ITS Laboratory

The Intelligent Transportation Systems (ITS) Laboratory is a dedicated facility supporting ITS research and education. The lab’s mission is to develop and provide state-of-the-art resources for researchers, students, and collaborators pursuing research in ITS.

Focused on supporting research in surveillance, monitoring, and management of traffic systems, the ITS Laboratory works in partnership with other University of Minnesota research facilities including the HumanFIRST Program and the Intelligent Vehicles Laboratory to enable a full spectrum of ITS research.

The lab’s facilities are used by faculty and students in civil, mechanical, and electrical engineering, computer science, and affiliated disciplines. The lab’s data-gathering capabilities and modeling expertise serve as the foundation for the development of interactive laboratory modules to support ITS-related courses at the University. The lab also hosts training and outreach events.

The ITS Laboratory has developed several generations of data-acquisition systems to meet the needs of researchers working on freeway traffic-flow issues. The most recent of these is the Beholder system, a fully independent network of video detectors providing space- and time-continuous coverage of the I-35W/I-94 commons freeway area in Minneapolis.

Beholder expands on the pioneering Autoscope system, originally developed at the University of Minnesota and now in commercial use. Beholder’s portable monitoring stations are currently deployed on the roofs of several high-rise buildings overlooking the freeway, and transmit data back to the lab via a high-speed IEEE 802.16 wireless network.

Besides the data provided by the Beholder system, the lab is supplied with eight switchable compressed/streamed Internet video feeds by the Minnesota Department of Transportation (Mn/DOT). Researchers have the ability to switch...
between any of the approximately 300 Mn/DOT cameras monitoring the metropolitan freeway network.

Several traffic simulation packages are used in the ITS Laboratory, chiefly AIMSUN2 for microscopic flow simulation based on individual vehicles, and the KRONOS 9 package—developed at the ITS Institute—for macroscopic or platoon-based simulations. Other packages such as Vis-Sim are used as needed.

Recent simulation and modeling projects at the ITS Laboratory have focused on improving the efficiency of metered access to urban freeway networks and on developing a dynamic, centrally regulated traffic signal preemption system for emergency vehicles.

Putting the researcher inside the simulation is the goal of the ITS Laboratory’s Digital Immersive Environment, or DEN. Three large rear-projection screens surround the user; behind the scenes, a bank of six computers controls a visual environment developed using Open Scene Graph (OSG) and driven by data from an AIMSUN2 traffic simulator.

Each screen displays both left- and right-eye projections simultaneously, and polarized eyeglasses fuse the image channels to create a three-dimensional virtual world where the corners of the DEN melt away. Users can navigate and interact with the simulated world using a handheld wand; a high-accuracy tracking system constantly adjusts the

Around 70 undergrads at the University of Minnesota will control stoplights on Washington Ave. S.E. for a few weeks each semester, but don’t get too worried—it’s only a simulation. A Web-based traffic control simulator designed by ITS Senior Systems Engineer Chen-Fu Liao is being used to teach civil engineering students in an introductory transportation engineering course how to optimize traffic flow at intersections, from their home computers if they choose.

The interactive lab module, designed to meet the needs of civil engineering educators, is the second traffic control lab module Liao has developed in the ITS Lab. It is a vast improvement over the first, a static lab module featuring only 12 pre-planned scenarios. The second version allows users, via four AIMSUN nodes located in the ITS Lab, to change several variables of a four-way intersection: traffic demands, turning proportions, and timing of the signals. This creates “an infinite number of possible situations,” said Liao. Users can also track individual vehicles, visualize congestion, and view any point within the simulated time range to observe traffic conditions in the two-dimensional Java interface—three advantages of the simulator, which supplements classroom lectures and formulas on paper.

Senior Michael LaCasse, an Institute of Technology student in the transportation engineering class that used Liao’s simulator, said he was quickly aware of these advantages when traffic conditions in an intersection did not match his expectations. “With the simulator I could quickly see what was happening,” he said. “If all I had was data output in a listing… I would have wondered why the traffic signal did not perform similar to my mathematical calculations,” said LaCasse.

Another advantage of this simulator over previous methods of instruction is the variable speed allowed by the AIMSUN nodes. When a scenario is created, the user can not only view the traffic conditions at a one-to-one speed (also known as “real-time”), but at any desired speed. The key to this is to have the AIMSUN nodes process the scenario entirely, then send the packet to the remote user. The user may then select any time within the simulation and view the traffic data at that point. This also frees up the nodes to process other simulations, allowing many people to use the program at the same time—people, Liao says, he hopes will one day include lawmakers.

The Java-based user interface for the Web-based traffic simulation module. Students can select a vehicle and monitor the distance traveled on the time-space diagram overlaid with the signal phases along the corridor.
The University of Minnesota is recognized as a leader in developing and testing driver-assistive systems.

The perspective of the projected scene according to the position and orientation of the user’s head.

The DEN can help investigators understand traffic flow within the context of urban design constraints, pedestrian uses, and other factors that have been impossible to visualize using conventional display technologies. It also complements the vehicle simulation capabilities of the Human-FIRST Program, including the ability to use the same virtual worlds in both environments.

**Intelligent Vehicles Laboratory**

The Institute’s Intelligent Vehicles Laboratory focuses on developing and testing innovative, human-centered technologies that improve the operational safety, mobility, and productivity of vehicles. These human-centered technologies integrate sensors, actuators, computer processors, and custom human interfaces to provide drivers with needed information under difficult driving conditions, including low visibility, severe weather, and narrow and congested roadways. Initially, these driver-assistive systems have been tested on specialty vehicles, including snowplows, patrol cars, ambulances, heavy vehicles, and transit vehicles. Ultimately, these systems will also be used on passenger vehicles, providing drivers with warnings and assistance with collision-avoidance and lane-keeping tasks.

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

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

The IV Laboratory’s lane-assist technology is unique in that it uses DGPS and does not require hardware in the roadway surface. The technology is transferable between various transportation modes and works in all low-visibility situations, including snow, fog, smoke, heavy rain, and darkness. In addition, these systems use human-centered technologies to enhance driving ability and reduce driver
error due to distractions, fatigue, and other factors related to difficult driving situations.

Other difficult driving conditions are encountered by drivers on a daily basis. For instance, the vast majority of vehicle crashes occurring at rural, unsignalized intersections are the result of drivers incorrectly gauging the size of a gap between oncoming vehicles, not running stop signs. The IV Lab has developed a sophisticated rural intersection data collection system used to study how drivers waiting at a low-volume minor road enter or cross a high-speed, high-volume expressway. The data collected at the intersection will be used to model driver behavior to determine where the gap-acceptance decision-process fails and leads to a crash, and to then design countermeasures to reduce the number of these crashes.

Additional research topics include the design and testing of custom human interfaces, collision-avoidance sensors and algorithms, and wireless communication among vehicles and with the infrastructure. The IV Laboratory’s partnership with the Minnesota Department of Transportation provides access to roads and other infrastructure, including the Minnesota Road Research Project (Mn/ROAD) test track, which consists of a freeway and a low-volume road pavement test track with 40 different road material test sections, 4,500 electronic sensors, a weigh-in-motion scale, a weather station, and DGPS correction signals. The IV Laboratory also has relationships with a number of other organizations and government agencies, including the U.S. Department of Transportation’s Research and Innovative Technology Administration, Federal Highway Administration, and Federal Transit Administration; Twin Cities’ Metro Transit; Minnesota’s Local Road Research Board;
Testing new methods for improving traffic safety is essential in order to learn how well they will perform. However, testing that begins in the controlled conditions of laboratories and driving simulators often cannot be reliably replicated in more natural, “real-world” test environments.

This led the HumanFIRST Program to develop a new method to transfer controlled simulator scenarios to test-track and field studies. One component is an instrumented lead vehicle fitted with DGPS and operating within a digital map generated for the test environment. This vehicle is linked by wireless communication and DGPS to a test vehicle. Onboard computers produce specific driving scenarios, which can be the same as those used in the driving simulator, as both are programmed with the same control logic.

In this application, a prior simulator study examined driver response in a rear-end crash scenario during which the driver of the following car was distracted with a secondary task. This involved linking an eye tracker and the secondary task to the simulator in order to automatically trigger the car-following scenario when distraction was detected. The lead vehicle would follow a specified speed profile and then “hunt” for the subject in the following car to move within a defined range of headway (to create a desired hazard level). When the eye tracker detected that the driver was distracted with the secondary task, a trigger would result in the lead vehicle braking with a specified deceleration rate.

In the test track study, the test vehicle was also equipped with an eye tracker and the secondary task. The gaze direction of the driver and interaction with the secondary task was again used to define distraction. The onboard computer, linked to the control actuators of the lead vehicle, was programmed to autonomously create a similar speed profile as used in the simulator study. The driver of the lead vehicle needed only to steer, since the parameters of all events were controlled precisely by the computer control system.

At a determined point in the scenario, the lead vehicle would hunt for the test vehicle and also monitor the output from the eye tracker and secondary task. As soon as the driver was distracted, the lead vehicle executed its specified scenario braking event. By virtue of the DGPS and digital map, the test vehicle recorded the same types of data as the simulator with comparable levels of reliability.

The second component of this method is a virtual “safety net.” The researchers developed an algorithm to automatically trigger evasive acceleration in the lead vehicle and braking in the test vehicle if the headway was detected to move into a specified hazard region. In addition, a “watch dog” system continuously monitored the safety-critical components of the integrated system, and, if it detected failure, the system alerted the drivers and stopped both vehicles.

The combination of the automated lead vehicle and safety net provides a way to translate scenarios from a driving simulator to real-world conditions with the same level of data reliability and control without risking safety. Conversely, this system allows the researchers to replicate test track infrastructure perfectly within the simulated environment. Moreover, the use of the safety net extends the range of risk that can be developed in the test scenarios.

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

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

Recent research topics include:
• driver distraction from in-vehicle tasks and cell phones
• rural and urban driver attitudes and crash risk
• interventions for crash reduction at rural intersections
• bus rapid transit using dedicated narrow shoulders
• driver fatigue and methods for its detection
• intelligent driver-support systems such as vision-enhancement, collision-avoidance, hazard-awareness, and lane-keeping systems for passenger and specialty-purpose vehicles
• learned and inherited factors related to unsafe driving
• alcohol impairment
• attention-deficit/hyperactivity disorder and novice drivers
• in-vehicle use of Advanced Traveler Information Systems (ATIS)

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

Much of the research of the HumanFIRST Program uses a state-of-the-art driving simulator (supplied by AutoSIM and OKTAL) engineered specifically for human factors research in surface transportation. This Virtual Environment for Surface Transportation Research (VESTR) is a versatile and realistic simulation environment linked to a full-cab SC2 vehicle donated by Saturn using software that can create virtual environments that precisely reproduce any geospecific location. This visual environment is generated with high-resolution images (2.5 arcmin per pixel) over a wide field of view (210-degree forward, 50-degree rear, 2 by 20-degree side mirror images). This immersive driving experience is enhanced by realistic motion generated by a three-axis motion base and both high- and low-frequency vibration units, including a surround-sound system. With multiple sound systems, configurable touch panel displays (including head-up displays), haptic feedback through the seat and accelerator pedal, and a head-free eye-tracker that can detect in real time what a driver is looking at, this simulator supports the investigation of a wide range of interface options for ITS development, design, and assessment. These features make VESTR one of the premier driving simulators in North America and Europe.

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

Northland Advanced Transportation Systems Research Laboratories
The Northland Advanced Transportation Systems Research Laboratories (NATSRL) is located at the University of Minnesota Duluth. Its mission is to study comprehensive winter transportation systems and the transportation needs of cities in small urban areas. To accomplish this, NATSRL collaborates with the Minnesota Department of Transportation, city and county engineers, and other agencies on research that covers a wide range of topics, including opti-
Determining an optimal time to replace snowplows and other fleet assets could save state transportation departments a significant amount of money: replacing too early requires a great deal of capital and replacing too late results in extra maintenance and operations costs for older trucks. In addition, life-cycle times affect the economics and deployment of new vehicle technologies.

In a recent research study conducted through NATSRL, David Wyrick, professor and head of the Department of Mechanical and Industrial Engineering at the University of Minnesota Duluth, set out to investigate how to improve fleet operating costs through effective vehicle replacement, to validate (or challenge) the current vehicle life standard of 12 years, and to understand utilization issues at the Minnesota Department of Transportation (Mn/DOT).

Wyrick used the Equivalent Uniform Annual Cost (EUAC) method as one way to determine an appropriate life-cycle standard for Mn/DOT’s fleet, focusing on the class 330 snowplow. This method analyzes the costs associated with owning a fleet asset throughout its life to reveal the time range with the lowest annualized costs. Over the life of a vehicle, the annualized acquisition cost comes down as the annual operating costs go up. Using EUAC, the researcher looks for the area in the middle after the acquisition cost has gone down enough and before the operating costs have gone up too high. This is the “window of opportunity” for replacing assets, Wyrick says.

Good data were hard to find because of inconsistent entering and tracking of data, but Wyrick was able to make some tentative conclusions based on his analysis. He provided examples from two Mn/DOT districts: District 6, in the southeast corner of the state, and District 1, in the north. The results showed an average optimal life cycle of 10.76 years for District 6, and 9.26 years for District 1. Assuming the results can be generalized, if the life cycles of Mn/DOT’s snowplows were reduced from 12 years to 8 years, Mn/DOT could save up to $330,000 per year statewide on the class 330 snowplows alone.

However, Wyrick says that a statewide life-cycle standard “may not be optimal” because of differences among districts and among individual vehicles. He suggests that life-cycle analysis could be conducted on an individual unit basis to dispose of problem vehicles earlier and to keep reliable vehicles longer. This could be done by using trend analysis, which tracks whether the cost is increasing or decreasing for each vehicle and then replacing those for which the costs are increasing.

NATSRL’s current laboratories are the Advanced Sensor Research Laboratory, the Transportation Data Research Laboratory, and the Transportation Engineering Research Laboratory. The Advanced Sensor Research Laboratory tests advanced sensing technologies for pavement and road conditions (speed, weather impact, and traffic density), researches the development of new techniques to detect incidents and abnormal traffic conditions, and analyzes real-world and real-time measurements of road, weather, and traffic information. The Transportation Data Research Laboratory has developed a statewide traffic data archival and analysis system that is used by Mn/DOT for long-range planning and the development of strategic traffic management plans, and continues research in the improvement of data integrity retrieved from the road sensors. The Transportation Engineering Research Laboratory is developing, in conjunction with Mn/DOT, an automated inventory management system for transportation infrastructure and the design of efficient management practices through benchmarking state DOT procedures.

Other NATSRL projects include developing a traffic counter for low-volume roads and student development of software tools to manage large volumes of transportation-related data.

In addition, NATSRL partners with Mn/DOT District One each year to provide a day-long formal presentation of ongoing research efforts.

An RTMS sensor monitors traffic on Highway 35 in Duluth. NATSRL researcher Taek Kwon is using it to integrate traffic data with R/WIS for analysis and archiving.