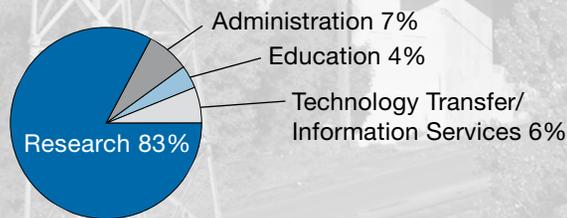
Finally, I would like to take this opportunity to thank five departing members of the ITS Institute Board: Kathryn Swanson, who served as director of the Minnesota Department of Public Safety's Office of Traffic Safety; Toni Wilbur, technical director of operations research and development at the Federal Highway Administration; Randy Halvorson, director of the Minnesota Department of Transportation's program management division; Vince Magnuson, vice chancellor for academic administration at the University of Minnesota Duluth; and Anthony Strauss, assistant vice president of patents and technology on the University's Twin Cities campus. During their tenure on the Board, all made important and vital contributions to the Institute's mission; their abilities and enthusiasm will be missed.



Max Donath, Director
ITS Institute

Financial Report

Expenditures for Year Eight: July 1, 2006–June 30, 2007



Mission Statement

The Intelligent Transportation Systems Institute is a national University Transportation Center (UTC) funded through the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), the federal surface transportation bill passed in 2005. This funding continues the Institute's efforts initiated under SAFETEA-LU's predecessors, the Transportation Equity Act for the 21st Century (TEA-21) and the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA).

The Institute plans and conducts activities that further the mission of the United States Department of Transportation's UTC program: to advance U.S. technology and expertise in the many disciplines that make up transportation through education, research, and technology transfer activities at university-based centers of excellence.

Our focus is human-centered technology that enhances the safety and mobility of road- and transit-based transportation. To that end, we direct the collective energies of researchers from multiple disciplines to advance the state of the art in the core ITS technologies of computing, sensing, communications, and control systems in order to surmount the significant transportation problems of the day.

Based on our theme, we bring together engineers and cognitive psychologists from the University with our partners—the USDOT, the Minnesota DOT, other government agencies, and private industry—to ensure that Institute-developed technologies become tools that help us understand and overcome human limitations as they relate to transportation.

Additionally, we address issues related to transportation in a northern climate, investigate technologies for improving the safety of travel in rural environments, and consider social and economic policy issues related to the deployment of core ITS technologies.

Management Structure

The ITS Institute is located on the Twin Cities campus of the University of Minnesota and is housed within the Center for Transportation Studies (CTS). Much of the Institute's successful leadership in the development and application of intelligent transportation systems and technologies results from its state and national partnerships, including those with CTS, the Minnesota Department of Transportation, private industry, and county and city engineers.

The Institute director leads the Institute's operation, implements its strategic plan, and assumes overall responsibility for its success. In this role, he directs Institute programs, personnel, and funds.

The Institute's board guides and oversees the implementation of the Institute's work. The board works with the director to ensure that the USDOT's Research and Innovative Technology Administration requirements are met, approves annual plans and budgets, and meets at least twice yearly to provide direction to, and approval of, the Institute's activities.

Institute staff and University researchers, drawing from various areas of expertise, help create and disseminate knowledge related to intelligent transportation systems through research, education, and technology transfer activities. In addition, the leadership and staff of CTS provide connections and access to an extensive transportation research and education network. The Institute's affiliation with the Center allows it to work seamlessly with CTS staff and benefit from its diverse outreach, administration, and communications capabilities.

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Northland Advanced Transportation Systems Research Laboratories

The NATSRL program director is Eil Kwon. Support and guidance for NATSRL is provided by its advisory board and research advisory panel, whose members include the staff from partnership agencies, including Mn/DOT, St. Louis County, and the City of Duluth.

Faculty and research staff conducting ITS-related research for NATSRL include the following:

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Natural Resources Research Institute

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Minnesota Traffic Observatory

Researchers' ability to study the complex dynamics of traffic flow throughout the Twin Cities region took a big step forward with the opening of the Minnesota Traffic Observatory (MTO), a joint effort of the ITS Institute and the Department of Civil Engineering. The observatory combines real-time traffic data with state-of-the-art simulation systems, giving researchers and engineers the ability to analyze existing conditions and compare real-world observations with the results of simulated conditions.

"Instead of looking at just one or two locations, the observatory offers the ability to look at large systems where many different parts interact," said director John Hourdos.

Video feeds flow into the observatory from an extensive network of traffic cameras. The observatory is connected by fiber-optic lines to the Minnesota Department of Transportation's traffic operations center, allowing it to capture live feeds from up to 16 of the more than 300 cameras the agency uses to monitor the metropolitan freeway system. In addition, the observatory operates a dedicated system of cameras overlooking the I-94/35W Commons interchange—turning one of the most accident-prone intersection areas in the state into a real-world laboratory for the study of traffic flows and vehicle crashes.

The availability of a wealth of high-quality video data is ideal for the use of machine-vision systems to monitor and categorize vehicle movements. Computer image-processing algorithms developed by University of Minnesota researchers enable the observatory to track and analyze complex traffic patterns at intersections, on freeway interchanges, and in other areas that are difficult to study using other data sources.

Another key component of the MTO is a virtual traffic control center and simulation lab. Interfacing traffic signal control hardware with realistic traffic network models creates a powerful tool for examining system performance under a variety of conditions.

Given the complexity of the traffic issues that the observatory is designed to study, robust visualization tools are critical. In addition to a large projection wall, two innova-

MTO lab manager Ted Morris, senior systems engineer Chen-Fu Liao, and MTO director John Hourdos in the Minnesota Traffic Observatory

tive pieces of equipment provide researchers with powerful interactive visualization capabilities.

The GIS/MAP table, built by Hourdos and the observatory staff, combines the large horizontal working surface of a traditional drafting table with the interactive capabilities of geographic information systems technology. Two ceiling-mounted digital projectors create a seamless image covering the entire conference-table-sized surface, which can be manipulated using a tabletop pointing device to pan and zoom in on specific areas. In contrast to traditional ways of viewing digital maps and models on a desktop monitor, the table allows users to comfortably survey the entirety of a large traffic system and quickly focus in on areas of interest.

The Digital Environment, or DEN, takes a different approach—putting viewers in the center of the action via 3-D immersive graphics. Three sides of the cubical structure are made up of large rear-projection screens made of a polarized material that actually transmits two slightly different images; a user wearing specially polarized glasses sees a different image with each eye, producing a realistic sense of three-dimensional space. A tracking system mounted in the DEN's ceiling monitors the position of the user's head and adjusts each projector to provide accurate perspective.

Right: A pointing tool allows users to zoom in on specific areas of the traffic system displayed on the GIS/MAP table.



Novel traffic model to improve wilderness experience

A single public road winds through the six million acres of unspoiled Alaskan wilderness that make up Denali National Park and Preserve, one of the crown jewels of the United States national park system. For thousands of visitors every year, this road offers their best chance to view and photograph the wildlife for which the park is famous.

Faced with an ever-increasing demand from visitors eager to come face to face with Denali's wildlife, the National Park Service turned to the Minnesota Traffic Observatory and the ITS Institute to help balance the transportation demand from park visitors with the need to protect and preserve the natural habitat of the area's wildlife.

Denali is a popular destination because it offers visitors the opportunity to see Alaskan wildlife up close in an unspoiled environment. In order to maintain this experience, traffic on the park road is limited to bus tours operated by designated tour operators. Adding more tours in response to increasing demand runs the risk of degrading the visitor experience by driving away the very wildlife that visitors have journeyed so far to encounter.

In order to gather accurate information on wildlife sightings, the researchers developed a prototype

data-logging system to be used by bus drivers. With a touch-sensitive LCD panel and a customized graphical user interface, the system allows drivers to quickly input data on sightings as well as note any other reasons for stopping the vehicle along the roadway. Data will be incorporated into a digital map of animal sightings, allowing researchers to model the effects of the presence of wildlife on the movements of vehicles along the route.

The new traffic model being developed by the Minnesota researchers combines traffic demand modeling with data on wildlife movements and habitat requirements gathered by biologists, and information on visitor experience factors such as what types of wildlife have been encountered under various conditions. In its

complete form, the model will give park managers and other researchers the ability to carry out scenario-based planning—evaluating the potential impacts of different use cases or road capacity levels in order to guide decisions about how to use the park's natural resources.



Photo courtesy of John Hourdos and the National Park Service

Research explores differences in rural and urban driving attitudes, behavior

Throughout the United States, the fatality rate from vehicle crashes in rural areas is considerably higher than in urban areas. HumanFIRST Program director Nicholas Ward and research fellow Mick Rakauskas are working to better understand the differences and similarities in attitudes and behaviors of drivers in these different geographic areas.

The researchers conducted a large-sample survey of urban and rural residents throughout Minnesota that focused on known risk factors—alcohol, speeding, and safety belt use—that may be related to the significantly higher crash rate on rural roads. The survey also examined crash and citation frequencies as well as attitudes toward current and proposed safety interventions suggested by the Minnesota Toward Zero Deaths (TZD) initiative.

Although both urban and rural drivers reported engaging in various unsafe driving behaviors, rural drivers coupled dangerous behavior with an attitude that such behavior was acceptable. For example, rural drivers chose to drive without safety belts more often than their urban counterparts while reporting that it was less dangerous to do so. Rural drivers also felt that proposed enforcement, education, and engineering safety interventions were less useful than did drivers in urban areas. Further, rural respondents

considered driving while intoxicated less dangerous than did urban drivers, which seems to agree with the higher fatal crash risk prevalent in rural counties.

These findings suggest that although drivers from all geographic areas engage in risky behaviors, rural drivers may engage in more behaviors that lead to fatal crashes while believing that their behaviors are not risky. Rakauskas and Ward extended this work by studying driving behavior using simulator experiments in which participants from rural and urban areas “drive” in various simulated rural and urban settings. Results from these experiments suggest that the rural environment may encourage less safe driving, especially among high-risk groups such as teen drivers. The team identified potential interventions, such as education programs that focus on increasing awareness of the danger of driving without a seat belt, that might be accepted by target populations. The team also hopes the results from their work will give weight to suggestions for policy change where problems exist in both rural and urban areas.



Images from the Metropolitan Design Center Image Bank
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Human Factors Interdisciplinary Research in Simulation and Transportation

The mission of the Human Factors Interdisciplinary Research in Simulation and Transportation (HumanFIRST) Program is to apply human factors principles in order to understand driver behavior and support the design and evaluation of usable intelligent transportation systems. As implied by its name, the program’s research strategy is based on a driver-centered approach, considering the “human first” within the transportation system.

The HumanFIRST Program has a core staff of transportation research specialists made up of psychologists and engineers who provide a consistently available base of expertise. This core group is linked to a broad interdisciplinary network of experts in basic and applied sciences throughout the University to provide a flexible and comprehensive research capacity. This network is supported by affiliations with additional University research units, which allows the program to create responsive interdisciplinary teams to investigate a range of complex human factors research issues in transportation safety. The program also has close relationships with the Minnesota Departments of Transportation and Public Safety, private industry, traffic engineering consultants, and other related entities. These connections provide support for implementing research that will influence transportation policy in response to real-world problems both regionally and nationally. In addition, to ensure that research takes into account developments on the world stage, the program’s work is supported by international collaborations with experts in relevant disciplines.

Research in the HumanFIRST Program seeks to propose, design, and evaluate innovative methods to improve transportation safety based on a scientific understanding of driver performance and the psychological processes associated with traffic crashes. This research considers how a driver will accept and use a proposed system while also considering the possibility of its producing undesirable driver responses and adaptation (e.g., distraction, complacency, fatigue, risk-taking) that could undermine the system goal of improved safety.

Recent research topics include:

- ◆ driver distraction from in-vehicle tasks and cell phones
- ◆ rural and urban driver attitudes and crash risk
- ◆ interventions for crash reduction at rural intersections
- ◆ intelligent driver-support systems such as vision-enhancement, collision-avoidance, hazard-awareness, and lane-keeping systems for passenger and specialty-purpose vehicles
- ◆ alcohol impairment including motorcycle safety
- ◆ intelligent driver-support systems for novice teen drivers
- ◆ in-vehicle use of advanced traveler information systems

The facility includes equipment for basic research on driver psychological functioning including a vision tester, DOT-certified alcohol Breathalyzer, mobile psychophysiology recording system, mobile eye-tracking system, video editing and behavior analysis suite, and a comprehensive psychometric test battery validated for traffic psychology.

Much of the research of the HumanFIRST Program uses a state-of-the-art driving simulator (supplied by AutoSIM and OKTAL) engineered specifically for human factors research in surface transportation. This Virtual Environment for Surface Transportation Research (VESTR) is a versatile and realistic simulation environment linked to a full-cab SC2 vehicle donated by Saturn using software that can create virtual environments that precisely reproduce any geospecific location. In addition, specialized visual-effect software can produce realistic weather and lighting—including light and shadow that correspond with season and time of day—as well as vehicle headlights with nighttime glare and water reflections.

The visual environment is generated with high-resolution images (1.97 arcmin per pixel) over a wide field of view (210-degree forward, 50-degree rear, 2 by 20-degree side mirror images). This immersive driving experience is enhanced by realistic motion generated by a three-axis motion base and both high- and low-frequency vibration units, including a surround-sound system. With multiple sound systems, configurable touch panel displays (including head-up displays), haptic feedback through the seat and accelerator pedal, and a head-free eye-tracker that can detect in

real time what a driver is looking at, this simulator supports the investigation of a wide range of interface options for ITS development, design, and assessment. These features make VESTR one of the premier driving simulators in North America and Europe.

Additionally, to support the validity of HumanFIRST research, the program has access to a variety of closed test tracks and road network field sites for on-road studies with instrumented vehicles.



HumanFIRST researchers include, in back: Mike Manser, Peter Easterlund, program director Nic Ward, and Mick Rakauskas; in front: Gerald Cowart, Janet Creaser, and Praveen Balachandran

Intelligent Vehicles Laboratory

The Institute's Intelligent Vehicles (IV) Laboratory develops and tests innovative, human-centered technologies that improve the operational safety, mobility, and productivity of the transportation network in general, and highway vehicles in particular. These human-centered technologies integrate sensors, actuators, computer processors, and custom human interfaces to provide drivers with needed information under difficult driving conditions such as low visibility, severe weather, and narrow and congested roadways.

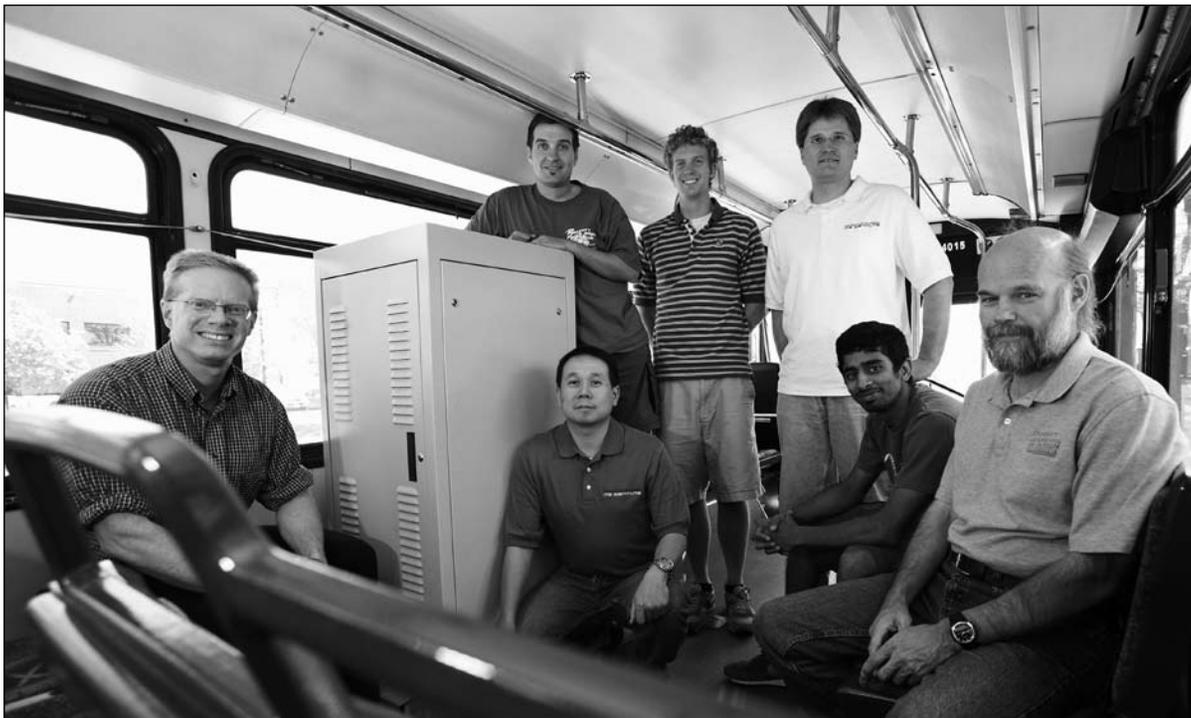
Although the IV Lab is focused primarily on vehicles, it also considers the roadway, supporting infrastructure, and electronic wireless communication as part of the transportation network and uses all of these elements in generating solutions to today's transportation problems.

Driver-assistive systems developed by the IV Lab have been tested on specialty vehicles, including snowplows, patrol cars, ambulances, heavy vehicles, and transit vehicles. Ultimately, these systems will also be used on passenger vehicles, providing drivers with warnings and assistance with collision-avoidance and lane-keeping tasks. Numerous vehicles utilizing IV Lab driver-assist technologies have been deployed in both Minnesota and Alaska.

The University of Minnesota is recognized as a leader in developing and testing driver-assistive systems and is one of a small number of universities nationwide conducting this work. The IV Laboratory's core staff consists of engineering professionals who work closely with an interdisciplinary team of specialists, including cognitive psychologists specializing in human factors from the ITS Institute's HumanFIRST Program. The staff has developed expertise in wireless communications, embedded computing, visibility measurement and quantification, geospatial databases, virtual environments, image processing, driver-assistive technologies, control systems, and sensors.

IV Laboratory research seeks to increase driver safety in difficult driving conditions through the use of vehicle-guidance and collision-avoidance technologies. Several vehicles serve as experimental testbeds, including the SAFETRUCK (an International 9400 tractor-trailer), the SAFEFLOW (an International 2540 crew-cab snowplow), a state highway patrol car, and a Minnesota Valley Transit Authority (MVTA) bus. Using these vehicles, IV Laboratory researchers are developing, testing, and integrating advanced technologies including centimeter-level differential global positioning systems (DGPS); high-accuracy digital-mapping systems; range sensors, including radar and laser-based sensors; a windshield head-up display (HUD), a virtual mirror, and other graphical displays; and haptic and tactile feedback.

The IV Laboratory's lane-assist technology is unique in that it uses DGPS and does not require hardware in the roadway surface. The technology is transferable between various transportation modes and works in all low-visibility



Clockwise from left: Mike Abegg with the Minnesota Valley Transit Authority and IV Lab researchers Alec Gorjestani, Eddie Arpin, Bryan Newstrom, Lee Alexander, Arvind Menon, and Pi-Ming Cheng

ity situations, including snow, fog, smoke, heavy rain, and darkness. In addition, these systems use human-centered technologies to enhance driving ability and reduce driver error due to distractions, fatigue, and other factors related to difficult driving situations.

Other difficult driving conditions are encountered by drivers on a daily basis. For instance, the vast majority of vehicle crashes occurring at rural, unsignalized intersections are the result of drivers incorrectly gauging the size of a gap between oncoming vehicles—not running stop signs. The IV Lab has developed a sophisticated rural intersection data-collection system used to study how drivers waiting at a low-volume minor road enter or cross a high-speed, high-volume expressway. This test intersection is located in Minnesota at the junction of U.S. 52 and Goodhue County Road 9 approximately eight miles south of Cannon Falls,

Minnesota. The data collected at the intersection are being used to model driver behavior to determine where the gap-acceptance decision process fails and leads to a crash, and to then design countermeasures to reduce the number of these crashes.

Because safety systems can produce improvements only if they are deployed, the IV Lab works with a variety of states to collect data and evaluate system performance. For instance, three vehicles (and a fourth planned) with driver-assist technology have been deployed in Alaska, where high snowfall rates and dry, blowing snow routinely cause whiteout conditions and zero visibility. By March 2008, the Minnesota Mobile Intersection Surveillance System (MMISS) will have collected driver behavior at rural expressway through-stop intersections in Wisconsin, Iowa, Michigan, North Carolina, Georgia, New Hampshire,

IV Lab expands technology for bus rapid transit

Mn/DOT and local transit authorities operate more than 200 miles of bus-only shoulders throughout the Twin Cities Metro area. Allowing transit vehicles to use shoulders during periods of traffic congestion provides passengers reliable, on-time service regardless of congestion levels in the normal traffic lanes. Bus drivers, however, face a serious challenge: keeping a bus that is 9.5 feet wide from mirror to mirror on shoulders that are generally no more than 10 feet wide. This is difficult under good conditions and becomes extremely challenging in bad weather.

That's where the Institute's Intelligent Vehicles (IV) Lab is hoping to help. In an earlier pilot project funded by the Federal Transit Administration (FTA), IV

IV Lab researcher Bryan Newstrom demonstrates the head-up display on an MVTA bus.



Lab researchers successfully tested lane-keeping and collision-avoidance technologies on a Metro Transit bus—dubbed the TechnoBus. FTA funding for that project has expired, so to keep the work moving, the Minnesota Valley Transit Authority (MVTA) offered to support deployment of a test fleet of instrumented vehicles—the first such fleet in the country. Since then, the IV Lab team has transplanted technology from the TechnoBus to an MVTA bus, mapped a section of the Cedar Avenue “test” corridor, and conducted test runs and demonstrations for the FTA, the MVTA board, and MVTA drivers and driving trainers.

The four-year goal is to equip four or five buses with lane-assist systems and operate them along the Cedar Avenue corridor. In the first phase, researchers will enhance existing Global Position-

ing System (GPS) technology to provide seamless coverage when signals are lost under bridges. In the second phase, MVTA drivers will use the lane-assist system on a small number of training vehicles, ideally ranging from smaller buses to motor coaches. The third phase will extend use to in-service routes carrying actual passengers.

This research will provide tangible evidence of how technologies developed by the ITS Institute can help bus drivers navigate freeway shoulders used as part of a Bus Rapid Transit (BRT) system and improve system operations. Moreover, the baseline data collected in phase one will provide the economic foundation for a benefit/cost analysis, which could be used by other transit agencies considering lane-assist technologies for BRT operations.

The ITS Institute, MVTA, and Hennepin County have committed funds for phase one and are now establishing the necessary contracts. Local funding should be in place by September 2007. The hope is that by successfully demonstrating the system's robustness in phase one, the FTA will provide funding support for phases two and three.



Nevada, and California. Data collection throughout the United States will ensure a nationally deployable intersection safety system designed to save lives among rural drivers.

Additional research topics include the design and testing of custom human interfaces, collision-avoidance sensors and algorithms, and wireless communication among vehicles and with the infrastructure. The IV Laboratory's partnership with the Minnesota Department of Transportation provides access to roads and other infrastructure, including the Minnesota Road Research Project (MnROAD) test track (pictured at left), which consists of a freeway and a low-volume road pavement test track with 40 different road material test sections, 4,500 electronic sensors, a weigh-in-motion scale, a weather station, and DGPS correction signals. The IV Laboratory also has relationships with a number of other organizations and government agencies, including the U.S. Department of Transportation's Research and Innovative Technology Administration, Federal Highway Administration, and Federal Transit Administration; Twin Cities' Metro Transit; the Minnesota Valley Transit Authority; Minnesota's Local Road Research Board; and various counties. These partnerships provide additional support for implementing research that will influence transportation safety in the United States and around the world.

Northland Advanced Transportation Systems Research Laboratories

The Northland Advanced Transportation Systems Research Laboratories (NATSRL), founded in 2000, is an advanced research program located at the University of Minnesota Duluth. Its mission is to develop innovative ITS technologies that can make surface transportation systems in northern areas safe, efficient, reliable, and environmentally sound.

NATSRL has been strongly supported by its key stakeholders, including the Minnesota Department of

Transportation, St. Louis County, Washington County, and the City of Duluth.

Current research focus areas in NATSRL include advanced traffic/pavement sensor technologies; vehicle safety technologies; transportation data archival and analysis methods; renewable power for ITS operations in rural areas; and traffic safety and management strategies for rural and urban areas.

Specific NATSRL research projects in these focus areas

include a wireless detection network to measure spatial traffic data; a video-based vehicle tracking system designed to process a vehicle motion-detection algorithm in real time; an early detection and warning system for driver drowsiness; realistic snow modeling within a driving simulator environment to assess the effects of alternative snowplow truck color and lighting options on the perceived safety distance of following drivers; and development of a freeway travel time database and Mn/DOT weigh-in-motion data archive design.

In addition, NATSRL partners with Mn/DOT District 1 each year to provide a daylong formal presentation of on-going research efforts.



New system aims to prevent snowplow collisions with overhead bridges

Each year, Mn/DOT-operated snowplow trucks suffer collisions in which the dump box on the back of the truck hits a bridge while in the raised position. These collisions, which can shear off the dump box from the truck frame, typically incur \$30,000 to \$40,000 in repair costs per incident and result in potentially dangerous traffic conditions and delays in clearing snow along the affected plowing route.

NATSRL researchers Richard Lindeke and David Wyrick, professors in the Department of Mechanical and Industrial Engineering at the University of Minnesota Duluth, are working to develop both off-vehicle and on-vehicle control software solutions that may prevent these collisions.

Specifically, the researchers are investigating the frequency, location, and severity of snowplow-bridge collisions and are assessing the current “box-up” driver warning system in order to identify possible improvements.

Through this effort, the team is working to link onboard GPS technology used for automatic vehicle location with Mn/DOT’s bridge information database to create route-by-route collision maps. These maps could then be used to develop a warning system

that takes input from the plow’s GPS system, along with readings from its speedometer and odometer and from transponders mounted along the roadway, to alert plow drivers when they are approaching a bridge with the dump box at a dangerous height. This information will be integrated into an onboard position sensor that interfaces with an automated box controller to lower the box temporarily in the event of an unsafe situation. The controller will automatically re-elevate the box after the obstacle is cleared so the truck can continue sanding and applying chemicals.

So far, the researchers have developed the offline program for extracting obstacles and generating plow route files along each route. The files contain bridge identification data that note the underpass height, deck width, and location using longitude and latitude values. These files—specific to Mn/DOT District 1—are being used along with a recently purchased microprocessor unit and GPS hardware to build the onboard controller.

Lindeke and Wyrick also examined the effectiveness of different types of warnings—visual, auditory, or tactile—to be used during plow operation. They have determined that using a brief audio alert and

flashing lamp provides an effective warning to the driver that the box is being lowered automatically and helps reduce driver stress.

The team plans to conduct live onboard tests of the total system in 2007 in selected District 1 routes.



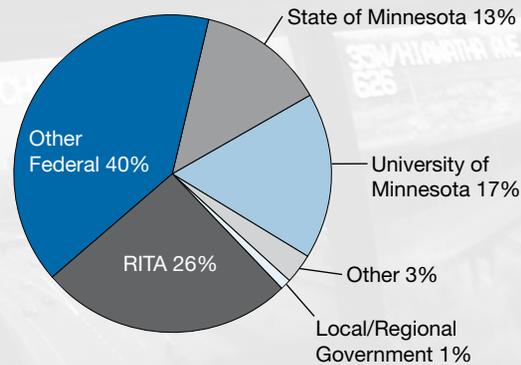
Richard Lindeke with graduate students Benjamin Wieggers and Ted Pelzer



Research funding sources for all ITS-related research projects

The total funding for ITS-related research projects was approximately \$9.6 million in FY07. Sources for projects receiving funding in FY07 are shown in the chart to the right.

During this period, 58 faculty and research staff and 69 students were involved in ITS-related research.



ITS Institute research is centered on safety-critical technologies and systems for efficiently moving people and goods in the following areas:

- ◆ human performance and behavior
- ◆ technologies for modeling, managing, and operating transportation systems
- ◆ computing, sensing, communications, and control systems
- ◆ social and economic policy issues related to ITS technologies

The Institute’s research program joins technologists—for example, engineers and computer scientists—with those who study human behavior to ensure that new technologies adapt to human capabilities, rather than requiring drivers to adapt to technology.

The Institute’s geographic location gives it a unique advantage for developing research applicable to transportation in a northern climate and transportation in rural environments in addition to the metropolitan Twin Cities area. The ITS Institute research program includes research projects funded by various partners, including federal funds from SAFETEA-LU legislation, the Federal Highway Administration, the Federal Transit Administration, and the Department of Homeland Security. Other funding partners include the Minnesota Department of Transportation (Mn/DOT), the Minnesota Local Road Research Board, the Metropolitan Council, Hennepin County, Metro Transit, and the Minnesota Valley Transit Authority in addition to local governments, agencies, and private companies that contribute funding and in-kind match.

Activities undertaken by the Institute support all ITS-related research projects, regardless of funding source; all current ITS-related projects are listed in this annual report. The research section comprises two parts. The first highlights in detail a selection of projects under way, while the second briefly describes other Institute projects either recently completed, in progress, or selected to begin this coming year.

Human performance and behavior

The Effectiveness and Safety of Traffic- and Non-Traffic-Related Messages Presented on Changeable Message Signs (Phase II)

Freeway volumes in the Twin Cities metro area grow by about 4 percent each year, according to the Minnesota Department of Transportation (Mn/DOT). This increasing demand coupled with shrinking resources is challenging Mn/DOT—and most state DOTs—to find ways to optimize existing freeway capacity. Changeable message signs (CMSs) are one tool the transportation department uses in conjunction with its Regional Transportation Management Center (RTMC) to do just that.

Changeable message signs are electronic signs posted at various overpasses on the freeway system. During rush hour, traffic incidents, adverse road conditions, and construction, they communicate real-time traffic information to passing motorists. The signs are also used in the AMBER Alert System to display emergency alerts when a child is abducted. Their use, however, has provoked questions about their effectiveness and about their possible safety impacts on traffic. To study these issues, human factors researchers Kathleen Harder and John Bloomfield, with the University of Minnesota's Center for Human Factors Systems Research and Design in the College of Design, are continuing their work looking at the effects of the signs on driver behavior.

In the first phase of research, Harder and Bloomfield conducted a baseline study on CMSs to learn whether they cause traffic slow-downs or affect traffic flow. In the second phase, taking place throughout 2007 and into early 2008, Harder and Bloomfield will again use a fully interactive, PC-based STISIM driving simulator to conduct experiments in which they will compare the effects of newly worded messages with data from the Phase I research.

While Phase I was purely a laboratory study, Phase II bridges the gap between theory and practice. In addition to the simulator experiments, Harder and Bloomfield will work directly with RTMC staff to examine a selected roadway incident in real time and will study characteristics such as when the incident occurred, when it was first noticed

by RTMC, when and where RTMC initiated CMS messages related to the incident, when and how the CMS messages were changed to reflect the changing status of the incident, and when the incident was cleared.

To the extent possible, the researchers will compare the driver simulator data with the real-world traffic data collected. Based on analysis of these data along with a review of traffic camera recordings of the actual incident and interviews with RTMC personnel who managed the incident, Harder and Bloomfield will offer recommendations on the best way to use CMS messages when managing such events in the future. Their analysis will consider the location of the CMS message boards, the content and duration of the messages, how the messages relate to the severity of the incident, and the effect of the messages on traffic flow.

“Phase I generated a lot of interest from other DOTs who want to improve their use of CMSs,” Harder noted. “We expect our findings from Phase II to further push the field forward in helping Mn/DOT and other DOTs create clear, concise, easily understandable messages that are safer for drivers to read and to respond accordingly, thus reducing traffic slow-downs and improving road safety.”



Researchers Kathleen Harder and John Bloomfield with Todd Kramasz (center), operations supervisor with Mn/DOT's Regional Traffic Management Center



Results of the study suggest policy and design recommendations for accessing 511 while driving.

Driving Performance During 511 Information Retrieval and Cell Phone Conversation Tasks (Phase II)

In July 2000, the Federal Communications Commission (FCC) designated “511” as the national traveler information phone number. Since then, many states, including Minnesota, have implemented information services that enable travelers to dial 511 from any phone to access current weather-related road conditions, construction, congestion, and other travel information 24 hours a day, 7 days a week. While there is little doubt that the 511 program provides a valuable service to travelers, at issue is the fact that more and more travelers are using cell phones while driving to access this information.

Currently, there is considerable debate about the crash risk associated with cell phone use while driving. To study this contentious issue, researchers from the University’s Human Factors Interdisciplinary Research in Simulation and Transportation (HumanFIRST) Program examined how the performance impairment from cell phone use compares to other types of impairment risks, such as driving while intoxicated or while operating common in-vehicle controls like a radio, fan, or air conditioning. They also examined, for the first time, the combined effects of being distracted and being intoxicated, given that many crashes result from a combination of risk factors. Their findings indicated that, generally, both the cell phone and in-vehicle sources of distraction caused more impairment than intoxication at the legal limit.

HumanFIRST Program director Nic Ward and research fellow Michael Rakauskas are now using these findings in a follow-up study to assess the effect of cellular phone access to Minnesota’s 511 (MN511) traveler information service on driving performance and driver mental effort. To begin this follow-up work, Ward and Rakauskas first conducted detailed usage and usability evaluations of MN511, which allowed them to determine the types of information users currently request and what portions of the system’s menu design are most problematic for users when searching for information. This thorough examination allowed the researchers to develop an alternative structure for the 511 menu they call V2. Specifically, the goal of V2 is to integrate the phone menu information with Mn/DOT’s Web-based

traveler information (www.511mn.org) while improving the user’s ability to locate relevant traffic and weather information.

The team then conducted experiments in the HumanFIRST Program’s virtual environment for surface transportation research (VESTR) driving simulator, during which participants drove a standard route that involved a car-following task. This methodology is typically used to assess a driver’s performance and attention to the road environment while completing peripheral tasks such as talking on a phone—in this case using a cell phone to access the 511 menus. Participants also were asked to drive through relatively slow traffic as they might do in rush-hour traffic to see how their performance in dense traffic conditions was affected by accessing the phone menus.

Each driver repeated these “drives” three times: two drives were completed while accessing a simulated version of either the current MN511 or V2 menus to answer questions about weather or road conditions. Testing both menu designs allowed Ward and Rakauskas to compare driving performance and information retrieval and determine if the changes implemented in V2 helped decrease mental distraction. During another drive, participants answered simple questions aloud without accessing a phone menu. This served as a baseline in comparison to the drives where 511 menus were accessed.

Through this experiment, the team will learn whether using the 511 system leads to more risky driving behavior compared to not accessing such a system at all. It also will allow them to find out if changing the 511 menu might affect driver performance for the better.

The results of this study will contribute to policy and design recommendations for 511 services accessed while driving. Gaining insight on the interaction between these factors will also contribute to the debate of crash risk associated with cell phone use and suggest policy and design recommendations for the conditions in which 511 may be accessed while driving. As such, this study supports the Minnesota state strategy to provide effective traveler services and promote zero fatality objectives.

Multi-Camera Monitoring of Human Activities at Critical Transportation Infrastructure Sites

The ability to accurately estimate the number or density of people in a scene has many useful applications in the transportation arena. Urban and regional planners, for example, can use this capability to design corridors based on typical pedestrian traffic patterns in an area. For traffic control, automatic pedestrian and crowd monitoring techniques can be used to increase safety and improve traffic signal timing. But employing the required computer vision techniques to monitor people in these situations is a difficult task.

One issue is that in many group-monitoring applications, most of the cues that aid in detecting and tracking individual people—such as shape, texture, and appearance—simply do not work with crowds, especially when low-resolution surveillance cameras are used. Thus, video monitoring methods that treat a group of people as a single entity instead of processing each person individually generally offer the best results. Although some research has been done on tracking people in crowded scenes in this way, there has been only limited research on the specific problem of counting the number of people in a scene.

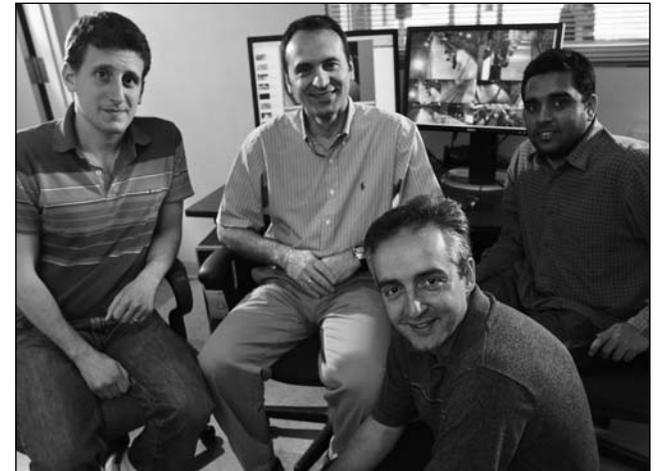
In their recently completed project, Professor Nikolaos Papanikolopoulos and graduate students Prahlad Kilambi, Evan Ribnick, and Ajay Joshi, all with the computer science and engineering department, tackled the problems of estimating the number of people in a group and being able to update this estimate reliably throughout the video sequence. For this study, they investigated using multiple video cameras for monitoring human activities at critical transportation infrastructure sites—airports and mass transit stops—and specifically examined how to reliably detect specified activities, such as crowd dispersion after a sudden event, and to count people in these crowded areas.

The researchers used two different methods—heuristic-based and shape-based models—to develop and test ways of accurately estimating the number of people in a scene, in real time, without the constraints of detecting individuals. In the heuristic-based method, the number of people in a group is estimated based only on the area it occupies.

Although this method provides an extremely simple and efficient solution to the problem of counting people in groups, there are some cases in which it fails, such as when a group is fairly sparse or is dispersed across a long distance. To account for these issues, the researchers also used the more flexible, probabilistic shape-based approach in which the shape of a group's intersected area is used to estimate the number of people present.

Experiments were performed on three different scenes with eight different camera positions. The videos were shot on the University's Twin Cities campus and at other crowded scenes, and both the heuristic- and shape- based approaches were tested on these video sequences. The cameras were carefully calibrated to each scene, first to estimate how many individuals fit to a specific number of video pixels and then to expand this estimate to the entire crowd. Using these methods, the team created a monitoring approach capable of counting and tracking people with 80 to 90 percent accuracy and without being significantly affected by occlusions—a typical problem when monitoring crowds or cases in which one group of people splits into two groups, then merges into one again. In addition, favorable results were also shown for counting and tracking groups of various sizes moving unconstrained and in adverse weather conditions.

This is the first system of its kind capable of counting people in both outdoor and indoor environments and as such offers significant improvement over past approaches. Although this approach has important benefits for the transportation field, it can also be used in other applications related to estimating the number of people walking through a crowded area. For example, knowing the size and density of a group outside of a school or at a public event could help authorities identify unsafe situations and regulate traffic appropriately.



Evan Ribnick, Vassilios Morellas, Nikolaos Papanikolopoulos, and Ajay Joshi

Cooperative Intersection Collision Avoidance Systems Initiative

In 2007, the Minnesota Department of Transportation and the ITS Institute were selected by the U.S. Department of Transportation to participate in the Cooperative Intersection Collision Avoidance Systems (CICAS) research initiative. ITS Institute director Max Donath and Intelligent Vehicles Laboratory director Craig Shankwitz announced the signing of a cooperative agreement outlining the roles of Mn/DOT, the ITS Institute's Intelligent Vehicles Laboratory, and the HumanFIRST Program in supporting the innovative and ambitious safety research effort.

CICAS brings together federal agencies, automobile manufacturers, and university transportation centers with the goal of developing new technologies to prevent collisions that kill thousands of Americans and injure more than one million more every year. Donath said that the effort put forth by the ITS Institute will focus on the prevention of crashes at rural highway intersections. This work is a direct outgrowth of the Institute's Intersection Decision Support (IDS) research, which over the past two years has developed a new approach to preventing collisions at rural unsignalized highway intersections.



IV Lab director Craig Shankwitz, with Max Donath and Arvind Menon, inspect equipment at Hwy. 52 and Goodhue CSAH 9.

In the past two years, IDS research has accomplished several important goals that will contribute to the CICAS effort, including:

- ◆ developing an advanced traffic sensor network
- ◆ developing an advanced vehicle-trajectory measurement and recording system
- ◆ studying driver gap-acceptance behavior on a microscopic level using a driving simulator
- ◆ testing new active displays in a driving simulator to determine what information a driver needs to safely maneuver through rural unsignalized intersections

The Institute is currently working with a consortium of other state departments of transportation in a complementary project to better characterize driver gap-acceptance behavior on a national basis.

The USDOT describes CICAS as a “cooperative” system, meaning it integrates data from both vehicle-based and infrastructure-based sensing systems via the newly allocated Dedicated Short-Range Communications portion of the radio spectrum. Warning display systems using this data are to be developed for both in-vehicle and outside-the-vehicle placement.

Minnesota's CICAS research, expected to last five years, will focus on infrastructure-based solutions and include five main components:

1. A microscopic, in-vehicle measurement of driver gap acceptance at an instrumented intersection.
2. Alert and warning algorithms to be used to appropriately inform drivers in a timely fashion of dangerous conditions.
3. A deployable sensor system used both to compute the dynamic “state” of the intersection and to feed data required for triggering the alert and warning algorithms.
4. A field validation and subsequent field operational test to quantify the performance and safety benefits of such systems.
5. Wireless communications between the vehicle and the roadside equipment.

Bus Signal Priority Based on GPS and Wireless Communications

In thousands of cities around the world, the bus is a key part of the public transportation system—and often the only form of public transportation.

Much of the success of buses is no doubt due to the inherent flexibility and low cost of operating on regular streets rather than on rails or other dedicated facilities. This flexibility, however, comes with a price: a bus carrying 40 passengers is subject to the same congestion as a private automobile with a single occupant.

University researchers Gary Davis, a professor in the Department of Civil Engineering, and Chen-Fu Liao, senior systems engineer for the Institute's Minnesota Traffic Observatory, are using intelligent transportation systems technologies to make bus transportation faster and more reliable. Combining newly available technologies such as onboard GPS and advanced traffic signal control systems, Davis and Liao's bus signal priority system will subtly adjust the operation of traffic signals along bus routes so that buses carrying passengers receive fewer red signals—with minimal disruption to other traffic.

Preempting the normal operation of traffic signals in order to help certain vehicles move through intersections has been widely applied in the area of emergency vehicle operations—to give an approaching ambulance an extended green light, for example. This strategy, although suitable for emergency vehicles that travel quickly and without stopping, is problematic in the case of buses. Many bus stops are located immediately before intersections, which causes problems for fixed-interval signal preemption systems because buses may stop to pick up passengers before proceeding through the intersection.

Current systems designed for emergency vehicles do not take this kind of movement into account, causing the green signal phase to expire while the bus is still picking up passengers. In other instances, a bus stop may be located on the far side of an intersection, or the intersection may have no bus stops nearby.

Metro Transit, the transit agency serving the Minneapolis-

St. Paul metropolitan area, has recently installed Automatic Vehicle Location (AVL) systems in its fleet of buses in an effort to improve service quality. These systems use GPS receivers to determine the exact position of each bus.

Davis and Liao are working to coordinate the operation of computerized traffic signal controllers with the movements of buses using wireless data transmission. Two protocols currently support this type of communication: the consumer-oriented wireless computer networking protocol such as IEEE 802.11a, b, and g, and the 802.11p Dedicated Short Range Communication (DSRC) protocol designed specifically for use in vehicle-to-vehicle and vehicle-infrastructure communications.

Rather than automatically changing the state of a traffic signal in response to the presence of a bus, Davis and Liao's experimental system gives individual traffic signal controllers the ability to decide how to respond to an approaching transit vehicle. Because only one bus at a time can receive priority, when determining which request to grant, the signal controller takes into account the time that priority was requested, the amount by which any bus is behind schedule, and the number of passengers on the bus.

An embedded controller feeds this information, along with the speed and location of the bus and predicted levels of traffic delay, into a digital model of bus movements around the intersection. This model includes the location of bus stops relative to the intersection and the predicted "dwell time" of a bus halting at the stop to pick up or let off passengers.



Chen-Fu Liao and Gary Davis collect and record intersection traffic data.

The model enables the signal controller to predict the state of the traffic signal at the time the bus requesting signal priority arrives at the intersection. If there is a sufficient green-signal interval for the bus to pass through the intersection, then the signal controller does not alter signal timing. However, if the bus arrives at a point in the signal phase with insufficient green time to pass through the intersection, the controller determines how to alter the signal timing—either by extending the green-signal interval or truncating the red-signal interval.

To return a preempted signal to its normal timing following a preemption request, the signal is resynchronized with those of neighboring intersections in a single cycle by reducing the length of the green signal phase and ignoring preemption requests during the recovery cycle.

To calibrate and test their system, Davis and Liao turned to the traffic simulation capabilities of the Minnesota

Traffic Observatory. With assistance from graduate student HunWen Tao, the priority strategy was applied to a model of a specific transit corridor in Minneapolis using the AIMSUN traffic simulator and historical traffic data.

Analysis of the simulation results showed a consistent decrease in bus travel times during both morning and evening rush hour conditions, despite the heavier volumes present on the corridor in the evening. Delays experienced by non-transit vehicles, on the other hand, were slightly increased by the signal priority strategy.

While any deployment of transit signal priority in the Twin Cities area is still some time off, Davis and Liao say they hope to work with Metro Transit to explore ways of implementing their work to improve transit service in the Twin Cities. The next phase of their research will focus on developing a prototype system to further validate signal priority using wireless communication.

Development of Real-Time Arterial Performance Monitoring System Using Traffic Data Available from Existing Signal Systems

While signalized arterial corridors such as Minnesota and U.S. trunk highways facilitate the bulk of the Twin Cities metro area's transportation needs, the signaled intersections along these arterials often fail to operate as a well-integrated system. Poor traffic signal timing contributes to traffic delay, and the subsequent frustration can lead to motorists running red lights or engaging in other forms of unsafe driving behavior.

Despite the growing need to improve signalized intersection management, addressing problems in this area is not easy. Although collecting and analyzing freeway traffic data is fairly straightforward, these tasks become much more complex when they involve signalized arterials. Signal lights are operated by a signal control box, frequently in conjunction with a vehicle detection system, located at the intersection. Usually low-resolution information from the controller, such as 15-minute intervals of traffic volume data, is collected and archived, but signal phase data—that is, how

long the green, yellow, and red lights last—are lost. With this control dimension missing from the equation, the true dynamics at play at a signalized intersection are not captured, making it difficult for traffic engineers to properly describe traffic conditions and identify problems in these areas. Further complicating matters is the fact that controllers do not record and store any data for later study; to evaluate signal system performance, technicians must manually collect information using inefficient, time-consuming, and expensive methods.

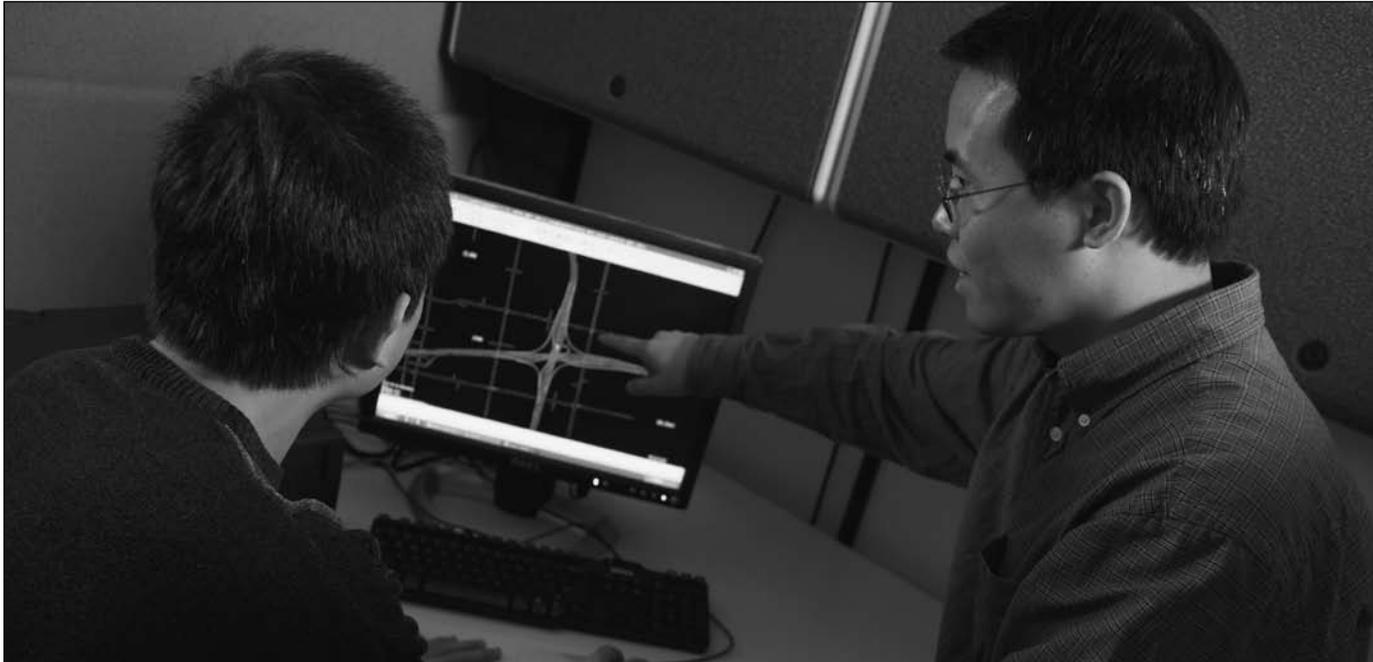
With support from the Minnesota Local Road Research Board, the ITS Institute, and Hennepin County's transportation department, assistant professor Henry Liu and graduate student Wenteng Ma, both with the University's civil engineering department, have developed a framework to automatically collect and record traffic data from signal controller cabinets and calculate the corresponding performance measures for an arterial road with a group of signal-

ized intersections. This Systematic Monitoring of Arterial Road Traffic and Signals (SMART-Signals), the first system of its kind in the United States, acts much like an airplane “black box” to record every event that happens at an intersection 24 hours a day, 7 days a week. Unlike standard low-resolution data-collection efforts for which traffic volume is counted only every 5 to 15 minutes, SMART-Signals data are considered “high resolution” in that every signal-light phase change is recorded, as is every time the vehicle detector is actuated. This system essentially reconstructs the entire history of an intersection or group of intersections, enabling traffic managers to study such performance elements as intersection delay, queue length, progression efficiency, and arterial travel time.

Since fully launching this project in October 2006, Liu and his team have installed and implemented SMART-Signals devices at 11 contiguous intersections on France Avenue in Hennepin County. These researchers are now retrieving

and analyzing the traffic surveillance data collected and working on procedures and methodologies to calculate the appropriate performance measures. Liu and Ma will use these performance measures in future research to identify problems, such as outdated signal phase timing, that occur within a signalized intersection or corridor, and will then fine-tune the signal timing parameters to respond to the identified problems.

Intelligent transportation systems such as SMART-Signals are critical in helping transportation departments cost-effectively manage and optimize existing transportation resources and deliver better services to road travelers. Specifically, the results from this research will help county and state DOTs create and maintain an efficient system along signalized arterial corridors that reduces travel times and delays—and may even help mitigate vehicle emissions and fuel consumption.



Graduate student Wenteng Ma and assistant professor Henry Liu

Social and economic policy issues related to ITS technologies

STAR: Networks and Productivity Search, Information, Learning, and Knowledge in Travel Decision Making

For the past six years, an interdisciplinary team of researchers from the Humphrey Institute's State and Local Policy Program (SLPP) and the ITS Institute have been working together to conduct a set of studies, collectively called the Sustainable Technologies Applied Research (STAR) initiative, on how transportation systems can be planned in an increasingly complex social, political, economic, and technological environment. In the final project of this initiative, David Levinson, an associate professor of civil engineering, advised graduate student Lei Zhang (now an assistant professor of transportation engineering at Oregon State University) as Zhang addressed some of the shortcomings of existing travel demand and travel behavior models.

Transportation planners use travel demand models to understand actual travel patterns and forecast future demand conditions. These models are based on travel behavior theories that describe individuals' travel decision-making processes. But traditional travel behavior theories tend to assume that drivers have "perfect" information that allows them to make rational choices about the best routes and modes available for a given trip. The reality is that drivers do not have perfect information. For example, they generally do not know real-time traffic congestion levels of various roadways and may not know every possible route available, so their travel choices are less likely to be optimal as assumed by existing travel models.

By studying how people actually make travel decisions, Zhang, constructed a general theoretical framework, called the SILK theory for its emphasis on the role of search, information, learning, and knowledge in travel decision mak-



Lei Zhang and David Levinson

ing, that describes an individual's actual decision-making process. He then looked at whether using these more realistic—or positive—behavior assumptions in a travel demand model could lead to different policy recommendations and could affect investment and other planning decisions.

Next, using the SILK behavior theory, Zhang developed a quantitative route choice model—or behavioral user equilibrium (BUE)

model—for estimating travel demand on different facilities. Rather than assuming that drivers have perfect information, the BUE model is based on the more realistic behavior assumptions from the SILK framework. In this case, Zhang derived a set of if-then rules using empirical data from route search/choice field experiments in the Twin Cities to describe individuals' travel decision-making process.

In a typical transportation analysis study area, millions of individuals behave simultaneously and interact with each other. To model these interactions, Zhang applied an agent-based simulation technique that aggregates the individual behaviors, enabling him to track the decision-making process of each individual in the study—something that traditional travel demand models cannot do. By tracking these individual behaviors, he could easily see how a particular policy or project affected individuals with different characteristics (income, age, gender, location, etc.) and how using different behavior assumptions could lead to very different, and sometimes opposite, policy recommendations.

Through the agent-based simulation, he also found that transportation policy analysis that relies on the "old" or normative travel demand and travel behavior models tends to overestimate the benefits of transportation policies and

projects and underestimate associated costs. By using the travel demand and travel behavior models developed in this research, which rely on more realistic behavior assumptions and more accurate estimates of demand responses, DOTs and other agencies can improve their transportation decision-making process and better allocate increasingly scarce resources.

For this study, Zhang compared the new positive approach to the existing normative approach, using only the

route choice dimension, to analyze its effect on two different transportation analysis scenarios: aggregate network flow estimation and the traffic diversion effects of ramp metering. However, there are other choice dimensions—e.g., destination, transportation mode, and time of day to travel—that individuals use to make travel decisions. Future work could involve modeling these other dimensions using the SILK theory and then using this new approach to analyze important transportation policies.

Developing ITS to Serve Diverse Populations

Minnesota remains one of the fastest-growing states in the Northeast and Midwest according to recent population estimates by the U.S. Census Bureau. With this growth comes an increasingly diverse population with increasingly diverse transportation needs. This requires new data and analysis to better predict future travel behavior and identify suitable intelligent transportation systems (ITS) technologies to meet these emerging travel needs, as well as plan transportation systems based on new demographic patterns.

In 2003, the State and Local Policy Program (SLPP) at the University of Minnesota's Hubert H. Humphrey Institute of Public Affairs began a series of research projects exploring how ITS could be used to deliver transportation services to Minnesota's changing demographics. The latest of these focused specifically on how ITS could be used to support transportation initiatives for people who do not drive an automobile either because they cannot drive or cannot afford a vehicle.

Researchers first conducted a series of analyses to identify the ITS applications that appeared most promising to improve mobility and access for Minnesota's diverse population. The team determined these applications to be community-based transit (CBT), car sharing, value pricing, and Web-based advanced traveler information systems (ATIS). Various studies were then carried out to address each of these applications individually.

Community-Based Transportation

Humphrey Institute researchers Frank Douma, Gary Barnes, Heather Dolphin, and Sarah Watters studied the community-based transportation (CBT) aspect. Past research in this arena indicated that CBT services could be improved in terms of both operational and administrative



Frank Douma and SLPP research assistants Britta Stein, Tyler Patterson, and Steve Petersen are working to determine the cost and time benefits of using a car sharing service or MnPASS for potential trips.

efficiency. In this study, the team examined whether ITS and related innovations could help achieve these goals. Specifically, this team sought to better understand the existing inefficiencies so that technologies could be identified or developed to address these specific needs.

From a set of surveys, the team determined that of the approximately 3,000 organizations in Minnesota providing and arranging transportation, most are unaware of each other. Nonetheless, these organizations showed some interest in collaboration but felt that several barriers, including insurance restrictions and legal constraints, got in the way of doing so. Other barriers result from the many rules attached to the variety of funding sources for these programs. Overall, the survey results suggested that coordination would be a large undertaking, given the multiple types of trips served by these organizations.

Car Sharing

Douma, along with graduate student James Andrew, examined car sharing services, which employ ITS technologies to efficiently and cost-effectively handle car reservations, access, and billing. They studied a number of perspectives to assess whether and where car sharing might succeed in the Twin Cities and how the conventional car sharing business model might be modified to bring the benefits of car sharing to low-income users.

The researchers interviewed car sharing organizations throughout the United States and conducted focus groups in Seattle and Chicago of members and non-members in car sharing neighborhoods. They used these findings to model ideal car sharing neighborhoods in the Twin Cities, assessed

the factors that could lead to the success or failure of such a model in different neighborhoods, and analyzed which of the neighborhoods in the Twin Cities would be most likely for such a model to succeed. They found that higher-density mixed-income neighborhoods in the Twin Cities (e.g., Uptown, Loring Park, the University of Minnesota) have the greatest potential for car sharing.

More research is needed to define the nature and travel behaviors of car sharing users in the Twin Cities. Andrew and Douma are now working with HOURCAR and Zipcar, two firms that offer car sharing services locally, to conduct a follow-up study to investigate the impact car sharing options have on travel behavior in the college marketplace.

Value Pricing

Researchers Johanna Zmud and Chris Simek, with the consulting firm NuStats, and Steven Peterson, with SLPP, analyzed preferences and travel behavior for individuals in the Interstate 394 (I-394) travel shed before and after the 2005 conversion of the high-occupancy vehicle (HOV) lane to a high-occupancy toll (HOT) lane, a change enabled in part through ITS technologies that allow for at-speed toll collection. Their primary objective was to assess attitudes and awareness of the MnPASS toll lane system and any resulting changes in travel behavior after the conversion.

Findings from three waves of attitudinal panel surveys show support for the HOV conversion across all income levels and genders. Most significant, both users and non-users of the HOT lane perceived that congestion went down after the lane was converted. In addition, users said they experienced high levels of satisfaction with



Toll charges posted near the entrance to the high-occupancy vehicle lanes

the all-electronic toll operations. Other technology-related aspects of MnPASS—such as ease of opening a transponder account, use of a credit card to replenish the account, ease of installing the transponder, clarity of prices on overhead signs, and toll amounts that vary with traffic levels—also received high satisfaction levels.

Mn/DOT continues to support ongoing research investigating changes that could further enhance and benefit the transit aspects of the MnPASS system and continues to invest in and research ways of making MnPASS even more user friendly.

ATIS evaluations

In their study of an ATIS (advanced traveler information system) evaluation model, Thomas Horan, with the Claremont Graduate University and the U of M's State and Local Policy Program at the Humphrey Institute, and Tarun Abhichandani, also with Claremont, examined the experience of individuals who used metropolitan transit authority Web sites to plan transit trips. They conducted user surveys and focus groups in Minneapolis and Los Angeles to gather reactions to Web sites for Minneapolis/St. Paul Metro Transit and Los Angeles County Metropolitan Transportation Authority, based on trip-planning scenarios presented to participants.

The study showed that in terms of general usability, the two Web sites studied provided a good way to plan transit trips. However, respondents in both the cities indicated the need for improved customization features such as the ability to store trips for future planning, more location information, and standard interactive Internet-ready maps.

Although the Web sites considered in this study represent only one type of many Web-based interactive services, they do characterize citizens' experience using a government-led ATIS. As such, the evaluation model in this study could be used by government agencies to assess other systems such as those for public library, water works, and tax payment services. Metro Transit, for instance, found the results of this study valuable and is undertaking further study with SLPP researchers.

Human Performance and Behavior

■ **Janet Creaser**, Department of Mechanical Engineering
[Evaluation of Minnesota's NightCAP](#)
Status: *Completed*

This project evaluated the Minnesota Department of Public Safety's Operation NightCAP (Concentrated Alcohol Patrol) program. This overtime enforcement program uses saturation patrols to identify impaired drivers.

The research project consisted of three tasks: a crash data analysis, a driver survey, and an officer survey. The crash analysis indicated that saturation patrols have a marginal statistically significant effect on the decrease in fatal and severe-injury alcohol-related crash rates in Minnesota. The effect of a single saturation is small (about 0.1 percent), indicating that many patrols would be needed to see significant decreases in alcohol-related crash rates.

A survey of 5,000 Minnesota drivers in six counties resulted in 838 completed surveys. Responses showed that approximately 19 percent of Minnesota drivers are aware of the program. Drivers' beliefs about impaired driving influenced their perception of alcohol-enforcement programs and their choices about whether to drive after drinking.



Fourteen program coordinators and 86 law enforcement officers from the program also responded to a survey and shared their perceptions about the program's effectiveness. The main conclusions drawn from the surveys were that saturation patrols are not highly visible to the public and the current program advertising is not very effective in communities where it is

active. The primary recommendations from the research are to improve patrol visibility and associated advertising.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2006032

■ **Motorcycle Riding Impairment at Different BAC Levels**

Status: *Completed*

Alcohol is known to disrupt the effect of neurotransmitters and impair various psychomotor skills. Indeed, alcohol intoxication is a significant risk factor for fatal traffic crashes, especially for riding a motorcycle. At present, there is sparse research on the impairing effects of alcohol on skills involved in motorcycle control. This study was designed to measure the effect of alcohol (up to BAC 0.08%) on a broad set of basic riding skills. These riding skills were assessed on a test track with task scenarios based on the Motorcycle Safety Foundation's (MSF) training program. The study used a balanced incomplete block design to remove confounding artifacts (learning effects) by randomizing four BAC levels across three test days. Performance was characterized in terms of riding strategy used to cope with the effects of alcohol as a neurological stressor and the amount of resulting impairment with reference to specified performance standards. The analysis controlled for rider gender and age, riding skill, and drinking history.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2006085

■ **Kathleen Harder**, Center for Human Factors Systems Research and Design
[Low-Cost Innovative Approaches to Improve Safety at Unsignalized Intersections on Four-Lane Highways](#)
Status: *In progress*

Intersection crashes represent a significant portion of total crashes nationwide, accounting for an average of 9,000 fatalities and 1.5 million injuries annually. Without resorting to roundabouts or grade separations, there are a number of relatively low-

cost approaches—either already in use in other countries or that could be developed—to improve the safety of unsignalized intersections on four-lane divided highways.

In the first stage of this research, the principal investigators (PIs) will use their expertise, along with computer simulation, to develop innovative and viable safety improvements at unsignalized intersections. A select group of traffic engineers will participate in a roundtable discussion to give input on the recommendations of the PIs, who will incorporate their suggestions. In the second stage, the recommended strategies will be tested at one representative intersection. Mn/DOT will implement the recommended interventions and provide data-collection technology. The PIs will conduct the field test, analyze the data collected, and write the final report. Recommended improvements will likely have a significant impact on reducing the number and severity of crashes at unsignalized intersections on four-lane divided highways, benefiting motorists in Minnesota and across the United States.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2006049

■ **Psychological and Roadway Correlates of Aggressive Driving (Phase II)**

Status: *In progress*

This research was conducted to better understand the psychological and roadway correlates of aggressive driving. The study had two phases. In Phase I, survey data were used to investigate the relationship between personality, emotional, and behavioral variables and self-reported driving behavior. In Phase II, the findings were validated in a driving simulator experiment. The data yielded a number of interesting findings—in particular, there were significant differences in driving behavior between drivers characterized as “high hostiles” and those characterized as “low hostiles.”

Our focus on psychological traits, emotional states, and behavioral tendencies is proving to be a valuable

way to understand aggressive driving behavior. A future goal is to begin the process for determining mitigative strategies.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2002034

■ **Kathleen Harder and John Bloomfield**, Center for Human Factors Systems Research and Design
[The Effectiveness and Safety of Traffic- and Non-Traffic-Related Messages Presented on Changeable Message Signs \(Phase II\)](#)

Status: *In progress*

See page 17 for coverage of this project.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2007024

■ **Stephen Simon**, Law School
[Second Generation In-Vehicle Driver Assistance for Teenagers \(Year 2\)](#)

Status: *Newly funded*

Motor vehicle crashes are the leading cause of death for teenagers. With this project, systems with the potential to reduce the incidence of teenage-driver crashes was investigated. A first-generation prototype Teen Driver Support System (TDSS) has been designed and developed. This system has demonstrated the technical feasibility to develop systems that may reduce staggering teenage crash rates. However, the lack of sufficient parental interfacing severely limits the system's use as a feedback tool. Before the start date of this project, a second-generation TDSS system (TDSS2) will have been built that ports some or all of the first-generation TDSS technologies into a smart phone. Year 2 will involve developing feedback tools within TDSS2 that provide feedback to the teen driver and that help parents monitor teen driving progress. The researchers' ultimate goal is to develop a tool to improve the effectiveness of graduated driving licensure.

Project URL: www.its.umn.edu/Research/Proposed/200806.html

■ **Stephen Simon**, Law School, and **Max Donath**, Department of Mechanical Engineering
[In-Vehicle Driver Assistance for Teenagers](#)

Status: *Completed*

Based on statistics from the Centers for Disease Control and Prevention (2003), motor vehicle deaths are the leading cause of teenage fatalities. A possible approach to mitigate the incidence of teenage driver crashes and fatalities is through the use of in-vehicle technology.

The design and development of a first-generation prototype Teen Driver Support System (TDSS) to explore the feasibility and opportunities of such technology has been completed. The TDSS system includes technology designed to address several primary contributing factors associated with the majority of teen fatal crashes: speeding, seat belt use, driver inexperience, and alcohol use. This has been implemented using a combination of what the researchers call forcing, feedback, and/or reporting functions.

Forcing functions take the form of ignition interlocks to enforce seat belt compliance and sober driving. A feedback function provides real-time tutoring and warnings about illegal or unsafe speeds through auditory warnings. A reporting function records vehicle information for parents to review and supervise (and enforce) teen driver performance. A speed feedback and reporting component is used for driver compliance with safe travel speeds. The system correlates the location (using GPS) of the vehicle to a digital road map and the road's corresponding speed limit. A weather-based speed element incorporates current weather information that is used to warn a driver if the vehicle's speed is too high for current weather conditions. Similarly, speed warnings specific to curves are included to warn if speed is excessive for the prevailing geometry.

With the prototype TDSS, the researchers developed a method of integrating a seat belt interlock that requires the driver's seat belt to be

engaged before the vehicle will start. Seat belt use is continuously monitored during each trip, and lack of seat belt use is recorded for later review. An additional interlock for alcohol is reserved for teen drivers with preexisting alcohol-related convictions. Since alcohol interlock systems are commercially available, they can be demonstrated as an optional component of the TDSS.

In anticipation of potential future applications, such as the enforcement of certain graduated driver licensing (GDL) requirements, the system includes a biometric fingerprint component, which uses a fingerprint sensor to identify the driver and parent so that the system can log the number of training hours spent behind the wheel.
Project URL: www.its.umn.edu/research/projectdetail.pl?id=2004057

■ Craig Shankwitz, Department of Mechanical Engineering
[Analysis of Highway Design and Geometric Effects on Crashes](#)
Status: *Newly funded*

Forty percent of fatal highway crashes in Minnesota involve road departure crashes. Road geometry (e.g., curves or tangential sections) and road design (e.g., lane width, shoulder width, shoulder pavement type) likely play a role in these crashes. Previous research indicates that two key elements of design—horizontal curvature and shoulders—are primary factors affecting crash frequency and severity. However, the actual effect on crash frequency is not well documented; most of the cited safety strategies are considered experimental or tried (as opposed to proven) so that effectiveness ratios are questionable, and none of the supporting data are from Minnesota.

This research will address these shortcomings. The first objective is to identify the features or characteristics associated with shoulders (type and width) and curve geometry (degree of curve and frequency) that affect road departure crashes. The second

objective is to determine, where design changes or countermeasures have been deployed, whether these practices or other countermeasures have quantifiably decreased the frequency and/or severity of these crashes. The third objective is to identify which emerging technologies could be used as an appropriate countermeasure(s) to reduce the frequency and/or severity of these crashes.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2008005

■ Thomas Smith, School of Kinesiology, and **Nikolaos Papanikolopoulos**, Department of Computer Science and Engineering
[Warning Efficacy of Active and Passive Warnings for Unsignalized Intersection and Mid-Block Pedestrian Cross-Walks](#)
Status: *In progress*

The efficacy of active warnings has received research attention in relation to pedestrian crosswalks, advance warnings at signalized intersections, and railroad crossings. Previous research results have shown that active warnings are clearly more effective than passive warnings at railroad crossings and in advance of signalized intersections. However, results regarding the relative warning efficacy of active versus passive pedestrian crosswalk warnings have been mixed. Given that the cost of active crosswalk warnings is substantially higher than that of passive warnings, further research is needed to ascertain the comparative warning effectiveness of active and passive warnings and to explore low-cost alternative designs. This project includes a literature review of research findings relevant to crosswalk warning systems, a field study of the relative warning efficacy of active versus passive warnings at selected pedestrian crosswalks, and a design analysis of low-cost alternatives for pedestrian crosswalk warnings.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2007028

■ Nicholas Ward, Department of Mechanical Engineering
[Driver Performance During 511 Information Retrieval and Cell Phone Conversation Tasks, Combined Under Varying Levels of Traffic Density](#)
Status: *In progress*

See page 18 for coverage of this project.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2006028

■ Nicholas Ward and Michael Manser, Department of Mechanical Engineering
[Generational Perspectives on Teen and Older Drivers on Traffic Safety in Rural and Urban Communities](#)
Status: *In progress*

Traffic fatalities are a significant issue for society, especially in rural environments. On a state and national level, two distinct demographic groups emerge with the highest risk of traffic fatalities: teen drivers (under 20 years old) and older drivers (65 or older). To significantly reduce traffic fatalities, it is necessary to implement traffic safety interventions designed to target each of these high-risk groups. This study uses focus groups and structured questionnaires given to various age groups (cohorts) of at-risk drivers. The data obtained will support recommendations for the type and form of intervention likely to be most effective and acceptable within each risk group and community area.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2007067

[The Use of Video Feedback in Urban Teen Driving](#)

Status: *In progress*

Newly licensed teens have an extremely high risk for crashes. According to the Insurance Institute for Highway Safety, in 2003 5,691 teenagers died in motor vehicle crashes. This amounts to more than one-third of deaths from all causes for teenagers.

In response, the Universities of Iowa and Minnesota are leading a pilot project to examine the use of new

methods to motivate safe teen driving. This method will examine teen driving during the first 6 to 12 months after teens obtain a driver's license and is based on using an event-triggered video system to record and give feedback about unsafe driving behavior.

The proposed system has the ability to provide feedback in two distinctly different ways. First, the system has an LED that blinks to tell the teen driver that an event trigger has been detected and recorded, giving the driver immediate feedback. Data from the on-board diagnostics port such as speed, throttle position, and brake activity may also be recorded and synched with the video clips. The video data makes it possible to understand the context of the unsafe event and the task occupying the driver at that time, such as distraction or risky behaviors with passengers. Second, the video recorded during the “unsafe” driving episode is sent to the parent to allow for a second form of feedback: a parent-teen “coaching” session.

This project will examine the use of event-triggered video feedback to reduce unsafe driving behaviors of newly licensed urban teens. This research differs from other interventional studies because it gives clear, contextual feedback in the form of video and audio of each unsafe driving episode captured. It is hoped that this type of feedback will help teen drivers become aware of the driving behaviors they engage in that may be unsafe, to recognize any patterns of unsafe behavior, and to improve their driving for the long-term.
Project URL: www.its.umn.edu/research/projectdetail.html?id=2007104

■ Nicholas Ward and Michael Rakauskas, Department of Mechanical Engineering
[Rural and Urban Safety Cultures](#)
Status: *In progress*

Motor vehicle crashes are a predominant cause of mortality in rural areas. Persons involved in a rural crash are three times more likely to die than

persons involved in an urban crash. Since most rural crashes involve rural drivers, it is necessary to consider the pertinent human factors by examining the relationship between the personalities and attitudes of rural drivers toward safety and the higher rural crash rate and driving style relative to an urban context. This project is attempting to support the development of a human-centered intervention to reduce the loss of life resulting from the high rural crash rate in Minnesota by investigating psychological and social factors that may predispose rural drivers to drive less safely.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2005058



■ Xun Yu, Department of Mechanical and Industrial Engineering (Duluth)
[Real-time Nonintrusive Detection of Driver Drowsiness](#)

Status: *Newly funded*

Driver drowsiness is a major cause of serious traffic crashes. Continuous monitoring of drowsiness is therefore important for reducing crashes resulting from it. This research aims to develop a real-time, nonintrusive driver drowsiness detection system. Biosensors will be built on the automobile steering wheel to measure a driver's heart beat. This will enable heart rate variability (HRV), a physiological signal with established links to waking and sleeping stages, to be analyzed to detect driver drowsiness. The novel design of measuring heart rate from biosensors on the steering wheel means the system will cause little annoyance for the driver, while the use of physiological signals ensures the accuracy of the drowsiness detection.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2008017

Computing, Sensing, Communications, and Control Systems

■ **Max Donath, Craig Shankwitz,** and **Nic Ward**, Department of Mechanical Engineering, and **Gary Davis**, Department of Civil Engineering
Intersection Decision Support
Status: Completed

Minnesota joined with California, Virginia, and the FHWA in a pooled-fund consortium (the Infrastructure Consortium) dedicated to improving intersection safety. The Minnesota team's objective is to develop effective strategies to mitigate high crash rates at rural intersections.

Rural Intersection Decision Support (IDS) focuses on enhancing a driver's ability to successfully negotiate rural intersections. The system uses sensing and communication technology to identify safe gaps in traffic on a high-speed rural expressway and communicate this information to drivers waiting to enter the intersection from a minor intersecting road. The goal of this system is to improve safety without introducing traffic signals, which on high-speed rural roads often lead to an increase in rear-end crashes.

The Rural IDS research program achieved four main research results through an analysis of rural expressway intersections: (a) the development of a technique to identify those with higher-than-expected crash rates; (b) the development of a statistical model that can be used to estimate the benefits of deploying IDS at a specific rural intersection; (c) the design and implementation of a rural intersection surveillance and data-acquisition system capable of quantifying the behavior of drivers; and (d) a task analysis, design study, and simulator-based evaluation of Driver Infrastructure Interface (DII) concepts for communicating relevant information to stopped drivers.

The second item (b) was the result of a project led by Professor Gary Davis. In this project, statistical modeling was applied to crash data from 198 two-way, stop-controlled intersections on Minnesota rural expressways in order to identify intersections that were plausible candidates for future

IDS deployment; develop a method for estimating the crash-reduction effect of IDS deployment; develop a method for predicting the crash-reduction potential of IDS deployment; and test the hypothesis that older drivers were over-represented in intersection crashes along U.S. Trunk Highway 52.

These objectives were accomplished using hierarchical model structures similar to those employed in the interactive highway safety design model. Five rural expressway intersections were identified as having crash frequencies that were atypically high, and this group included the intersection of U.S. Trunk Highway 52 and Goodhue County Highway 9, the site chosen for the prototype IDS deployment.

It was then determined that a three-year count of crashes after deployment would probably be sufficient to detect any crash reduction effect due to the IDS, although a reliable estimate of the magnitude of this effect would require a longer test period. Assuming that IDS deployment would make the frequency of crashes at treated intersections similar to that of typical intersections, it was estimated that deployment of the IDS at the five high-crash intersections would, over a 15-year period, result in about 308 fewer crashes. Finally, using an induced-exposure approach, 12 intersections were showed an over-representation of older drivers, with 5 of these located on U.S. Trunk Highway 52.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2001048



CICAS Stop Sign Assist (SSA) System
Status: In progress

This research project is an extension of the intersection decision support (IDS) research initiative. Important results from IDS research include: (1) An analysis of rural expressway intersection crashes in Minnesota, including the development of a technique to identify intersections having crash rates higher than expected; (2) A statistical model that can be used to estimate or project the societal benefits of deploying a rural stop-sign assistant at rural intersections; (3) The design, development, and implementation of a comprehensive rural intersection surveillance and data acquisition system; and, (4) A task analysis, design study, and simulator-based evaluation of innovative driver-infrastructure interface (DII) concepts.

As a follow-on to the IDS research, this project is a five-year effort culminating in a field operational test (FOT) performed at the Minnesota test intersection in Goodhue County. This research is separated into two components: a three-year, pre-FOT effort to finalize the design of the DII, and a two-year FOT to validate the safety benefits and driver acceptance of the system.

This project investigates the integration of a cooperative element into the IDS system. Under the IDS program, no vehicle or driver information was delivered from the vehicle to the infrastructure. The infrastructure, however, did estimate vehicle classification using a laser-scanner-based system. This system was used to determine differences in gap acceptance as a function of vehicle length, height, and profile and to test the hypothesis that larger vehicles require larger gaps. This current project, however, takes advantage of new resources emerging from the USDOT Vehicle-Infrastructure Integration (VII) initiative. Under VII, a communication mechanism between vehicles and the infrastructure is emerging that will facilitate the efficient

transfer of relevant data between vehicles and infrastructure.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2006050

■ **Max Donath** and **Craig Shankwitz**, Department of Mechanical Engineering
Toward a Multi-State Consensus on Rural Intersection Decision Support
Status: In progress

Minnesota has partnered with California and Virginia in a pooled-fund consortium, the Intersection Decision Support (IDS) project, to improve safety at intersections. The consortium is looking at both near- and long-term solutions that are effective, deployable, affordable, and beneficial to not only the participating states but to the nation as a whole.

The Minnesota effort is focusing on rural intersection safety. Crashes at rural intersections, although less frequent than those at urban or suburban intersections, are often more catastrophic than their counterparts because of the high vehicle speeds associated with them. The National Safety Council estimates that 32 percent of all rural crashes occur at intersections, and approximately one in every four fatal crashes occurs at or near an intersection.

To create a system that can be deployed nationwide, the extent of the national problem must be understood, and a nationally applicable solution to that problem must be designed, developed, tested, and evaluated. The University of Minnesota and the Minnesota Department of Transportation have initiated a state pooled-fund study to gain a national basis for deployment of its IDS Project.

The plan consists of three facets. The first is a review of state intersection crashes for each participating state. The crash data will be used to understand rural intersection crashes on a national basis and to identify candidate intersection(s) for subsequent instrumentation and study. The second

facet is participation in the process to design and refine candidate intersection Driver Infrastructure Interfaces (DII). Representatives from the pooled-fund states will participate in driver interface workshops and give input on the effectiveness of the design and its feasibility from the deployment, operations, and maintenance viewpoints. The third facet is development of a portable intersection surveillance system that can be used to instrument candidate intersections as a means to acquire data regarding the behavior of drivers at rural intersections over a wide geographical base. Collection and analysis of such data will indicate whether regional differences exist regarding how drivers accept gaps at rural intersections and whether these differences are likely to affect the operation of the IDS system. Moreover, states choosing to instrument intersections will be well positioned to participate in the second phase of the IDS program, a field operational test designed to evaluate the performance of these systems.

The portable system has been developed and tested at the Minnesota test intersection at U.S. 52 and County 9 near Cannon Falls, Minn. The system was run for one month; a few problems were identified (e.g., carburetor icing, occasional wireless problems) but have been corrected. The next step is to acquire data in each of the partner states by February 2008.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2004039

■ **Max Donath**, Department of Mechanical Engineering, and **Ted Morris**, Department of Civil Engineering
Modeling Traffic Impact on Denali Park Road
Status: In progress

The primary objective of this project is to develop management tools to predict and access interactions between traffic volume, wildlife behavior, visitor experience, and park

(road) maintenance. The University of Minnesota's contribution is to develop an accurate, state-of-the-art traffic simulation model that facilitates the integration of all the social and biological elements. The model could then be used to forecast outcomes based on hypothesized road capacity scenarios. Such scenarios are influenced by changes in bus and transit use and scheduling, road facility restriction policies, and road maintenance plans. A final objective is to provide an implementation that gives park managers and other researchers the ability to further expand on the simulation model framework and devise new scenarios for new applications, such as guiding decisions for preparing environmental impact statements.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2006061

■ Ahmed El-Geneidy, Department of Civil Engineering, and **Kevin Krizek**, Humphrey Institute (formerly) **Using Archived ITS Data to Improve Transit Performance Management**
Status: *In progress*

In the past, in order to measure transit performance, collecting the necessary data was difficult and costly. With the recent implementation of intelligent transportation systems (ITS)—and especially advanced public transit systems (APTS)—data collection is no longer an issue, but there is a concern with how these data can be meaningfully analyzed, creating information relevant for service planning and control.

Metro Transit, the local transit authority in the Twin Cities, has recently implemented an APTS, which it has been testing since 1999. Metro Transit uses the data obtained from the APTS for live transit operations through its transit management center to identify early and delayed buses and apply some strategic decisions in the field to address such problems. Metro Transit also archives this information for future

research to help improve its operations and planning process.

This research is using the archived ITS data to introduce and explore various research methodologies that can help Metro Transit improve service reliability, schedule adherence, and on-time performance. Visualizations of the data will be part of the research.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2007005

■ John Evans, Department of Chemistry (Duluth) **Detection of Water and Ice on Bridge Structures by AC Impedance and Dielectric Relaxation Spectroscopy**
Status: *Newly funded*

This research seeks to develop low-cost sensing systems for monitoring ice and water on bridge deck surfaces. These sensing systems are based on the measurement of impedance of the sensor in contact with or in close proximity to ice, water, or aqueous solutions of deicing chemicals. The researchers will explore two alternative technologies. Impedance analysis at lower frequencies will determine the presence of solutions of deicing electrolyte (a type of “conductivity measurement”), while high-frequency dielectric relaxation using time-domain reflectometry will probe the physical state of precipitation and deicing chemicals on the deck or road surface. In both approaches, the methodologies will use significantly lower-cost electrodes in the respective impedance analysis schemes.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2008020

■ Taek Kwon, Department of Electrical and Computer Engineering (Duluth) **Development of Data Warehouse and Applications for Continuous Vehicle Class and Weigh-in-Motion (WIM) Data**
Status: *In progress*

The Mn/DOT Office of Transportation Data & Analysis (TDA)

manages 29 vehicle classification (VC) sites and 6 weigh-in-motion (WIM) sites installed on various roadways in Minnesota, and the numbers are expected to grow significantly within a few years. Consequently, the amount of data is expected to grow substantially, requiring an efficient data warehousing and management system.

This research will develop a VC/WIM data warehouse at the UMD Transportation Data Research Laboratory (TDRL) and provide the data reporting needs of TDA through online automation. For the data warehouse design, the characteristics of VC and WIM data will be carefully analyzed, and then the two types will be integrated as a single data resource from which a statistical summary can be queried directly from both types of data.

Since the TDRL currently archives statewide R/WIS data and Minneapolis-St. Paul freeway traffic data, the addition of WIM and VC data is expected to increase the amount and quality of information by allowing researchers and engineers to cross-reference various types of transportation data.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2007036

Development of Portable Eight-Channel WIM Analysis System Based on Analog WIM Signals
Status: *In progress*

Weigh-in-motion (WIM) data have long served as a key component for traffic data. Over the past few years, Mn/DOT has begun moving from the traditional expensive bending plates and load-cell-based systems to low-cost quartz Lineas technologies. In using quartz Lineas technology, one of the challenges has been determining how trustworthy the sensor readings are, since the only available outputs from the present systems are the converted weight and axle data.

This research aims to significantly improve WIM data quality by developing an eight-channel WIM analysis sys-

tem that could simultaneously probe and analyze eight channels of analog signal and provide signal diagnostic data.

During the preliminary study on WIM funded by NATSRL over the past year, the researcher found that adding WIM measurement to the probe is not significantly difficult. The new system should be developed to operate in two operational modes: a probe mode and a data-collection mode. In the probe mode, it will simultaneously probe eight WIM channels, analyze the raw analog signals of each channel, and report the analysis results. In the data collection mode, the system should compute real-time weight translation and record the data so that it can operate as a stand-alone WIM data-collection system of up to eight channels (four lanes). The base system will be developed based on off-the-shelf components so that Mn/DOT can easily reproduce in-house WIM data collection systems at a low cost.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2006022

Cellular Wireless Mesh Sensor Network for Comprehensive Spatial Traffic Movement Detection and Data Fusion (Phase II)

Status: *Newly funded*

The overall goal of this project is to develop a practical method for monitoring detailed movements of traffic using a mesh network of wireless sensor nodes. This approach was motivated by the fact that low-power wireless nodes naturally form cell coverage areas that can be easily configured as a mesh network and used to detect the motion of vehicles in the coverage area. In the first year, anisotropic magnetoresistive (AMR) sensor nodes were designed and integrated with the commercially available 802.15.4 chip sets to form the basic wireless node. Basic node-to-node protocols were then developed and implemented.

The objective of the second year is to complete development of the remaining required protocols and soft-

ware for the mesh network so that the network functions as a working prototype. The performance of the prototype for tracking vehicle movements in an intersection will then be evaluated.

The primary protocols to be developed include ones for congestion control and for network and sensor management. Once the protocol implementation is complete, the researchers will develop a vehicle-tracking algorithm based on the aggregated sensor data and will install the system in a live intersection, enabling them to evaluate the network's performance and to learn about field installation and operational issues.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2007039

Development and Field Test of Advanced Dynamic LED Warning Signals for Unsignalized High-Speed Rural Blind Intersections Powered by Renewable Energy

Status: *Newly funded*

Motorists traveling through unsignalized, high-speed rural intersections that contain blind areas (where the view of approaching or crossing vehicles is blocked) are at a high risk for crashes. Static advanced warning signs or flashers in such intersections have been ineffective. This research proposes to develop and evaluate a new, dynamic LED (light-emitting diode) warning system to actively detect vehicles near the intersection and notify approaching vehicles that are crossing it.

The project will be conducted over two years, with the first year spent on developing system and control logic, and the second year on implementing and evaluating the advanced warning system.

There are two challenging aspects of rural implementation: the installation should not involve extensive construction, and the operation should not require connections to the power grid. Two ITS technologies developed by the current UMD research team solve the

two rural implementation challenges. The first is the solar/wind integrated renewable power station, which eliminates the need for connection to the electric grid. The second enabling technology is low-cost wireless magnetometers for detecting vehicle movements, which eliminates the wiring requirements in the intersection.

Project URL: www.its.umn.edu/Research/Proposed/200801.html

■ Nikolaos Papanikolopoulos, Department of Computer Science and Engineering
Multi-Camera Monitoring of Human Activities at Critical Transportation Infrastructure Sites

Status: Completed

See page 19 for coverage of this project.

Project URL: www.its.umn.edu/Research/projectdetail.pl?id=2006018



Data Mining of Traffic Video Sequences

Status: In progress

This project addresses the problem of data extraction from traffic video sequences. The researchers plan to automatically learn the layout of a traffic site (e.g., an intersection) from trajectories of vehicles obtained by a vision tracking system. This approach will enable the automatic extraction of sophisticated and complex data such as unusual events, near misses, and vehicle trajectory clusters. The researchers will use a similarity measure suitable for use with spectral clustering in problems that emphasize spatial distinctions between vehicle trajectories. The researchers will evaluate the robustness of the method to small perturbations and its sensitivity to the

choice of parameters, and will also integrate the algorithms with a previous system recently delivered to Mn/DOT.

Project URL: www.its.umn.edu/Research/projectdetail.html?id=2008003

Freeway Network Traffic Detection and Monitoring Incidents

Status: In progress

Freeway management requires advanced data-collection methods. In particular, special emphasis is given to data such as vehicle trajectories, gaps, lane changes, and accelerations in weaving sections, freeway bridges, tunnels, and freeway segments around airports, rail, and bus stations.

The process of collecting traffic data and recognizing patterns or events of interest is complex, since it often involves crowded scenes. The researchers suggest using cameras in the visible range in order to collect data and classify certain events as meriting further examination by a human operator. Examples include a car stopped on a bridge or a car driving erratically.

Several states and federal agencies use humans to observe these events and collect data. This project is working toward developing an automated system to collect this information and notify human operators about interesting data or events in the vicinity of the freeway network.

Project URL: www.its.umn.edu/Research/projectdetail.pl?id=2005070

Counting Empty Parking Spots at Truck Stops

Status: Newly funded

With this project, the researchers plan to develop an automated truck stop management system that computes occupancy rates at stops and informs drivers of the availability of parking spots using variable message displays located about 30 or 40 miles before the stop. The proposed system will detect, classify, and localize vehicles on the truck stop's grounds by using a set of video cameras, from

which video frames will be analyzed in real time. Since the system will know exactly which spots are occupied, variable message displays onsite will be able to direct drivers to free spots. In some cases it would be possible for two or more smaller vehicles to share a single parking spot, so the system will also determine partial spot occupancy. The system will operate in two basic modes—a day mode and a night mode—that would typically require different methods for vehicle detection. For vehicle dimensions to be accurately estimated, the managed sites will be calibrated so that the correspondence between the camera views and actual site dimensions is available.

Project URL: www.its.umn.edu/Research/Proposed/200803.html

■ Nikolaos Papanikolopoulos and Osama Masoud, Department of Computer Science and Engineering
Portable Traffic Video Processor

Status: Completed

Automatic extraction of events from video sequences has important applications for a variety of ITS problems including scene monitoring, traffic data collection, and intersection monitoring. When deploying a system that recognizes events automatically from video sequences, two important things to consider are the real-time analysis of the video sequences and the short time required for learning the different classes of events in a scene. A related requirement that is often ignored is the limited reliance of the learning system on user-provided knowledge.

In this work, the researchers developed an innovative technique for detecting the different events in video sequences through a semi-supervised learning method. More concretely, the events are recognized from the tracked trajectories of the targets in the scene, which in turn are represented as a collection of actions or strings. By parsing these strings as reversible context-free grammars, the researchers detected and classified the different events.

Learning consists of extracting the relevant grammar for each class of events from the data. To accomplish the learning goal, the system makes use of a small number of trajectories corresponding to each class as provided by a user to obtain a preliminary model of the grammar.

Using this model, the system iteratively refines the grammar from new trajectory data obtained directly from the scene. Given that the system requires only a very small number of labeled trajectories and can iteratively learn from the observed data, the system is easily portable to new scenes with little system initialization from the user.

Project URL: www.its.umn.edu/Research/projectdetail.pl?id=2006033

■ Rajesh Rajamani, Department of Mechanical Engineering
Automated Winter Road Maintenance Using Road Surface Condition Measurements

Status: In progress

This project aims to develop an automated road sander control system for a snowplow using the friction coefficient of the road surface and pavement temperature as key measurements for feedback. The project consists of two major technical activities, both of which have been completed. The first was the development of an improved tire-road friction measurement system on the SAFEFLOW. The performance of the friction measurement system in terms of accuracy and reliability is being evaluated using experimental tests on different types of road surfaces with the snowplow.



The second activity was automation of the snowplow sander using real-time measurements from the friction measurement system and a pavement temperature measurement sensor. Included was an experimental evaluation of the performance of the automated system on the SAFEFLOW.

The project will lead to the development of valuable winter maintenance technology, in which knowledge of pavement conditions is used to help reduce material costs and better utilize maintenance crews, resulting in safer roads in winter.

Project URL: www.its.umn.edu/Research/projectdetail.pl?id=2005037

New Battery-less Wireless Traffic Sensors as a Replacement for Loop Detectors

Status: In progress

This project is developing new battery-less wireless sensors to measure traffic volume, vehicle speed, vehicle length, and number of axles on each vehicle. Each sensor will consist of two components: a piezoelectric element embedded in the road and a data processing unit located on the road shoulder. Compared to existing loop detectors, these sensors have several advantages: cost (\$50–\$100 each, compared to more than \$700 in hardware for a typical loop detector); ease of installation (drilling a small hole in the road surface, with no wiring required to connect with the data processing unit on the shoulder); gathering new types of data (reliable measures of vehicle speed, length, and number of axles, as well as an estimate of vehicle weight); and significantly smaller roadside data-processing units.

This project aims to develop both a basic sensor (capable of measuring traffic volume, speed, and number of axles on each vehicle, emphasizing minimal size and ease of installation) and a full sensor that can also measure vehicle weight. Research activities include experimental tests to evaluate

the performance, reliability, and accuracy of both sensors. Finally, a sensor network that can enable short-term applications such as turn analysis at rural intersections will be developed and evaluated.

Project URL: www.its.umn.edu/Research/ProjectActive.html?id=2007047

Automated Vehicle Location, Data Recording, and Applicator Control for Winter Road Maintenance

Status: Newly funded

This project proposes to develop and evaluate an automatic anti-icing/deicing applicator control system based on the use of real-time road/weather information system (R/WIS) data. The proposed system will also continuously record data on the rates of chemical or abrasive application together with measurements of vehicle location and road geometries.

A commercial wireless cellular network will be used to access R/WIS data, including air temperatures, surface temperatures, precipitation, wind speed, and snow depth. Access to 24-hour weather forecasts of the same variables will also be utilized. A GPS-based vehicle location system and a previously developed geographical information roadway database will provide vehicle location information for recording. A rugged, portable computer-based system that obtains and records R/WIS data, automatically determines chemical or abrasive application rates, and interfaces with the controller on the snowplow will be implemented. The proposed system will be tested in the field by Mn/DOT personnel and its performance compared to that of manual applicator control.

Successful deployment of the technology could lead to significant savings for Mn/DOT by reducing the amount of unnecessary deicing chemicals applied to the road. This is also likely to result in less damage to Minnesota's waters, vegetation, and transportation infrastructure. At the same time, the technology can ensure

that roads are kept safe by applying deicing chemicals whenever needed.

Project URL: www.its.umn.edu/Research/Proposed/200804.html

Automatic Safety Alert System for Work Zones with Flag Operators

Status: Newly funded

This project will develop and evaluate an automatic alert system for work zones that warns the violating vehicle, flag operator, and crew in the work zone to ensure their safety. The proposed system will be portable and will utilize radar-based threat assessment to predict potential work zone intrusion. A special thin-film audio speaker system will be developed to provide a clear, loud warning to a specific vehicle in the targeted lane while being almost inaudible to vehicles in other lanes. The project will also evaluate and compare a number of different audio warning signals to test their effectiveness. The team will work with Mn/DOT maintenance engineers to test the developed systems in realistic work zone intrusion scenarios.



Among the potential benefits of the system are that it will ensure the safety of the flag operators and the crew inside the work zone, and it will be inexpensive and portable. (The audio speaker system will cost less than \$200, and the complete system including the radar-based automated intrusion warning system will cost less than \$2,000. The audio speaker system could be used manually by itself by the flag operator to provide warnings to both the intruding vehicle and the work crew). The system will lead to fewer panic-stops and rear-end collisions

and smoother transitions as traffic flows through the work zone, and the flag person will have better control of the traffic and will feel empowered with regard to safety.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2008004

**Craig Shankwitz, Department of Mechanical Engineering
Advanced BRT: Innovative Technologies for Dedicated Roadways**

Status: Completed
This research sought a novel approach to vehicle positioning using radio-frequency identification (RFID) technology (Vehicle Positioning System, or VPS). By installing in the road RFID tags encoded with the road name or other designation, the specific lane, the direction of travel, and the longitudinal distance from a known reference, a vehicle outfitted with an RFID tag reader can determine its position each time it passes over and reads a tag, thus providing precisely the information needed for many ITS applications: the longitudinal position of a vehicle in a particular lane on a particular road of the transportation network.

Knowledge of lane of travel and distance from a known reference provided by VPS enables many transit applications, including headway control of bus platoons, merge/lane change assistance, rear-end collision avoidance, and bay mark-up applications. For lane assist systems, VPS and a "within-lane" lateral positioning system can augment DGPS in urban areas, providing seamless operation where DGPS availability is insufficient for lane keeping.

This research focused on designing and building a prototype VPS using existing third party RFID hardware. The hardware was evaluated and characterized to determine if it could be used to create a viable, robust VPS. After the development and characterization of the positioning system,

an implementation of a rear-end collision-avoidance system was built to demonstrate the use of VPS. Finally, a more sophisticated rear-end collision avoidance system was designed and simulated, after which its implications to the accuracy specifications for VPS were analyzed.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2002041

Infrared Sensors for Driver-Assistive Systems

Status: Completed

A driver-assistive system that uses high accuracy, differentially corrected GPS (DGPS), high-accuracy geospatial databases, radar, computers, and driver interfaces (both a head-up display, or HUD, and a tactile seat), has been developed to help drivers maintain lane position and avoid collisions during periods of low visibility. These systems have been tested and deployed both in Minnesota and in Alaska.

Collision avoidance information is provided to a driver through the HUD. Objects located within the HUD field of view determined to be a threat to a driver are indicated as square boxes. White boxes represent an advisory, and if the detected object is fewer than 50 feet or three seconds from a collision, the box turns to red (a warning).



Drivers who have used the system have speculated that a more accurate representation of the object projected on the HUD would make the driving task easier. Emerging Super and High Dynamic Range Cameras (SDRC and HDRC, respectively) appeared to be a feasible, inexpensive means with which to address drivers' concerns.

SDRC and HRDC technology failed to meet expectations, but infrared imagery was successfully integrated with the standard HUD.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2004056

Multiuse, High-Accuracy, High-Density Geospatial Database

Status: In progress

High-accuracy (2-8 cm) DGPS and high-accuracy (5-20 cm) geospatial databases are the primary components of the IV Lab driver-assistive systems. In addition to vehicle-based systems, the IV Lab geospatial database has found utility in other applications. For instance, the database has recently been used for the Intersection Decision Support (IDS) project, where radar sensors are used to determine the state of an intersection as a first step in warning drivers when it is unsafe to enter an unsignalized intersection. The geospatial database is used in this application to improve the ability of the radar system to determine whether a target represents a legitimate threat at the intersection. The IV Lab geospatial database was designed and optimized for vehicle applications and provides real-time access to extremely accurate, dense geospatial data. Because of this optimization, its functionality in other applications is somewhat limited.

As new applications arise, a more "global" approach to the design of the existing geospatial database is required. This research is pursuing a redesign of the geospatial database and database manager and the development of a new front end to serve a wide application base.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2005047

Guidance Augmentation Using VPS for Transit Applications (Phases I and II)

Status: In progress

High-accuracy, dual-frequency, carrier-phase differential Global Positioning System (DGPS) units can provide kinematic positioning estimates with accuracies of a few

centimeters under favorable conditions. High-accuracy DGPS serves as the basis of the various driver-assistive systems developed by the Intelligent Vehicles Lab.

Under FTA sponsorship, a DGPS-based lane-assist system was pilot tested by 16 trained Metro Transit bus drivers in mixed traffic on bus-only shoulders in 2002. Results of the pilot testing showed that the lane-assist system improved lane-keeping capability by approximately 75 percent compared to shoulder operation without assistance. However, driver stress did increase somewhat, indicating that more than a four-hour training session is needed to familiarize a driver with the system.

The DGPS system described above was tested on a suburban corridor. Urban areas offer significant obstacles to implementation of such systems, including restricted views of satellites, multipath reflection of satellite signals, and cellular network holes that interfere with DGPS correction. This project addresses these issues with urban DGPS by fusing the position information provided by a vehicle positioning system (VPS) with data from scanning laser sensors. In a previous ITS Institute project, VPS was developed to provide lane-level positioning. This provides the information needed to determine the lane of travel of a bus, as well as the length of the path traveled from a known reference. Also developed (albeit to a lesser degree) was a technique that uses laser scanners to identify the presence and location of curbs with respect to a moving vehicle. The goal of this project is to demonstrate an integrated urban lane-assist system for dedicated bus lanes, integrating information from VPS, laser scanners, and a map representation describing the optimal distance from bus to curb as a function of distance traveled along the lane.

Project URL: www.its.umn.edu/Research/Proposed/200805.html

■ Craig Shankwitz and Max Donath, Department of Mechanical Engineering
GPS Augmentation for Robust Lane Assistance

Status: *In progress*

The Minnesota Valley Transit Authority operates express bus service linking the southern suburbs with downtown Minneapolis. This express bus service uses bus-only shoulders to maintain bus route schedules during periods of high congestion. During periods of poor weather and low visibility, MVTA drivers are often unable to use the shoulders. To improve passenger service, MVTA hopes to operationally test lane-assist technology on the Cedar Avenue Corridor.

The Intelligent Vehicles Lab at the University of Minnesota has developed a number of differential GPS-based lane-assist systems for snowplows, state patrol cars, and transit applications, and MVTA has identified this as the technology it wants to deploy on Cedar Avenue.

Cedar Avenue between Apple Valley, Minn., and the Crosstown (Minnesota Trunk Highway 62) passes under a number of bridge decks. These bridge decks block GPS signals, rendering the lane-assist system inactive while under the bridge deck and for a period of 7 to 10 seconds after emerging from under it. This research is working to develop and test a DGPS-augmentation system designed to provide seamless vehicle positioning while passing through bridge decks. This project will facilitate a potential FTA-sponsored operational test and field demonstration of lane-assist technology on buses. This work does not address the problem where GPS signals are unavailable across larger geographical areas, such as those found in urban canyons or central business districts (i.e., downtowns). The proposed solution is not based on inertial measurements. In a narrow shoulder application, a bus that is 9.75 feet wide across the mirrors may operate in a 10-foot-wide lane. Moreover, after passing under a bridge, a GPS outage may last 5 to 10

seconds. To maintain lane position in this situation, an inertial system would have to allow only 6 inches of lateral error in a 10-second time span. With the technology available today, this requirement far exceeds the capability of an inertial solution.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2007093

■ Shashi Shekhar, Department of Computer Science
Decision Support System for Evacuation Route-Schedule Planning

Status: *In progress*

Contraflow is a potential remedy for congestion during an evacuation resulting from a national security incident or natural disaster such as a hurricane. Given a transportation network having source nodes with evacuees and destination nodes, the researchers have aimed to find a contraflow network configuration—i.e., an ideal direction for each edge—to minimize evacuation time. This problem is computationally challenging because of the very large search space. This work presents possibly the first macroscopic approaches for the solution of contraflow network reconfiguration incorporating road capacity constraints, multiple sources, congestion factors, and scalability. The researchers formally define the contraflow problem based on graph theory and provide design decisions to classify their approaches. An integer programming formulation is designed to produce optimal contraflow configuration, a greedy approach is applied to produce high-quality solutions, and a minimum cut is used to create a heuristic to deal with the infinite number of evacuees. Finally, the researchers evaluate proposed approaches both analytically and experimentally using a real-world data set; experimental results show that their contraflow approaches can reduce evacuation time by 40 percent or more.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2004006



■ Hua Tang, Department of Electrical and Computer Engineering (Duluth)
Development of a New Tracking System Based on CMOS Vision Processor Hardware (Phase I)

Status: *Newly funded*

Vehicle tracking processes on roads are computationally very intensive. In the past, the different algorithms employed in vehicle tracking have been implemented using various software-based approaches. While software approaches have an advantage of flexibility in implementation and future modifications, the long computational time of these approaches often prevents real-time vehicle tracking from high-resolution spatial or temporal data. This gives rise to a need for direct implementation of tracking algorithms in hardware.

The goal of this project is to build a tracking system with a new algorithm based on vehicle motion detection, which is implemented in hardware whenever possible so that the computation time for tracking is minimized. The proposed overall tracking system consists of two parts. One is a hardware processor for vehicle motion detection. The other part is the software for tracking vehicles. The main computational time-saving for the tracking process comes from the hardware aspect, since the core of the new tracking algorithm—motion detection—is run on dedicated hardware for that particular purpose. The performance of real-time vehicle tracking can be greatly improved with such a hardware-based tracking system.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2008016

■ Pete Willemsen, Department of Computer Science (Duluth)
Snow Rendering for Interactive Snowplow Simulation: Supporting Safety in Snowplow Design

Status: *Newly funded*

During a snowfall, following a snowplow can be extremely dangerous. This danger comes from the human visual system's inability to accurately perceive the speed and motion of the snowplow, often resulting in rear-end collisions. For this project, the researchers' goal is to use their understanding of how the human visual system processes optical motion, under the conditions created by blowing snow, to create a simulation framework that could be used to test emergency lighting configurations that reduce rear-end collisions with snowplows. Reaction times for detecting the motion of the snowplow will be measured empirically for a variety of color set-ups on a simulated snowplow that slows down while driving on a virtual road with curves and hills. The simulated driving environment will utilize a head-mounted, virtual reality display to render an improved snow cloud model behind the snowplow. This driving simulator environment will serve as the basis for testing the effects of color and lighting alternatives on snowplows. The results of this work will move the researchers closer to determining optimal color and lighting configurations on real snowplows.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2008014

Technologies for Modeling, Managing, and Operating Transportation Systems

■ **Gary Davis**, Department of Civil Engineering

[Access to Destinations: Estimation of Arterial Travel Times](#)

Status: Completed

The primary objective of this project was to identify and evaluate parametric models for making default estimates of travel times on arterial links. A review of the literature revealed several candidate models, including the Bureau of Public Roads (BPR) function, Spiess's conical volume-delay function, the Singapore model, the Skabardonis-Dowling model, and the Highway Capacity Manual's model.

A license plate method was applied to a sample of 50 arterial links located in the Twin Cities seven-county metropolitan area to obtain measurements of average travel time. Also obtained were the lengths of each link, measurements of traffic volume, and signal timing information. Default values for model parameters were obtained from the Twin Cities planning model's database. Using network default parameters, we found that the BPR and conical volume-delay models produced mean average percent errors (MAPE) of about 25 percent, while the Singapore and Skabardonis-Dowling models, using maximal site-specific information, produced MAPE values of around 6.5 percent. As site-specific information was replaced by default information, the performance of the latter two models deteriorated; however, even under conditions of minimal information the models produced MAPE values of around 20 percent. A cross-validation study of the Skabardonis-Dowling model showed essentially similar performance when predicting travel times on links not used to estimate default parameter values.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2006016

[Safety Effect of Left-Turn Phasing Schemes at High-Speed Intersections](#)

Status: Completed

This research estimated crash modification factors (CMFs) associated with

different left-turn phasing schemes at intersections where the major approach speed limit exceeds 40 mph. For installation of signals at what were previously thru/stop-controlled intersections, rear-end crashes increased while right-angle crashes decreased. Installation of the signal had no effect on major or minor approach left-turn crashes as long as the protected-only left-turn phasing was used on the major approaches. At one intersection where a signal was originally installed with permitted/protected phasing on the major approaches, the researchers found evidence for an increase in major approach left-turn crashes, which vanished when the major approach left-turn treatment was changed to protected-only. For several other phasing changes it was not possible to construct an after-treatment data set of sufficient size to permit reliable estimation of an effect.

This project also described a simple simulation model for left-turn, cross-path crashes, where a probabilistic gap acceptance model for the turning driver is combined with a standard braking model for the opposing driver. The model characterizes left-turn crashes as the result of the turning driver accepting a minimal gap and taking a longer time to complete his/her turn, while the opposing driver takes a longer time to react before braking. Reconstruction of an actual fatal crash, however, was more consistent with the opposing driver reacting normally, but with the turning driver selecting an atypically short gap. Characterizing the rate at which such selection errors occur would then be necessary to accurately predict left-turn crash frequencies.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2002043

[Cross-Median Crashes—Identifications and Countermeasures](#)

Status: In progress

A cross-median crash occurs when a vehicle leaves its traveled way, completely crosses the median divid-

ing the highway's directional lanes, and collides with a vehicle traveling in the opposite direction. AASHTO's Roadside Design Guide recognizes two countermeasures for preventing cross-median crashes: medians wide enough to provide adequate "clear zones" where a driver can stop or regain control of the vehicle before crossing into the opposing traffic stream, and installation of median barriers when medians are less than 10 meters wide and annual daily traffic is greater than 20,000 vehicles per day.

As with any safety countermeasure, installation should begin with those locations showing the greatest expected benefits. This project will first review the state of the art in median-crossing crash protection through a literature review and a survey of current practices. This will be followed by statistical modeling of the frequency of median-crossing crashes in Minnesota, with the goal of identifying those locations where countermeasure installation is most likely to pay off. Finally, this project will investigate method(s) for predicting the crash-reduction benefits of median barrier treatments on particular highway sections.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2005057

■ **Gary Davis** and **Henry Liu**, Department of Civil Engineering
[Access to Destinations: Arterial Data Acquisition and Network-Wide Travel Time Estimation \(Phase II\)](#)

Status: In progress

This research is a continuation of a previously funded project on arterial travel-time estimation. In Phase I, a suite of link-performance functions based on demand flow, traffic control, and geometric characteristics was developed and evaluated; the goal was to produce plausible default estimates of travel times when given predicted flows. The expectation was that these estimates could be updated where and when field measurements are available.

In Phase II, field measurement data such as traffic volumes, speeds, and traffic control plans will be acquired and a relational database integrating appropriate geographic information systems (GIS) capabilities will be constructed. The primary objectives of Phase II are to compute default estimates of arterial travel times on all Twin Cities arterial links by applying the methods developed in Phase I, to update these default estimates using the collected traffic data, and to incorporate these data into the database. Considering the correlation among network links, the travel time update with the link performance functions is non-trivial and the methodology needs to be designed carefully. The final product of this project will be a database of arterial link travel times on the Twin Cities network for the years 1995 and 2005.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2007060

■ **Gary Davis** and **Chen-Fu Liao**, Department of Civil Engineering
[Bus Signal Priority Based on GPS and Wireless Communications \(Phase I: Simulation Study\)](#)

Status: Completed

See page 21 for coverage of this project.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2005038

[Bus Signal Priority Based on GPS and Wireless Communications \(Phase II: Signal Priority System Development\)](#)

Status: In progress

Providing signal priority for buses has been proposed as an inexpensive way to improve transit efficiency and productivity while reducing operation costs. Bus signal priority has been implemented in several U.S. cities to improve adherence to schedules, reduce transit operation costs, and improve customer ride quality. Current signal priority strategies implemented in various U.S. cities mostly use sensors to detect buses at a fixed or

preset distance away from an intersection. Traditional presence-detection systems, ideally designed for emergency vehicles, usually send signal priority request after a preprogrammed time offset as soon as transit vehicles are detected without the consideration of bus readiness.

This study's goal is to take advantage of the already equipped GPS/AVL system on Minneapolis buses and develop an adaptive signal priority strategy that would consider bus schedule adherence, number of passengers, location, and speed. Buses can communicate with intersection signal controllers using wireless technology to request signal priority. Communication with the roadside unit (e.g., traffic controller) for signal priority may be established using the readily available 802.11x WLAN network or the DSRC (Dedicated Short Range Communication) 802.11p protocol currently under development for wireless access to and from the vehicular environment. This research will develop a prototype system using a bus's existing GPS and wireless technologies to provide signal priority for buses.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2007089

■ **Robert G. Feyen**, Department of Mechanical and Industrial Engineering (Duluth)

[Assessing Coordination Between Agencies Involved in Traffic Incident Management](#)

Status: Newly funded

One of the key roles of the Minnesota Department of Transportation's Regional Transportation Management Center (RTMC) is managing adverse incidents that may affect traffic flow within the Twin Cities metro highway system. This is accomplished through a number of partner agencies involved in the overall traffic incident management (TIM) system.

Prior research at other TIM locations in the United States has examined in-

teragency coordination issues through self-assessment surveys and on-site interviews at a macro level, but few studies appear to have examined the efficiency and effectiveness of coordination among agencies in detail at an individual level. Further, many TIM system users in the U.S. have reported that evaluating the performance of TIM operations has been the least successful area of activity.

This project aims to initiate a benchmarking study using human factors and work measurement methods to document and assess the procedures, information requirements, and knowledge sharing needed to coordinate efforts among the various stakeholders in TIM (e.g., agencies represented by the Incident Management Coordination Team in the Twin Cities such as traffic operations, maintenance, and State Police personnel) for a single incident type. If successful, future studies would establish benchmarks and assessments for other incident types. The benefits of benchmarking include providing a baseline metric and methodology for interagency quality management activities (e.g., evaluating and maintaining overall TIM effectiveness, comparing actual and documented procedures, and assessing proposed procedural changes across agencies). In turn, a consistent set of performance metrics having interagency consensus could also be used to justify TIM programs and communicate the benefits of TIM systems both to the public and to those officials whose decisions can significantly affect TIM resources.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2008018

Demoz Gebre-Egziabher, Department of Aerospace Engineering and Mechanics
[Methodology for Evaluating the Concept of Operation for Traffic Management and Infrastructure](#)

Security Using Remotely Operated Aerial Vehicles

Status: *In progress*

Recently, the idea of using remotely operated aerial vehicles (ROVs) for traffic management and infrastructure security has received significant attention. The economic and social motivations for using ROVs in this application are very compelling. For this vision to become a reality, however, methods for inexpensively building and safely operating these ROVs must be developed. Safety is paramount, since these ROVs are expected to operate over populated areas and potentially share the same national airspace with passenger-carrying aircraft.

This work will aim to develop and demonstrate a systematic methodology for evaluating whether the operational concept of using multiple ROVs to monitor vehicles and other traffic management parameters meets safety requirements established by regulation. The methodology involves identifying hazards associated with the operation and quantifying the likelihood of their occurrence. For hazards for which the likelihood of occurrence is judged to be too great, risk mitigation strategies will be developed. This methodology will be useful for establishing certification standards by federal and state agencies responsible for the safe operation of ROVs and for designers of ROVs, since they could be used to map operational requirements into hardware specifications. Operational procedure designers could also use them to determine the required operator qualifications.

Project URL: www.its.umn.edu/Research/Proposed/200807.html



Demoz Gebre-Egziabher, Department of Aerospace Engineering and Mechanics, and **Ted Morris,** Department of Civil Engineering
[RPV/UAV Surveillance for Transportation Management and Security](#)

Status: *In progress*

This work is aimed at developing the capabilities to investigate the technical and operational issues of using Remotely Piloted Vehicles (RPVs) or Uninhabited Aerial Vehicles (UAVs) for traffic monitoring. The outcome of this work will be a prototype flying platform, sensors, algorithms, and operational procedures that enable autonomous monitoring of highways and relaying of information in real time to remotely located decision makers.

To this end, a low-cost RPV instrumented with an inexpensive georeferencing sensor suite and camera system has been built and flight-tested. The georeferencing sensor suite consists of a GPS receiver for generating estimates of position and velocity and a GPS-aided inertial measurement unit for attitude determination. A dual camera system is used to capture video images. The georeferencing data and video images are transmitted via a data link to a ground station and used for real-time highway infrastructure monitoring and pilot-in-the-loop control of the RPV. In addition to the video image, a synthetic image of the RPV's area of operation is generated by fusing information from a digital terrain and cultural database with the GPS position solution. This synthetic image is displayed on the ground station computer and is used for enhanced situational awareness, which ensures that RPV operations occur outside controlled airspace at all times.

Soon, a GPS-based attitude determination system will be added to the RPV, which will enhance the georeferencing accuracy. In addition, the ground station will incorporate georeferencing and video data archiving capabilities. This will allow users to monitor vehicle cohorts to

determine traffic parameters useful for traffic management. Operation of the systems and procedures developed will be validated in a final capstone demonstration. The demonstration will show how the navigation state vector of a ground vehicle can be estimated using remotely sensed data from an RPV.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2005040

John Hourdos and Gary Davis, Department of Civil Engineering
[TH-36 Full Closure Construction: Evaluation of Traffic Operations Alternatives](#)

Status: *In progress*

Transportation professionals are sensitive to public dissatisfaction with work zone congestion, delay, and safety and are continually developing new approaches to improve traffic operations in and around work zones. Transportation agencies are also challenged to balance the increasing need for work zones with mobility and safety concerns expressed by the public and government agencies. Full road closure is one method that transportation agencies are considering as a potential way to balance these conflicting needs. It is a relatively new strategy never before employed in Minnesota.

The purpose of this study is to analyze the effects and measure the benefits of utilizing full closure construction. This study has the unique advantage of using an actual ongoing project as a test case. Metro District has selected the full closure of Highway 36 to construct a project in North St. Paul. A comprehensive analysis of such a construction strategy includes the evaluation of all traffic operation alternatives in the greater project area, the cost/benefit comparison with other construction alternatives, market research to identify the public's acceptance of the project during and after completion, and an identification of lessons learned.

The final product of a comprehensive study will be a guide for other projects considering full road closure as a construction alternative. This project covers the first part of the aforementioned comprehensive study, which is the evaluation of traffic operations and extraction of performance measures from the four basic traffic operation alternatives: no-build, build, non-full closure construction, and full closure construction. This research will provide valuable data for the cost/benefit analysis as well as effective traffic management on future full road-closure projects.

Project URL: www.cts.umn.edu/Research/ProjectActive.html?id=2007077



Henry Liu, Department of Civil Engineering
[Development of a Platoon-Priority Control Strategy and Smart Advance Warning Flashers for Isolated Intersections with High-Speed Approaches](#)

Status: *In progress*

This research is in response to a request from Mn/DOT for the development of an intelligent control system for isolated intersections with high-speed approaches, including a platoon-priority control strategy and smart advance warning flashers (AWF). A significant number of Mn/DOT signalized intersections operate under isolated control. At many of these signals, it is not uncommon for an approaching platoon of vehicles to face a red signal because of a single vehicle on one of the conflicting approaches.

In addition, Mn/DOT uses advance warning flashers—which warn motorists on high-speed approaches that the signal phase will be turning yellow—for selected intersections. However, the system introduces a trailing overlap of a fixed interval (leading flash) at the end of the arterial phase every cycle, which may cause some dilemma zone problems.

To address these issues, the researchers aim to develop an intelligent traffic control system for detecting vehicle platoons approaching a traffic signal with or without AWF to eliminate dilemma zone problems and adapt to time-variant traffic conditions. To evaluate and improve the proposed control system, the researchers will use hardware-in-the-loop simulation and quantify system performance improvements in terms of operational efficiency and safety.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2007087

Evaluation of Cell Phone Traffic Data

Status: *In progress*

Cellular phone tracking is one of the most promising vehicle-probe methods likely to produce reliable travel-time information. This pilot project intends to demonstrate the capabilities of a traffic data system based on cellular phone tracking. As part of the demonstration, traffic data provided by a private contractor through cell phone tracking will be evaluated and compared with data from alternative sources. The alternative travel-time data include freeway travel-time information derived from inductive loop detector data, travel-time runs using instrumented probe vehicles, and “ground truth” travel times determined by matching license plates on recorded video. The researchers will then conduct a statistical data comparison and analysis and summarize results in the final report to the Minnesota Department of Transportation.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2007022

Responding to the Unexpected: Development of a Dynamic Data-Driven Traffic Operation Model for Effective Evacuation

Status: *In progress*

Recent natural and man-made disasters around the world have stressed the need for effective evacuation traffic management to maximize use of the transportation system. This research is responding to the need for innovative evacuation operation strategies and for evaluation of current evacuation planning models with advanced traffic modeling techniques. The goal is to advance the state of the art in evacuation modeling from the planning stage to real-time, dynamic operation by developing a suite of conceptual, analytical, and simulation tools for evacuation traffic management.

To squeeze additional capacity out of current traffic networks and fully utilize available network capacity within the evacuation time window, this research is examining the idea of adaptive adjustment traffic operation strategies by comparing the difference between system-optimal states and real-world observations. The system-optimal states will be generated using a reference model in a rolling horizon scenario, and researchers will develop a feedback control mechanism using the data from real-world observations. The model will be tested and evaluated using microscopic traffic simulation software with the network data set from the Minneapolis-St. Paul road network.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2007045

Development of Algorithms for Travel-Time-Based Traffic Signal Timing (Phase I)

Status: *Newly funded*

This research is in response to a Mn/DOT request for algorithms for travel-time-based traffic signal timing. With nationwide demonstrations of vehicle infrastructure integration (VII) and cell phones used as traffic probes, travel times may someday be a param-

eter available on roadways in real time. The USDOT envisions that one future use of real-time travel times may be to select timing plans for traffic signals. However, the theory on how to relate current real-time travel times to desired traffic signal timing does not exist.

This project will study this relationship and develop algorithms that use real-time travel-time data for traffic signal control purposes. With available travel time, intersection delays can be estimated, and it is possible to use movement delay for green time split and offset. In addition, the researchers also plan to investigate travel-time data requirements for such applications. Data requirements include the spatial and temporal resolutions, time latency, and data accuracy. With different data requirements, it is likely different algorithms should be developed to relate travel time with traffic signal timing.

Project URL: www.its.umn.edu/Research/Proposed/200802.html



■ **Henry Liu and Panos Michalopoulos**, Department of Civil Engineering

Development of a Real-Time Arterial Performance Monitoring System Using Traffic Data Available from Existing Signal Systems

Status: *In progress*

See page 22 for coverage of this project.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2007035

■ **Panos Michalopoulos**, Department of Civil Engineering

Access to Destinations: Twin Cities Metro-Wide Traffic Micro-Simulation: Feasibility Investigation

Status: *In progress*

As traffic demand increases, the economic importance of effective traffic management is increasingly evident. Well-designed and well-managed roadway systems reduce the cost of transporting goods, cut energy consumption, and save countless person-hours of driving time. To reduce congestion, many countries have been investing heavily in road construction as well as improving their traffic control systems. However, since traffic management improvements are costly, alternatives must be carefully evaluated for their impact on the entire system. Traditional methods of design and evaluation have relied on empirically supported guidelines such as the Highway Capacity Manual. These methodologies work well for isolated systems such as freeway interchanges that are sufficiently distant from each other, but their use has encouraged the common practice of evaluating traffic management systems in isolation rather than as parts of a system. Several metropolitan areas—including Toronto, London, Barcelona, Tokyo, and Paris—have realized this problem and have invested in the creation of metro-wide simulation systems; some larger regions, such as the German state of Hessen, have also taken this path. In the United States, preliminary investigations of metro-wide simulation models have begun in Milwaukee, Wis., the San Francisco Bay area, and Orange County in California. Such undertakings are not simple. Microscopic simulation requires a lot of information even for a small-scale application. The objective of this first phase toward the creation of a Twin Cities metro-wide microscopic simulation model is to evaluate the feasibility of such a program, taking into account local needs and capabilities.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2006051

Development of Real-Time Traffic Adaptive Accident Reduction Measures for the I-94/35W Commons Section

Status: *In progress*

According to Mn/DOT statistics, the westbound section of Interstate 94 at the I-94/35W commons south of downtown Minneapolis, Minnesota, has the highest crash rate in the Twin Cities. In an ongoing project related to crash prevention and the detection of crash-prone conditions, this site was heavily instrumented and observed, and detailed traffic measurements were analyzed. Data showed that these incidents occur under certain traffic conditions that can be detected prior to a crash.

This project is capitalizing on the results of the ongoing research by utilizing the available techniques for the early detection of crash-prone conditions to develop a traffic calming/driver warning system for reducing crashes. The system will be specifically tuned for maximum effectiveness on the I-94 section. The goals of this first phase are to define relevant solutions based on available technologies and site characteristics; implement the designs in an appropriate visualization environment; and perform a preliminary evaluation and prioritization of the proposed solutions. The most promising solutions will later undergo thorough human factors analysis (e.g., driving simulator studies). Work will commence on the development of new and improved microscopic simulation models. These models should overcome the current model deficiency—the inability to emulate unsafe driving behavior—and will be capable of evaluating traffic safety solutions based on intelligent transportation systems approaches.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2005056

Employment of Traffic Management Laboratory for the Evaluation and Improvement of Stratified Metering Algorithm (Phase III)

Status: *In progress*

Evaluation results from a previous phase of this research demonstrated that the stratified zone metering (SZM) strategy was generally beneficial. However, freeway performance degraded by reducing ramp delays. Therefore, it is desirable to improve the effectiveness of the current SZM control.

There were two objectives for this project. One was to improve the control logic of the current SZM strategy. This was accomplished through an estimation algorithm for the refined minimum release rate. The simulation results indicate that the improved SZM strategy is very effective for postponing and decreasing freeway congestion while resulting in smoother freeway traffic flow compared to the current strategy. The second objective was to improve the current queue-size estimation. Depending on the counting error of queue and passage detectors, freeway ramps are classified into three different categories, and different methods are applied, respectively, for improved queue-size estimation. The surveillance video data were recorded, and results indicate that the proposed methods can greatly improve the accuracy of queue-size estimation compared to the current methodology. In addition, the proposed method was evaluated by microsimulation, results of which indicate the performance of the freeway mainline was significantly improved, and the total system performance is better, than with the original SZM control.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2005044

Enhanced Micro-Simulation Models for Accurate Safety Assessment of Traffic Management ITS Solutions

Status: *In progress*

In recent years, much research has been conducted in the development, implementation, and evaluation of various innovative ITS technologies aiming to improve traffic operations and driving safety. As part of the

process, microsimulation has become an increasingly indispensable tool for assisting in system design and evaluation. As such work has proceeded, it has become clear that existing microsimulation models are deficient when evaluating sophisticated safety-related ITS techniques because they target only normal driving behavior under typical traffic flow conditions. Vehicle collisions are artificially excluded from simulation. To date, realistic car-following models pertinent to the true nature of driver behaviors that take into account subjective judgments, misperceptions, and randomness in driver's reactions are lacking.

The goal of this research is to expand, or create new if necessary, car-following models capable of replicating real-life car-following behaviors with all its risks and imperfections. The research will capitalize on the detailed car-following data collected in Germany, Japan, and the Twin Cities to assist with model development, calibration, and validation. Concepts such as less-than-adequate perception-response times, stochastic selection of desired space headways, and driver inattention and misperception will be introduced to the improved (or new) car-following model. Research outcomes will help advance knowledge of real-life car-following behavior while improving microsimulation modeling to help assess freeway safety concepts at the high-definition microscopic level.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2006043

Transportable, Low-Cost Traffic Data Collection and Wireless Surveillance Device for Rapid Deployment for Intersections and Arterials

Status: *Newly funded*

In spite of recent advances in technology, most traffic engineering studies at intersections and arterial streets are still performed manually. This is especially true for measuring turning volumes at intersections. This is a task that needs to be performed at regular intervals for retiming traffic

signals in order to minimize delays, stops, excess energy consumption, and pollution levels as well as to improve coordination and reduce congestion levels. Not only are manual measurements subject to errors but also, because of time, logistics, and cost considerations, they are usually performed only when absolutely necessary (e.g., as a result of reconstruction, excessive public complaints, congestion, unusually high accident rates, or other emergencies).

This project aims to develop and test a rapidly deployable turnkey, low-cost, non-intrusive, stand-alone video data-collection and surveillance system. Such a system will automatically measure traffic volumes, turning movements, speeds, and other characteristics to improve and study traffic operations at intersections and urban arterials. The device will have additional features needed for visual verification such as video recording and wireless video for remote surveillance.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2008011

Panos Michalopoulos and John Hourdos, Department of Civil Engineering Accident Prevention Based on Automatic Detection of Accident-Prone Traffic Conditions (Phase I)

Status: *Completed*

The goal of this research was to provide low-cost innovative solutions for identifying the causes of crashes in crash-prone freeway locations and to develop a crash avoidance and prevention system. This was accomplished by simultaneously video-recording crashes and extracting raw traffic detector measurements utilized in understanding crash dynamics as well as the causes of crashes.

New traffic measurements such as traffic pressure, quality of flow, and others that can be derived from the raw data were defined, extracted, and analyzed to determine whether they

were related to crashes and to identify crash-prone condition patterns. Based on this, a proactive algorithm for warning drivers and TMC operators was developed. This algorithm can be the cornerstone of a system aimed at calming traffic flow and effectively preventing crashes. The developed algorithm successfully established a relationship between fast evolving real-time traffic conditions and the likelihood of a crash. Testing was performed in real time during 10 days not previously used in the model development, under varying weather and traffic conditions. The crash likelihood model and the detection algorithm succeeded in detecting 71 percent of the crashes accompanied by a 5.4 false-decision rate. Most important, the algorithm is based on raw detector data (e.g., speed, occupancy, volume, time headway) that can be extracted from conventional sensors such as loops. In this manner the resulting system can be low-cost and implementable in both urban and rural settings.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2003031

Panos Michalopoulos and Henry Liu, Department of Civil Engineering Employment of Traffic Management Laboratory for the Evaluation and Improvement of Stratified Metering Algorithm (Phase IV)

Status: *In progress*

This project continues the work of the currently ongoing project related to improving and evaluating the effectiveness of Mn/DOT's stratified zone metering (SZM) strategy.

From field operations and offline evaluation, the improved SZM strategy was found to be effective in meeting the maximum ramp delay objective, at the expense of freeway and system performance, as expected. However, the strategy can be further improved in several ways. This research aims to address the most promising improvements by developing an efficient and streamlined optimization methodology

to identify the best control parameter set for the strategy based on site and demand characteristics. These parameters are currently estimated by trial and error and are constant for the entire freeway system.

In addition, this research aims to produce a more reliable ramp demand-prediction technique and an improved location-dependent bottleneck capacity estimation methodology based on real-time traffic conditions. All the enhancements and improvements to the SZM strategy will be computationally feasible, and their effectiveness will be assessed by comparing it with the current prototype version through microscopic simulation. This will avoid costly, uncertain, and time-consuming field-testing as well as disruption of traffic flow.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2006074

Social and Economic Policy Issues Related to ITS Technologies

Frank Douma, Hubert H. Humphrey Institute of Public Affairs
[Developing ITS to Serve Diverse Populations](#)

Status: Completed

See page 25 for coverage of this project.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2004047

Improving Car Sharing and Transit Service with ITS

Status: In progress

In partnership with the Minnesota Department of Transportation and the University of Minnesota's Center for Transportation Studies, the State and Local Policy Program at the University of Minnesota's Humphrey Institute of Public Affairs has performed a wide range of previous research regarding development of transportation policies enabled by intelligent transportation systems (ITS). Most recently, that research examined how ITS can serve Minnesota's increasingly diverse population and the increasingly diverse types of trips that population takes. Findings from that research showed that car sharing and advanced traveler information services (ATIS) were two ITS applications that could offer significant benefits. This research project focuses on developing policies to allow potential users to maximize the benefits of these services.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2006013

TechPlan—ITS and Privacy: Developing New Rules for Virtual Roads

Status: Newly funded

This project will explore federal and state privacy laws as they apply to modern technology and transportation systems. The research will investigate the legal status with regard to privacy laws of various ITS technologies, particularly traffic management and in-vehicle applications. It will address privacy with respect to both government entities such as law enforcement and private entities such as insur-

ance companies. The research should help ITS developers and providers construct and deploy ITS technologies that avoid or survive legal challenges and that comply with public expectations of privacy. It may also help legal professionals and public policymakers update privacy law to take into account the development of ITS.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2008010

Thomas Horan, Hubert H. Humphrey Institute of Public Affairs and Claremont Graduate University
[TechPlan—ITS and Transportation Safety: ITS and EMS System Data Integration for Safety, Emergency, and Crisis Response Planning](#)

Status: Newly funded

SAFETEA-LU legislation mandates the creation of Strategic Highway Safety Plans (SHSPs) that are collaborative, comprehensive, and based on accurate and timely safety data. Transportation planners are challenged to identify and use a range of new data sources beyond traditional crash data systems; they must also identify strategies for sharing a wide range of data across multiple agencies to support evidence-based safety planning and emergency response. Likewise, while ITS has long promised safety benefits, the extent to which it is capable of providing safety-related data for assessment and planning purposes has not been emphasized.

This research project will examine the linkages between ITS systems and the SHSP, focusing on the role of ITS and emergency medical services (EMS) to provide timely and visually oriented safety data for system performance improvement and informed decision making. It will also consider how these systems might be adapted to the context of emergency/crisis planning.

Methods that will be employed in this project include analysis of existing data from safety reports (SHSP), ITS, EMS, and health information systems.

TechPlan: Transportation Planning and Policy Applications of ITS-Related Technologies

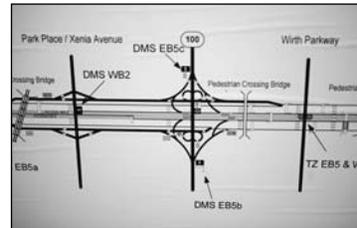
TechPlan: Transportation Planning and Policy Applications of ITS-Related Technologies is a research, education, and outreach program that addresses the ITS Institute's high-priority transportation application area of societal issues related to ITS technologies. It is housed at the Hubert H. Humphrey Institute of Public Affairs's State and Local

Policy Program and funded by the ITS Institute at the Center for Transportation Studies. The overall objective of TechPlan is to investigate and propose policies that will take advantage of the increased presence of intelligent transportation systems (ITS) and ITS-related information and communication technologies (ICT) in the planning of transportation

and related infrastructure. The work will include analysis of skills and challenges related to planning and managing regional and local transportation and infrastructure systems from a technological perspective, including identifying opportunities for training for both professionals and those seeking graduate degrees in the field.

ITS, EMS, and health information system data will be used to develop and populate a geospatial model aimed at enhanced safety and emergency response decision support. Analysis of these data sets will provide a multi-layered understanding of statewide safety performance features. Feedback analysis from policymakers, planners, public health officials, EMS, safety engineers, and citizens will inform the usability, success factors, and value proposition of an enhanced ITS and EMS data system. Policy and planning recommendations, including those for safety and crisis planning, will be constructed, presented, and reported.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2008012



David Levinson, Department of Civil Engineering

[TechPlan—The Role of Social Networks and ICT on Destination Choice](#)

Status: Newly funded

This research proposes to investigate the impact of traditional

social networks and information and communications technology (ICT) on travelers' destination choices. The extent to which social networks and ICT affect where destinations are located is an area that is gaining more attention. This research will focus on two areas of interest. The first is the role that social networks and communication technologies play in establishing individuals in long-term arrangements such as finding their work. The second is the role that social networks play in day-to-day activities that individuals choose to engage in outside of their work. By using a survey about how people identified their current job, the physical locations of their social activity destinations, and the social networks and communication technologies they adopt to mediate both these long- and short-term decisions, this study aims to advance the researchers' understanding of the role of social networks in everyday travel decisions. In two phases this project hopes to develop models that incorporate important elements of social networks and ICT for different trip purposes.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2008008

Kevin Krizek, Hubert H. Humphrey Institute of Public Affairs (formerly)
[Understanding the Potential Market of Metro Transit Ridership and Services](#)

Status: Completed

Ridership is a key element in the transit industry. Conventional travel analysis focuses on two types of transit users: captive and choice riders. Captive riders are typically those who lack an alternative to transit; they therefore use it as their primary mode of transportation to reach their destination. Choice riders are those who have realistic alternatives (e.g., driving) but choose to use transit for various trips. Service reliability and availability affects the ridership of both populations. However, it is assumed that substantial increases in ridership are usually derived only from choice riders. Populations not using transit may be further considered as two distinct populations: auto captives and potential riders. Auto captives are mainly auto users who don't have transit as a potential mode of transportation or would not even realistically consider using transit. Potential riders are currently not using transit for certain reasons and/or concerns, but may consider using transit based on certain criteria.

This research analyzed results from two surveys conducted in the Twin Cities metropolitan region: one of existing riders and the other of non-riders. The aim was to understand the characteristics of both captive and choice riders, with an eye toward the factors that can increase ridership of the latter population. This research classified riders and non-riders differently from previous research. In addition to the captivity of modes, the

classification considers regularity of commuting. Accordingly, transit riders are classified as one of four categories: captive riders with regular commuting habits, captive riders with irregular commuting habits, choice riders with regular commuting habits, and choice riders with irregular commuting habits. Similarly, there are four types of non-riders: auto captives with regular commuting habits, auto captives with irregular commuting habits, potential riders with regular commuting habits, and potential riders with irregular commuting habits. Using the survey data to uncover such populations, this research then commented on how using advanced forms of technology could increase the ridership from various populations.

Project URL: www.its.umn.edu/research/projectdetail.pl?id=2004060



■ **Elizabeth Wilson and Kevin Krizek**, Hubert H. Humphrey Institute of Public Affairs, and **Julian Marshall**, Department of Civil Engineering [TechPlan—School Travel and the Implications for Advances in Transportation-Related Technology](#)
Status: *Newly funded*

This project will evaluate how children’s school travel has been affected by new information and transportation technologies and by changes to education and transportation policy. How can ITS technology be effectively employed to address school travel, and how does its impact vary by age

of student and travel distance? How can children’s travel to school be most accurately simulated—accounting for issues of school choice—to address congestion and safe routes to school? This project will begin to address such questions.

A basic understanding of how children travel to school and which factors influence parents’ decisions for school travel mode is critical for the deployment of innovative information and transportation technologies but has not yet been established. This research will establish accurate baseline information to evaluate how new forms of information, emerging transportation technologies, and other possible changes to education or transportation policy could affect children’s school travel. First, information will be collected on where children go to school and how they get there. Parents in three local school districts will be surveyed to learn: (1) the geography of where children live and attend school, (2) parent concerns about school travel and how technology may alleviate them, (3) travel modes used for school travel, (4) factors influencing travel and school choice, and (5) relevant socio-demographic information.

In collaboration with the Association of Metropolitan School Districts and local school districts, surveys will be distributed to parents. Distances traveled by each transportation mode will be mapped using Geographic Information Systems (GIS). Then the project will evaluate parents’ travel choices and the district’s use of buses, and compare travel behavior among districts with differing school-choice policy. This study will inform future investigations of emerging technological developments by providing essential information about which technologies might provide the most realistic utility for school transportation.

Project URL: www.its.umn.edu/research/projectdetail.html?id=2008009



Selected Publications



Lee Alexander

Alexander, L., Cheng, P., Donath, M., Gorjestani, A., Menon, A., Newstrom, B., Shankwitz, C., Ward, N., and Starr, R. (2007). Gap acceptance analysis for a rural unsignalized intersection.

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Panos Michalopoulos

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Kevin Krizek

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Rajamani, R., and Cho, Y.M. (2006). An upper bound on the maximum stability radius achievable by state feedback. *ASME Journal of Dynamic Systems, Measurement and Control*, vol. 128, no. 3.

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Nikos Papanikolopoulos

Ribnick, E., Atev, S., Masoud, O., Papanikolopoulos, N., and Voyles, R. (2007). Real-time detection of camera tampering. *Proceedings of the IEEE International Conference on Advanced Video and Signal Based Surveillance.*

Smith, P., Ward, N.J., and Waterman, M. (2006). Driving aggression in forensic and non-forensic populations; relationships to self-reported levels of aggression, anger, and impulsivity. *British Journal of Psychology*, 97.

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Veeraraghavan, H., and Papanikolopoulos, N. (2006). Deterministic sampling-based switching Kalman filtering for vehicle tracking. *Proceedings of the IEEE ITSC 2006 Intelligent Transportation Systems Conference.*

Veeraraghavan, H., Schrater, P., and Papanikolopoulos, N. (2006). Deterministic sampling-based switching Kalman filtering for vehicle tracking. *Computer Vision and Image Understanding.*

Veeraraghavan, H., Schrater, P., and Papanikolopoulos, N. (2006). Robust target detection and tracking through integration of color, motion, and geometry. *Computer Vision and Image Understanding*, 103(2).

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Ward, N.J., Shankwitz, C., Gorjestani, A., Donath, M., de Waard, D., and Boer, E. (2006). An evaluation of a lane support system for bus rapid transit on narrow shoulders and the relation to bus driver mental workload. *Ergonomics*, 49.

Xin, W., Hourdos, J., and Michalopoulos, P.G. (2006). Evaluation of a new integrated freeway ramp control strategy. *Transportation Research Record*, no. 1959.

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Yonas, A., and Zimmerman, L. (2006). Improving the ability of drivers to avoid collisions with snowplows in fog and snow. Report no. Mn/DOT 2006-29.



Rajesh Rajamani

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Yu, X., Rajamani, R., Stelson, K.A., and Cui, T. (2006). Active control of sound transmission through windows with carbon nanotube based transparent actuators and moving noise source identification. *Proceedings of the American Control Conference, 2006.*

Yu, X., Zhu, H., Rajamani, R., and Stelson, K.A. (2006). Acoustic transmission control using active panels: an experimental study of its limitations and possibilities. *Proceedings of the 2006 International Symposium on Flexible Automation.*

Zhang, L., and Levinson, D. (2007). The economics of transportation network growth. *Essays in Transportation Economics*. Vicente Inglada (ed.); Edward Elgar Publishers.

Zou, X., and Levinson, D. (2006). A multi-agent congestion and pricing model. *Transportmetrica*, 2(3).

Selected Presentations

Alexander, L., Cheng, P., Gorjestani, A., Menon, A., Newstrom, B., Shankwitz, C., Donath, M. (2006). Minnesota Mobile Intersection Surveillance System. IEEE Intelligent Transportation Systems Conference, Toronto, Canada.

Boer, E.R., de Bruin, J., Abbink, D., Ward, N.J., and Manser, M.P. (2006, October). Are drivers with small feet or long legs at greater risk for rear end collisions? 50th Annual Human Factors and Ergonomics Society Meeting, San Francisco, Calif.

Boer, E.R., Manser, M.P., Ward, N.J., and Kuge, N. (2006, July). Impact of an ecologically valid haptic driver support on visual sampling and multi-tasking strategies. Vision in Vehicles Eleventh Annual International Conference, Dublin, Ireland.

Creaser, J.I., Ward, N.J., Shankwitz, C., and Boer, E. (2007, January). An overview of the University of Minnesota research methodology: study to determine motorcycle impairment at different BAC levels. 86th Annual Meeting of the Transportation Research Board, Washington, D.C.

Creaser, J. (2006, November). Evaluation of Minnesota's Operation NightCAP. Toward Zero Deaths Conference, Duluth, Minn.

Donath, M. (2006, April). Human centered technology to reduce road fatalities. Field Hearing of the National Surface Transportation Policy and Revenue Study Commission, University of Minnesota, Minneapolis.

Donath, M. (2006, November). Cooperative intersection collision avoidance system (CICAS): stop sign assist. Towards Zero Death Conference, Duluth, Minn.

Donath, M. (2006, October). Future directions in RFID application and research in transportation. TRB Conference on Research Opportunities in RFID

Transportation Applications, National Academies Keck Center, Washington, D.C.

Donath, M. (2006, December). Reducing fatalities and managing congestion: emerging technologies enabling "Outside the Box" Solutions. Port Authority of New York/New Jersey.



Frank Douma

Douma, F. (2006, September). Developing ITS to serve diverse populations. Advanced Transportation Technologies Seminar Series, University of Minnesota.

Douma, F. (2007, May). Twin Cities bus-only shoulders—why do they work? CTS 18th Annual Transportation Research Conference, St. Paul, Minn.

Harder, K.A. (2006, November). Using visualization and experimentation in context sensitive design. Invited talk at Context Sensitive Solutions in Practice: What You Need to Know—An American Society for Civil Engineers Specialty Conference, Atlanta, Ga.

Harder, K.A. (2006, November). Evaluation of the Minnesota Speed Management Project (HEAT). 2006 Toward Zero Deaths Conference, Duluth, Minn.

Harder, K.A. (2007, February). Stopping behavior at real-world stop-controlled intersections with and without in-lane rumble strips. CTS Transportation Safety and Traffic Flow Research Council, Minneapolis, Minn.

Katmale, H., and Wyrick, D.A. (2006, October). "Difficulties in Fleet Management: Intangible Factors, Information Overload, and Data Integrity." 27th Annual National Conference of the American Society for Engineering Management, Huntsville, Ala.

Kokotovich, A. (2007, January). Thinking privacy with intelligent transportation systems: policies, tools, and strategies for the transportation professional. 86th Annual Meeting of the Transportation Research Board, Washington, D.C.

Liao, C.F., and Davis, G. (2007, January). Simulation study of a bus signal priority strategy based on GPS/AVL and wireless communications. 86th Annual Meeting of the Transportation Research Board, Washington, D.C.

Liu, H., and He, X., (2007, June). Bi-level variational inequalities model and solution algorithm for link-based road pricing. 11th World Congress on Transportation Research (WCTR), Berkeley, Calif.

Liu, H., He, X., and He, B. S. (2007, January). Method of successive weighted averages (MSWA) and self-regulated averaging schemes for solving stochastic user equilibrium problem. 86th Annual Meeting of the Transportation Research Board, Washington, D.C.

Liu, H., and Ma, W., (2007, January). Time-dependent travel time estimation model for signalized arterial network. 86th Annual Meeting of the Transportation Research Board, Washington, D.C.

Liu, H., He, X., and Ban, J. (2007, January). A cell-based many-to-one dynamic system optimal model and its heuristic solution method for emergency evacuation. 86th Annual Meeting of the Transportation Research Board, Washington, D.C.

Liu, H., Jabari, S., and Ma, W. (2007, January). Peak spreading methodology for future scenario evaluations using microsimulation. 86th Annual Meeting of the Transportation Research Board, Washington, D.C.

Liu, H., He, X., and He, B.S. (2006). Box-constrained inverse variational inequality for link-based road pricing with limited

information. 2006 INFORMS Annual Meeting, Pittsburgh, Penn.



Henry Liu

Assignment, University of Leeds, United Kingdom.

Liu, H. (2006). A cell-based dynamic system optimal model and its heuristic solution method for orderly emergency evacuation. Northwestern University Transportation Center seminar, Evanston, Ill.

Liu, H. (2006). Model-based prescriptive control for real-time emergency evacuation. Department of Civil Engineering presentation, Tsinghua University, Beijing, China.

McGehee, D., Anton, D., Fethke, N., Meyers, A. Boer, E., Manser, M, and Ward, N. (2007). The use of EMG in immersive driving simulation for crash avoidance research: lessons learned. Driving Simulation Conference—North America. Iowa City, Iowa.

Ma, W. (2007, January). Time-dependent travel time estimation model for signalized arterial network. 86th Annual Meeting of the Transportation Research Board, Washington, D.C.

More, A. (2007, May). Identifying best practices in rural transportation safety: a national analysis. CTS 18th Annual Transportation Research Conference, St. Paul, Minn.

Morris, T., Donath, M., and Hourdos, J. (2007, January). A predictive study of use impacts on the Denali park road. 86th Annual Meeting of the Transportation Research Board, Washington, D.C.

Patterson, T. (2007, May). Examining rural safety: A Minnesota case study. CTS 18th Annual Transportation Research Conference, St. Paul, Minn.

Wacker, J. P., Wang, X., Brashaw, B.K., and Ross, R.J. (2006, August). Estimating bridge stiffness using a forced-vibration technique for timber bridge health monitoring. NDE Conference on Civil Engineering: A joint conference of the 7th Structural Materials Technology: NDE/NDT for Highways and Bridges and the 6th International Symposium on NDT in Civil Engineering, St. Louis, Mo.

Ward, N.J. (2007, January). Intelligent technology and traffic safety. Minnesota State Senate Transportation Committee, Policy and Budget Division, St. Paul, Minn.

Ward, N.J. (2006, October). Alcohol and traffic safety. Human Factors Workshop: Driver Behavior and Safety, University of California, Berkeley, Calif.

Ward, N.J. (2006, October). Traffic safety culture. Human Factors Workshop: Driver Behavior and Safety, University of California, Berkeley, Calif.

Ward, N.J. (2006, November). The battle for zero traffic fatalities: Musings of a psychologist. 2006 Toward Zero Death Conference, Duluth, Minn.

Ward, N.J. (2006, July). Setting the safety agenda for rural traffic safety. 2006 Summer Institute of the Center for Excellence in Rural Safety, Humphrey Institute, Minneapolis, Minn.

Wu, X. (2007, January). Improving queue size estimation for Minnesota's stratified zone metering strategy. 86th Annual Meeting of the Transportation Research Board, Washington, D.C.



The ITS Institute's education activities consist of a multidisciplinary program of coursework and experiential learning that supports the Institute's theme. The educational program includes the disciplines of computer science and engineering, electrical and computer engineering, civil engineering, mechanical engineering, human factors, public policy, and others.

By supporting and sponsoring a variety of educational initiatives for students, the Institute is generating interest in its core ITS science and technologies. These initiatives include developing new curriculum and courses, involving undergraduate and graduate students in research projects, sponsoring students to attend national conferences, giving awards that recognize outstanding students, and offering research assistantships to help attract more students to the study of transportation. This section of the annual report highlights some of our efforts in the area of education.

Seminar series highlights varied work in ITS

This was the sixth year that the Institute sponsored the multidisciplinary Advanced Transportation Technologies seminar series at the University. These seminars feature presentations by local and national researchers addressing diverse areas of ITS research such as traffic management



Rob Foss, University of North Carolina, with Institute director Max Donath. Foss discussed how teenage and other driver behavior contributes to crashes during an advanced transportation technology seminar.

and modeling, human factors, intelligent vehicles, sensing, controls, communications, and policy issues as they relate to road and transit-based transportation. At the seminars, researchers report on recent findings from their work and bring new information to the ITS community.

This seminar series, which is a required course in the University's Graduate Certificate Program in Transportation Studies, is offered as a one-credit graduate-level course, or attendees can earn one professional development hour for each seminar. Presentations are recorded onto DVD and are available for loan by request.

The past year's seminars were:

- ◆ "Developing ITS to Serve a Diverse Population," Frank Douma, assistant director, State and Local Policy Program, Hubert H. Humphrey Institute of Public Affairs
- ◆ "Addressing the Driver's Role in Motor Vehicle Crashes: Past Failures, Future Successes," Rob Foss, senior research scientist and manager of alcohol studies, Highway Safety Research Center, University of North Carolina
- ◆ "Development and Evaluation of a Novel Traffic-Friendly Commuter Vehicle," Rajesh Rajamani, professor, Department of Mechanical Engineering
- ◆ "Toward Scalable and Privacy-Aware Location-Based Services in Transportation," Mohamed Mokbel, assistant professor, Department of Computer Science and Engineering
- ◆ "Portable Video Data Processor," Nikolaos Papanikolopoulos, professor, Department of Computer Science and Engineering
- ◆ "Collective Responsibility in Freeway Rear-end Collisions—An Application of Causal Models," Gary Davis, professor, Department of Civil Engineering

- ◆ "Where is the U.S. VII Program Going?" Ron Heft, senior principal engineer, Nissan Technical Center-North America

University team places high at annual Intelligent Ground Vehicles Competition

A year's worth of hard work paid off for a team of University students at the 15th annual Intelligent Ground Vehicles Competition in Rochester, Michigan. Mechanical engineering master's students Eddie Arpin and Rich Hoglund, along with computer science doctoral student Seth Berrier, took second and fourth place in two of the June competition's three categories with their robot vehicle, AWESOM-O. There were 36 other teams in this year's competition.

Arpin and Hoglund became involved with the project when they were students of Professor Max Donath, who told his class about the competition. The two contacted Berrier and began planning their vehicle in June 2006.



Seth Berrier, Rich Hoglund, Eddie Arpin, and Max Donath with AWESOM-O, the intelligent ground vehicle the team built.



At the competition, the U of M team's vehicle maneuvered through an obstacle course during the autonomous challenge.



CTS associate director Cheri Marti, ITS Student of the Year Adam Kokotovich, and Lee Munnich



Nic Ward, Matthew J. Huber award recipient Mick Rakauskas, and Marti



Marti, Matthew J. Huber award recipient Xiaozheng He, and Henry Liu

With funding from the ITS Institute, the team worked to design a vehicle that would meet the contest's criteria. There were two primary challenges. The autonomous challenge, in which the team placed second, required the vehicle to move around an outdoor obstacle course under a prescribed time limit while traveling no faster than 5 mph and avoiding obstacles on the track. Judges ranked the vehicles based on the adjusted time each one took to complete the course. The navigation challenge, in which the team placed fourth, required the vehicle to travel from a starting point to a number of target destinations and return to home base, given only the coordinates of the targets in latitude and longitude. Finally, the vehicles were judged in a design competition based on a written report, oral presentation, and examination of the vehicle.

The team outfitted the 220-pound vehicle with several features. A camera served as the robot's "vision," enabling it to see objects and lines painted on the track. Since that provided only 2-D vision, AWESOM-O was also outfitted with a laser measurement system that allowed the vehicle to know what objects were around it and how close they were. In addition, the robot also used GPS and a digital compass for location and vehicle heading information.

The team's placement this year is significantly higher than that of the last team that represented the University in 2005, which placed 8th in the autonomous challenge and 11th in the navigation challenge.

"We were happy with the quality of our robot compared with the other teams," Arpin said of his team's vehicle. "I think it went as well as it could, since it was our first year in the contest." Donath, who served as the team's adviser, was pleased with the team's performance. "They worked very well as a team. I've really never seen three people work so well together."

Arpin said the team is considering entering the competition again next year, but would need to recruit a few more team members, as the project would be too big for the three of them to undertake again.

Kokotovich named Student of the Year

Adam Kokotovich received the ITS Institute's 2006 Outstanding Student of the Year Award at the annual TRB meeting in Washington, D.C., in January. Kokotovich was also recognized at the annual Center for Transportation Studies award luncheon and ceremony, held in Minneapolis in April. Kokotovich is working toward his master's degree in science, technology, and environmental policy. His research focused on emerging technologies and their social and ethical implications, including privacy concerns related to some ITS technologies. His advisor, Lee Munnich of the Humphrey Institute, said Kokotovich did "more than an outstanding job" on the privacy-related research. Kokotovich said he was pleased to be involved so that "the full potential of ITS technology can be realized."

Huber Award goes to ITS students

The Matthew J. Huber Award for Excellence in Transportation Research and Education was awarded this year to two students involved in ITS research. Michael "Mick" Rakauskas, a research fellow with the HumanFIRST Program and a Ph.D. candidate in the psychology department, was nominated by Nic Ward, director of HumanFIRST. Ward said Rakauskas "balanced lots of responsibility with grace and humor."

The other recipient was Xiaozheng "Sean" He, a second-year graduate student pursuing both M.S. and Ph.D. degrees in the Department of Civil Engineering. He is advised by assistant professor Henry Liu, who said He's unique background in mathematics helped in tackling transportation network modeling.

TEL grant brings traffic signal simulators online

Work began in June 2007 on a project that Henry Liu, assistant professor of civil engineering, envisions as an "active textbook." Through an interactive Web-based traffic signal simulator dubbed OASIS (Online Application of Signalized Intersection Simulation), transportation students will be

able to realistically experiment with complex signal logic without worrying about banging up cars. Until now, the alternative for students has been textbook reading and calculating equations, but with OASIS they'll develop different strategies and watch how traffic reacts in real time. After Chen-Fu Liao, senior systems engineer with the Minnesota Traffic Observatory, develops the module, the simulator will go before one of Liu's classes for testing and evaluation in March 2008.

A \$10,000 Technology-Enhanced Learning grant (matched by the ITS Institute), along with additional civil engineering department funding, will support the year-long project. The University of Minnesota's Academic Affairs and Information Technology offices award the grant each year to select university instructors with proposals to integrate technology and education.

Over the last year, Liao and associate professor of civil engineering David Levinson developed a similar project, a Web-based roadway geometry design tool they dubbed ROAD (Roadway Online Application for Design). ROAD lets students design and easily modify a roadway design with given economic and environmental parameters. A 3-D roadway geometry model can be generated by the software to allow students to put themselves in the driver's seat and drive through the designed roadway at a maximum speed. ROAD was deployed and tested in civil engineering undergraduate classes in spring and fall semesters of 2006 and spring 2007.

Institute funds student travel

This past year, the Institute sponsored eight University of Minnesota students to attend and participate in the national meeting of the Transportation Research Board in Washington, D.C. The students were Xiaozheng He, Saif Jabari, Wenteng Ma, Ryan Wilson, Xinkai Wu, Feng Xie, Wuping Xin, and Shanjiang Zhu.

In addition, Mick Rakauskas was given a travel award to attend and present at the 4th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design.

Speaker addresses teen driving challenges, potential solutions

The ITS Institute sponsored the CTS Winter Luncheon in February, where speaker Bruce Simons-Morton discussed ways technology may help improve teenage driving.

Simons-Morton is chief of the Prevention Research Branch in the Division of Epidemiology, Statistics, and Prevention Research at the National Institute of Child Health and Human Development, National Institutes of Health.

Inexperience is the root of the young driver problem, and one of the most promising ways to solve it is graduated licensure, Simons-Morton said. Used in many states, GDLs impose limits on night driving, passengers, and other behaviors.

Another solution is more effective parent management, such as limiting night driving, passengers, and the types of roads novices can use (to those under 55 mph).

Institute director Max Donath, who introduced the presentation, and his research team are also conducting research on teen driving.



The Institute could not accomplish its goals without the transfer of its expertise and research results to local, national, and international audiences for use in real-world applications. Technology transfer also communicates to the world who we are, raising the profile of the Institute and its research, and serves to educate students, policymakers, and the general public about ITS issues and solutions.

Our efforts in this area are far-ranging in order to reach a broad and diverse audience of researchers, students, practitioners, policymakers, and others among the general public. Over the past year, we have provided tours and demonstrations of our research and facilities, sponsored seminars, published printed pieces, and redesigned and updated our Web site. But perhaps the most direct method of transferring technology has been to send graduating students out into the workforce.

This section of the annual report highlights some of our technology transfer activities over the past year.

USDOT officials hear local researchers comment on transportation policy

University researchers and other expert witnesses testified at a field hearing convened by the National Surface Transportation Policy and Revenue Study Commission April 18 and 19 on the University of Minnesota campus.

The commission, chaired by Secretary of Transportation Mary Peters (pictured at left), conducted a series of field hearings around the country to hear testimony from transportation experts and members of the public.

ITS Institute director Max Donath told the commission that technology has an important role to play in reducing fatalities and serious injuries on the nation's roads, but it must be combined with a strong policy emphasis on improving safety.

While on campus, the commissioners visited the HumanFIRST Program's lab, where director Nic Ward put them behind the wheel of the program's advanced immersive driving simulator and showed how the system is being used to develop crash-reduction strategies tailored to the

specific problems and needs of high-risk groups, including teen drivers and the elderly.

Members of the commission also toured the I-394 MnPASS system and visited Mn/DOT's Regional Transportation Management Center, a state-of-the-art facility that integrates traffic operations control, State Patrol dispatch, and maintenance dispatch.

The commission is now preparing recommendations for a new national transportation policy, which it expects to present to Congress in December 2007.

ITS Institute research leads to new lane markings on I-94

Based on findings from researchers at the ITS Institute, the Minnesota Department of Transportation painted new markings on a stretch of westbound I-94 in Minneapolis in October 2006. The double white lines are intended to reshape the flow of merging traffic, thus reducing driver conflicts and preventing accidents.

The findings came from the first phase of research by civil engineering professor Panos Michalopoulos and MTO director John Hourdos. Their goal is to develop real-time algorithms needed to create a driver-warning system that will help prevent crashes in high-risk areas.

Their first step was to study the reasons for, and mechanics of, crashes. The researchers designed and assembled a set of unique sensors and surveillance equipment, with assistance from MTO manager Ted Morris, and collected individual vehicle speeds, headways, and lengths at 52 points along the freeway. In addition, they simultaneously recorded video 12 hours a day for two years, capturing all of the crashes and near misses occurring during that time.

As they reviewed the collected data, the researchers pinpointed the entire sequence of events leading to each crash and identified three specific elements contributing to nearly all crashes in this area: congestion shock waves that propagate backward from the merge area of a downstream entrance ramp; the large difference in driving speeds between the right and middle lanes, which makes chang-

ing lanes difficult and therefore dangerously distracting for drivers; and last, the fact that in the area where the shock waves begin, vehicles are simply too close to each other to allow drivers time to take evasive actions.

Researchers also verified that the same elements contributing to crashes also cause near-miss events. With these findings, the team developed an algorithm capable of accurately detecting the presence of crash-prone conditions nearly 70 percent of the time.

The project was featured in an article in the October 16 Minneapolis *Star Tribune*.

MVTA explores deployment of ITS Institute technology

Also in October, Minnesota Valley Transit Authority (MVTA) board members saw first-hand how technologies developed by the ITS Institute could help bus drivers navigate freeway shoulders used as part of a Bus Rapid Transit (BRT) sys-



HumanFIRST program director Nic Ward, far right, gave USDOT study commission members a tour of the program's facilities, including its immersive driving simulator.

tem and improve system operations. MVTA, which in 2006 donated a bus to the IV Lab, has expressed interest in field-testing a fleet of instrumented buses on the Cedar Avenue corridor.

Following the board's October meeting, Shankwitz and IV Lab research fellow Bryan Newstrom demonstrated the technologies to approximately 25 board members in a half-hour trip along the corridor.

Updated Web, publications highlight Institute work

In May, the ITS Institute Web site (www.its.umn.edu) was redesigned to incorporate better navigation and organization as well as a new graphic design. Among the improvements made to the site was a reorganization of research project information to make finding it faster and easier.

"Because intelligent transportation systems research moves fast, the Web is a key communications tool for us," says Institute director Max Donath. "These improvements really enhance our ability to reach a worldwide audience of researchers and transportation professionals."

Nine ITS-related research projects were featured in articles in the Center for Transportation Studies' *Research E-news* electronic newsletter, which is mailed to about 4,000 subscribers and is available on the Web at www.cts.umn.edu/news/renews. These stories also provided links to more information about the project.

Electronic mail announcements were used to publicize upcoming events, including Advanced Transportation Technologies Seminars, conferences, luncheon presentations, and other ITS-related events.

In print communications, Institute publications continued to raise awareness of the ITS Institute's work in academic and professional communities and disseminate the results of research.

Beginning with the summer 2007 issue, the *Sensor* newsletter was redesigned and expanded in scope and size. To meet new requirements of the Research and Innovative Technology Administration and SAFETEA-LU funding, the

newsletter, which had previously focused primarily on the Institute's research activities, expanded its scope to include coverage of educational and technology transfer activities as well as upcoming ITS-related events and recently published research reports. The publication also doubled in size, from two to four pages.

The *Sensor* is available in print and online and reaches about 2,100 subscribers three times each year. It continues to be one of the primary vehicles for increasing the visibility of the ITS Institute, and its high circulation represents a broad knowledge of and interest in ITS research activities among academic and professional audiences.

The seventh ITS Institute annual report (fiscal year 2005–06), with photos and coverage of researchers, their students, and their projects, was published and mailed to more than 1,600 individuals and was made available as a PDF file for download from the Institute's Web site.

Institute researchers address traffic safety issues at national, local events

Institute researchers discussed traffic safety issues at the annual Toward Zero Deaths conference, held in November in Duluth. The event, which drew more than 500 attendees, serves as a forum for exploring ways to reduce the number of fatalities and injuries on Minnesota's roads.

In one session, Nicholas Ward, director of the ITS Institute's HumanFIRST Program, discussed some possible avenues for intervention to change people's attitudes toward safety. These include social approaches based on family and community and technological approaches such as cameras to detect speeding and red light running.

In another session, Max Donath, the Institute's director, highlighted rural intersection decision support (IDS) systems that may reduce intersection fatalities. The Institute's IDS research focuses on giving drivers better information about gaps between vehicles when crossing a rural highway.

Kathleen Harder spoke about her work with fellow human factors researcher John Bloomfield evaluating the results of Minnesota's Highway Enforcement of Aggressive Traffic

(HEAT) Program. Harder and Bloomfield used speed data gathered by automated traffic detectors inside and outside enforcement zones to look for changes in driver behavior as a result of the year-long federally funded effort.

Janet Creaser, another researcher with the HumanFIRST Program, analyzed the effects of Minnesota's Nighttime Concentrated Alcohol Patrol (NightCAP) program. Creaser and her team found that increasing the number of "saturation" enforcement actions in a given year resulted in a marginally significant decrease in the fatal alcohol-related crash rate.

On the conference's final day, Lee Munnich and Tom Horan, with the State and Local Policy Program (SLPP) at the Humphrey Institute of Public Affairs, introduced the newly established Center for Excellence in Rural Safety, which was created from a directive in the SAFETEA-LU federal transportation legislation.

Institute researchers were among those who presented their work at the Transportation Research Board's 86th annual meeting, held January in Washington, D.C. University faculty, staff, and student presenters included:

- ◆ ITS Institute: Max Donath, Chen-Fu Liao, Ted Morris
- ◆ HumanFIRST Program: Nic Ward, Janet Creaser, Arvind Menon, Bryan Newstrom
- ◆ Intelligent Vehicles Program: Craig Shankwitz, Pi-Ming Cheng, Alec Gorjestani
- ◆ Northland Advanced Transportation Systems Research Laboratories (NATSRL): Eil Kwon
- ◆ Department of Civil Engineering (faculty and researchers): Gary Davis, David Levinson, Henry Liu, Panos Michalopoulos, Rania Wasfi
- ◆ Department of Civil Engineering (graduate students): Xiaozheng He, Saif Jabari, Woosung Kim, Xinjun Li, Wenteng Ma, Raul Andres Velasquez, Rania Wasfi, Qiang Wang, Thomas Westover, Ryan D. Wilson, Xinkai Wu, Feng Xie, Wuping Xin, Shanjiang Zhu, Adam Zofka
- ◆ Hubert H. Humphrey Institute of Public Affairs (staff and students): Frank Douma, Ahmed El-Geneidy, Michael Iacono, Adam Kokotovich, Kevin Krizek, Lee Munnich

Several Institute researchers provided an overview of rural traffic safety issues at the first meeting of what is planned to be an annual CERS (Center for Excellence in Rural Safety) Summer Institute, held in July 2006, to develop strategies for improving rural safety. Nic Ward probed the behavior of rural drivers and the relationship to traffic safety. Max Donath added a technological perspective to the research panel, updating attendees on the latest tools and systems to help drivers avoid crashes. Tom Horan presented his research into rural emergency response systems.

In November, the Northland Advanced Transportation Systems Research Laboratories (NATSRL) held its fifth annual Research Day, which gave ITS researchers at the University of Minnesota Duluth a chance to present their ongoing work in transportation. The event was held at Mn/DOT District 1 headquarters in Duluth. Eil Kwon, director of NATSRL, opened the half-day event.

Among the UMD presenters and topics were:

- ◆ Taek Kwon, Electrical and Computer Engineering, "Portable Wireless Mesh Sensor Networks for Traffic Movement Detection and Data Collection"
- ◆ Richard Lindeke and David Wyrick, Mechanical and Industrial Engineering, "Impending Box Impact Warning System for Prevention of Snowplow-Bridge Impacts"
- ◆ Peter Willemsen and Umesh Maitipe, Computer Science, "Snow Rendering for Interactive Snow Plow Simulation"
- ◆ John Evans, Chemistry and Biochemistry, "Installation and Performance Evaluation of SafeLane Overlay on Bridge Decks"
- ◆ Hua Tang, Electrical and Computer Engineering, "Feasibility Study on Development of a SMOS Vision Processor for Pedestrian/Vehicle Tracking"
- ◆ Rich Maclin, Computer Science, "Automatic Detection of RWIS Sensor Malfunctions (Phase II)"
- ◆ Ron Moen and Gerald Niemi, Natural Resources Research Institute, "A Self-Powered Video Camera Observation System for Monitoring Roadway Crossings"

Institute facilities toured by national and international visitors

In April, Denali National Park representatives were on campus to meet with Institute staff working on a project for the Alaskan park. The traffic-modeling project is aimed at helping manage transportation demand from the park's visitors while protecting wildlife. John Hourdos and Ted Morris, with the Minnesota Traffic Observatory (MTO), and Institute director Max Donath gave assistant superintendent of parks Philip Hooge, ecologist Laura Philips, and wildlife biologist Tom Meier a tour of the MTO in addition to discussing the program and plans for the coming year.

Representatives from the Rubenstein School of Environment and Natural Resources Park Studies (University of Vermont) and Montana Fish and Wildlife were in attendance as well.

In May, representatives from the Swedish Roads Administration toured the MTO and the Intelligent Vehicles Laboratory as part of a career training program. The Minnesota segment of the program, which lasted approximately five weeks, was organized by Mn/DOT to help the transportation professionals-in-training learn more about ITS, safety, public involvement, planning, maintenance, and information technology.



Representatives from the Swedish Roads Administration toured the Minnesota Traffic Observatory in May.

HumanFIRST director testifies before state transportation committee

In January, Nic Ward, HumanFIRST Program director, along with Robert Johns, Center for Transportation Studies director, testified before the Minnesota Senate Finance Transportation Budget and Policy Division Committee. Ward discussed the latest ITS technology designed to reduce

traffic fatalities, especially those caused by high-speed rural collisions. He explained that understanding how people drive and supporting them is key to advancing traffic safety as fatality rates continue to decline. Ongoing development of collision and lane-departure warning systems will aid drivers who are fatigued or distracted, Ward said, while intersection decision support technology will allow drivers to act with more information of the traffic patterns around them. Lawmakers were particularly interested in technologies to reduce crashes due to impaired or inexperienced drivers.

Media feature Institute researchers

Institute research that led Mn/DOT to paint new markings on the state's most crash-prone stretch of freeway was featured in a Minneapolis *Star Tribune* article in October. "Drawing a new line against I-94 crashes" described the three-year study by John Hourdos, director for the Institute's Minnesota Traffic Observatory, in which he monitored the area through video surveillance and made recommendations for improving a trouble spot by redirecting merging traffic.

Hourdos was also quoted in a *Star Tribune* article in May on how area road construction might affect commuters' driving behavior and patterns.

Professor Stephen Simon of the Law School was featured in the *Brief*, the University of Minnesota staff and faculty weekly news digest, for his work with the DWI legal process. Simon is the founder and director of the Minnesota Criminal Justice System DWI Task Force and has recently led ITS Institute research on development of a Teen Driver Support System, which is aimed at reducing risky driving behavior (e.g., speeding, driving while impaired) common among new drivers.

Institute researchers distinguished with honors, awards

Professor Nikolaos Papanikolopoulos of the Department of Computer Science and Engineering (CSE) was a recipient of the 2007 Distinguished McKnight University Professorship.

The professorship recognizes and rewards the University's most outstanding mid-career faculty. Recipients are honored with the title Distinguished McKnight University Professor while at the University of Minnesota and a \$100,000 five-year grant.

Papanikolopoulos, who has led numerous ITS Institute research projects, is a leading figure in robotics and automation, with groundbreaking contributions in distributed robotics, computer vision algorithms, and transportation systems. In addition, transportation safety has been greatly influenced by his work on vision-based monitoring of traffic and humans.

A paper coauthored by Rajesh Rajamani, a professor in the Department of Mechanical Engineering, was selected for the 2007 O. Hugo Schuck Award, given by the American Automotive Control Council. The paper was titled "Algorithms for Real-Time Estimation of Individual Wheel Tire-Road Friction Coefficients." The award was presented during the 2007 American Control Council Awards Luncheon in July in New York City.

Demoz Gebre-Egziabher, an assistant professor in the Department of Aerospace Engineering and Mechanics, was named a 2006 McKnight Land-Grant Professor by the Office of the Provost and the Graduate School. Along with the year's other recipients, Gebre-Egziabher was honored by the Board of Regents in March.

Finally, Max Donath received the 2007 Richard P. Braun Distinguished Service Award. Donath has been the ITS Institute's director since 1997 and is also a professor in the Department of Mechanical Engineering. He was recognized for creating one of the most successful ITS research programs in the world, leveraging ITS Institute funds to attract major projects on lane-keeping, human-machine interfaces, bus rapid transit, and intersection control technologies.

Donath also received the George W. Taylor Award for Distinguished Service from the University's Institute of Technology in May. Established in 1982, the award recognizes outstanding service to the University and voluntary public service to governmental or other public groups.

Transportation researchers among U's 'greatest minds'

Two Institute researchers are among 92 University of Minnesota faculty and alumni represented on the Wall of Discovery—a 253-foot-long artistic mural depicting the great moments of discovery—that was unveiled in September on campus.

Civil engineering professor Panos Michalopoulos is on the wall for his patented Autoscope artificial vision system, which integrates miniature video cameras and microprocessors for traffic sensing and measurement extraction to control congested street and highway networks, detect incidents, improve safety and security, and manage traffic efficiently.

Max Donath is noted for a patented system using GPS, a digital map database, obstacle detection radar, and a head-up display to provide drivers with a virtual reality represen-



The Wall of Discovery showcases University researchers, including research done through the Institute.

tation of the road when driving conditions make it almost impossible to see. Coinventors Craig Shankwitz, Heon Min Lim, Bryan Newstrom, Alec Gorjestani, Sameer Pardhy, Lee Alexander, and Pi-Ming Cheng are also mentioned.

Both displays include handwritten notes, sketches, or drawings to illustrate the inscribed text upon a metaphorical blackboard.

Visiting researchers bring expertise, build partnerships

During the past year, the Institute continued to work with visiting researchers and instructors, allowing for an exchange of information and dissemination of research results to the visitors' students and colleagues.

The Advanced Transportation Technologies Seminar Series provided an opportunity to host two national researchers. Rob Foss, senior research scientist and manager of alcohol studies at the University of North Carolina's Highway Safety Research Center, shared his work on the driver's role in motor vehicle crashes. Ron Heft, senior principal engineer with Nissan Technical Center-North America, gave an overview of the U.S. Vehicle and Infrastructure Integration (VII) program, including its objectives, participants, content, and current status.

Thomas Horan, an associate professor at Claremont Graduate University and visiting scholar at the Humphrey Institute of Public Affairs, is part of the Sustainable Technologies Applied Research (STAR) Initiative and the new TechPlan research program. Horan is investigating wireless EMS and telecommunication network planning and access in a rural context.

Other visiting researchers, all working with the Institute's HumanFIRST Program, include Nobuyuki Kuge of Nissan, Erwin Boer of the University of California, Jeff Caird of the University of Calgary, Andras Kemeny of the College de France, Jason Laberge of Honeywell, and Dick de Waard of the University of Groningen.

