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

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

The Institute’s geographic location gives it a unique advantage for developing research applicable to transportation in a northern climate and transportation in rural environments in addition to the metropolitan Twin Cities area.

The ITS Institute research program includes research projects funded by various partners, including federal funds from TEA-21 legislation, the Federal Highway Administration, and the Federal Transit Administration. Other funding partners include the Minnesota Department of Transportation (Mn/DOT), the Minnesota Local Road Research Board, and Metro Transit, in addition to local governments, agencies, and private companies that contribute funding and in-kind match.

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

The total funding for all ITS-related research projects was nearly $6 million in FY04. Funding sources for projects receiving funding in FY04 are shown in the chart below.

**RESEARCH FUNDING SOURCES FOR ALL ITS-RELATED RESEARCH PROJECTS**

- **Federal** 42%
- **State of Minnesota** 27%
- **University of Minnesota** 14%
- **Private Industry** 12%
- **Local Government** 1%
- **Other** 4%
When it comes to clearing snow from roadways, poor-visibility conditions come with the territory. But in the process of clearing roads, snowplows can temporarily create even worse conditions for the drivers behind them. Under these “low-luminance contrast” conditions, drivers often can see the presence of a snowplow ahead, but are unable to tell how far away it is or even that they are approaching it. Some recent experiments also indicate that under low-luminance contrast conditions, people perceive themselves to be traveling significantly slower than they actually are. To compensate, they speed up. Together, these issues constitute some of the most hazardous conditions drivers in Minnesota commonly experience and are why snowplows are particularly vulnerable to rear-end collisions.

Through a series of simulated and real-world experiments, Professor Albert Yonas, with the Institute of Child Development, Lee Zimmerman, an adjunct professor in the Department of Electrical and Computer Engineering at Duluth, and a team of University researchers are testing how people perceive motion and space under low-luminance contrast conditions and how these relate to chromatic contrast conditions. Understanding whether these two phenomena are governed by the same neural mechanism could lead to a variety of solutions for reducing some of the hazards drivers face in poor-visibility conditions and possibly decrease the likelihood of rear-end collisions with snowplows.

“The safety of both motorists and plow operators is our main concern,” explains Sue Lodahl, a maintenance research and training engineer with the Minnesota Department of Transportation. “So we are extremely interested in this innovative look at how drivers perceive the speed of a snowplow and the speed at which they are approaching the truck in heavy snow and fog.”

Using a simple computer driving simulator to replicate the effects of blowing snow and fog, Yonas and his team monitored test participants who were asked to decide whether a simulated truck approached or withdrew as the luminance contrast of the simulator display was varied. This experimental setup enabled the researchers to study snowplow designs and color characteristics that influence a driver’s detection of approach and impending collision. Through these efforts, the team found that lowering the luminance contrast between the image of a vehicle and the background greatly reduces one’s ability to perceive approach. They also discovered that flashing lights, such as those mounted on snowplows to attract attention, interfere with motion perception.

These findings will be incorporated into a second year of research in which the team will use more realistic driving-simulator methodology to develop new markings and lighting designs for snowplows. One new design approach may be to ensure that rear-facing lights and markings on snowplows create optimal luminance contrast while reducing the offending chromatic contrasts. A second possibility involves structuring rear-facing markings to help drivers better tell when they are approaching a snowplow. In the future, Yonas hopes to team up with Mn/DOT to further test the effectiveness of new markings and lighting designs on minimizing the effects of blowing snow on drivers’ ability to properly perceive both their speed when moving toward a snowplow and their distance from it.
The overall findings of this work will likely result in improvements in driving safety through the careful choice of color warning markings, chromatically controlled lighting, and special fog tints on snowplows, as well as through better public education. “These improvements and changes would stand to significantly reduce the number of rear-end collisions with Mn/DOT plow trucks,” Lodahl says.

**Ramp meter delays, freeway congestion, and driver acceptance**

In a number of cities across the nation, including Minneapolis and St. Paul, ramp meters have been installed at freeway entrance ramps in an attempt to reduce congestion and produce smooth traffic flow. However, there has been considerable controversy as to whether or not ramp meters reduce delay on the road system and concern regarding how delay is distributed (e.g., some drivers must wait longer in order for other drivers to proceed more easily).

In their current study, human factors researchers Dr. Kathleen Harder and Dr. John Bloomfield, from the College of Architecture and Landscape Architecture, are working with Professor David Levinson, Civil Engineering, on a multidisciplinary investigation of the differences between perceived time and actual time spent waiting at ramp meters and in congested traffic.

This research attempts to quantify the value drivers associate with qualitatively different experiences of travel time when they encounter ramp meters. Drivers may feel that time passes more slowly when waiting at a ramp meter than when they are driving very slowly in stop-and-go traffic on the freeway. As a result, although the ramp metering system may actually reduce total travel time, it may not reduce drivers’ perceived travel time.

For this study, the team employed two different types of experiments. One involved a variant of the often-used Computer-Aided Stated Preference (CASP) methodology in which a number of travel time distributions, each with a different ramp meter wait time and drive time, were presented to participants who then distributed their preferences among the alternatives. The second experiment used a novel methodology known as the Virtual Experience Stated Preference (VESP) method. It involved using a 210-degree forward-field-of-view immersive driving simulator to capture drivers’ perceptions of the distributions of their travel time.

While CASP is the more frequently used methodology, with it participants are much further removed from driving experiences and are simply asked to state their preference. Conversely, the main benefits of the VESP method are that it more closely parallels a real driving experience, and it enables researchers to get participants’ feedback immediately after they’ve driven a simulated route.

According to Harder and Bloomfield, a driving simulator has never been used to collect driver preference data for driving scenarios involving ramp meters. Ramp meter timing has been
investigated using traffic simulation models, but human preference models cannot be derived from these simulation models. Another feature of the study is that it allows the results obtained with the CASP and VESP methods to be compared. Though the team is continuing to analyze the information collected from these experiments, early results indicate that while in some cases the data obtained using the VESP and CASP methods are similar, in others they may be different. Harder and Bloomfield are still looking into these disparities to determine the significance.

The researchers also are working to determine the weight that drivers give to the qualitatively different travel times they experience—due to variations in the waiting time at ramp meters, the level of traffic congestion, and in the resultant freeway driving speeds. They will then use this information to develop models regarding the value of travel time that will enable Mn/DOT to better address driver perceptions of travel time as they manage the ramp metering system in the Minneapolis/St. Paul metro area.

TECHNOLOGIES FOR MODELING, MANAGING, AND OPERATING TRANSPORTATION SYSTEMS

Measuring the equity and efficiency of ramp metering

The Twin Cities’ ramp metering system was originally designed to maximize traffic flow throughout the metro freeway network as a whole. Although the metering system has successfully increased the efficiency of freeway traffic flow, it also has been subject to increased political scrutiny due in part to perceptions of “inequity” in the system. The inequity emerges when drivers accessing area freeways at different times and at various entrance ramps experience different ramp waiting times; essentially, some drivers are delayed by the system in order to save travel time for others.

In order to scientifically study the issue, Assistant Professor David Levinson and research assistant Lei Zhang, of the Department of Civil Engineering, led a research effort to identify and develop performance measures that evaluate both the efficiency and equity of ramp metering strategies to determine the system’s overall effectiveness. Based on the findings of that study, Levinson and Zhang were then able to develop a freeway control strategy that considers both efficiency and equity.

The duo looked to various fields of study—including urban planning, geography, engineering, public policy, economics, and management—to collect a well-rounded set of perspectives on what “effectiveness” means. In the initial stage of this work, Levinson and Zhang defined and developed ramp meter performance measures over short-term and long-term scales. To provide a complete picture of ramp meter effectiveness, these performance measures were computed for ramps, freeway mainline segments, and origin-destination (O-D) pairs. The researchers then applied the newly developed performance measures to observed data collected for selected

David Levinson
highway segments by Mn/DOT’s Regional Traffic Management Center before and during an experimental ramp meter shutoff period mandated by the state legislature.

Interestingly, until this study began, the traffic data collected before and after the ramp meter shutoff were not available to researchers. Special data collection efforts to obtain ramp queue lengths were undertaken by Mn/DOT to assist the University researchers. Additionally, through this work, a broader spectrum of performance measures was developed and applied to evaluate on-ramp control strategies, giving decision makers a more complete view of system effectiveness than previously available. And, while traditional freeway control strategies try to minimize total delay in the system, which sometimes results in unequal distribution of delays among users, the new control objective developed in this study considers both efficiency and equity in a systematic way. Specifically, efficiency-oriented ramp coordination, which prevents freeway traffic flow from breaking down, and equity-oriented coordination, which more evenly distributes delays among users, are distinguished and enforced under a common objective function rather than independently of each other.

The results of this work reveal that freeway mainline speeds and flows are consistently higher with ramp metering than without. Levinson and Zhang also found, however, that overall trip speeds, including those on both the freeway and the ramp, are not uniformly higher with ramp metering than without. This suggests that long trips benefit from metering at the expense of short trips. Finally, this work also shows that if people value their time differently—for example, one minute waiting on a ramp versus one minute of free-flowing travel on the mainline—a ramp metering system that satisfies users must consider ramp delay in addition to freeway throughput. “The results show, analytically, that the most efficient control strategy is also the least equitable one,” Levinson added.

These conclusions have led to the development of a new family of balanced efficiency and equity (BEE) freeway ramp control strategies based on “optimization theory.” Optimization theory recognizes that one minute of delay at entrance ramps is more onerous for drivers than one minute of free-flowing travel time on the freeway mainline. With these new BEE strategies in hand, decision makers are able to identify an optimal balance between efficiency and equity objectives when setting ramp meter times, which can be adjusted in response to public perception without any additional cost.

Mn/DOT has already applied some of the study findings, including limiting individual delay, to update its own control strategy. As the conflict between efficiency and equity goals in freeway on-ramp control heats up as congestion increases, freeway traffic engineers elsewhere may learn something from the empirical results that they can apply to their own control strategies.
Accident prevention based on automatic detection of accident-prone traffic conditions

Some stretches of highway are more hazardous than others. In the Twin Cities metro area, one of the most crash-prone areas is the commons where interstate highways 94 and 35W come together. If traffic researchers could find out why crashes occur here, they might be able to help prevent them.

The ITS Lab’s Beholder system is playing an integral role in helping two University researchers do just that. Professor Panos Michalopoulos and research fellow John Hourdakis of the Civil Engineering Department are working to develop a crash avoidance/prevention system for crash-prone freeway locations. Their first step was to study the reasons for and mechanics of crashes by recording them and extracting raw traffic-detector measurements.

The Beholder system is providing the team with real-time video and traffic measurements, allowing them to observe and verify the incident represented in the recorded measurements. The advantage of using the Beholder system, Hourdakis explains, “lies in the detail and resolution of the collected measurements. There is no other site in the world that [reliably and continuously] collects such information.” For a stretch of highway that is more than a mile long, Beholder provides continuous individual vehicle speeds and headways around the clock. Having such detailed measurements for a specific location is essential for the success of the study, Hourdakis adds.

So far, Michalopoulos and Hourdakis have collected data on approximately 150 crashes and 300 near misses and have recorded and collected enough information to get an idea of the year-round traffic conditions in the area and the variety of crashes that occur there. What they have found so far is that crashes are not entirely random but rather depend on the traffic and geometric characteristics of each location. Specifically, the team has learned that crashes in this location are frequently related to two things: the congestion shockwaves that propagate backwards from the merge area at the entrance ramp and further downstream, and the vast difference in driving speeds between the right and middle lanes, which makes changing lanes difficult and therefore dangerously distracting for drivers.

“We have identified most of the causes of crashes in this I-94 section and have analyzed the data and built models that so far look promising in detecting accident-prone conditions (APCs),” Hourdakis explains. “We’ll incorporate these models into algorithms that can automatically detect APCs and produce alarms when such conditions are present.”

The current phase of research is reaching its conclusion, but the methods developed and lessons learned during the search for APCs on I-94 can be employed in research at other accident-prone locations. Along with the algorithms for APC detection, researchers John Hourdakis, Vishnu Garg, Adinarayana Beegala, Panos Michalopoulos, and Wuping Xin. The rooftop cameras behind them are collecting data on the I-94 and 35W commons area just south of downtown Minneapolis.
Michalopoulos and Hourdakis hope to produce such a methodology for tuning the system to another crash-prone site study and to produce specific models for the I-94 location.

The next phase, set to begin in November, involves implementing designs where different alternatives for traffic calming and/or raising driver attention will be evaluated and prepared for deployment.

COMPUTING, SENSING, COMMUNICATIONS, AND CONTROL SYSTEMS

Recognition of human activity in Metro Transit spaces

Since the events of September 11, the surveillance of public spaces has taken on greater importance and urgency. As video cameras are increasingly used at vulnerable areas—bridges, seaports, and potentially on airplanes—the volume of video data generated will be enormous. It simply won’t be feasible for human operators to monitor and evaluate it all.

According to Professor Nikolaos Papanikolopoulos, of the University’s Department of Computer Science and Engineering, autonomous vision-based systems are ideal for monitoring human activities in public places because they are more “attentive” than a human. A computer system could be used to first screen data, then highlight significant cases for human operators to evaluate.

Papanikolopoulos and research associate Osama Masoud developed a system to test the feasibility of this type of computerized monitoring. The project is aimed at helping Metro Transit, the Twin Cities transit bus operator, recognize drug dealing and other suspicious activities at bus stops. Because drug dealing is characterized by individuals loitering for long periods at bus stops, it offered a good target behavior for the system.

Drawing on his and Masoud’s earlier work on human detection and crowd monitoring, Papanikolopoulos, along with graduate students Guillaume Gasser and Nathaniel Bird, developed such a system. Across the street from a busy bus stop on the University of Minnesota campus, the researchers installed a video camera to watch people come and go at their test site.

The system uses standard equipment: an off-the-shelf video camera and a computer. The monitoring process itself is divided into three distinct phases: background subtraction, object tracking, and human recognition.
Background subtraction involves separating the background scene supplied by the video feed from the foreground. By comparing each new frame in a video sequence to a background model of the scene (without activity), the system can detect moving objects. These objects are then separated from the background image and tracked. The researchers used a method based on an adaptive background modeling and subtraction technique known as nonparametric kernel density estimation, which allows for the detection of moving objects in outdoor environments with respect to changes in the background like changing illumination.

To enable the system to track objects in real time—here, people as they walk around a bus stop—the researchers developed algorithms to recognize pre-specified actions. As individuals enter the scene, the system assigns each a unique number and creates a database of these individuals. Because presence history information is generated for each target, the system can recognize individuals who leave and return.

For the human recognition component, the researchers chose a short-term biometric technique—clothing color. The system’s human recognition module segments the image of an individual into three portions corresponding to the head, torso, and legs. Using the median color of these regions, two people can be quickly compared to see if they are the same person.

Results of the researchers’ test showed that the system could successfully track individuals in sparsely-populated outdoor scenes, with limited occlusion, in near real time. The system was also robust in handling image size changes due to differences in perspective as an individual walked across the scene, Papanikolopoulos says.

Expanding the system to recognize certain behaviors, such as leaving a package unattended, is a priority for future work. The Department of Homeland Security has recently funded the continuation of their research for the purpose of detecting security threats.

Defining what constitutes a threat, or threatening behavior, may be the toughest issue, Papanikolopoulos admits. “For me, this is one critical question that we need to answer. Can we learn what is suspicious activity?” he asks.

Designing efficient bandwidth and power modulations for better wireless transmissions

In today’s media-rich world, more and more communication is done over wireless networks, and the demand for new mobile services seems unlimited as these systems now handle not only voice, but also video and image transmissions. Despite the increasing use of mobile multimedia communication, wireless systems still face two major problems: signal fading and limited bandwidth. Associate professor Mohamed-Slim Alouini and a team of researchers from the Electrical and Computer Engineering Department are embarking on research to help allay these particular challenges.

Unlike cable or fiber optic networks, for which the transmission length is fixed, the unknown transmission lengths of a wireless system create random signal behavior. This leads to lost signals, signal degradation, and overall unreliable performance.
Traditionally, one way to tackle this “fading phenomenon” problem was to use worst-case design methodology in which the channel is characterized and calibrated based on the worst possible transmission scenario. But while this approach may improve performance, it requires a lot of power, quickly drains the battery of a mobile device, and creates a significant amount of interference to other wireless applications.

Instead of using the worst-case approach, Alouini’s team is working to design adaptive communication techniques in which signal quality is estimated and tracked in real time. With adaptive modulation, when a signal fades, the power and rate are backed down and the data being transmitted are buffered until the signal improves; then, transmission resumes at higher rates when the channel quality improves. According to Alouini, this technique uses much less power and actually allows for faster average data transmission rates.

The researchers’ are also investigating the competition for bandwidth, or spectrum. Because the radio spectrum used in wireless communication is congested and in short supply, wireless applications, including intelligent transportation systems (ITS), must be able to transmit as much data as possible using as little bandwidth as possible. Alouini is working to develop spectrally efficient “hierarchical” transmission techniques whereby both voice and data are imbedded into a single signal.

After first creating simple, mathematically trackable models of a wireless system and of the fading phenomenon, the team developed unique performance analysis models that quantify channel imperfections using formulas. “We were the first to come up with a mathematical framework to evaluate the exact performance of several hierarchical transmission schemes over communication channels,” Alouini notes.

These newly developed modulation techniques were compared to traditional ones to determine what gains have been made using what scenarios. The team continues to study different types of adaptive modem concepts that may be even more efficient, and they have collaborated with researchers at the University of British Columbia in Vancouver, Canada, to develop a multimedia modem that capitalizes on the concept of hierarchical constellations to transmit simultaneously voice and multiple classes of data over fading channels. Computer simulations show that this newly developed modem is more bandwidth-efficient than previously proposed modems for simultaneous voice and data transmission.

These research efforts will be instrumental in improving the reliability of wireless networks used in traffic management applications, and by other industries and individuals to extend battery time for mobile devices with less interference.

**SOCIAL AND ECONOMIC POLICY ISSUES RELATED TO ITS TECHNOLOGIES**

**Sustainable Technologies Applied Research Initiative: Spatial impacts**

Back in the 1980s at the dawn of the Internet age, futurists predicted that as telecommunications improved, people would stay home more. They could work, shop, and bank from home, and would save time and energy, reduce air pollution, even eliminate traffic. Though this hasn’t happened yet, it’s not for lack of technology. People could travel less—they just don’t.

The relationship between information and communication technologies and household travel decisions is more complicated than futurists could have imagined. Unraveling that relationship to help transportation planners understand how urban areas may change as technology becomes pervasive is at the core of Kevin Krizek’s research.
As part of the Sustainable Technologies Applied Research (STAR) project, Krizek, an assistant professor at the Humphrey Institute, is in the middle of a six-year study of the impact of telecommunications on urban spatial structure and its subsequent impact on urban transportation demand and intelligent transportation systems. “We are looking at the degree to which information and technology affect personal travel habits,” he explained. “At one point, we thought that e-commerce could replace a lot of physical travel and therefore we’d eliminate our congestion woes. The emerging thought is that information technologies are not replacing household travel but are complementing it.”

Krizek is collecting and analyzing data on household travel decisions in three cities: Seattle, Pittsburgh, and the Kansas City metropolitan area. The urban areas differ from one another in degree of technology use and in congestion levels. Examining such different cities, Krizek feels, will produce a clearer picture of how telecommunications will affect travel under a variety of circumstances.

The first step in this study was an extensive review of earlier studies into the influence of technology on household decisions. Earlier research found that many kinds of household activities could be replaced by telecommunications. Generally, researchers found that activities could be divided into subsistence activities (such as commuting for work), maintenance (such as grocery shopping or banking), and leisure. For each of these activities, telecommunications could have a variety of effects: it could be a substitute for travel, such as working at home instead of commuting; it could modify travel in terms of time or location; and finally, telecommunications devices could generate travel that otherwise might not have occurred.

During the second phase of the research, Krizek conducted an extensive survey of several thousand households in the three study cities. The questionnaire asked residents about their use of technology for banking, shopping, and entertainment. It also asked about attitudes toward technology and various travel issues such as congestion and walking as a travel option.

Although he has not yet finished analyzing and interpreting the data, Krizek has already discovered some interesting results. “There are a lot of things we have to figure out,” says Krizek. “One study found, for instance, that you can take a family out of the suburbs, but you can’t take the suburbs out of the family. That is, if a family moves from the suburbs into the city, they will take just as many trips using their car. The trips may be shorter, but the habit of driving is very hard to change.”

By understanding the demographics of those who use telecommunications and how, Krizek hopes to gain important
Insight into transportation issues. The overall results of this work will help provide a stronger basis for formulating transportation policy now and in the future.

[This article has been adapted from material originally published by the Humphrey Institute of Public Affairs in *Places and Networks: New Hierarchies in Access and Activity*. See www.hhh.umn.edu/centers/slp.]

**Sustainable Technologies Applied Research Initiative: ITS and industry clusters**

Businesses worldwide are continually being reshaped by advances in ITS technologies. Yet despite the rapid development of these technologies, ITS research generally focuses on the systems from the standpoint of the transportation agency or technology provider; the ways in which ITS affects transportation system users, especially businesses and industry, have gone largely unexplored.

To help fill that gap, Lee Munnich, senior fellow with the Hubert H. Humphrey Institute of Public Affairs, and research assistants Chandler Duncan and James Lehnhoff began a research effort to examine ITS technologies from the user’s perspective. In this multi-year study, the researchers are working to learn more about the economic development aspects of transportation to find out how it can be used to improve a regional economy and to identify key policy actions or intermediaries that may better enable firms, communities, and regions to maximize the benefits of ITS technologies.

Because regional economies often are driven by the presence of industry clusters—that is, groups of companies making a similar product or components for that product that congregate naturally in a specific region—the team chose two rural industry clusters located in northwestern Minnesota for which to analyze ITS use. Despite disadvantages that might have a negative economic impact—its distance from the Twin Cities (more than 300 miles) and lack of access to an interstate highway—the region enjoys a per capita income higher than that of other non-metro regions of the state, due in large part to the success of its industry clusters.

“Transportation is a huge issue for these industry clusters,” says Munnich. “They’re located in a very sparsely populated region. There are no interstate highways. The weather conditions can be horrible and have a severe effect on transportation. We’re trying to discover to what extent technology improvements affect the clusters and what improvements likely will be needed for the future.”

The two clusters involved in this particular study are those for recreational transportation equipment, which primarily involves the manufacture of snowmobiles and all-terrain vehicles, and wood products. To date, the researchers have conducted interviews and focus groups with industry representatives in order to learn how businesses within each cluster communicate with customers and suppliers, how they link suppliers and customers through transportation and communication networks, how they move goods, how the cost of transportation affects the firm’s location, how their transportation needs have changed over time, and what changes they anticipate making in communication and transportation strategies in the future.

Although the study is ongoing, Munnich and his team have already uncovered some interesting differences between the two clusters. In the recreational equipment industry, for example, businesses are experiencing a rising demand for their products locally, nationally, and internationally. Many of these firms are already using technology to their advantage to handle product, inventory, and/or supply tracking and supply-chain management. For many firms in this cluster, technology also has enabled more cost-effective transportation options. The wood products cluster,
however, primarily serves only local and regional markets, and most firms in this industry have not widely implemented any supply, product, or inventory-management systems. Generally, these firms have smaller supply chains and are not as concerned with using ITS technologies for connectivity among companies. The bottom line so far is that the use of ITS technologies is “necessary but not sufficient” to business vitality in these clusters, Munnich says. This initial finding has opened up several other areas for further exploration and has led the researchers to ask sharper questions about these clusters regarding which technologies are used, how they are used, and what benefits they provide.

In the next phase of the study, researchers will take a broader look at the state as a whole in terms of what ITS is doing or could be doing for industry in Minnesota. The study’s long-term objective is to determine specifically what technologies are needed and to identify any market barriers businesses face to using these technologies. The findings from this project will help transportation professionals make better decisions on how to use new technologies to strengthen industry clusters and enhance economic vitality in cluster areas.