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A portable weigh station for rural roads

The Roman engineers who created the empire's remarkable network of paved roads recognized the importance of protecting their transportation system from damage by heavy vehicles. By the fifth century, Roman law set weight limits on different classes of vehicles and specified punishments—including exile or hard labor in the mines—for violators.

Modern engineering research has quantified the link between axle weight and road wear: a linear increase in loading produces a fourth-power exponential acceleration in wear, so doubling axle weight is estimated to accelerate road wear by roughly 16 times the original rate. This calculation is a key component of pavement design and maintenance planning.

Today, however, the large number of commercial vehicles moving at speeds no Roman oxcart driver could have imagined has made the problem of regulating vehicle weights extremely challenging. Transportation agencies around the world are turning to new technologies to help monitor the impact of heavy vehicles on valuable pavements.

Professor Taek Mu Kwon of the University of Minnesota–Duluth electrical and computer engineering department is developing a portable weigh-in-motion (WIM) system that will enable highway engineers to measure truck weights in areas far from highway weigh stations.

Kwon is also the director of the Transportation Data Research Laboratory. His past research has included developing novel portable, wireless, self-powered vehicle detector systems as well as managing the archiving and distribution of traffic data from the Twin Cities freeway system.

Highway engineers charged with maintaining rural roads have noted more heavy vehicles in recent years. The increase, according to researchers, is being driven by the rapid development of the biofuels industry and its need for large quantities of corn and soybeans.

The potential for increased heavy truck traffic to damage local roads concerns highway engineers in rural areas. Estimating road wear due to heavy trucks is difficult in rural areas, however, because constructing traditional weigh stations in these areas is unfeasible. WIM technology has the potential to monitor truck loads more economically. Kwon is designing a system that is portable and can be deployed where it is needed to monitor vehicle loads.

Traditionally, weigh stations staffed by trained personnel have been the primary tool for determining compliance with weight limits. After a vehicle has been stopped and weighed, weigh station staff determine whether its weight is within the limits prescribed for its classification and any applicable permits.

Constructing and maintaining weigh stations on low-volume rural roads, however, is not economically feasible. A portable WIM system gives engineers the flexibility to deploy monitoring equipment quickly and change locations as necessary, which makes monitoring vehicle weights in multiple locations cost-effective.

Weigh stations have several other disadvantages. Requiring commercial vehicles to stop for inspection can cause significant delays, especially on heavily traveled routes where many vehicles may be forced to wait their turn on the scales. Weigh-in-motion systems avoid these drawbacks by replacing staffed weigh stations with automated equipment. Instead of pulling off the highway to be inspected, vehicles simply drive over WIM scales at a constant speed. Weight sensors can be combined with automated vehicle classification systems and identification via license plate recognition or other means, enabling direct communication of violations to enforcement personnel.

One of the known problems of permanent WIM systems is that calibration is laborious and difficult. A WIM system calibration method recommended by

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INSIDE

Fall seminars explore technology, policy issues; available online

Xun Yu

Fall 2009 seminar presentations by University of Minnesota researchers and visiting ITS experts highlighted key research areas in technology and public policy. Video recordings of the seminars are available on the ITS Institute Web site.

Two distinguished visitors gave presentations on their recent research during this semester. Their work has significant links to research being carried out on the University of Minnesota campus.

Steven Shladover, research engineer with California PATH at the University of California–Berkeley, described current work on wireless communication systems to link vehicles and transportation infrastructure. The Vehicle-Infrastructure Initiative, now known as IntelliDrive℠, was originally created to alert drivers to roadway hazards; however, researchers are now using it to support ITS-related "cooperative technology" applications such as active traffic management, cooperative adaptive cruise control, and automated truck platooning.

Lily Elefteriadou, director of the University of Florida's Transportation Research Center, described her recent work on using real-time freeway congestion data to enhance the performance of ramp-metering systems. Elefteriadou used data

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from Highway 494 in the Twin Cities in her research.

Several University of Minnesota researchers and faculty members also presented their work during the fall seminar series.

Research fellow Frank Douma of the Hubert H. Humphrey Institute of Public Policy gave a presentation on the implications of current and emerging privacy law for ITS, highlighting the legal issues raised by the rapid development of new technologies for monitoring and enforcement, such as automated camera systems to catch red-light runners. Douma's work was profiled in the Spring 2008 *Sensor*.

Janet Creaser, research fellow at the HumanFIRST Program in human factors engineering, presented her recent work on measuring the effects of alcohol on motorcycle driving skills September 24. Using a test motorcycle modified by the Intelligent Vehicles Laboratory to protect the rider in case of a loss of control, researchers ran motorcyclists with varying blood alcohol levels through training tasks from courses created by the Motorcycle Safety Foundation. Riders were tested in four areas: control and maneuverability, hazard avoidance, curve negotiation, and emergency stops.

Because the test track was designed with typical types of motorcycle crashes in mind (e.g., running off the road, going off curves), Creaser said the results showing impairment in the test tasks are indicative of the types of crashes seen among motorcycle riders in the real world. The observed impairment in the test track study, where tasks were low-speed (less than 25 mph) and the environment highly controlled, would be magnified in the real world, where motorcyclists are often driving at much higher speeds, she noted.

HumanFIRST research associate Ensar Becic asked "Should I Drive or Should I Talk?" in his November 5 presentation, which focused on research examining the effects of cellular phones and other devices on driver attention.

On November 19, assistant professor Xun Yu (mechanical and industrial engineering, Duluth) described his efforts to develop a nonintrusive in-vehicle system to detect driver drowsiness. Using piezoelectric sensors integrated into the steering wheel, Yu's system continuously monitors the driver's heartbeat in order to detect heart rate variability, a physiological change that indicates a shift from waking to sleeping. The specially designed sensors enable the system to monitor heart rate even if only one of the driver's hands is on the wheel.

Professor Rajesh Rajamani (mechanical engineering), speaking at the final seminar of the semester December 3, described the development of a new type of traffic sensor that does not rely on batteries for power and communicates data wirelessly. The project was featured in the Spring 2009 *Sensor*.

Chairman Oberstar visits University for transportation research update

Rep. Oberstar in the HumanFIRST driving simulator

U.S. Rep. James L. Oberstar, chairman of the House Transportation and Infrastructure Committee, visited the University of Minnesota on November 12 for an update on the latest University transportation research. He met with Transportation Engineering and Road Research Alliance (TERRA) board members, tried out the HumanFIRST driving simulator, and toured the Minnesota Traffic Observatory (MTO), guided by CTS acting director Laurie McGinnis and ITS Institute director Max Donath. "I love what you're doing here," Oberstar said.

Middle schoolers prepare for robotics competition on campus

Mechanical engineer Eddie Arpin, 2008 ITS Institute Student of the Year, spoke to middle schoolers about robotics research at the University of Minnesota.

More than 250 young science enthusiasts from across Minnesota converged on the University of Minnesota campus October 13 for a morning of educational workshops and tours of research facilities. The event, hosted by the University's Institute of Technology, the Center for Transportation Studies, and educational nonprofit organization High Tech Kids, was planned to help the students prepare for "Smart Move," the 2009 FIRST LEGO League robotics competition, an international competition for elementary and middle school students.

The theme of this year's competition is transportation. During the competition, students will be challenged to build small autonomous robots from a kit of more than 1,000 parts that includes LEGO pieces and other elements such as sensors, motors, and gears, and accomplish missions related to transportation. Participants must also complete an eight-week research project in which they identify a transportation problem in their community and create an innovative solution.

Max Donath, director of the ITS Institute and professor of mechanical engineering, gave an opening presentation highlighting a variety of research projects under way at the University, including the Teen Driver Support System (TDSS) and driver-assistive technology that allows snowplow operators to stay on the road in low-visibility conditions.

Minnesota Traffic Observatory director John Hourdos led a tour of his lab and demonstrated equipment for traffic visualization and modeling, and civil engineering professor Joseph Labuz explained how soil and pavement materials influence road performance.

Educational outreach includes State Fair exhibit, Gridlock Buster activities

The ITS Institute and the Center for Transportation Studies (CTS) participated in the 2009 Minnesota State Fair with a booth featuring the latest transportation innovations. In addition, *Star Tribune* "Roadguy" blogger and admitted "transportation geek" Jim Foti hosted four rounds of "Transportation Jeopardy" as fairgoers competed for prizes.

Young fairgoers had the opportunity to check out Gridlock Buster, an interactive traffic-control game designed by the ITS Institute. The game incorporates tools and ideas used by traffic engineers every day to give players a taste of what goes into managing traffic flow.

A presentation on Gridlock Buster was included in a session titled "Enhancing Students' Understanding of Core Concepts in Transportation" at the Transportation Research Board Annual Meeting.

The ITS Institute also sponsored a "Train the Trainer" webinar for educators to learn how to use Gridlock Buster in the classroom. David Glick of David B. Glick & Associates, LLC, the developer of high school curricula for the ITS Institute, presented the webinar on February 23. A video recording of the webinar is available on the ITS Institute Web site at http://www.its.umn.edu /Events/GridlockBusterWebinar/.

Young fairgoers tried managing traffic flow at the ITS Institute's exhibit.

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the FHWA requires trucks of known weights to make multiple passes over the sensors so that the statistical average of recorded weights can be calibrated against the known weights. Unfortunately, weight measurements by permanent WIM stations can be affected not only by the truck's actual weight but also by the pavement surface conditions and winds. In addition, the calibration truck must run along with regular traffic, so engineers must manually insert markers into the data to designate passes by the calibration truck, which is cumbersome.

Kwon's solution is to place the portable WIM side-by-side with a permanent WIM station and collect data over a longer period under the same environment, instead of over only a few runs. Since a portable WIM station can be calibrated in a controllable environment such as a parking lot using a vehicle with a known weight, it is much easier to calibrate the portable system.

To develop a portable WIM system, several technical obstacles had to be overcome. First, the sensor pads needed to be small and light enough to be moved to remote locations while remaining strong enough to withstand being driven over by heavy trucks.

The heart of Kwon's WIM design is a pressure sensor consisting of a thin strip of piezoelectric material, which converts mechanical pressure into a measurable electrical signal.

To protect the piezoelectric beam, Kwon examined a variety of flexible materials for the weigh pad. Cementing together layers of neoprene fabric and ballistic nylon (a fabric used in bulletproof vests) to create a flexible pad proved problematic due to the difficulty of bonding the layers together without causing the pad to warp. He then turned to industrial reinforced-rubber conveyor-belt material. A groove is carved into one layer of belt material to hold the piezoelectric beam, and a second layer is cemented over the top to fully enclose and protect the sensor.

A second obstacle was maintaining accuracy under tough real-world conditions. The signal processing system must be capable of measuring axle weights while isolating peripheral forces from the main load force. The impact of heavy wheels can cause anchored sensor pads to shift slightly, resulting in erroneous measurements. Temperature variations can also interfere with measurement.

Taek Mu Kwon

Finally, to be deployable in remote areas that lack electrical service, the system must run entirely on battery power and be able to operate continuously for long periods. Because calculating vehicle weights from raw sensor data is computationally intensive, the data processor must be powerful but draw little electricity.

The system design includes a signal conditioning circuit to prepare raw analog signals from the sensor pad for digital processing. This critical circuit minimizes electrical impedance mismatch, removes noise in the signal caused by thermal fluctuations, and maps the raw charge signals onto linearly proportional voltage signals for digitization. The conditioning circuit will incorporate specially designed amplifiers tuned to the characteristics of the input signal, currently under development in Kwon's laboratory.

Following the conditioning circuit, final processing of signals from the sensor pad will be accomplished by software that includes modules for real-time plotting, digital data conversion, vehicle segmentation, axle spacing and weight computation, and vehicle classification. The primary focus of software development will be on a vehicle segmentation algorithm based on axle spacing and weight.

Development of the portable WIM system has been made easier by a hardware-in-loop (HIL) testing system developed by Kwon in a previous WIM research project. The HIL system allows developers to run an unlimited number of signal tests in the laboratory using analog signal inputs controlled by software. The HIL system can also produce erroneous signals to test the WIM device's handling of errors.

Field testing of the prototype WIM system is scheduled to take place during 2011 at the Minnesota Department of Transportation's MnROAD pavement testing facility, where vehicles of known weights can be operated on a variety of pavement types to conduct controlled verification of the system.

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STREET creates new learning tools for transportation courses

STREET (Simulating Transportation for Realistic Engineering Education and Training) is a project focused on developing a set of Web-based simulation modules and other learning tools for use in introductory undergraduate transportation engineering courses. The modules are also suitable for upper-division transportation courses and cover a variety of topics fundamental to the practice of transportation engineering, including travel demand modeling, geometric design, traffic flow, and traffic signal control.

The *Transportation Education E-News*, a new electronic newsletter published by the Center for Transportation Studies, is also a component of the STREET project. Funding for the STREET project comes from the National Science Foundation with matching support from the ITS Institute. Minnesota Traffic Observatory educational systems manager Chen-Fu Liao is a key member of the development team.

As part of the STREET project, Associate Professor David Levinson and his students at the University of Minnesota's Department of Civil Engineering have developed an online simulation model for transportation planning called the Agent-Based Demand and Assignment Model (ADAM). ADAM is intended for classroom use as a tool for introducing students to the fundamental concepts of travel forecasting in a user-friendly, interactive format. It was first tested in a classroom setting in an introductory transportation engineering course at the University of Minnesota.

The Web-based modules developed as part of the STREET project complement a wikibook on the *Fundamentals of Transportation*. The modules will be tested in the curricula of a number of undergraduate transportation engineering courses at various universities. More than a dozen faculty members have agreed to incorporate STREET into their curricula.

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