2008 – 2009
Annual Report

The Pennsylvania State University ▪ University of Maryland
▪ University of Virginia
▪ Virginia Polytechnic Institute & State University
▪ West Virginia University

Table of Contents

Figures

MAUTC THEME

MAUTC's theme, *Technology for Integrated Transportation Systems Operation and Performance*, recognizes the critical link between technology and management of our transportation infrastructure, and it provides for a multidisciplinary approach to many critical transportation issues facing the Mid-Atlantic Region. MAUTC's research, education, and technology transfer programs focus on the integration of knowledge and expertise in transportation operations, organizational management, and infrastructure management. The theme clearly reflects the strengths of the five universities of MAUTC and the interests of the faculty and state agencies that support much of the research conducted by MAUTC.

The distinctive elements of MAUTC's theme include the following:

- Design and implementation of research and educational programs that apply advanced technologies for information acquisition, analysis, and application to the management of the transportation system.
- Multidisciplinary approach to research, education, and technology transfer activities.
- Emphasis on the operations and management of the transportation system.
- Multimodal mission that addresses passenger and freight transportation, highway, transit, and intermodal facilities.

MANAGEMENT STRUCTURE

Penn State has been the lead university and grantee for the University Transportation Centers (UTC) Program since 1986. MAUTC is administered through the Thomas D. Larson Pennsylvania Transportation Institute (Institute).

The MAUTC executive director and principal investigator, Dr. Martin T. Pietrucha, delegates day-to-day responsibility for MAUTC partner activities to each partner university: University of Maryland, University of Virginia, Virginia Polytechnic Institute and State University, and West Virginia University.

Dr. Paul Jovanis, professor, civil engineering, and director, Transportation Operations Program, represents the Institute's faculty interests in MAUTC activities.

Ms. Janice Dauber, MAUTC coordinator, is responsible for MAUTC's technology transfer activities, publicity, and report preparation.

Ms. Mara Poorman, staff assistant, provides clerical support for the overall MAUTC administrative effort as well as for Penn State's MAUTC projects and programs. Additional Institute staff support MAUTC as needed.

MAUTC FUNDING AND EXPENDITURES

MAUTC meets the U.S. Department of Transportation's 1:1 match requirement through state and local agencies, private companies, and universities. Maryland, Pennsylvania, Virginia, and West Virginia departments of transportation provide the majority of matching funds. (See figures 1 and 2.)

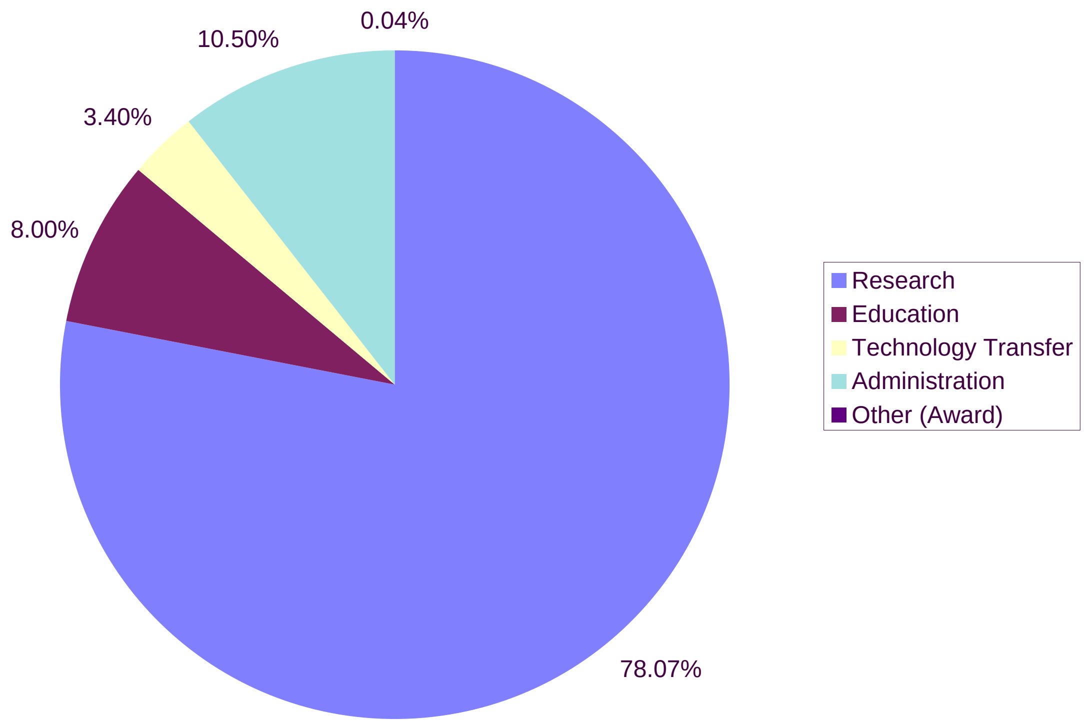


Figure 1 Expenditures by Activity

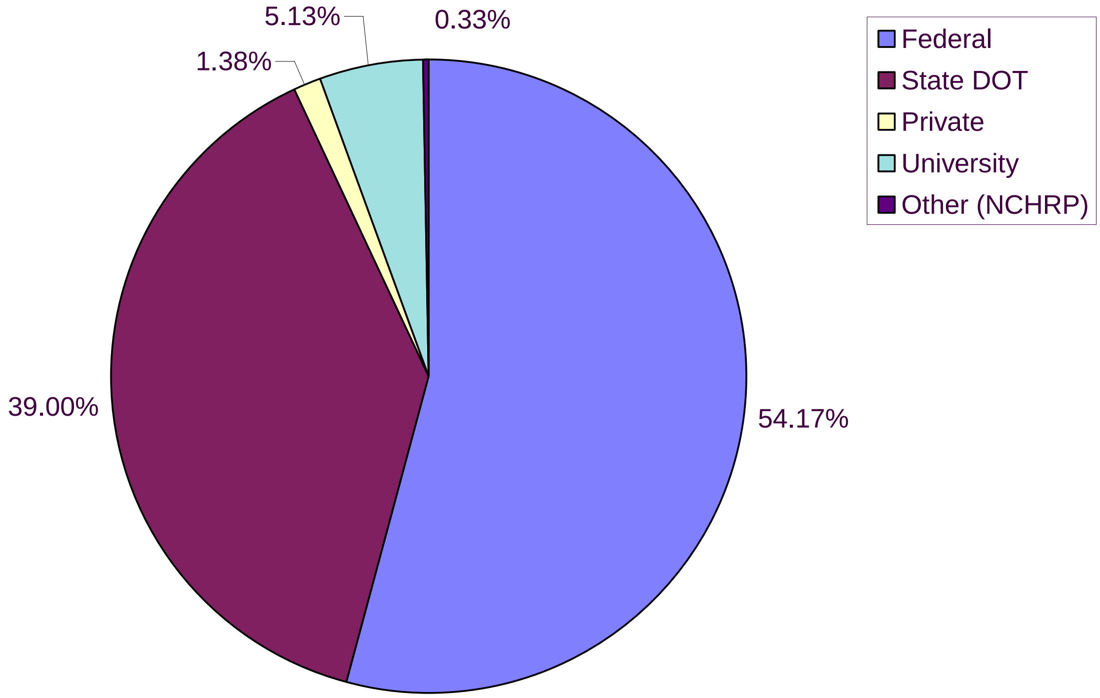


Figure 2 Expenditures by Source

Figure 3. Larson Institute

The Pennsylvania State University

The Thomas D. Larson Pennsylvania Transportation Institute is one of the nation's leading university transportation centers. Since its first days in 1968, the Institute has pursued a mission of interdisciplinary research that today involves laboratories, departments, and colleges throughout Penn State and numerous state, federal, and private collaborators. The Institute supports University faculty and students by providing interdisciplinary educational and research opportunities that complement and enhance the University's undergraduate and graduate education programs.

The Institute is the locus for transportation-related research conducted by Penn State faculty from more than 14 colleges and research centers. Many of these faculty hold joint appointments with the institute and Penn State's academic colleges and schools; areas of specialization include civil, computer, electrical, industrial, and mechanical engineering as well as agriculture, information sciences and technology, supply chain management, architectural engineering, economics, geography, psychology, and statistics. Through its multidisciplinary structure and supportive research environment, the Institute provides a unique focal point of collaboration for faculty from many different areas of the University.

Three programs comprise the Institute: Transportation Infrastructure Program, the Transportation Operations Program, and Vehicles Systems and Safety Program. Faculty, researchers, and students from all three programs contribute to and benefit from the research projects funded under the auspices of MAUTC.

University of Maryland

The University of Maryland (UMD) became a partner in 2007 when MAUTC re-competed for the Region 3 University Transportation Center. Professor Elise Miller-Hooks serves as MAUTC director for UMD.

The University of Maryland transportation research effort benefits from the new Intelligent Transportation Systems Laboratories in the recently completed state-of-the-art Engineering Research Building. New laboratories for transportation research include: Real-time Traffic Management Systems Research and Education Laboratory, Collaborative Decision-Making Laboratory for Large-Scale Distributed Dynamic Systems, Traffic Safety and Operations Laboratory, and Intelligent Transportation Systems Planning Laboratory. Direct connections exist from the various cameras and sensors installed along the freeway and highway system under the Maryland CHART traffic management center to provide live quasi-continuous feeds to the ITS Laboratories. Access to all archived CHART traffic data is also available through the University of Maryland laboratories. The

Collaborative Decision-Making Laboratory provides unique capability to conduct interactive simulation-based experiments with multi-agent transportation decision systems.

The University of Maryland offers transportation-related undergraduate and graduate degrees in civil engineering and mechanical engineering.

University of Virginia

The transportation program at UVA has expanded since its inception in the late 1940s when the University of Virginia School of Engineering and Applied Sciences began an ongoing partnership with Virginia Transportation Research Council (VTRC), the research branch of the Virginia Department of Transportation. The Center for Transportation Studies (CTS) was established to organize the existing academic program and research activities and to lay the groundwork for future growth.

The Center is located within the Civil Engineering Department on the grounds of the University of Virginia. With offices and laboratory facilities located on two floors, including the Smart Travel Lab, the Center also shares the resources, laboratories and library of the VTRC facility, a 100-employee research complex at the University of Virginia. The academic and research programs of the Center are closely associated with the Virginia Transportation Research Council. Through this partnership, faculty hold joint appointments, VTRC research scientists teach specialized courses, and graduate student work is supported through a Graduate Research Assistantship Program. The Research Council also supports the Virginia Technology Transfer Center, the Smart Travel Lab, shared computational facilities, and the largest transportation library in the State of Virginia.

Today the Center oversees a flourishing program that includes education, research, and public service. Its faculty, which span the departments of Civil Engineering and Systems and Information Engineering at the University, are highly regarded both as teachers and as researchers. They have been the recipients of University teaching awards and include two members of the National Academy of Engineering.

Thanks to the extensive, longstanding ties with such organizations as VTRC, MAUTC, as well as the Federal Highway Administration and the Institute of Justice, the center has a stable, flourishing research program, covering such areas as transportation and land use, traffic simulation, highway safety, freight operations, and traffic operations.

Virginia Polytechnic Institute and State University

Virginia Technology and Transportation Institute (VTTI) was established in August 1988 in response to the U.S. Department of Transportation's University Transportation Centers Program and in cooperation with the Virginia Department of Transportation. VTTI pursues its mission by encouraging research, attracting a multidisciplinary core of researchers, and educating students in the latest transportation technologies through hands-on research and experience. The institute is both an FHWA/FTA ITS Research Center of Excellence and a Mid-Atlantic Universities Transportation Center.

VTTI is housed in a 30,000-square-foot building located in Blacksburg, Virginia. It was built at the western end of Virginia's Smart Road, a road designed specifically for testing new transportation technology. The building accommodates the Smart Road Control Center, where researchers monitor and control data collection, weather-generation, lighting, power grids, and roadway surveillance cameras. The building is equipped with office and laboratory space for VTTI, VDOT's Christiansburg Residency, and companies that contract for use of the facility. Additionally, it holds a fully staffed garage and shop for experimental vehicles.

VTTI is used by more than 90 researchers and faculty. In addition, approximately 80 students have access to the facility as well as its laboratories and equipment.

West Virginia University

Harley O. Staggers National Transportation Center

The Staggers Center at West Virginia University (WVU) is a comprehensive transportation research institute that has served regional and national transportation research, education, and technology transfer needs since 1977. The center includes nearly 20 core faculty and staff members currently conducting nearly $2 million of research, education, and technology transfer activities. As part of a large university, the center can bring the necessary expertise to bear on virtually any client's problem. The Staggers Center has five primary research areas: Infrastructure Management, Planning and Economics, Transportation Design and Operations, Energy and Environmental Impacts, and Transportation Structures.

Public service is one of the center's primary missions, in concert with WVU's role as the land grant institution for the state. The center strives to ensure that benefits of research extend beyond the solving of technical problems. Through the technology transfer center, routine training sessions are held for transportation engineering and maintenance personnel. Faculty and researchers serve as technical and educational support to state agencies, legislature, municipalities, and private citizens. In addition, the research program provides the primary support for graduate students while they pursue their studies, a tremendous investment in the future of transportation engineering.

RESEARCH

The Pennsylvania State University

Geocomposite Interlayer Testing

Placing a structural asphalt overlay atop existing pavements is one of the conventional methods used in pavement rehabilitation. However, reflective cracking in the new overlay has presented a serious challenge associated with pavement rehabilitation. Reflective cracking involves the development of cracks in

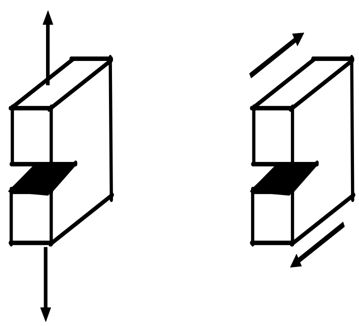


Figure 4 Two modes of crack propositioning, I. Opening mode; II. Shearing mode

the new overlay that mirror the cracks and/or joints in the old, existing pavement. Traffic loading and environmental effects are the primary external causes of reflective cracking.

Under daily temperature variations or rapid temperature changes, the shrinkage and expansion of the underlying pavement layers result in the opening and closure of cracks. Bending moments from traffic loading can also lead to crack development.

A geocomposite interlayer combining a high-modulus geogrid with a lightweight non-woven geotextile may help delay and reduce reflective cracking by providing reinforcement and strain relief. Researchers are investigating mechanisms of the geocomposite interlayer for mitigating crack propagation.

Quantification of the reinforcement will provide a better understanding of the interlayer's effectiveness and offer an opportunity to identify important factors that affect the reinforcing performance.

Hydrogen Plant Module (HPM) and Vehicle Fueled by Same

Hydrogen is a leading alternative fuel candidate for transportation because it is clean and can be acquired from a wide variety of renewable and conventional energy feed-stocks offering greater energy independence for the country going forward.

There are major barriers and challenges to widespread hydrogen deployment as a transportation fuel. One of the most significant barriers to fuel cell vehicle commercialization is on-board storage.

The ideal hydrogen storage technology would be low cost, small, light weight, high capacity, low pressure, reasonable temperature, non-toxic, safe, one-way, and efficient from well to wheels. None of the existing hydrogen storage technologies possesses all of these attributes.

This project, a collaboration between Alloy Surfaces Company, Inc. and Penn State, seeks to develop an aluminum alloy and water-based chemical energy carrier technology to deliver hydrogen on-board vehicles, which could potentially surpass previous technologies in system performance to the above metrics.

Technology Evaluation in Characterization of the Air Void System in Concrete

The objective of this project was to evaluate current technologies that have the capability of characterizing the air void system in concrete within the first several hours of placement. Early detection of these parameters can significantly improve the quality control of concrete pavements at an early construction stage. The research work was supported and funded by the Pennsylvania Department of Transportation (PennDOT).

Researchers first conducted a comprehensive technology assessment and literature review. Based on this assessment, two technologies were identified by PennDOT as candidates for a laboratory evaluation: ultrasound, using Rayleigh waves, and thermography, using an FLIR infrared camera. Both technologies demonstrated the potential to characterize the air void system in concrete within the first several hours of placement.

The ultrasound tests were able to show that the Rayleigh wave speed is influenced by the air void system in fresh concrete. A significant difference was found on the measured Rayleigh wave speeds for concrete with and without entrained air. These measurements were made as early as four hours after concrete placement, thus they reflect properties of the fresh concrete state. The equipment used was portable and therefore can be implemented in field evaluations.

Thermography tests were able to effectively recognize concrete with and without entrained air by comparing measured spatial thermal gradients. These differences were consistent both at the fresh and hardened state and indicate a possible correlation with the air void system. Finite element simulations confirmed that the concrete air void structure affects the heat conduction. Experimental measurements were successfully taken as early as two hours after concrete placement but could be taken immediately, proving that fresh concrete can be characterized. In addition, the portable features of the equipment used are suitable for field applications.

Study of Bead Gun Angle when Applying Glass Beads on Waterborne Paint

PennDOT asked researchers to investigate the application angle of glass beads on waterborne paint to determine which angle(s) and the optimal speed for the application of pavement markings provided the highest retroreflectivity and visibility.

To evaluate pavement marking performance as a function of truck speed and glass bead gun angle, the research team applied pavement markings to a section of the Larson Institute Test Track Facility that is used in a bus testing program. The application of the paint was recorded by a high-speed digital camera. Buses passed over the markings approximately 3,125 times a month for one year.

Human factors evaluations were conducted twice at the test track to determine the “just noticeable difference” of the pavement markings at night time, three months and nine months after applying the markings. Thirty-six research volunteers, varying in age, participated in the experiment.

In addition, during the application process 36 test plates were fastened to the pavement to collect samples of the 18 pavement markings for use in laboratory evaluation. The test plates were subjected to accelerated-wear and weathering tests with the MMLS3.

The results of the laboratory and field testing indicate a strong correlation between end detection distance measured in the nighttime driving experiment and pavement marking retroreflectivity. Researchers concluded that a 12 mph/-20 degree bead gun angle provided the best speed/angle combination.

University of Maryland

Tools to Support Greenhouse Gas (GHG) Emissions Reduction: A Regional Effort

This is a regional, collaborative project being jointly conducted by the University of Maryland and Virginia Tech.

The transportation sector plays a very significant role in Greenhouse Gas emissions in the United States. According to the U.S. Environmental Protection Agency (EPA), approximately 27% of GHG production in the United States (as of 2003) can be attributed to this sector. With weak economic growth and steady national support for reducing our carbon footprint, this is an ideal time to take action that fosters mitigation efforts to reduce the transportation-related environmental impacts from GHG emissions through improved monitoring, technology development and personal accountability.

Construction and maintenance of our roadways contribute, as well, to the nation's carbon footprint through emissions produced by deforestation, heavy equipment usage, pollutants resulting from on-site production and use of large quantities of off-gassing materials (such as asphalt and concrete), and resulting traffic delays. This regional effort seeks to develop tools to support GHG emissions reduction.

To reduce fuel consumption and emissions, significant effort is required to enhance vehicle technologies. Several research efforts have quantified the impact of aggressive driving on fuel consumption and emission rates. Figure 5 demonstrates that CO emissions vary considerably as a function of vehicle speed and acceleration levels. Additionally, as a consequence of high engine-load conditions, only a small percentage of the total trip contributes to the majority of trip-related CO emission. Consequently, a reduction of high-emitting driving behavior can significantly improve air quality. In this effort, eco-driving strategies, including strategies that involve combining energy and emission models with navigation programs, will be developed that can reduce vehicle fuel consumption levels. Such strategies provide consumers with feedback on the impact of aggressive acceleration maneuvers and permit them to consider traffic congestion and other factors in "greener" route selection. The impact on the network-wide efficiency will be quantified and the potential for integrating system efficiency with environmental measures will be investigated.

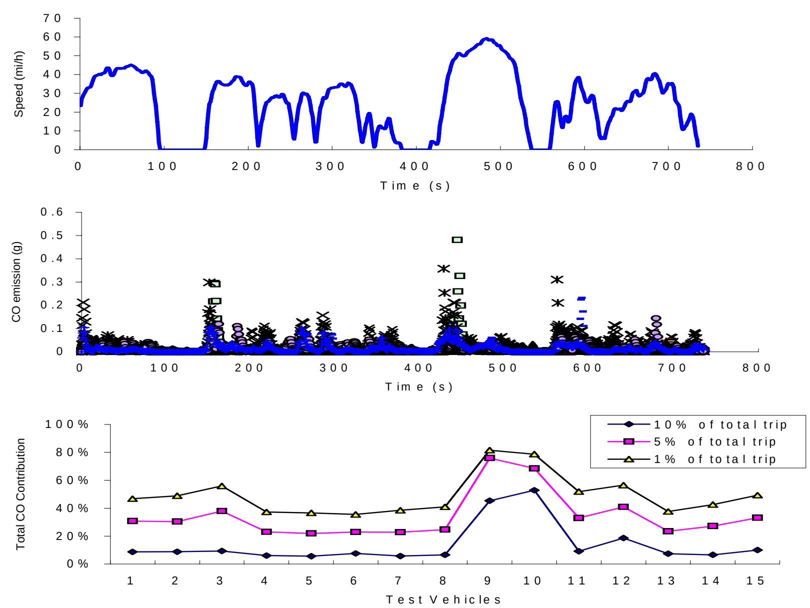


Figure 5 CO Emissions for the ARTA Cycle

Agencies such as state departments of transportation (DOTs) manage and fund enormous construction projects. Contractors compete for these projects based on estimated costs, project duration, and reputation. These firms may be required to follow pre-specified guidelines to reduce emissions, such as the Non-road Diesel Tier System developed by the EPA, requiring that no more than a small percentage of all equipment present on a construction site fall under one of several high-emission tiers. Rarely is environmental impact considered in choosing the winning bid. A set of tools is under development to support (1) the measurement of carbon footprint of transportation construction projects, including impacts from both deforestation and reforestation, and (2) decision-making tools to aid contractors in trading off project cost, duration and resulting emissions in bid creation. These tools will: support carbon footprint estimation of an entire roadway construction project by the contractor, state DOT or environmental agency; support contractors in making green construction decisions and proposing bids that simultaneously consider cost, project duration and resulting emissions; allow state DOTs to consider emissions in addition to cost and duration in assessing bids; support current standards and anticipate new regulations; allow state agencies to monitor companies in accordance with recent GHG reduction laws at state and federal levels; and account for recent laws that might affect construction, including the EPA Tier System and possible future carbon tax or cap and trade programs. This effort will result in a prototype carbon footprint estimator and set of decision tools with applicability to the transportation construction sector. These tools will be demonstrated in a case study involving a 7-mile portion of Maryland's Intercounty Connector (ICC), currently under construction.

Integrated Urban Systems Model with Multiple Transportation Supply Agents

Transportation agencies at federal, state, and local levels, as well as private road authorities in some cases, all participate in transportation supply and investment decision-making with mobility, accessibility, welfare, and/or profitability objectives. For instance, transportation investment in the Washington, DC-Baltimore region involves three state DOTs, two large MPOs, six small MPOs, more than a dozen counties, several state and regional transit agencies, and toll road authorities. Due to this multi-jurisdictional and multimodal institutional structure, the allocation of transportation revenue to various needs has become a complex process that depends on both agency internal procedures and inter-agency dynamics.

From a systems operation and planning perspective, it is desirable that all investment decisions are made coordinately to maximize the overall transportation system effectiveness. This goal would be much more achievable if the transportation system in a region is completely controlled by an efficient centralized agency. However, transportation and planning agencies in the real world often have dissimilar and sometimes competing objectives, and their self-interests may not always lead to desirable system outcomes. This type of marginalization or even ignorance of system-wide objectives by individual decision-makers is a common problem in integrated systems management.

This project summarizes and analyzes the decision rules and processes currently adopted by various agencies (see Figure 6) in the Washington, DC and Baltimore region, and how these decisions translate into transportation facilities on the ground. Interviews have been conducted with staff members at the county, metropolitan, state, and regional transportation and planning agencies. The key research questions are how multimodal highway and transit investment decisions are made in this region, how transportation funds are allocated to different modes, different jurisdictions, and different projects, and how agencies at different levels of government interact with each other. Figures and tables are developed to visually present the research findings and the actual investment process. Findings suggest that policy initiatives, political factors, and technical evaluation intertwine in the decision-making process, and conflicts often arise when regional and local interests collide. Agencies have developed qualitative and quantitative methods to handle competing objectives and various considerations. Analyzing the existing transportation planning and investment process is the first step toward the comparison of alternative investment processes (e.g., more centralized or decentralized processes) and toward modeling future transportation system states under current and alternative investment processes. A prototype quantitative model of transportation investment decision-making has also been developed in this project based on the interview findings. The model is currently being tested for the Washington, DC area.

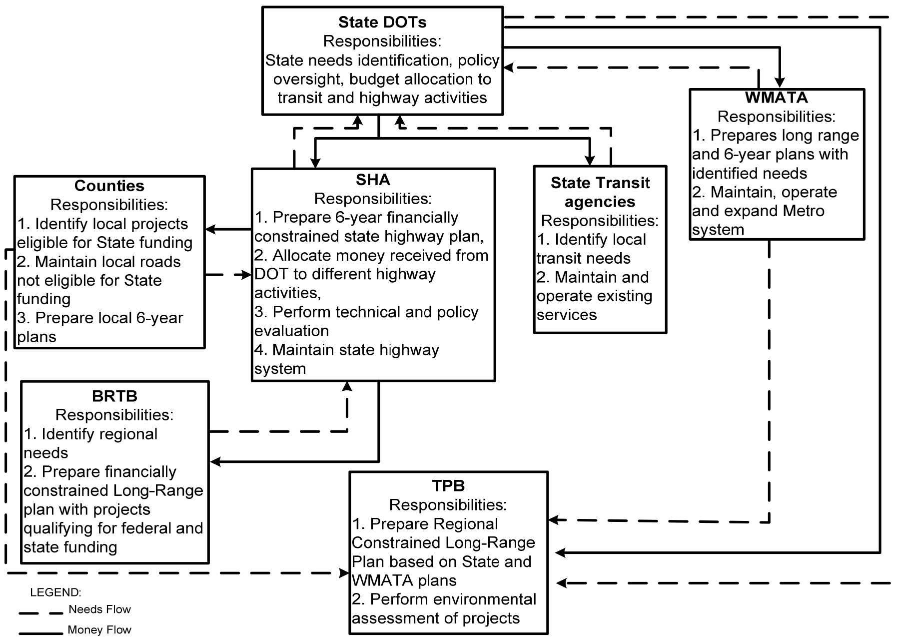


Figure 6 Multimodal and Multi-Jurisdictional Transportation Investment Processes in the Washington DC–Baltimore Region

Supply Chain Management in Disaster Response

The global increase in the number of natural disasters highlights the need for better planning and operation of responding agencies. During emergencies various aid organizations often face significant problems of transporting large amounts of many different relief commodities including food, clothing, medicine, medical supplies, machinery, and personnel from different points of origin to different destinations in the disaster areas. The transportation of supplies and relief personnel must be done quickly and efficiently to maximize the survival rate of the affected population and minimize the cost of such operations. The major devastations of hurricanes Katrina and Rita in the Gulf Coast of the United States followed by inadequate response from FEMA, is an example that shows the need for and importance of this research.

It is difficult, if not impossible, to efficiently operate such a complex structure without comprehensive mathematical models. Unfortunately, there is no research in the academic literature that considers a humanitarian supply chain in compliance to FEMA's structure. Offering a centralized, comprehensive model that describes the specifics of disaster supply chains is the main goal of this research. The aim is to

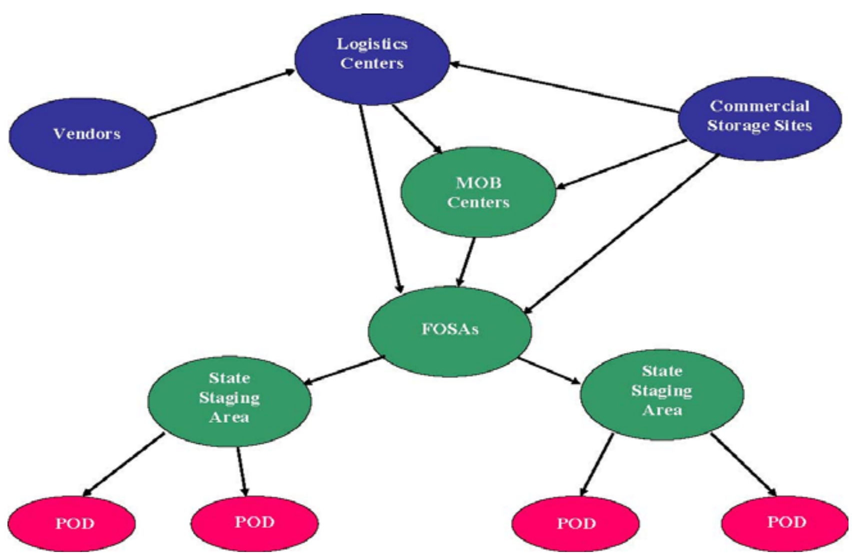


Figure 7 FEMA's Supply Chain Structure

develop a system of computer and mathematical models that can track the operational details of large-scale disaster response operations and find the optimal allocation of scarce resources to the most critical tasks to minimize loss of life and human suffering.

This project provided a compendium of previous research in this area and analyzed the advantages and disadvantages of the other works available in the literature. Also for the first time, this project has provided a systematic view of FEMA's complicated supply chain structure that shows the relationship between the components of the chain and is suitable for network modeling and freight transportation studies. Figure 7 shows this structure in general form. The results of this research extend the state of the art by presenting an integrated model at the operational level that describes the details of supply chain logistics in major emergency management agencies such as FEMA, in response to the immediate aftermath of a large-scale disaster.

Among the US DOT objectives, this research aims at improving the safety and security of the general public in the event of natural or man-made disasters.

The results of this project will be incorporated into undergraduate and graduate-level UMD transportation courses.

Applying the proposed model to a series of imaginary case studies verified the model and showed its capabilities to handle large-scale problems. Using the proposed model provided a high level of transparency and control over the disaster response operations that was not available before. Development of fast and efficient solution algorithms and heuristics for the proposed model will be the other major contribution of this research

Analysis and Design of Vehicle Sharing Systems

Vehicle sharing programs have been gaining ground around the world for providing an environment-friendly, socially responsible, and economical mode of transport. These programs involve a fleet of vehicles positioned strategically at stations across the transportation network. Users are free to lease vehicles to complete a trip and drop the vehicle at a station close to their destination. The shared vehicle fleet can be comprised of cars, electric vehicles, or bicycles (see Figure 8). Such systems offer innovative solutions to the larger mobility problem and can have positive impacts on the transportation system as a whole by reducing urban congestion.

By transferring control of vehicles to the user, the system becomes vastly more flexible, offering more choices with regard to departure time, destinations, and transit routes. However, this user flexibility places exceptional logistical challenges on operators, who must ensure adequate vehicle stock at each station to service all demand. Balking users strike at the heart of the viability of the system. In research done this past year, strategies to better manage

Figure 8 A Bike sharing station in Washington D.C. (photo: Rahul Nair)

fleets under demand uncertainty were developed.

These strategies involve anticipative fleet redistribution that operators initiate to correct short-term demand asymmetry (since flow from one station to another is seldom equal to flow in the opposite direction). When these strategies were tested on the Singapore car-sharing program, the system operated at higher reliability levels and serviced more demand than would be possible without capital improvements to the system.

Future research on such systems will involve looking at their interface with transit by providing "last-mile" connections. Additional work will examine several design decisions that are critical for the success of such systems (pricing, station locations, fleet composition and size).

UNIVERSITY OF VIRGINIA

Investigation of Connectivity between Major Freight Handling Facilities

This study investigates the location and connectivity issues of critical major freight handling facilities in Virginia. These facilities include distribution centers, ports, intermodal terminals, modal terminals, and major industrial centers. A GIS framework will be incorporated to include point facilities, the transportation system, and major commodity flows. Forecasts will be made to anticipate future bottlenecks in the system and strategies will be recommended for their mitigation.

Access Management Performance Measures, Phase 2

Due to the high political and monetary expenses associated with access management strategies, stakeholders in the highway improvement process want a way to measure the effectiveness of these strategies.

The Virginia Department of Transportation's (VDOT) dashboard provides diverse information about Virginia's highway system such as the number of roadway fatalities, the cost of recent improvements, and the condition of the pavement. Although important, these existing performance measures do not provide the information needed to judge the effectiveness of access management strategies, which are beginning to receive emphasis from the Department.

The purpose of this project is to identify performance measures that can be used to evaluate access management programs and, if appropriate, to develop a method of integrating these measures into VDOT's dashboard. The project will focus on the selection of appropriate performance measures and the validation of their applicability and usefulness.

Modeling Single Occupant Vehicle Behavior in High-Occupancy Toll (HOT) Facilities

High-occupancy toll lanes are being proposed and implemented in many major metropolitan areas. The basic concept of HOT lanes is to allow single-occupant vehicles (SOVs) to pay a toll to use high-occupancy vehicle (HOV) lanes. The toll is dynamically set at a level to ensure the HOV lanes continue to offer a high level of service. Therefore, in order to operate and model HOT facilities effectively, there is a need to understand SOV behavior in an HOT environment.

While there have been theoretical decision models developed in an attempt to address this need, no models currently exist which are based on empirical data. This project will focus on the use of a large set of field data collected on I-394, a HOT facility in Minneapolis, MN known as MnPASS. Using both traffic and tolling data from MnPASS, the research team will attempt to develop robust models to predict SOV behavior under different traffic and tolling environments.

VIRGINIA TECH

Calibrating Traffic Simulation Software Car-following Models

This completed project developed procedures for calibrating the steady-state and non-steady state components of various car-following models using macroscopic loop detector data. The calibration procedures were developed for a number of commercially available microscopic traffic simulation software, including: CORSIM, AIMSUN2, VISSIM, Paramics, and INTEGRATION. The procedures were applied to a sample dataset for illustration purposes. The research then compared the various steady-state, car-following formulations. Figure 9 illustrates a sample model calibration of the Gipps model that is implemented in the INTEGRATION software. The key benefit of this mobility-related project is the enhancement of existing procedures for use of traffic simulation software. The correct calibration of traffic simulation software is critical in developing and evaluating approaches to reduce traffic congestion on urban networks.

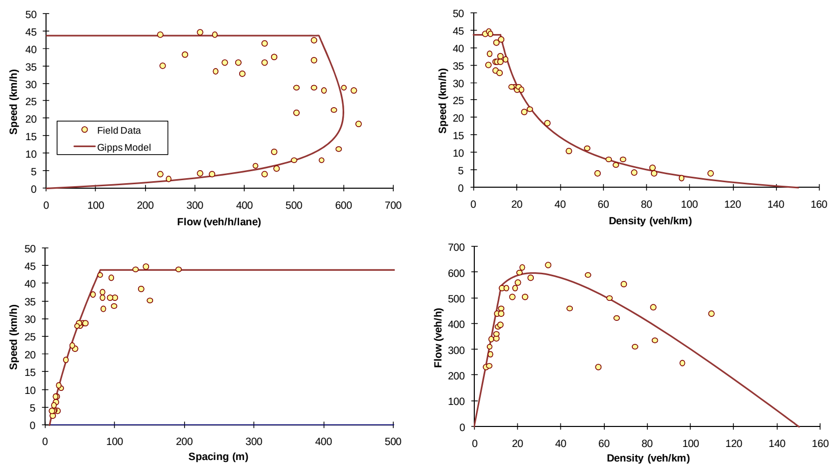


Figure 9 Example Illustration of Gipps Model Calibration

Investigating and Developing Alternative Transportation Safety Modeling Techniques

This project investigated different linear regression model approaches that can be applied to crash data to predict vehicle crashes. Currently linear regression is not applied because of its assumptions; namely, error structure normality and homoscedasticity are not valid with crash data. A novice approach was developed to ensure that the assumptions of linear regression are valid. The model was tested and validated using data from 186 access road sections in the State of Virginia. This safety project will help enhance and simplify procedures for quantifying safety benefits of alternative traffic operational scenarios.

Evaluation of Alternative Lane Management Strategies along I-81

This completed research effort compared alternative truck and lane management strategies along a significant grade section of I-81 in the State of Virginia. These strategies were compared in terms of the transportation system efficiency, energy consumption, environmental, and safety impacts using microscopic traffic simulation. The study conducted a benefit-cost analysis to compare all alternatives in an objective manner. Network-level impacts were determined from an analysis of microscopic simulation results using the INTEGRATION traffic simulation software. Four scenarios were analyzed.

The first scenario represented the base case with no addition of lanes. The second scenario involved adding an additional lane from milepost 125 to 120.7 and restricting the median lane to cars only from milepost 128 to 118. The third scenario was identical to scenario 1, with one additional lane from milepost 128 to 118. The two leftmost lanes within the four-lane sections were dedicated as car-only lanes while a single lane was dedicated to cars only for the section from milepost 125 to 120.7. The final scenario was identical to Scenario 3 with the addition of a fourth lane from milepost 125 to 120.7 and restricting the two leftmost lanes to light-duty vehicles only. The average light-duty and heavy-duty vehicle speeds produced by the simulation model were found to be consistent with field observations for the base condition.

Three scenarios were considered, including: (a) adding a single lane from milepost 125.0 to 121.7; (b) adding a single lane from milepost 128.1 to 119.6; and (c) combining (a) and (b) to result in four lanes from milepost 128.1 to 119.6. The results of the analysis indicate that all three scenarios produce travel time, energy, and HC, CO, CO_2 emission, and crash savings relative to the base do-nothing scenario. These benefits increase as the travel demand increases from the base year, 2004, to the horizon year, 2035. A benefit-cost analysis was conducted and the results demonstrate that the most cost-effective upgrade is to add a third lane to section 2 (benefit-cost ratio of 5.35) followed by the addition of a single lane to sections 1 through 3 (benefit-cost ratio of 2.30). The addition of a fourth lane to section 2 in addition to an additional lane to sections 1 through 3 still offers benefits, with a benefit-cost ratio of 1.60.

The benefit of this practical project is that it assisted the Virginia Department of Transportation in enhancing the operations of a section of I-81.

Improvement of Supervisory Control Intelligent Adaptive Module (SCIAM) for Intersection Safety and Efficiency

To improve intersection safety, the research team deployed a series of research tasks on how to better provide a dilemma zone protection system. The first step was to develop a model to measure the unsafe level of vehicles caught in the dilemma zone (having difficulty determining whether to stop or go at the onset of yellow indication) according to their instantaneous positions and speeds, to provide a better understanding of the driving behaviors and dilemma zone issues at signalized intersections. Next, a systematic method was advanced to optimize one of the traditional dilemma zone protection systems, the multi-detector green extension system (GES). GES is a widely used dilemma zone protection system, but the design of GES has been partially based on engineering judgment and therefore it has potential to be more effective just by optimizing the design. The researchers developed a simulation engine to simulate GES, optimized its detectors' configuration, and designed a new dilemma zone protection algorithm using the Markov process. The Markov process is a random process that can be used to model a wide range of systems. However, it has limited application to traffic signal systems. The possibility of applying the Markov process to the dilemma zone protection was also investigated, as was the recent development of simulation-based optimization, and the retrospective approximation concept (RA) was introduced into the community of traffic signal systems. It can help answer such questions as, "How many simulation efforts are necessary but not excessive to model a true problem?" A simulation test-bed for innovative signal control and operation was developed during these studies. Using a newly developed middleware, namely VTDatex, the team succeeded in setting up real-

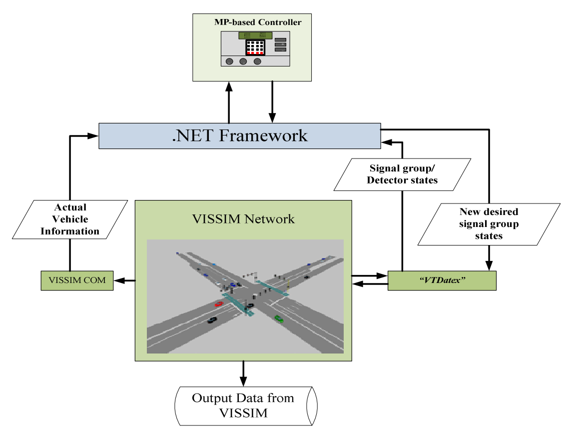


Figure 10 VISSIM Simulation Environment for Testing Alternative Traffic Signal Control Strategies

time communication between a prevailing commercial traffic simulation package, VISSIM, and the team's signal controller emulators.

Many innovative traffic signal control algorithms were evaluated in the test bed, which was superior to a significantly simplified and therefore biased simulation environment. The team presented its developing work at a PTV User Group Meeting 2009.

There are many potential applications for the dilemma hazard model. For example, it can be used as a new safety measure for the DZ protection systems as well as for the determination of optimal clearance interval. Optimal design for GES: By optimizing the detectors configuration, the new detectors' configuration for GES can lower both the dilemma hazard and the control delay. The new optimal design for GES was also compared with other traditional designs under the same traffic condition and the results showed that the new GES could substantially improve the effectiveness of dilemma zone protection. The associated findings were presented at TRB 2009.

Regarding the Markov-process dilemma zone protection algorithm, the simulation results showed that the new algorithm can outperform the prevailing dilemma zone protections and can be even better if a more precise data collection technique is available in the future. An associated paper will be published at the winter simulation conference in December 2009.

Inspired by the RA concept, the team developed a new simulation-based optimization algorithm that can converge quickly as well as accommodate the requirements by the RA. Four replications are recommended as a sufficient simulation effort for a typical isolated intersection.

All of these research efforts help us to better understand the driving behaviors and dilemma zone issues at signalized intersections. The new Markov-based dilemma zone protection algorithm can be adopted for deployment in the field. It is anticipated that it can provide better protection to vehicles in the dilemma zone. Based on the above findings, we can study, design, or optimize dilemma zone systems by either optimizing the existing dilemma zone protection systems or designing new systems. Meanwhile, the state-of-art test bed significantly facilitates future research of innovative signal control algorithms.

Link State Correlations for Traffic Incidents

This project investigates the relationships among link states when incidents occur in a traffic network. Link states refer to traffic conditions such as congestion level that can be quantitatively described by time-dependent traffic flows. It is expected that incidents like traffic accidents, natural disasters, and other events with negative impact will undermine the capacity of a traffic network.

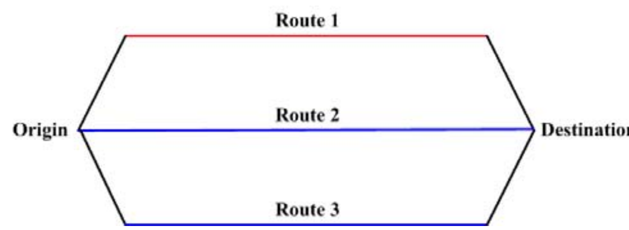


Figure 11 Diversion Behavior in a Simple Traffic Network

A road may be closed for an extended period of time. Under the circumstances, travelers try to avoid the incident location and thus divert to other roads. This diversion behavior is common and becomes additional traffic to the roads to which travelers divert. Figure 11 illustrates the situation in which an incident occurs on Route 1 and thus it becomes very congested.

Travelers divert to Routes 2 and 3. It should be pointed out that traffic patterns with diversion behavior could be complicated in a real traffic network due to the fact that more parallel roads can be used in a real-world transportation network and paths may overlap.

Due to the existence of diverting traffic, the traffic conditions on the alternate roads need to be fully evaluated with the purpose of making temporary changes to control and management tactics in order to accommodate the additional traffic. It should be noted that prediction of the network-wide traffic conditions after the disruption is the first priority since information about the possible traffic changes is necessary. It can be expected that understanding the link states would be conducive to congestion management under incident conditions.

The project involves a mathematical model that can analytically predict the traffic flows over time within the whole network. The proposed model is expected to enjoy a computational speed suitable for large-network applications.

Driver Route Selection and Response to Traveler Information

Within the context of transportation modeling, driver route selection behavior is typically captured using mathematical programming. These approaches assume that drivers have full knowledge of the transportation network state in attempting to minimize some objective function. Typically, drivers are assumed to either minimize their travel time (user equilibrium) or minimize the total system travel time (system optimum). Given the dynamic and stochastic nature of the transportation system, the assumption of a driver's perfect knowledge is at best questionable. Consequently, there is a need to develop novice approaches for the modeling of driver route choice. Unlike most route choice research that is primarily focused on the conscious part of the route selection task, this research effort explores the subconscious nature of route selection. Conscious route selection assumes that drivers are constantly aware of their route selection behavior in selecting the travel route that provides them with the maximum utility. However, it is well documented in human psychological behavior that humans tend to minimize their cognitive efforts and follow simple heuristics to reach their decisions, especially under uncertainty and time constraints. In addition, with repetition, cognitive activities descend to the subconscious level.

This mobility project will enhance current traffic simulation software by extending the routing logic used in traffic simulation software. In addition, the results of the study can assist transportation managers in developing real-time traffic information systems that are best suited for the driving public.

Preliminary results demonstrate that (a) Wardrop's first principle, user equilibrium, may not be consistent with actual human route choice behavior, (b) significant differences exist between driver perceptions and actual experiences, (c) drivers' route choice behavior seems to be influenced by short-term rather than strategic gains, (d) perceived travel speeds seem to influence route choice more than perceived travel times, (e) drivers' route choice behavior differs between different driver groups, and (f) drivers' route choice evolution varies; while some drivers do not evaluate the various alternative routes, others do not decide on a specific route, as demonstrated in figure 12.

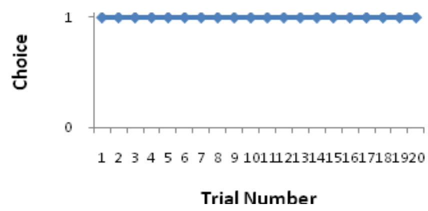
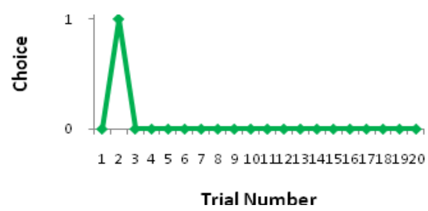
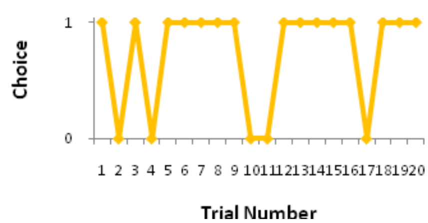
Pattern	Sample Figure	Description	Frequency Percentage
1		A driver starting by arbitrarily picking a route, is apparently satisfied with the experience, and continues making the same choice for the entire 20 trials, until the end of the experiment.	14%
2		A driver starting by arbitrarily picking a route, is apparently not satisfied with the experience, tries the other route, decides that the first route was better, switches back to the first choice, and continues with this choice until the end of the experiment.	16%
3		A driver switches between the two alternative routes until the end of the experiment. The driver, however, drives on route 1 much more than on route 0. This reflects the driver's preference for route 1.	38%
4		A driver switches between the two alternative routes during the entire time of the experiment. The driver drives both routes with approximately equal percentages. This reflects a lack of preference toward either of the alternatives.	32%

Figure 12 Patterns of Driver Route Choice Evolution

Environmental Modeling of Ground Transportation Systems

This research effort involves developing energy and emission models for light-duty vehicles, assessing the energy and environmental impacts of alternative traffic-calming measures, and evaluating the energy and environmental impacts of various emerging intersection control strategies including roundabouts and continuous flow intersections (CFIs).

This environmental project, which is co-sponsored by Navteq Inc., is still underway. Preliminary research includes the development of a simple vehicle powertrain model that can be incorporated into car-following models within microscopic traffic simulation software. This simple model can be calibrated using engine and powertrain parameters that are publically available without the need for field data collection. The model uses the driver throttle level input to compute the engine speed, models the transmission system (manual and automatic), and computes the vehicle's acceleration, speed, position, and fuel consumption level. The model was validated against field measurements and was demonstrated to produce vehicle acceleration, speed, and position estimates that are consistent with field observations. In addition, the research developed a simple fuel consumption model that can be implemented within energy-saving driving assistance tools or microscopic traffic simulation software. The proposed model utilizes instantaneous power as an input variable and can be calibrated using publicly available fuel economy data (city and highway fuel consumption rates). The model has been demonstrated to estimate vehicle fuel consumption rates consistent with in-field measurements (coefficient of correlation above 0.90). The fuel consumption factor and idling fuel consumption rate can be calibrated using engine displacement and vehicle fuel economy data. Also, a procedure for estimating CO_2 emissions has been developed, producing emission estimates that are highly correlated with field measurements (greater than 95%). Further refinements to the idling fuel consumption rate may be needed to reflect the variations in idling fuel consumption levels at low engine power. The development of this model attempts to bridge the existing gap between traditional power-based fuel consumption models and vehicle operational control systems such as fuel-optimized cruise control systems, real-time eco-driving systems, and adaptive cruise control systems on passenger cars using road topography information.

Finally, a preliminary evaluation of CFIs indicates that a CFI results in operational improvements, fuel savings, and vehicle emissions reductions at different total traffic demand levels and for varying left-turn volumes. The study demonstrates that CFIs are more robust to fluctuations in overall intersection demand levels and left-turning volumes compared to conventional signalized intersection control.

Traffic Signal Control Enhancements under Vehicle Infrastructure Integration Systems

Traffic signal systems are currently operated using a very archaic traffic detection simple binary logic (vehicle presence/non-presence information). The logic was originally developed to provide input for old electro-mechanical controllers that were developed in the early 1920s and was sufficient for that purpose only. Many decades later, both the controller and detection technology have evolved significantly. Vehicle infrastructure integration (VII) promises to “bridge the gap” between the infrastructure and individual drivers. VII can offer significant benefits to traffic operations and control. Nevertheless, basic research in this area is still lacking and does not provide enough guidance on how to use the existing system to its fullest potential. There is a wide range of underutilized control capabilities, including advanced traffic signal timing, the use of second-by-second vehicle location data to estimate approach delays and queue size information. Currently, only vehicle presence is provided to and used by the existing controllers. There is therefore a need to investigate the potential of using VII data to enhance traffic signal control capabilities. Furthermore, in conjunction with traffic signal control there is a need to reduce the traffic demand on a network. One of these approaches includes the use of roadway tolling. VII again can assist in the charging of roadway usage given that the location of vehicles will be known to the second-by-second level.

The objectives of this operational project are (a) to investigate the potential to utilize VII data to characterize system operation and estimate system-wide measures of performance and (b) to develop advanced signal timing procedures that can capitalize on VII data and enhance traffic signal system operations.

WEST VIRGINIA UNIVERSITY

Evaluation of Remote Sensing Aerial Systems in Existing Transportation Practices

Aerial photographs from remotely controlled (r/c) aircraft could benefit transportation research in the areas of work zone management, traffic congestion, safety, and the environment, to name just a few. Un-manned aircraft are less expensive to purchase and maintain and provide excellent flexibility.

Researchers at West Virginia University are evaluating the possibility of using r/c aircraft to gather data to complement existing department of transportation (DOT) measurement systems by supplying high-quality imagery for highway research and operations.

An r/c aircraft named "Foamy" will be outfitted with a GPS receiver, flight data recorder, downlink telemetry hardware, digital still camera and a shutter-triggering device (see Figure 13). A ground pilot will then control the aircraft and camera to collect high-resolution, geo-tagged aerial photographs.

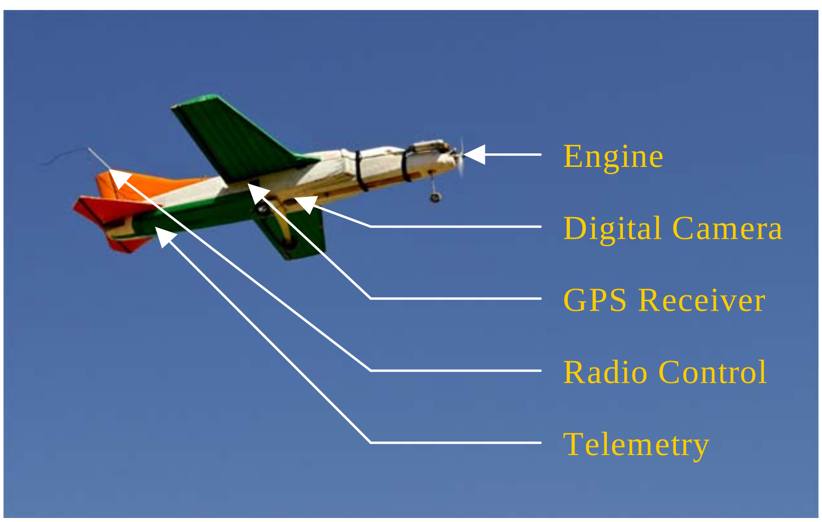


Figure 13 Foamy Aircraft Configuration

Investigation of Fiber Wrap Technology for Bridge Repairs

The technical and cost-effective application of externally bonded Fiber Reinforced Polymer (FRP) for the repair and rehabilitation of concrete bridges is well established and documented. Based upon this and previous PennDOT District 3-0 studies, the repair of concrete T-beam bridge no. 49-4012-0250-1032, using carbon fiber-reinforced polymer (CFRP) fabrics, has been designed, and plans have been prepared for the bridge to be rehabilitated by contract. West Virginia University researchers are assisting PennDOT with this rehabilitation project by using existing accepted practices and documenting the applicability of FRP technology specifically for concrete T-beam bridge repair by PennDOT. The objective of this project is to develop design and construction guidelines for the effective and economical structural repair of concrete T-beam bridges. These guidelines will be used as standards for future PennDOT projects.
The project is funded by MAUTC and PennDOT through the PennDOT/ MAUTC Partnership contract with Penn State's Larson Institute.

Education

The five universities comprising MAUTC offer more than 35 transportation-related graduate degree programs ranging from civil engineering to systems engineering to supply chain and information systems. In academic year 2008/2009, there were 94 students enrolled in transportation-related master's programs and 84 students enrolled in transportation-related doctoral programs. Most of these students participated in transportation research activities, which enrich their classroom experience.

MAUTC Student of the Year

Stephen Joseph Damin, a master's degree candidate in civil engineering and student researcher at the Thomas D. Larson Pennsylvania Transportation Institute (LTI) at Penn State, received the Mid-Atlantic Universities Transportation Center (MAUTC) Student of the Year Award. Damin was honored for his accomplishments at the 12th Annual CUTC Awards Banquet, held in conjunction with the Transportation Research Board's (TRB) annual meeting.

The MAUTC Student of the Year Award recognizes an individual for noteworthy technical research, academic performance, professionalism and leadership.

Damin received a certificate and $1,000. Evidence of research merit is based on faculty nomination and evaluation of written papers or reports. Academic performance is based on completed coursework and grades attained. Professionalism and leadership can be in the form of presentations at professional society meetings and symposia, and leadership in student professional activities.

Stephen J. Damin graduated from Penn State with a B.S. degree in civil engineering in May 2007, earning a 4.0 GPA in his transportation engineering coursework. His graduate studies focused on traffic operations, transportation planning, transportation safety, and roadside design and management. He received his MSCE degree from Penn State in May 2009.

Damin was an integral member of a team of student researchers working on human factors in transportation safety and engineering research in the Transportation Operations Program of the Larson Institute. His involvement in research included a pavement markings state-of-the-practice study, controlled field testing at the Larson Institute's test track to evaluate the effectiveness of non-standard color channelizing devices to delineate exit paths in lane closure work zones, full-scale assessment of in-service work zones across Pennsylvania, and evaluation of the effectiveness of internally versus externally illuminated on-premise commercial sign lighting on visibility and traffic safety.

Damin is employed by Kiewit Construction.

Technology Transfer

Transportation Engineering and Safety Conference

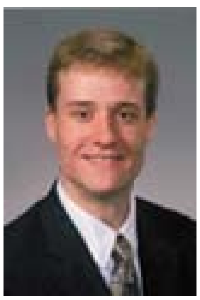
Penn State's 14th Annual Transportation Engineering and Safety Conference offered 29 sessions in four broad areas: safety, operations, design and planning. In addition, four pre-conference workshops provided more in-depth discussion of the current state of traffic signal technology, highway occupancy permits, FHWA's work zone safety and mobility policy, and land development in Pennsylvania for traffic engineers.

Faculty and Researchers

The Pennsylvania State University

Joel R. Anstrom, Ph.D.
Director, Hybrid and Hydrogen Vehicle Research Center and DOE Graduate Automotive Technology Education Center

Research Interests: Modeling of electric, hybrid electric, and fuel cell vehicles for efficiency and dynamic handling



Sean Brennan, Ph.D.
Assistant Professor, Mechanical and Nuclear Engineering

Research Interests: vehicle dynamics and automation, mechatronics and embedded systems, modeling and control of dynamically similar systems

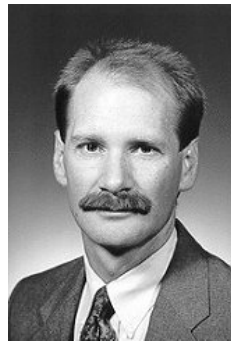
Ghassan Chehab, Ph.D.

Assistant Professor of Civil Engineering Affiliate, Materials Research Institute

Research Interests: Pavement engineering and materials of construction, advanced characterization of asphalt concrete, laboratory and accelerated pavement testing, pavement design, and management non-destructive testing

Eric T. Donnell, Ph.D., P.E.
Assistant Professor, Civil Engineering

Research Interests: Geometric design of highways and streets, highway safety, roadside design and management, traffic engineering



Jeffrey A. Laman, Ph.D, P.E.
Associate Professor, Civil Engineering

Research Interests: Bridge monitoring, bridge dynamics, bridge analysis and load distribution, substructures and foundations, integral abutment bridges, bridge load models, fatigue loading, steel structure design, weigh-in-motion, optical fiber sensors

Daniel G. Linzell, Ph.D, P.E.
Associate Professor of Civil Engineering

Research Areas: Bridge engineering, curved and skewed bridges, construction design and analysis, force protection, advanced materials and structures, steel structures, advanced finite element analysis, field testing, structural health monitoring, large-scale laboratory testing

Martin T. Pietrucha, Ph.D.
Director, Science Technology and Society Program
Associate Professor, Civil Engineering Chair, Transportation Engineering and Safety Conference

Research Interests: Highway safety, ergonomics, highway traffic operations, traffic impact analysis, highway design, older drivers, and pedestrians

Zoltan Rado, Ph.D.
Research Associate, Larson Transportation Institute

Research Interests: Vehicle dynamics, vehicle surface interaction, surface characteristics, friction, braking, crash safety

Venky Shankar, Ph.D, P.E.
Associate Professor of Civil Engineering

Research Interests: Transportation Planning and Programming, Access Management, Travel Demand Modeling, Traffic Flow Modeling, ITS Evaluation, Traffic Safety, Design Policy, Freight Planning, Pedestrian and Bicycle Safety, Infrastructure Pricing, Environmental Issues in Transportation, Urban Simulation

Mansour Solaimanian, Ph.D, P.E.
Director, Northeast Center of Excellence for Pavement Technology
Senior Research Associate, Larson Transportation Institute

Research Interests: Pavement Materials, Pavement Instrumentation, Asphalt Pavement Construction, Testing and Characterization of Asphaltic Materials, Finite Element Modeling of Asphalt, Concrete Behavior, Moisture Damage in Asphalt, Recycled Materials in Pavements

University of Maryland

Cinzia Cirillo, Ph.D.
Assistant Professor, Civil Engineering

Research Interests: Discrete choice analysis, advanced demand modeling, activity based models, revealed and stated preference surveys, large scale model systems, and value of time studies

Ali Haghani, Ph.D.
Professor and Chairman, Department of Civil and Environmental Engineering

Research Interests: Large scale network optimization, emergency preparedness and response, logistics and freight transportation analysis, public and private sector fleet management, traffic control and optimization, transit operations, port operations and water transportation

Elise Miller-Hooks, Ph.D.
Associate Professor, Civil and Environmental Engineering

Research Interests:
Stochastic and Dynamic Network Algorithms, Optimization and Mathematical Modeling in Transportation, Routing and Scheduling, Hazardous Materials Transport, Intermodal Goods Transport, Regional and Building Evacuation, Emergency Preparedness, Response and Recovery, Collaborative and Multi-objective Decision-Making, Concurrent Flow Lane Operations, Freeway Service Patrols

Gang Len Chang, Ph.D.
Professor of Civil Engineering

Research Interests:
Network Traffic control, Freeway traffic management and operations, Real-time traffic simulation, Dynamic urban systems

Paul Schoenfeld, Ph.D.
Professor of Civil Engineering

Research Interests:
Transportation Engineering

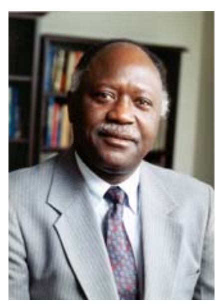
Lei Zhang, Ph.D.
Assistant Professor

Research Interests:
Transportation and urban systems analysis, Land use and transportation planning, Transportation economics and policy, Innovative pricing and financing, Infrastructure project and policy evaluation, Traveler information systems, Mathematical and agent-based simulation models with applications in ITS, demand forecasting, and network dynamics.

University of Virginia

Michael J. Demetsky, Ph.D.
Chair and Professor of Civil Engineering

Research Interests:
Intermodal freight transportation planning and operations, evaluation of ITS deployments, decision support systems for transportation systems management, performance analysis of transportation systems



Nicholas J. Garber, Ph.D., P.E.
Henry L. Kinnier Professor of Civil Engineering

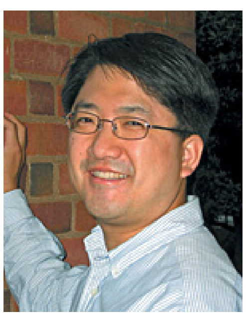
Research Interests:
Traffic operations and highway safety, intelligent transportation systems, speed management on high-speed roads, work zone safety, large truck safety

Lester A. Hoel, D. Eng., P.E.
L.A. Lacy Distinguished Professor of Engineering
Director, Center for Transportation Studies

Research Interests:
Management, planning and design of surface transportation infrastructure with emphasis on highway and transit systems

Brian L. Smith, Ph.D.
Associate Professor of Civil Engineering
Director, Smart Travel Laboratory

Research Interests:
Intelligent Transportation Systems, particularly in advanced transportation management; statistical modeling, traffic flow theory, software engineering, simulation, data mining, geographic information systems, and artificial intelligence

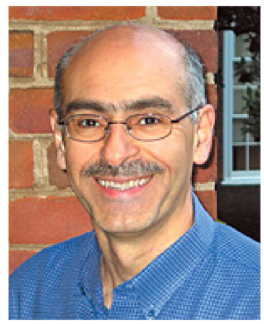


Byungkyu (Brian) Park, PhD.
Assistant Professor of Civil Engineering

Research Interests:
Stochastic Optimization of Traffic Signal Timing Plan, ITS Evaluation Using Simulation Model, Travel Time Estimation, and Traffic Flow Theory

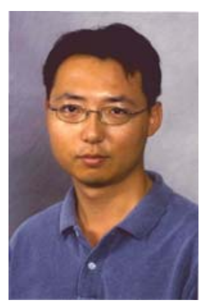
Steven B. Chase, Research Professor of Civil Engineering

Research Interests:
Nondestructive Evaluation of Civil Infrastructure, Sustainable Infrastructure Engineering, Infrastructure Asset Management



Saeed Eslambolchi
Director of Research Administration, Center for Transportation Studies

Virginia Polytechnic Institute and State University



Kyoungho Ahn, Ph.D.
Senior Research Scientist

Research Interests:
Transportation environmental modeling, traffic flow theory, and traffic modeling and simulation. He is also knowledgeable in the areas of operations research, urban planning, and transportation planning

Hesham A. Rakha, Ph.D.
Leader, Transportation Systems and Engineering

Research Interests:
Traffic flow theory, traffic modeling and simulation, intelligent transportation systems and optimization, traffic control, energy and environmental modeling, and safety modeling

Ihab El-Shawarby, Ph.D.
Research Scholar

Research Interests:
Operations research, optimization, modeling and simulation

Alejandra Medina, Ph.D.
Senior Research Associate

Research Interests:
Network traffic modeling, traffic simulation, identification of driver errors, pavements, and infrastructure management

Mazan Arafeh, D.Eng.
Senior Research Associate

Research Interests:
Travel time analysis, automatic vehicle identification tag readers, interstate planning, truck management, and traffic evacuation strategies. Specific projects include “The Reliability of Trip Travel Estimations,” an ITS implementation project, and the I-81 Planning Study sponsored by the Virginia Department of Transportation (VDOT)

West Virginia University

L. James French, Ph.D., P.E.
Research Assistant Professor

Research Interests:
Traffic engineering, highway design, and intelligent transportation systems

David M. Martinelli, Ph.D., P.E.
Chairman and Associate Professor, Department of Civil and Environmental Engineering

Research Interests:
Structural dynamics, finite element modeling, pavement dynamics, measurements and instrumentation, digital signal processing, mechanical design, and intelligent structures

Samir N. Shoukry, Ph.D.
Professor, Departments of Civil and Environmental Engineering and Mechanical and Aerospace Engineering

Research Interests:
Application of advanced technologies in transportation, pavement modeling and evaluation, transportation systems analysis, and transportation planning and economics

Mid-Atlantic Universities Transportation Center
The Thomas D. Larson Pennsylvania Transportation Institute
The Pennsylvania State University
201 Transportation Research Building
University Park, PA 16802

814.863.1909
www.pti.psu.edu/mautc