

More information on the research projects listed in this section can be found on the ITS Institute's Web site at [www.its.umn.edu/Research](http://www.its.umn.edu/Research).

## HUMAN PERFORMANCE AND BEHAVIOR

**Janet Creaser and Michael Manser, Department of Mechanical Engineering**  
**Development and Evaluation of a Second Generation In-Vehicle Driver Assistance for Teenagers to Facilitate a Reduction in Crash Rates**

**Status:** *In progress*

Motor vehicle crashes are the leading cause of death for teenagers, with speeding, seat belt noncompliance, alcohol, and distractions serving as the primary contributors to an unacceptably high crash rate. In an effort to mitigate this situation, a prototype teen driver support system (TDSS) has been designed and developed. This computer-based system provides real-time feedback to teens on speed limit violations and warns of upcoming speed zone changes. A unique feature of this system is that speed limit feedback is relative to the speed limit posted on the roadway on which the teen is driving. By informing teens of speeding behavior, it is hoped this system will reduce teen crash rates.

To date, this project has integrated a smart-phone-based TDSS system into a vehicle, which has been tested within a small road network around the University of Minnesota. Additionally, a usability study of the TDSS has been completed for which a small sample of teen drivers (aged 18–19) drove with and without the system and then answered questionnaires about the TDSS and its functions. Data collection for this task is complete and data analysis is currently under way.

The second phase of this project is to develop a mechanism within the TDSS structure to provide feedback to parents when their teens have committed an infraction and to identify a tentative structure for graduated driver licensing (GDL)-related incentives and restrictions that will contribute to the overall goal of reducing the rate of teen deaths due to motor vehicle crashes.

**Usability Evaluation of the Teen Driver Support System**

**Status:** *Newly funded*

Motor vehicle crashes are the leading cause of teen fatalities. One approach to

reduce fatalities is graduated driver licensing (GDL) programs that limit teens' exposure to risky situations. However, these programs suffer from weak compliance monitoring because they are based on an honor system and depend on parent reporting. A teen driver support system (TDSS) is currently being developed by the ITS Institute that will allow parents to accurately monitor teens' driving behavior, with or without GDL restrictions. Additionally, the system provides real-time feedback to drivers about unsafe behaviors that are known risks factors for teen crashes.

The goal of this project is to conduct a usability review of the TDSS that will identify the extent to which parents and teens perceive it meets proposed expectations for monitoring behavior and increases safe driving behaviors, with and without GDL restrictions, and to make suggestions for design changes to improve the effectiveness and acceptance of the system.

**Kathleen Harder, College of Design**  
**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." The research 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 mitigating strategies.

**Kathleen Harder and John Bloomfield, College of Design**  
**The Effectiveness and Safety of Traffic- and Non-Traffic-Related Messages Presented on Changeable Message Signs (Phase II)**  
**Status:** *In progress*

This project is the second phase of a study conducted to examine the effects of changeable message signs (CMSs) on driver behavior. That research, which was conducted as a baseline study to provide an initial understanding of their effects, found that some drivers decrease their speed in the presence of CMSs currently used by the Minnesota Department of Transportation (Mn/DOT), and drivers decrease their speed more in response to AMBER Alerts than to time-specific traffic-related CMSs. Further, the study revealed that the content of both the AMBER Alert and the time-specific traffic-related CMSs was not readily understandable to drivers, and this affected their response to the signs.



This second phase of research compares the effects of newly developed messages (both a time-specific traffic-related message and an AMBER Alert) with data from the first phase of research. Comparisons focus on two areas: message comprehensibility and driver slowing behavior. In addition, given Mn/DOT's interest in knowing the effects on driver behavior of posting travel-time information on CMSs, another component of this study assesses the perceived value of travel-time information to the drivers who participate in the study. Real-world data associated with selected traffic incidents, collected at areas with CMSs by the Regional Traffic Management Center, are being analyzed to assess the effects of messages on driver behavior. A comparison of

real-world traffic data and driver simulator data will be made to the extent possible.

**Michael Manser, Department of Mechanical Engineering (previous principal investigator: Nic Ward, formerly with the Department of Mechanical Engineering and now at Montana State University)**  
**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 for those who live 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 (age 65 and above). To significantly reduce traffic fatalities, it is necessary to implement traffic safety interventions designed to target each of these high-risk groups.

The current study employed focus groups and structured questionnaires administered to each age group of at-risk drivers, and a draft final report has been submitted to the project sponsors. The data obtained from this study can be employed to support recommendations for the type and form of interventions likely to be most effective and acceptable within each risk group and community area.

**Thomas Smith, School of Kinesiology, and Nikolaos Papanikolopoulos, Department of Computer Science and Engineering**  
**Warning Efficacy of Active Versus Passive Warnings for Unsignalized Intersection and Mid-Block Pedestrian Crosswalks**  
**Status:** *In progress*

This study evaluated the efficacy of active versus passive warnings at uncontrolled pedestrian crosswalks by comparing how these two warning types influenced the behavior of drivers approaching such crosswalks. Vehicle-crosswalk interactions were observed at 18 sites with passive, continuously flashing, or pedestrian-activated warnings, yielding 7,305 interactions

in which no pedestrians were present and 596 interactions in which pedestrians were present. Vehicle velocities and accelerations were averaged for each interaction. Findings show no significant effect of warning type on overall velocities for either interaction type. With pedestrians present only, for average velocities at successive 5-meter distances from the crosswalk, a downward trend in velocities from 25 meters to 5 meters was observed for passive and active warning sites, but not for pedestrian-activated warning sites. Various lines of evidence point to a number of sources of ambiguity regarding the salience of uncontrolled crosswalk warnings, resulting in behavioral uncertainty by drivers interacting with such warnings. Mixed findings on the effects of warning type in this study point to the need for further analysis of this problem area.

**Nic Ward (formerly with the Department of Mechanical Engineering, now at Montana State University)**  
**Driving Performance During 511 Information Retrieval and Cell Phone Conversation Tasks, Combined Under Varying Levels of Traffic Density**  
**Status:** *Completed*

As a logical and necessary extension of previous research (Rakauskas, et al., 2005), this study aimed to assess the risk of cell phone use for traveler information applications—namely, while using Minnesota's 511 interactive voice response (IVR) menu.

First, detailed usage, utility, and usability evaluations of the MN511 were conducted. The goal of this design was to help harmonize the transfer of knowledge between access methods while also easing implementation concerns for the MN511 developers. Next, a simulated driving experiment was conducted with the goal of discovering whether using an IVR menu leads to more risky driving behavior compared to driving while not accessing a menu. It also allowed the researchers to see if changing the MN511 menu might affect driver performance. While using both phone menus, drivers seemed to compensate for the additional mental workload by delaying their

reactions until they felt comfortable taking action. There were no differences between the two menu types for the majority of driving performance measures.

This study addresses issues with the 511 IVR menus identified during the study and offers recommendations for future development.

**Nic Ward** (formerly with the Department of Mechanical Engineering, now at Montana State University) and **Michael Rakauskas**, Department of Mechanical Engineering  
**Rural and Urban Safety Cultures**

**Status: Completed**

The number of annual traffic fatalities and the rate of fatalities per vehicle-mile traveled are considerably higher in rural areas compared to urban areas. This project aimed to be one of the first studies to systematically explore the contribution of rural driver attitudes and behavior that may be a causal factor of these trends.

The researchers first conducted a survey of self-reported driver behavior and traffic safety attitudes. The analysis of this survey examined differences between rural and urban drivers in terms of risk taking and attitudes toward safety interventions proposed as part of the Minnesota Comprehensive Highway Safety Plan. The results suggest that rural drivers engage in riskier behavior such as seat belt noncompliance and driving while impaired because they have lower perceptions of the risks associated with such behaviors. Moreover, rural drivers perceive lower value in government-sponsored traffic safety interventions than their urban counterparts.



The researchers then measured driver behavior from driving simulator experi-

ments that compared the driving behavior of rural and urban drivers during traffic scenarios that embodied common crash factors (distraction, speeding, car following, intersections). The results suggest that the rural environment may encourage less safe driving. This study provides policy suggestions for developing safety interventions designed for the psychosocial factors that define rural culture.

**Xun Yu**, Department of Mechanical and Industrial Engineering (Duluth)  
**Real-Time Nonintrusive Detection of Driver Drowsiness**

**Status: In progress**

Driver drowsiness is a major cause of serious traffic crashes. Continuous monitoring of drowsiness is therefore important for reducing crashes that result from it. This research aims to develop a real-time, non-intrusive driver drowsiness detection system. Biosensors will be built on the automobile steering wheel to measure a driver's heart rate. 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 will ensure the accuracy of the drowsiness detection.

To date, the researchers have developed the heart-rate measurement systems both on the steering wheel and on the back of the driver's seat. An adaptive noise cancellation system has also been developed for canceling baseline measurement noise. Both systems have been tested in the lab with several subjects and for different situations, such as the measurement on the seatback with different cloth materials. They are currently working on the HRV analysis and building a driving simulator. Human subjects will be recruited for lab tests in the second phase, and the researchers also plan to prototype the system and install it on an actual vehicle for real-world data collection.

**Real-Time Nonintrusive Detection of Driver Drowsiness (Phase II)**

**Status: Newly funded**

This project is an extension of a previous project (Real-Time Nonintrusive Detection of Driver Drowsiness) that aims to develop a real-time, nonintrusive detection system to reduce crashes resulting from driver drowsiness. In this phase, biosensors will be built on the vehicle's steering wheel and the driver seatback to measure the driver's heart rate. Heart-rate variability (HRV), a physiological signal that has established links to waking/sleepiness stages, can thus be analyzed from the pulse signals to detect driver drowsiness. The novel design of the system (measuring heart rate from biosensors on the steering wheel and seatback) causes minimal annoyance for a driver, and the use of physiological signals ensures the accuracy of drowsiness detection.

In Phase I, a biosensor with a pair of electrodes built on the steering wheel was tested for measuring heart rate for HRV analysis. However, this design requires a driver to place both hands on the steering wheel. In Phase II, the researchers will design a biosensor that can measure heart rate when only one hand is on the steering wheel, which occurs more often in actual driving situations. In Phase II, the project will also incorporate real-world data acquisition and tests.

## COMPUTING, SENSING, COMMUNICATIONS, AND CONTROL SYSTEMS

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

The intersection decision support (IDS) research project was originally sponsored by a consortium of states (Minnesota, California, and Virginia) and the Federal Highway Administration (FHWA), whose objective was to improve intersection safety. The Minnesota team's focus was to develop a better understanding of the causes of crashes at rural unsignalized intersections and then develop a technology solution to address the cause(s).

In the study mentioned above, a review of Minnesota's rural crash records and past research identified poor driver gap selection as a major contributing cause of rural intersection crashes. Consequently, the design of the rural IDS technology has focused on enhancing the driver's ability to successfully negotiate rural intersections by communicating information about the available gaps in the traffic stream to the driver. In order to develop an IDS technology that has the potential to be nationally deployed, the regional differences at rural intersections must first be understood. Only then can a universal solution be designed and evaluated. To achieve this goal of national consensus and deployment, the University of Minnesota and the Minnesota Department of Transportation initiated a state pooled-fund study in which nine states are cooperating in intersection-crash research, and collecting data on driver behavior at selected intersections in participating states.



**Max Donath, Michael Manser, and Craig Shankwitz**, Department of Mechanical Engineering  
**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 examined the possibility of integrating 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 and older drivers require larger gaps.

**John Evans**, Department of Chemistry and Biochemistry (Duluth)  
**Detection of Water and Ice on Bridge Structures by AC Impedance and Dielectric Relaxation Spectroscopy (Phase I)**  
**Status: In progress**

This research aims 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 deicing electrolyte solutions (a sort 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 (via dielectric relaxation). In both approaches, the methodologies will use low-cost electrodes in the impedance analysis schemes.

#### Detection of Water and Ice on Bridge Structures by AC Impedance and Dielectric Relaxation Spectroscopy (Phase II)

**Status:** *Newly funded*

Based on the evaluation of competitive technologies in Phase I (impedance spectroscopy versus time domain reflectometry (TDR)), the researchers have decided to focus on the more viable choice of TDR. Experiments were carried out with prototype passive stainless steel sensors using TDR in a laboratory test fixture. These sensors gave unique responses when immersed in air versus liquid, and solid water versus liquid and solid electrolyte. Preliminary data analysis suggests that these media may be distinguished reliably at the 90 percent confidence level with appropriate pretreatment of the transients acquired from a given sensor. Future work will require examination of the need to calibrate each sensor and will also focus on more sophisticated chemometric- and neural network-based software to automate the analysis.

These software refinements are likely to become more important as the researchers move toward the second generation of sensor designs, which have appropriate geometries to be embedded in bridge deck and road bed installations. The first set of these second-generation sensors will be

evaluated in experiments carried out in the lab using a temperature-controlled testing stand. Pending these results, the researchers will apply refinements to the sensor design, hardware, and software and construct an outdoor test stand incorporating the optimized cell designs in a concrete pad to simulate the ultimate application. Although this test pad will not simulate all aspects of the final deployment format (e.g., traffic flow over sensors), it will provide a preliminary experience of installing sensor systems in a simulated bridge deck, including issues associated with cabling, fixture of the sensors, and the like.

#### Taek Kwon, Department of Electrical and Computer Engineering (Duluth) Development of a Portable Eight-Channel Weigh-in-Motion (WIM) Analysis System Based on Analog WIM Signals

**Status:** *Completed*

Weigh-in-Motion (WIM) data provide vital information for pavement design and maintenance. The purpose of this research project was to improve the present piezoelectric WIM technologies through a better system design and signal processing algorithms. Current WIM systems are only available as proprietary systems—i.e., the internal system design and algorithms are highly guarded, making it difficult to compare and improve the underlying technology. Therefore, the second objective of this research was to develop a WIM system based on an open architecture, using a standard personal computer and off-the-shelf components, and to publish the details of the design to promote an open architecture for continuous future improvements by other developers. The research team was able to successfully develop a working eight-channel WIM system, and the details are described in the project’s final report.

The main innovation introduced in this research is a hardware-in-the-loop (HIL) WIM simulator that can generate analog axle and loop signals through software control. The HIL simulator can create ideal axle signals as well as erroneous signal conditions that can be fed directly into WIM systems. The main advantage of using

a WIM HIL simulator for developing a WIM system is that the developers may run an unlimited number of signal tests without actually driving a single vehicle through the WIM sensors, thereby significantly reducing the development time and cost. The erroneous signal conditions generated by the HIL simulator can also identify the error-handling capabilities of a WIM system. The proposed HIL simulator for WIM system development is new and provides an elegant solution to the unavailability of an ideal axle signal.

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

**Status:** *In progress*

This project continues research begun in fiscal year 2006–07 under the same project title, with the overall research goal of developing a practical method for detailed monitoring of traffic movements using a mesh network of wireless sensor nodes. The motivation for this approach is 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 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 of the study is to complete the development of the rest of the required protocols and software for the mesh network so that the network functions as a working prototype. The performance of the prototype will then be evaluated for tracking vehicle movements in an intersection. The main protocols required include a congestion control protocol and a set of network and sensor management protocols. Upon completion of the protocol implementation, a vehicle-tracking algorithm based on the aggregated sensor data will be developed. The completed system will be installed in a live intersection to evaluate the perfor-

mance of the network and to learn about the field installation and operational issues.

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

**Status:** *In progress*

Motorists traveling through unsignalized, high-speed rural blind intersections, for which views of approaching or crossing vehicles are blocked, are known to be at high risk for crashes. Because static advanced warning signs or flashers at such intersections are largely ineffective at reducing crashes, the goal of this research is to develop and evaluate a new advanced warning system that economically integrates static signs described in the *Minnesota Manual on Uniform Traffic Control Devices* (MN MUTCD) into a dynamic sign system. The only difference in the sign itself is the addition of light emitting diodes (LEDs) on the circumference of the sign, a practice that is already approved by the Federal Highway Administration and used in Minnesota. In addition, the proposed advanced warning system actively detects vehicles in the proximity of the sign or intersection and utilizes that information for initiating or terminating the flashing of LEDs.

The first phase of this project comprises system design and instrumentation, and the second focuses on field implementation and evaluation. The main ITS technologies integrated in the system under development are low-power LED signals, wireless vehicle detection, and a self-sustainable renewable power supply.



#### 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. With the potential growth of the number of VC/WIM sites and the corresponding amount of data, development of an efficient data warehousing and management system has become essential.

The purpose of this research is to develop an efficient VC/WIM data warehouse at the UMD Transportation Data Research Laboratory (TDRL) to provide the data analysis and reporting needs of TDA through online automation. This effort is an expansion of the present data system at TDRL that provides online data services to TDA, and a similar data service system will be developed and deployed for the VC/WIM data. 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 data can be queried directly from both types. Since TDRL currently archives the statewide Road/Weather Information Service (R/WIS) data and the Twin Cities freeway traffic data, the addition of WIM and VC data is expected to increase the amount and quality of information by allowing cross-reference to various types of transportation data.

#### Development of a Weigh-Pad-Based Portable WIM System

**Status:** *Newly funded*

With the emphasis on mechanistic designs in the 2002 AASHTO design guide, weigh-in-motion (WIM) data have become more important, as the information is used as a primary input to pavement design. Also, the recent increase in heavy truck volumes on local roads raised great concerns for the life of existing roadway infrastructure, elevating the necessity of truck-weight data and enforcement. Installing many WIM sites could address these needs, but the in-

infrastructure cost for installing a permanent WIM site is expensive (over \$200,000) and requires recurring costs of electricity and communication. For county roads with limited average daily traffic (ADT), such a high cost of installation and maintenance is rarely justifiable.

One solution for bringing WIM technologies to local roads is to develop a low-cost portable WIM system. This research aims to develop a weigh-pad-based portable WIM system that can be easily installed and used much like a tube counter. The developed system will be battery operated, low cost, and easy to install on both rigid and flexible pavements. An additional benefit of the weigh-pad-based WIM system is that, since it does not cut into pavements during installation, it does not weaken the pavement structure. As a result, the system can be safely used in structurally sensitive areas such as bridge decks.

**David Levinson**, Department of Civil Engineering, **Kevin Krizek** (formerly with the Humphrey Institute of Public Affairs, now at the University of Colorado) and **Ahmed El-Geneidy** (formerly with the Department of Civil Engineering, now at McGill University)

**Using Archived ITS Data to Improve Transit Performance Management**

**Status: Completed**

The widespread implementation of automated vehicle location (AVL) systems and automatic passenger counters (APC) in the transit industry has opened new venues in transit operations and system monitoring. Metro Transit, the primary transit agency in the Twin Cities, Minnesota region, has been testing various intelligent transportation systems (ITS) since 1999. In 2005, it fully implemented an AVL system and partially implemented an APC system. To date, however, there has been little effort to employ such data to evaluate different aspects of performance.

This research capitalized on the availability of such data to better assess performance issues of one particular route in the Metro Transit system. The researchers used the archived data from the location systems of buses running on an example

cross-town route to conduct a microscopic analysis of performance and reliability issues. They generated a series of analytical models to predict run time, schedule adherence, and reliability of the transit route at two scales: the time point segment and the route level. The methodology included multiple approaches to display ITS data within a GIS environment to allow visual identification of problem areas along routes. The methodology also used statistical models generated at the time point segment and bus route level of analysis to demonstrate ways to identify reliability issues and what causes them. The analytical models showed that while headways are being maintained, schedule revisions are needed in order to improve run time. Finally, the analysis suggests that many scheduled stops along this route are underutilized and so should be consolidated.



**Nikolaos Papanikolopoulos**, Department of Computer Science and Engineering

**Freeway Network Traffic Detection and Monitoring Incidents**

**Status: Completed**

Shadow detection is an important part of any surveillance system, as it makes object shape recovery possible as well as improves accuracy of other statistics-collection systems. As most such systems assume video frames without shadows, shadows must be dealt with beforehand. This research proposes methods to distinguish between moving cast shadows and moving foreground objects in video sequences, including a multi-level shadow identification scheme that is generally applicable without restrictions on the number of light sources, illumination conditions, surface orientations, and object sizes.

The first level uses a background segmentation technique to identify foreground regions that include moving shadows. In the second step, pixel-based decisions are made by comparing the current frame with the background model to distinguish between shadows and actual foreground. In the third step, this result is improved using blob-level reasoning that works on the geometric constraints of identified shadow and foreground blobs. Results on various sequences under different illumination conditions show the success of the proposed approach. Finally, the researchers propose methods for physical placement of cameras in a site so as to make the most of the number of cameras available.

**Counting Empty Parking Spots at Truck Stops**

**Status: In progress**

This research is working to develop an automated truck stop management system that can compute occupancy rates at stops and notify drivers about 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 precise knowledge of which stops are occupied will be available, variable message displays at the site of the stop itself will be able to direct drivers to free spots. Since in some cases it would be possible for two or more smaller vehicles to share a single parking spot, the system will also determine partial spot occupancy. The system will operate in two basic modes—a day mode and a night mode—which would typically require different methods for vehicle detection. In order 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 are available.

**Data Mining of Traffic Video Sequences**

**Status: In progress**

This project addresses the problem of data extraction from traffic video-sequenc-

es. The researchers automatically learn the layout of a traffic site (e.g., intersection) from trajectories of vehicles obtained by a vision-tracking system. This approach enables the automatic extraction of sophisticated and complex data such as unusual events, near misses, and vehicle trajectory clusters. The contributions of this work are focused on a novel adaptive technique for detecting moving shadows and distinguishing them from moving objects in video sequences.

Most methods for detecting shadows work in a static setting with significant human input. To remove these limitations, the researchers devised a more general semi-supervised learning technique to tackle the problem. First, they exploit characteristic differences in color and edges in the video frames to come up with a set of features useful for classification. Second, they use a learning technique that employs support vector machines and the co-training algorithm, which relies on a small set of human-labeled data. The research team observed a surprising phenomenon: co-training can counter the effects of changing underlying probability distributions in the feature space.

From the standpoint of detecting shadows, once deployed, the proposed method can dynamically adapt to varying conditions without any manual intervention and is better at classifying than previous methods on static and dynamic environments alike. The strengths of the technique are that it requires a small quantity of human labeled data and that it is able to adapt automatically to changing scene conditions.

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

**Status: Completed**

Real-time measurement of tire-road friction coefficient is extremely valuable for winter road-maintenance operations and can be used to optimize the kind and quantity of the deicing and anti-icing chemicals applied to the roadway.

In this project, a wheel-based tire-road friction coefficient measurement system was first developed for snowplows. Unlike a traditional Norse meter, this system is based on the measurement of lateral tire forces, has minimal moving parts, and does not use any actuators, making it reliable and inexpensive. A key challenge was quickly detecting changes in the tire-road friction coefficient while rejecting the high levels of noise in measured force signals. Novel filtering and signal processing algorithms were developed to address this challenge, including a biased quadratic mean filter and an accelerometer-based vibration-removal filter.

Detailed experimental results are presented on the performance of the friction estimation system on different types of road surfaces. Experimental results show that the biased quadratic mean filter works very effectively to eliminate the influence of noise and quickly estimate changes in friction coefficient. Further, the use of accelerometers and an intelligent algorithm enables elimination of the influence of driver steering maneuvers, thus providing a robust friction measurement system.

In the second part of the project, the developed friction measurement system was used for automated control of the chemical applicator on the snowplow. An electronic interface was established with the Force America applicator to enable real-time control. A feedback control system that utilizes the developed friction measurement sensor and a pavement temperature sensor was developed and implemented on the snowplow.



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

**Status: In progress**

The first component of this project is a detailed evaluation of the ability of a new friction measurement system to provide an accurate measure of road conditions and correspondingly a reliable performance measure for determining how well winter road maintenance has been performed. This component includes the development of a system that records friction coefficient as a function of road location, as well as studies to evaluate the ability of visual inspection to predict road surface conditions and whether recordings from the friction coefficient measurement system can serve as a reliable performance measure of all winter road maintenance tasks completed by a snowplow. The second component of this project is a detailed evaluation of the performance of a closed-loop system that utilizes friction measurement for automatic applicator control. This includes evaluating the performance of the applicator control system in terms of its ability to adequately apply deicing chemicals or sand on slippery spots on a road. Finally, the project enhances the developed automatic applicator control system by using real-time data from a geographical information system (GIS) that provides information on upcoming geometric road alignment and known problematic segments of roadway.

#### Automatic Safety Alert System for Work Zones with Flag Operators

**Status:** *In progress*

This project focuses on the development and evaluation of an automatic alert system for work zones that provides audio warnings both to the violating vehicle and to the flag operator and crew in the work zone so as to ensure their safety. The proposed system will be portable and will use radar-based threat assessment to predict potential work-zone intrusion. A special thin-film audio speaker system that provides a clear warning to a specific vehicle in the desired lane, while being less audible to neighboring vehicles in other lanes, will be developed. The project will also evaluate and compare a number of different audio warning signals to test their effectiveness.

In work completed so far, an audio system that can deliver directed acoustic warnings, which are 10 decibels louder in the intended highway lane compared to adjacent lanes, has been developed. Experiments have been conducted to evaluate the developed system.

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

**Status:** *In progress*

See page 20 for coverage of this project.

**Rajesh Rajamani, Department of Mechanical Engineering, and John Hourdos, Department of Civil Engineering Enhancement and Field Test Evaluation of New Battery-less Wireless Traffic Sensors**

**Status:** *Newly funded*

In a previous project, this research team developed a new type of battery-less wireless traffic sensor. Each sensor consists of a very thin beam-like structure embedded in the roadway and includes all required electronics inside its structure. The sensor requires no batteries, electrical supply, or any other power source. It provides wireless transmission of traffic flow rate measurements to a roadside receiver several hundred feet away. Compared to existing inductive loop detectors, the new sensors have the additional advantages of being much easier to install (smaller, no power lines or any other wires) and of being significantly less expensive, more reliable, and consuming no energy.

In this project, the design of the sensor will be enhanced so as to significantly increase its wireless telemetry distance. It will be able to directly transmit traffic flow rate measurements to a circuit board in a regular traffic cabinet on the freeway. This would eliminate the need to have a roadside computer to receive signals. Since cabinets exist every 0.5 miles on all freeways and within 500 feet of all major traffic intersections, the traffic flow measurements can subsequently be received directly at the Mn/DOT Traffic Operations Center. Furthermore, the sensors will be enhanced so as to accurately measure vehicle speed (in addition to flow rate and number of

axes). Vehicle speed measurement will not require two consecutive sensors but will be done using just one embedded sensor in the roadway. Finally, the sensors will be used in a field test where their performance will be compared to traffic flow rate measurements from a camera-based infrastructure available at the Minnesota Traffic Observatory. Conducting the field tests and verifying the performance of the sensors under a variety of real-world conditions will firmly establish their credibility and lead to their subsequent use and commercialization.

**Craig Shankwitz, Department of Mechanical Engineering Analysis of Highway Design and Geometric Effects on Crashes**

**Status:** *In progress*

Forty percent of fatal highway crashes in Minnesota are 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; also, 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.

#### GPS Augmentation for Robust Lane Assistance

**Status:** *In progress*

To support a new non-contact sensor installed on a test bus, an improved means to estimate vehicle heading is required. Previous embodiments of the IV Lab system found that heading estimates with one-degree accuracy were sufficient to properly guide the bus, maintaining an error of approximately 10 centimeters in a narrow lane. However, when GPS is lost, the sensitivity of the non-contact guidance of the bus is extremely sensitive to heading initial conditions errors. Because of this, work is under way to improve the heading estimation of the bus when DGPS is available to improve the accuracy of the vehicle heading. The performance and design will be used to pursue a patent for this technique.

#### Guidance Augmentation Using a Vehicle Positioning System (VPS) for Transit Applications, Year 2

**Status:** *In progress*

In urban areas, Differential Global Positioning System (DGPS) devices suffer from problems with satellite view and with the reception of DGPS corrections over the cellular phone network. Moreover, the signals that do reach a GPS antenna suffer from multipath interference, producing high-variance position estimates. These DGPS issues are addressed by fusing the position information provided by a vehicle positioning system (VPS) based on radio frequency identification (RFID) technology with data from scanning laser sensors. VPS provides "which lane" in the "lateral" direction, and a path distance from a known reference in the "longitudinal" direction. From this, the location of a bus in a particular lane can be computed. Position within the lane can be determined using a horizontal laser scanner mounted on the bus, which identifies the presence and location of curbs in order to determine the position of the bus in the lane with respect to the curb. Integration of VPS information, laser scanner information, and a "map" representation describing the optimal distance of the bus from the curb as a function of distance traveled along a lane,

will provide the lane information needed for driver assistance in a dedicated lane. This project will produce a demonstration of a VPS-laser scanner-based positioning system capable of operating the IV Lab driver-assist system on an urban road in Minneapolis.



#### 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's 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.

### In-Site Testing of State Patrol Vehicle Lighting, Retro-reflectors, and Paint

**Status:** *Newly funded*

More U.S. law enforcement officers are killed in collisions during roadside stops than are killed by felonious acts. A number of causal factors affect police safety at roadside stops, including conspicuity of the officer, conspicuity of the squad car, weather conditions, and the attention and fatigue level of drivers in oncoming traffic. Many officers have opinions as to what constitutes an optimal light bar arrangement (colors, vertical rows of lights, lighting patterns, brightness) and what are optimal markings and retro-reflective treatments for squad cars. This project will test lighting, retro-reflectors, and possibly paint (subject to State Patrol opinion) to determine whether particular combinations improve “move over” behavior of oncoming traffic. Tests will be performed at a fully instrumented rural intersection (U.S. 52 and County Highway 9 in Goodhue County) and will rigorously quantify and document the effects that lighting, retro-reflective markings, and (possibly) paint colors have on oncoming traffic during roadside stops. This project is a cooperative effort between the Minnesota Department of Public Safety, the ITS Institute, Emergency Automotive Technologies, Inc., and police safety equipment manufacturers. The goal is to provide insight and guidelines that may ultimately improve officer safety at roadside stops.

### 2-D Optical Sensor for DGPS Augmentation

**Status:** *Newly funded*

The Differential Global Position System is susceptible to outages due to blocked or missing satellite signals and/or blocked or missing DGPS correction messages. Outages arise primarily due to environmental reasons: passing under bridges, passing under overhead highway signs, adjacent foliage, etc. Generally, these outages are spatially deterministic and can be accurately predicted. The outages distract drivers using DGPS-based driver-assistive systems and limit the system robustness. Inertial measurements have been proposed as an augmentation

for DGPS. Tests have shown, however, that error rates for even emerging technologies are still too high; a vehicle can maintain lane position for less than three to four seconds. Ring laser gyros can do the job, but \$100,000 per axis is still too expensive for road-going vehicles. To provide robust vehicle positioning in the face of DGPS outages, the Intelligent Vehicles Lab has developed a technique (and applied for a patent) by which a non-contact, two-dimensional true ground velocity sensor is used to guide the vehicle. Although far from fully developed, the system can maintain vehicle position within a lane for more than 20 seconds. This research may lead to the development of an inexpensive two-dimensional non-contact velocity sensor optimized for vehicle guidance during periods of DGPS outages.

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

**Status:** *Completed*

Given a transportation network having source nodes with evacuees and destination nodes, the researchers aimed to find a contraflow network configuration, i.e., ideal direction for each edge, to minimize evacuation time. Contraflow is considered a potential way to reduce congestion during evacuations in the context of homeland security and natural disasters (e.g., hurricanes). This problem is computationally challenging because of the very large search space and the expensive calculation of evacuation time on a given network.

To the best of the researchers' knowledge, this work presents the first macroscopic approaches for the solution of contraflow network reconfiguration, incorporating road capacity constraints, multiple sources, the congestion factor, and scalability. The researchers formally defined the contraflow problem based on graph theory and provide a framework of computational structure to classify their approaches. A “Greedy” heuristic was designed to produce high-quality solutions with significant performance. A “Bottleneck Relief” heuristic was developed to deal with

large numbers of evacuees. They evaluated the proposed approaches both analytically and experimentally using real-world data sets. Experimental results show that their contraflow approaches can reduce evacuation time by 40 percent or more.

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

**Status:** *In progress*

This project is developing a hardware-based vehicle tracking system, retaining key elements of video-based tracking system design and using customized hardware whenever possible to shorten execution time, ultimately enabling real-time tracking at a high frame rate. Vehicle tracking processes on roads are computationally intensive. In the past, the different algorithms employed in vehicle tracking have been implemented using various software-based approaches. While software approaches have the 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.

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 major components: a hardware processor for vehicle motion detection, and a tracking algorithm based on motion estimation. Developing this hardware-based tracking system requires three steps: first, validation of the tracking algorithm using realistic video inputs; second, implementing the algorithm in hardware; third, construction and testing. To date, tracking results have been largely validated and technical issues identified. Improvements to the algorithm are being made, and customized hardware design is on the way.

**Peter Willemssen, Department of Computer Science (Duluth), Al Yonas,**

### Institute of Child Development, and Lee Zimmerman

### Snow Rendering for Interactive Snowplow Simulation—Supporting Safety in Snowplow Design (Phase I)

**Status:** *In progress*

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 actual snowplows.



### Snow Rendering for Interactive Snowplow Simulation—Supporting Safety in Snowplow Design (Phase II)

**Status:** *Newly funded*

In this project, the researchers will refine the snow simulation developed in previous work to provide a more realistic simulation

of blowing or falling snow surrounding a snowplow. This includes determining the optimal parameters for phase scattering, transparency, and ambient lighting terms. Aggregate snow modeling will also be included to produce a more thorough rendering system.

The researchers will develop the 3-D models for alternative lighting configurations on their 3-D snowplow model. Alternative paint color and materials will also be detailed. Based on experimental data collected in the last quarter of their previous project, the researchers will develop lighting configurations and paint colors and will run experiments to determine the best options. Finally, the data from those experiments will be analyzed and reported.

Since following a snowplow or any vehicle in snowing conditions is dangerous, designing snowplows that work within the limits of human perception may help prevent accidents. More generally, the results from this work may be applicable to all vehicles.

## TECHNOLOGIES FOR MODELING, MANAGING, AND OPERATING TRANSPORTATION SYSTEMS

**Gary Davis**, Department of Civil Engineering  
**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 dividing the highway's directional lanes, and collides with a vehicle traveling in the opposite direction. AASHTO's Roadside Design Guide recognizes two countermeasures for prevention of cross-median crashes: (1) medians wide enough to provide adequate "clear zones" in which a driver can stop or regain control of the vehicle before crossing into the opposing traffic stream, and (2) when medians are less than 10 meters wide and annual daily traffic is greater than 20,000 vehicles/day, installation of median barriers. As with any safety countermeasure, installation should begin with those locations showing the greatest expected benefits.

This project reviewed 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.



**Gary Davis and Chen-Fu Liao**, Department of Civil Engineering  
**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 and to reduce operation costs. Bus signal priority has been implemented in several U.S. cities to improve schedule adherence, reduce transit operation costs, and improve customer ride quality. Current signal priority strategies implemented in various U.S. cities mostly utilize 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.

The objective of this study is to take advantage of the already equipped GPS/AVL system on the buses in Minneapolis and develop an adaptive signal priority strategy that could 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 can be established using the readily available 802.11x WLAN or the DSRC (Dedicated Short Range Communication) 802.11p protocol currently under development for wireless access to and from the vehicular environment.

This work is exploring proposed priority logic and its evaluation using microscopic traffic simulation. Simulation results indicate that a 12%–15% reduction in bus travel time during morning peak hours (7 a.m.–9 p.m.) and 4%–11% reduction during afternoon peak hours (4 p.m.–6 p.m.) could be achieved by providing signal priority for buses. Average bus delay time was reduced in the range of 16%–20% and 5%–14% during peak periods, respectively. The Phase II study is developing a prototype system

using GPS and wireless technologies to provide signal priority for buses. A test site at Como and 29th Avenues was selected, and the researchers will test the Minneapolis and University of Minnesota wireless coverage at the intersection.

**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 (Phase II) is a continuation of the project on arterial travel time estimation (Phase I). In Phase I, a suite of link-performance functions based on the demand flow, traffic control, and geometric characteristics is being developed and evaluated. The expectation is that the recommended performance functions will produce plausible default estimates of travel times when given predicted flows and that these can be updated where and when field measurements are available.

In Phase II, field measurement data such as traffic volumes, speeds, and traffic control plans are being acquired and a relational database will be constructed through the integration of appropriate geographical information systems (GIS). The prime objective of Phase II is not only to compute default estimates of arterial travel times on all Twin Cities arterial links by applying the methods developed in Phase I, but to update these default estimates using the collected traffic data and incorporate these into the GIS-based relational database. Considering the correlation among network links, the travel time update with the link performance functions is significant 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.

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

**Assessing Coordination Between Agencies Involved in Traffic Incident Management**

**Status: In progress**

One role of any state's department of transportation is managing adverse incidents that affect traffic flow within the interstate highway system under its purview. In most urban locations, management is accomplished through different agencies (e.g., police, fire, maintenance, and traffic operations), each with a stake in the overall traffic incident management (TIM) system. A literature survey indicates that, although prior studies have examined interagency coordination issues, relatively few have examined how the effectiveness of interagency efforts can be externally compared or internally assessed quantitatively. Further, numerous TIM systems in the United States report performance evaluation of interagency TIM activities as one area of activity for which little success has been attained.

This research project takes a two-pronged approach in proposing a quantitative basis for comparison and performance assessment. The first is an external benchmarking study, providing potential baseline metrics and methodologies for interagency TIM activities for use in justifying and communicating the benefits of TIM systems both to the public and to officials whose decisions significantly affect TIM resources. Along these lines, existing data sources and surveys administered to TIM personnel in seven urban areas across the country with similarities to the Minneapolis-St. Paul metro area have been used to document and compare the effectiveness of interagency coordination efforts. For the second prong, an internal analysis of interagency coordination will be conducted at the Minnesota Department of Transportation's (Mn/DOT) Regional Transportation Management Center, which oversees the Twin Cities metro highway system. In this prong, a review of communications during past incidents and in-person observations will be used to ascertain the current work procedures, information requirements, and knowledge sharing needed to coordinate efforts between various TIM stakeholders.

**Demoz Gebre-Egziabher**, Department of Aerospace Engineering and Mechanics, and **Ted Morris**, Department of Civil Engineering

**Remotely Operated Vehicle Surveillance for Transportation Management and Security**

**Status: In progress**

This project is investigating the technical and operational issues associated with using Unmanned Aerial Systems (UAS) for surveillance in support of transportation infrastructure management and security. The objectives are to develop a UAS from off-the-shelf components and to identify technical and regulatory issues that need to be addressed before UASs can be routinely and effectively used in intelligent transportation system (ITS) applications.



The work associated with the first objective resulted in the development of a low-cost, miniature, hand-launched aerial vehicle and supporting ground systems suitable for surveillance of highways and traffic infrastructure. Except for the ground station software, this system was built completely from off-the-shelf components.

The researchers also developed software that enhances ground station operators' situational awareness and allows simultaneous analysis of the data transmitted from the aerial vehicle.

Work on the second objective resulted in the development of an open-source guidance, navigation, and control (GNC) software suite for autonomous operation of small aerial vehicles.

**Demoz Gebre-Egziabher and Greg Nelson, Department of Aerospace Engineering and Mechanics**

**Analysis of Uninhabited Aerial Vehicles—ITS Concept of Operations**

**Status:** *In progress*

See page 21 for coverage of this project.

**Nikolas Geroliminis and Panos Michalopoulos, Department of Civil Engineering**

**Development of the Next Generation Stratified Ramp Metering Algorithm Based on Freeway Density**

**Status:** *Newly funded*

This project is a natural next stage of earlier successfully completed projects for improving Mn/DOT's stratified ramp metering strategy. One important potential improvement could be obtained if the total metering rates per zone were not calculated from flow measurements but rather from freeway density estimation. This is because (as shown in earlier research) while values of occupancy near capacity are quite stable, bottleneck capacity has stochastic variations, and a control strategy based on flow thresholds is likely to underload the freeway or, conversely, lead to traffic congestion.

This research will suggest ways of developing a new strategy by providing a methodology to accurately estimate densities based on data from loop detectors and explore the feasibility of integrating densities in the calculation of metering rates without violating the maximum ramp delay objective. Finally, the effectiveness of the new stratified ramp control strategy will be assessed by comparison with the current prototype version through microscopic simulation. Critical parts for this research are (1) the development of a methodology to accurately estimate densities for different lengths of stratified metering zones (0.5–3 miles long); and (2) the design of new ramp metering strategies. The metering strategy will explore two possibilities: a multilayer strategy similar to the existing algorithm employed by Mn/DOT, and a redesigned, coordinated (i.e., global) metering strategy using control theory.

**M. Imran Hayee, Department of Electrical and Computer Engineering (Duluth)**

**Development of a Low-Cost Interface Between Cell Phones and DSRC-Based Vehicle Unit for Efficient Use of Vii Infrastructure**

**Status:** *Newly funded*

To save lives and prevent injuries on roadways, intervehicle communication as well as communication between vehicles and the roadside is required. Dedicated Short Range Communications (DSRC), which was approved for licensing by the FCC in 2003, promises to partially fulfill this goal.

This research aims to take advantage of the DSRC infrastructure by designing, building, and demonstrating a wireless communication interface device that can act as a traffic-safety-information transportation agent between a DSRC vehicle radio unit and a cell phone (or a navigation system) inside a vehicle. By having this interface device along with the DSRC radio unit in a vehicle, any driver will be able to receive the valuable traffic safety messages on a cell phone or from an in-vehicle navigation unit. Furthermore, the feasibility of communicating directly with the DSRC roadside unit from this interface device to reduce the cost of widespread use will be explored.



**John Hourdos and Gary Davis, Department of Civil Engineering**

**T.H.-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 giving increased consideration to during project planning and design as a potential way to balance these conflicting needs.

The purpose of this study is to analyze the effects and to 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 Trunk Highway (T.H.) 36 to construct a project in North St. Paul. The current phase of the study is evaluating traffic operations and extracting performance measures from the four basic alternatives: no-build, build, non-full-closure construction, and full-road closure construction. This phase will provide valuable data for the cost/benefit analysis as well as effective traffic management on future full-road closure projects. The final product of this study will be a guide for engineers considering full road closure as a construction alternative in future projects.

The evaluation of the T.H.-36 full-road closure is accomplished in two different ways. First, detector and other measurements were retrieved and analyzed for the time periods before, during, and after the full-road closure. Second, a comprehensive microscopic model of the area of influence of the T.H.-36 construction project will be built and used to quantify the traffic operations performance during the full-road closure as well as the alternative partial closure. The field measurements have so far shown a larger-than-anticipated area of influence for the full closure and have suggested that the road users did not always follow the prescribed alternative routes serving the area. In addition, a number of local streets around the project area have shown higher than expected traffic patterns, but without leading to major congestion problems. The project is progressing with the development of the simulation model as well as with interviews with major proj-

ect stakeholders to gauge their opinion and retrospective comments regarding lessons learned.

**Chen-Fu Liao and Gary Davis, Department of Civil Engineering**

**Bus Signal Priority Based on GPS and Wireless Communications (Phase III)—Bus to Roadside Infrastructure Communication Framework for Intelligent Transit Applications**

**Status:** *Newly funded*

This study seeks to develop a shared wireless communication framework using the already installed 802.11x equipment on Metro Transit buses for various transit-related ITS applications. The research will explore the opportunity and investigate the feasibility of developing a scalable and multiple-use solution by utilizing the existing bus onboard systems (GPS/AVL and wireless radio systems) to communicate with other roadside equipment through the 802.11x protocols for signal priority request, security gate/garage door opening, or other ITS transit-related applications. Utilizing the existing hardware operating on the buses will reduce the additional expenses of hardware installation, labor, and maintenance. Development of a general wireless communication framework between a transit vehicle and a roadside unit for related ITS applications will eliminate potential system compatibility issues and help facilitate the deployment of ITS technologies for transit management and operation.



This study will build upon the knowledge from previous research work—Bus Signal Priority Based on GPS and Wireless Communications (Phases I and II). The goal of the Phase I study was to develop an adaptive signal priority strategy and to conduct evaluation and simulation of the Franklin

corridor from Dupont to 27th Avenues South in Minneapolis. The Phase II project is developing a prototype system using the existing AVL/GPS systems and evaluating the performance of the Minneapolis Wi-Fi infrastructure and a DSRC implementation, the 5.9GHz WAVE (Wireless Access in Vehicular Environment) radio for providing signal priority for buses.

**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 the Mn/DOT problem statement on traffic safety and operations requesting the development of an intelligent control system for isolated intersections with high-speed approaches, including 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 common for an approaching vehicle platoon to face a red signal because of a single vehicle on one of the conflicting approaches. In addition, advance warning flashers, which warn motorists on high-speed approaches that the signal phase will be turning yellow, are used by Mn/DOT 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 and moving forward platoons approaching a traffic signal with or without AWF to eliminate the dilemma zone problem and adapt to time-variant traffic conditions. To evaluate and improve the proposed control system, hardware-in-the-loop simulation will be used and system performance improvements will be quantified in terms of operational efficiency and safety.

The research team has developed an analytical model that can evaluate platoon-



priority traffic signal strategy under various conditions and is testing the platoon-priority strategy using the hardware-in-the-loop simulation.

**Evaluation of Cell Phone Traffic Data**

**Status: In progress**

Cellular phone tracking is a promising vehicle probe method that is likely to produce reliable travel-time information. To demonstrate the capabilities of a cell phone traffic data system, a pilot demonstration project was initiated by Mn/DOT in cooperation with a private contractor. As part of the demonstration project, traffic data provided by the contractor through cell phone tracking were evaluated and compared with data from alternative sources. The alternative travel-time data collected in the evaluation study include the freeway travel times generated using inductive loop detectors, travel-time runs using instrumented probe vehicles, and “ground truth” travel times determined by matching license plates through recorded video. A statistical data comparison and analysis was conducted, and results were summarized in the final report, currently in final review at Mn/DOT.

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

**Status: In progress**

This research is responding to the current needs for innovative evacuation operation strategies and for evaluation of current evacuation planning models with advanced traffic models. The goal of this project is to advance the current state-of-the-art evacuation modeling from the planning stage to real-time and dynamic-operation stages by developing a suite of conceptual, analytical, and simulation models that are expected to function as real-time online tools for evacuation traffic management.

Recent natural and man-made disasters around the world have demonstrated the need for effective evacuation traffic management to maximize use of the transportation system. To “squeeze” the

spare capacity out of the current traffic network system and fully utilize the available network capacity within the evacuation time window, the researchers propose to develop a system optimal model that can generate time-dependent evacuation routes and intersection control strategies to minimize the total evacuation time. The computer model should take dynamic inputs such as road closures into consideration and must be able to generate solutions quickly. The transportation network of downtown Minneapolis is used in the model for testing purposes.

The research team has developed the analytical model that can provide the above functionalities and is coding the theoretical model into computer software, which will provide a user-friendly graphical interface.

**Systematic Monitoring of Arterial Road Traffic and Signals (Phase II)**

**Status: Newly funded**

This project is a continuation of the principal investigator’s ongoing research that focuses on the development of an arterial performance-measure system using traffic data available from existing signal systems. As part of the ongoing project, the SMART-Signals (Systematic Monitoring of Arterial Road Traffic and Signals) system is being developed and evaluated on 11 consecutive intersections of France Avenue in Hennepin County, Minnesota. The SMART-Signal system will be also tested on T.H.55 for 6 to 10 intersections, supported by Mn/DOT’s Innovative Ideas Program.

Currently, the SMART-Signal system can simultaneously collect and archive event-based traffic signal data and automatically generate real-time performance measures such as travel time and number of stops along an arterial, and delay, queue length, and level of services for intersections. This project aims to extend SMART-Signal’s capability for automatic diagnosis of operational problems and fine-tuning of signal control parameters. The ultimate goal is to develop a holistic framework that systematically measures, automatically fine-tunes, and realistically and practically models traffic flow on signalized urban

arterials. A significant opportunity to achieve this project goal lies in the fact that systematic monitoring of traffic signal systems is now feasible and implementable, given the recent advances in data collection technologies as demonstrated by the SMART-Signal system.



**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**

Despite recent developments in real-time measurement of freeway performance using routinely available loop detector data, no similar approaches exist for monitoring the performance of urban arterial street networks. This project aims to fill in that gap by developing a real-time online performance monitoring system for arterial streets. The arterial performance data will also be archived and made available to various stakeholders for operations, planning, research, and traveler information systems, similar to the way freeway performance data are used. In this project, data availability and requirements from existing signal systems will be analyzed, and algorithms for the estimation and prediction of real-time arterial travel time and speed will be developed depending on data resolution. The project has two distinct phases: the first will focus on the data from the existing system only, without additional field instrumentation; the second will attempt to obtain higher resolution data through the installation of additional field instrumentation.

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

**Status: In progress**

With nationwide demonstrations taking place on vehicle infrastructure integration (VII), high-resolution probe data from VII-equipped vehicles may one day soon be available to traffic engineers. But the existing signal-timing optimization techniques are based on traditional loop-detector data and historical field data, and these models cannot utilize the full potential of VII-probe data. To fill this gap, this research aims to develop a real-time online or offline performance monitoring and signal optimization system for isolated and coordinated signalized intersections. How to combine multiple data sources (VII and non-VII sources) to provide a reliable and efficient traffic signal control will also be explored. To evaluate and improve the proposed control system, the researchers will use hardware-in-the-loop simulation and quantity system performance improvements in terms of operational efficiency and safety. The purpose of this project is to support Mn/DOT and its partners in evaluating uses and benefits of VII-related data in traffic management. As such, the project complements parallel efforts of the USDOT, VII-C, and others to design and deploy the VII network, vehicle equipment, and initial applications.

**Panos Michalopoulos, Department of Civil Engineering**

**Access to Destinations: Twin Cities Metro-Wide Traffic Microsimulation: Feasibility Investigation**

**Status: Completed**

Under the umbrella of the Access to Destinations Study, several research teams are working to produce new metrics for transportation system performance based on the concept of accessibility. A key challenge of this research effort is how to estimate future levels of accessibility based on today’s growth estimates, land use decisions, and development plans.

One way to overcome these obstacles lies with the recent rapid advances in simulation and modeling, specifically

microscopic simulation. A simulation model encompassing the entire metropolitan area has the potential to greatly improve researchers’ ability to estimate travel times across the entire transportation network under actual or hypothetical demand, control, and event scenarios.

This project investigated the feasibility of such a large simulation project. The researchers completed a comprehensive search of the state of the art in large urban simulation projects both nationally and internationally. Through extensive interviews the project team surveyed the needs and data availability of local stakeholders including city and county governments, the local metropolitan planning organization, Mn/DOT, and area consultants. Based on this information and a survey of state-of-the-art commercially available simulation applications, the research team concluded the investigation with two important findings. First, a correlation of the needed data based on simulator methodology and the closest available data set in the Twin Cities was concluded and reported. Then, based on this “reality check,” the research team proposed a feasible modeling framework that would serve most of the stakeholders’ needs as well as the needs of the Access to Destinations Study.

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

**Status: Completed**

The evaluation results (done in Phase II) demonstrated that the stratified zone metering (SZM) strategy was generally beneficial. However, they also revealed that freeway performance was degraded by reducing the ramp delays. Therefore, the effectiveness of the current SZM control should be improved.

There were two objectives in this study. One was to improve the control logic of the current SZM strategy through an estimation algorithm for the refined minimum release rate. The simulation results indicate that the improved SZM strategy is very effective in postponing and decreasing

ing freeway congestion while resulting in smoother freeway traffic flow compared to the SZM 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 used to verify the improvement of the proposed methods. The results indicate that the proposed methods can greatly improve the accuracy of queue-size estimation compared to the current methodology. Also, the proposed method was evaluated by microsimulation, results of which indicate the performance of the freeway mainline is significantly improved, and total system performance is better than with the original SZM control.

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

**Status: In progress**

The project had two major objectives: utilize the Minnesota Traffic Observatory's Digital Immersive Environment (DEN) to design and visualize different driver warning systems for the I-94 westbound high-crash location, and investigate the use of existing microsimulation models in the evaluation of safety improvements for the high-crash area. Although these objectives were not accomplished, the project has produced a number of meaningful results and contributions. These are: (1) development of an I-94 westbound 3-D model and vehicle trajectory integration and model-building methodology; (2) development of an I-94 westbound microscopic model; (3) a historical review of car-following models, as well as identification of the research needs behind the use of simulators for safety assessment; and (4) an analysis of empirical safety-related data and an understanding of the I-94 high-crash location traffic patterns.

#### Enhanced Microsimulation Models for Accurate Safety Assessment of Traffic Management ITS Solutions

**Status: In progress**

In recent years, various safety concepts and innovative ITS technologies have been proposed, developed, and/or implemented in the field aimed at improving roadway safety. To achieve the desired safety benefits while avoiding prohibitive and potentially hazardous field testing, it is critical that proposed safety treatments be extensively evaluated during the design stage and prior to actual deployment. To this end, microsimulation is potentially the most viable tool of choice due to its level of resolution and modeling realism. However, existing microsimulation models by design only target normal driver behavior in typical traffic conditions—e.g., either the functional structure or the parameter distributions of these models are deliberately constrained to outlaw unsafe behavior; thus explicitly excluding the occurrence of vehicle crashes.



Recognizing such limitations of microsimulation, this research developed an enhanced behavioral car-following model to be implemented in microscopic simulation for facilitating design, testing, and evaluation of safety treatments. Compared to existing models, this new model is built on findings from traffic engineering, human factors, and psychological research, taking into account drivers' perceptual thresholds, perception errors, anisotropy of reaction times, and anticipatory behaviors to allow for vehicle crashes while still capturing typical freeway traffic patterns. High-resolution real-life, crash-inclusive, and crash-free vehicle trajectories collected from the field, in conjunction with aggregated loop detector data, were employed to aid the model

development, calibration, and validation. The project utilized fully the Minnesota Traffic Observatory I-94 Field Lab, a permanent deployment of sensors and cameras at the area with the highest crash rate in the Twin Cities freeway network. The project has been concluded and the final report is currently being written.

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

**Status: In progress**

See page 22 for coverage of this project.

#### 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: Completed**

Freeway ramp control has been successfully implemented since the mid-1960s as an efficient and viable freeway management strategy. However, the effectiveness of any ramp control strategy largely depends on optimum parameter values, which are preferably determined prior to deployment. This is certainly the case with the current stratified zone metering (SZM) strategy deployed in the 260-mile freeway network of the Minneapolis–St. Paul metropolitan area.

To improve the performance of the SZM, which depends on the values of more than 20 parameters, this research first proposed a general methodology for site-specific performance optimization of ramp-control strategies using a microscopic simulation environment, as an alternative to trial-and-error field experimentation, and implemented the methodology with the SZM. The testing results show that the new SZM control with site-specific optimum parameter values significantly improves the performance of the freeway system compared to the original SZM strategy.

Second, this research proposed a methodology to explore the common optimum parameter values for the current SZM strategy for the entire Twin Cities freeway

system in order to replace the site-specific optimum values, which have little practical value because they are difficult to implement and it is time-consuming to search the site-specific optimum values for all freeway sections. The common parameter values are identified applying the response surface methodology (RSM) based on four specific freeway sections that represent all types of freeway sections in the metropolitan area.

#### Carissa Schively Slotterback, Humphrey Institute of Public Affairs, and John Hourdos, Department of Civil Engineering

#### Technology in Planning and Participatory Processes: Identifying New Synergies Through Real-World Application

**Status: In progress**

This project is examining the use of planning support systems (PSS) or technological enhancements in transportation planning processes. The goal is to identify opportunities for using technology in various types of participatory processes, such as open houses, public hearings, and technical/advisory committee meetings. The study will develop a typology of participatory processes, identifying their characteristics, including goals, participants, inputs, and outputs. Researchers will then identify associated technological enhancements tailored to the unique characteristics of different types of planning and participatory efforts and will examine the strengths and weaknesses of each technological enhancement, working closely with planning practitioners to identify an appropriate application and practical solutions. The results of the analysis will produce important feedback about ways to integrate technology into planning and participatory processes and further insights related to the importance of tailoring technology to various settings.

#### Xun Yu, Department of Mechanical and Industrial Engineering (Duluth) Intelligent Pavement for Traffic Flow Detection

**Status: Newly funded**

This project aims to explore a new approach for detecting vehicles on a

roadway by making a roadway section itself act as a traffic flow detector. Sections of a given roadway are paved with carbon-nanotube (CNT)/cement composites, and the piezoresistive property of carbon nanotubes enables the composite to detect the traffic flow. Meanwhile, CNTs can also work as reinforcement elements to improve the strength and toughness of the concrete pavement. In contrast to current traffic flow detection technologies that require separate devices to be installed in either the pavement or over the road, this proposed sensing approach would enable the pavement itself to detect traffic flow parameters. The proposed sensor, therefore, is expected to have a long service life requiring little maintenance and to have wide-area detection capabilities.

## SOCIAL AND ECONOMIC POLICY ISSUES RELATED TO ITS TECHNOLOGIES

**John Bryson, Melissa Stone, and Barbara Crosby, Humphrey Institute of Public Affairs**

**TechPlan—Technology and Collaboration in Effective Transportation Policy**

**Status: In progress**

The problems faced by public managers today are often too large to be solved by a single entity and require collaboration across government, nonprofit, and business sectors. As new technologies and systematic approaches transform the transportation field, cross-sector collaboration has become an increasingly important policy development and implementation approach for policy-makers and managers. Intelligent transportation systems (ITS) and other technologies provide tools that both drive and enable collaboration to occur. Particularly within the transportation field, an assemblage of technologies is often critical to implementing system-wide strategies aimed at, for example, mitigating traffic congestion, ensuring highway safety, and increasing the mobility of people and goods. In many cases, designers and implementers of effective transportation policies must combine a variety of technologies with deft relationship building and management. Through in-depth analysis of the political, technical, and management processes required in the development and implementation of the Urban Partnership Agreement at multiple levels of government, this research study is examining how technology and collaborative processes may be combined to achieve important transportation goals and create public value more generally.

**Frank Douma, Humphrey Institute of Public Affairs**

**Improving Car Sharing 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 (SLPP) 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 they take. Findings from that research showed that car sharing and advanced traveler information services (ATIS) were two ITS applications that could offer significant benefits.

The focus of this project is twofold: (1) to understand if and how being a member of a car-sharing program affects travel behavior and auto ownership of its members. In particular, the travel behavior and auto ownership of students at the University of Minnesota is of interest; and (2) to empirically investigate how citizen use of an e-government Web site (e.g., transit planning site) affects citizen/user trust and confidence in the related government service (e.g., the public transit system) and the public service agency (transit authority). Representatives from ZipCar, HourCar, and Metro Transit have agreed to serve on a technical advisory panel, which will help to inform and guide the research process. The results of this research will aid in developing policies for a diverse population with increasingly diverse transportation needs. Data collection for the car-sharing work is complete and analysis under way. Data collection is under way for the ATIS task, hosted on the Metro Transit Web site.



**ITS and Privacy: Developing New Rules for Virtual Roads**

**Status: In progress**

See page 26 for coverage of this project.

**Thomas Horan, Humphrey Institute of Public Affairs and Claremont Graduate University**

**ITS and Safety Planning: ITS and EMS System Data Integration for Safety and Crisis Information and Decision-Making System**

**Status: In progress**

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. Correspondingly, while ITS has long promised safety benefits, there has traditionally been little emphasis on examining the extent to which emergency medical services (EMS) and trauma systems could provide safety-related data for both real-time benefits and assessment and planning purposes.

This research project is examining the linkages between EMS and trauma information systems and safety planning, focusing on the role of EMS and trauma to provide timely and visual-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 large-scale emergency and crisis planning.

Methods employed in this project include analysis of existing health-related data from safety reports (SHSP), EMS, trauma, and related health information systems. Analysis of these data sets will provide a multilayered 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.

Case studies and development of emergency planning data architecture are under way. The literature search is largely complete, and researchers expect to begin receiving feedback on a preliminary product in the latter half of 2008.

**David Levinson, Department of Civil Engineering**

**TechPlan—The Role of Social Networks and ICT on Destination Choice**

**Status: In progress**

This research is investigating the impact of traditional social networks and information and communications technology (ICT) on travelers' destination choice. The extent to which social networks and information and communication technologies affect where destinations are located is an area that is gaining more focus. This research focuses 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 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 these long-term and short-term decisions, this study aims to advance the researchers' understanding of the role of social networks in everyday travel decisions.

Thus far, a two-phase survey has been designed and administered to over 500 participants. In addition to data on work-finding mechanisms, detailed data on travel for different social activities including precise activity location, time, and purpose as well as relationship and individual characteristics, have been collected. The researchers hope to understand the behavior of social travel and to develop models that incorporate important elements of social networks and ICT for different trip purposes



**Elizabeth Wilson, Humphrey Institute of Public Affairs, Kevin Krizek, University of Colorado (formerly, Humphrey Institute of Public Affairs), and Julian Marshall, Department of Civil Engineering**

**School Travel and the Implications for Advances in Transportation Technology**

**Status: In progress**

See page 24 for coverage of this project.