MAUTC RESEARCH PROJECTS
2000-2001

Project: The MAUTC Freight Transportation Partnership
Principal Investigators: James H. Miller, Michael J. Demetsky, David Martinelli, Edward K. Morlok, Hesham Rakha
Universities: The Pennsylvania State University, University of Virginia, West Virginia University, University of Pennsylvania, Virginia Polytechnic Institute & State University
Sponsor: MAUTC

MAUTC researchers are developing a Region III Freight Transportation Partnership by surveying departments at prospective university partners for expertise in freight transportation. Each participating university will select two to three research topics that will benefit the Mid-Atlantic Region. The research partnership will run for the duration of the 1999-2004 MAUTC contract.

Project Title: Undergraduate Research Experience
Principal Investigator: Edward K. Morlok
University: University of Pennsylvania
Sponsor: MAUTC

A major goal of the University of Pennsylvania is to increase the involvement of undergraduates in research, and this initiative is directed toward transportation and logistics research. This is accomplished in three ways. One is to have students work part time on projects with faculty and graduate students. A second is to have them work on topics of interest to them that are related to research projects but not necessarily part of such projects. The third is to have students work on design, analysis, or strategy projects in the field with clients, advised by a faculty member and the client organization.

1. Eight undergraduates were involved in research during the past year. The specific efforts included: Development of a Simulation Model of the Philadelphia Bulk Mail facility for Operations Planning. This effort, supervised by Peter Hahn, involved four students in their Senior Design Project. They worked closely with staff of the U.S. Postal Service.

2. One senior worked closely with Edward Morlok in gathering data and analyzing trends in the intermodal freight system, as part of the project, Freight Transportation Trends and Services.

3. Three students worked on various aspects of the project on estimating the Capacity of Transportation Infrastructure Systems. Included were two systems engineering students and one economics major. Each of these student projects will be the subject of a paper to be published in a transportation journal.
Project Title: Real-World Vehicle Routing and Scheduling Problems  
Principal Investigator: Zhi-Long Chen  
University: University of Pennsylvania  
Sponsor: Manugistics, Inc.

Real-world vehicle routing and scheduling (VRS) problems can rarely be solved optimally because of many complicating constraints, such as prohibitions on mixing cargoes. The complexity of these problems will increase when the new U.S. Department of Transportation driver-hours-of-service rules take effect. The purpose of this research was to develop practical ways to incorporate these constraints into vehicle routing problems, and then to develop efficient ways to find good if not optimal solutions. Real problems from firms such as Hershey Foods were used for data and as test beds for the resulting methods.

Close collaboration between faculty, graduate students, and the sponsoring firm (Manugistics) resulted in development of two new approaches to significant VRS problems, involving innovative algorithms and theoretical development. Two papers jointly authored by the academic and industry researchers were prepared for distribution and publication in operations research and transportation science journals. The papers are:


These papers were presented at meetings of INFORMS, the major society in this field of work.

In addition, these procedures are being implemented for large-scale testing by the sponsor, and if they prove effective, will become part of the suite of transportation operations planning packages offered to trucking companies and shippers by that firm. Of course, the methods are in the published literature and can be used directly or built upon by others as well.

Project Title: Trends and Status of Freight Transportation in the U.S.  
Principal Investigator: Edward K. Morlok  
University: University of Pennsylvania  
Sponsor: United Parcel Service, Inc.

This project originated as a study of the size and impact of the intermodal parcel service industry in the United States. Completion of this effort revealed the extent to which data were available on freight transportation and the extent to which the data have never been mined to describe important characteristics of the industry. A major report was prepared and distributed by UPS on the first phase of this effort, which deals with the parcel industry:

One journal article and an article in a managerial and policy magazine are being prepared on the parcel service portion of this work.

The second phase of this work was to examine the remainder of the domestic freight industry, starting with rail and intermodal rail-based services. This work was largely postponed to 2001-2002, due to the medical leave of the principal investigator for most of the 2000-2001 academic year. However, during this period, staff and students assembled a data base consisting of all the known public sources of rail and related freight data.

**Project Title:** Exploratory Study of the Impact of Urban Congestion on Freight Transport and the Costs of Goods and Services  
**Principal Investigator:** Edward K. Morlok  
**University:** University of Pennsylvania  
**Sponsor:** Manugistics, Inc.

This project is an outgrowth of recent projects we have completed for United Parcel Service, the European Commission, and other studies of the growth of goods movement activity. The purpose is to identify the impacts of increasing congestion on goods movement via road, and to trace the indirect costs on producing goods and providing services. These then will provide the basis for one or more major research programs in such areas as assessing the magnitude of costs and whom they impact, identifying ways to avoid the problem, or identifying ways to deal with it directly.

Due to medical leave of the principal investigator during most of the 2000-2001 academic year, work on this project was postponed until 2001-2002.

**Project Title:** Operational Effects of Highway Geometrics in Mountainous Terrain  
**Principal Investigator:** J. French, D. Martinelli, and R. Eck  
**University:** West Virginia University  
**Sponsor:** West Virginia Department of Transportation

This project involves the collection of certain speed and headway data on highway geometry unique to mountainous terrain, including steep grades, sharp curves, and switchback curves. These data can support headway distributions, capacity studies, and traffic flow modeling and simulation. During the year, a theory was developed that demonstrated that part of downgrade force acts to the outside of horizontal curves, thus counteracting superelevation. Also, factors were identified that lead to crashes in this terrain. A peer review committee was established to provide a validation of these findings.

**Project Title:** Effect of Dowel Bonding Force on Stresses in Concrete Slabs  
**Principal Investigator:** Samir N. Shoukry  
**University:** West Virginia University  
**Sponsor:** West Virginia Department of Transportation
Experiments will be conducted on simulated doweled joints to determine the effectiveness of different types of bond breakers in eliminating the dowel-concrete bonding. The measured pulling forces will be used in finite element programs to compute the thermal stresses induced in concrete slabs.

**Project Title:** Finite Element Evaluation of the Structural Integrity of Composite Concrete-Steel Bridge Decks  
**Principal Investigator:** Carlos E. Orozco  
**University:** University of Virginia  
**Sponsor:** Virginia Department of Transportation

The Virginia Department of Transportation (VDOT) is interested in the development of efficient and economical procedures to evaluate the structural integrity of bridge structures. The project will develop a finite-element-based methodology for the evaluation of the structural integrity of composite bridge decks. Given that VDOT is interested in assessing the structural integrity of the New River Bridge along I-81, this bridge will be used to test the evaluation methodology. The New River Bridge on Interstate 81 has an unusual composite steel-concrete deck. This bridge presents severe deterioration problems in the deck. The methodology that will be developed will include a finite element model, the instrumentation of one of the spans of the bridge, and a load test. Actual strains in the girders of the bridge will be measured, and the results will be compared with those corresponding to the finite-element model. A direct comparison of these two sets of results will help VDOT assess the structural integrity of the bridge superstructure.

**Project Title:** Oversized Vehicle Routing and Scheduling  
**Principal Investigator:** Lester Hoel, Cheng Xu  
**University:** University of Virginia  
**Sponsor:** Virginia Department of Transportation

Current specifications allow for a wide range of starting times for oversized vehicles’ travel. This study will integrate routing and scheduling to accommodate time-varying network attributes, and in so doing, develop algorithms for the safest departure time for a selected route. The methodology will identify the hourly distribution of risk for oversized vehicles traveling on a specific roadway type. Risk will be estimated using oversized vehicle accident probabilities and accident consequences.
In June 1999, the Board of Visitors adopted a new Master Plan for the University of Virginia. The centerpiece of this plan is a 3-mile circulation spine linking North, Central, and West Grounds through a pathway system that favors pedestrian, bicycle, and mass transit modes of travel over private vehicles. The traditional 30-passenger bus that forms the backbone of the current UTS fleet, however, is unsuitable for use on the proposed route, which passes through some very narrow corridors next to neighborhoods where residents object to the noise and fumes from these diesel-powered vehicles. Therefore, the Office of the Architect for the university requested assistance from the Center for Transportation Studies in evaluating alternatives for a transit shuttle along the “Groundswalk” route.

The purpose of this project is to investigate the use of intelligent transportation systems (ITS) data in conjunction with other, more traditional, transportation data (such as data from planning, traffic engineering, construction, maintenance, etc.) to develop decision support tools to improve the Virginia Department of Transportation (VDOT) business processes. This effort will include the development of prototype tools built upon a web-enabled, geographic information system (GIS) platform. The project will conclude with the development of an implementation plan to assist VDOT in applying the lessons learned in the research project. This project will provide a tangible example of ways to integrate and use the many types of data that VDOT currently collects. The prototype, and the experience gained while developing the prototype, will improve VDOT’s use of GIS enterprise-wide, particularly in terms of web-based GIS applications; serve as the proving ground for the development of new models to support the analysis of integrated transportation data; and provide information that has the potential to help the Data Management Division’s data warehousing efforts, especially regarding ITS data. Project has developed "Build 1" of a mobility datamart for use in the prototype system and basic, web-based database-query-tools to support prototype program.

After the enactment of the Surface Transportation and Uniform Relocation Assistance (STURA) Act in 1987, several states changed the speed limit on rural interstate highways from 55 mph to
65 mph. Some of these states restricted truck speeds by imposing Differential Speed Limits (DSL), in which the maximum speed limit for trucks was 55 mph and that for passenger cars was 65 mph, with the objective being to reduce the impact of the increased speed limit on truck-involved crashes. Some of these states have subsequently increased the speed limit of trucks to 65 mph on rural interstate highways. Several studies have been conducted to investigate the extent to which DSL have been successful in achieving the desired objective. However, the data used for most of these studies were obtained for short periods after the change of the speed limit, and the results of these studies have not been consistent. It is now appropriate for the topic to be revisited, as additional data are available. This study will assess the nature and extent of the effects of DSL on vehicle speeds and crash characteristics. Data will be obtained on speed and crashes at test and comparison sites operating under DSL and non-DSL conditions in as many states as possible, including California, Maryland, Virginia, West Virginia, and North Carolina. The speed and crash data will be obtained for before-and-after periods of the speed limit change. The data will then be statistically analyzed to determine whether speed and crash characteristics changed significantly as a result of the higher speed limit. The analyses will be conducted for trucks and passenger cars separately. The t-test will be used to conduct the analysis on speeds, while both the t-test and the empirical Baye’s method will be used to conduct the tests on crashes.

**Project Title:** Investigation of Freight Commodity Flow O-D  
**Principal Investigator:** Michael J. Demetsky  
**University:** University of Virginia  
**Sponsor:** Virginia Department of Transportation

In a previous study by the principal investigator and others at the Virginia Transportation Research Council, freight generation and attraction relationships were defined, and predictive equations were developed for each of Virginia’s key commodities. This study used a database that was established from various sources, including commodity flow information and freight transportation modal networks.

The distribution of freight-commodity-generation-measures to show O-D flows was the next step in the development of a process that follows the logic of the person-travel forecasting process. Initially, a growth-factor model was investigated to initiate the distribution phase, because of its simplicity and application without calibration. However, this effort produced mixed results, and further investigation was needed. Alternative methods used for passenger traffic forecasting will be investigated to complete this phase of the forecasting process, along with other strategies, including input-output models. Subsequently, modal choice and route assignment models or variations will be studied. The resulting methodology will aid transportation planners in identifying infrastructure improvements and policies for enhancing the safety and efficiency of freight transportation in the state.
In the Pennsylvania Statewide Long Range Transportation Plan (PennPlan), the Pennsylvania Department of Transportation, with the help of The Pennsylvania Transportation Institute (PTI) at Penn State, created a new approach to long range planning in the Commonwealth. The approach contained an aggressive, two-stage, public involvement program and an extensive consensus building effort that are unprecedented. The approach provided for an update to the previously defined Statewide Transportation Long Range Policy Plan of 1995, while at the same time it designed an ongoing system for public involvement and statewide decision making to assist in project selection in Pennsylvania.

PennPlan used a unique approach to integrate the needs of people and firms within a complex system of corridors and facilities. From a transportation supply viewpoint, the building blocks of a transportation system are its facilities and the connections (or links) among these facilities, which may be unimodal or multimodal. Examples of these links are airline routes, rail routes, or highway routes. Examples of facilities are marine ports, airports, and major distribution centers. Unlike in other systems (e.g., telecommunications), in which the links perform simple functions, the links of a transportation system play significant roles in enhancing the residents’ and visitors’ quality of life and fostering economic development. For example, the existence and level of service offered by a transportation link determine the land use patterns and environment of settlements at the two ends of a link and also along each link. For this reason PennPlan considered corridors, instead of modal-specific links among facilities. Corridors were identified by their predominant theme (e.g., US 219, The Allegheny Mountains Corridor). They were described in terms of the area affected, existing conditions, connectively with other routes, objectives, and specific projects.

In the way that living organisms are made of many cells with specialized functions, PennPlan was envisioned as a living organism constituted by its specialized cells, which were the groups of people identified in the public involvement process. Each group was identified, data collection surveys were defined for it, and associated data were collected from each group to take advantage of the specialization in expertise and experience of the Commonwealth’s residents and visitors. The information was in turn used within PennPlan to identify goals, objectives, and priorities for the state as a whole and for each corridor and facility in the Commonwealth. PennPlan was published in January 2000, while its emphasis on public involvement continued into 2001 with publication of a report on first-year progress toward its statewide and corridor objectives. Research on theoretical issues about attitudes and long range planning as a knowledge-management activity for public agencies will continue to August 2002.
Penn State faculty and graduate students aim at developing new ideas in the area of intelligent transportation systems (ITS) and creating the foundation for new methods, software, and hardware to be moved into practice. This project will be renewed yearly, and changes in the emphasis of the MAUTC program at Penn State will be reflected. In addition, a review of new needs for ITS research and development will be performed at regular intervals and new directions will be incorporated. A sample of research topics is:

1. Traveler Information and Transportation System Utilization: Traveler information systems within the ITS arena claim major benefits to transportation system users and managers. Recent evidence may suggest the potential emergence of “induced demand” (i.e., trip making may increase because of information availability, thus, nullifying any gains from managing traffic). In addition, longer term changes in the ways people travel (e.g., peak spreading, increase in weekend travel) may require development of information systems different from most of the current systems, which target peak hour commuters. In this topic, Penn State researchers will identify the determinants of change in the nature of travel demand, study the relationship between travel demand and information systems, and provide specific guidelines for the design of information systems. Emphasis in this topic will be given to the type of information needed by prospective travelers, the use of multimedia in providing information to them, and their effect on trip-making propensity. In addition, statistical models that can analyze data of this type must be developed and tested.

2. Network Modeling and Stochastic Demand: Many ITS aim at improving network performance. However, network modeling and traffic assignment become extremely complex when one considers fluctuation in the demand for travel. These fluctuations may be due to predictable temporal variation of demand and predictable user variation of demand, but also unpredictable factors. In addition, network modeling under ITS is needed in real time. This implies that a traffic control center or an emergency management center requires traffic predictions in a very short time as new information about the demand for travel becomes available. Within this topic, researchers at Penn State will design new algorithms, methods, and software that advance the state of the art in network modeling.
distribution of traffic. The exact nature and magnitude of these changes are currently unknown, yet certainly hold the potential to impair traffic flow and bring congestion to neighborhoods. While grocery shopping generates only a small portion of all traffic, recent developments are changing its relationship to telecommunications, information, and travel, and they are indicative of potentially major impacts for the transportation industry.

A great deal of study will be required to accurately forecast the net effect on traffic that these changes will have. Models must be developed to forecast the usage of grocery delivery services that different grocery industries offer. Furthermore, as household replenishment and consumer direct develop, studies should be undertaken to measure their effects upon the traffic network. Time use and time allocation analysis may be required to determine how time freed from grocery shopping will be used, if grocery delivery will create more travel, and if delivery will change activity patterns spatially or temporally. Analytical studies may be needed to determine the traffic network effects of delivery services in terms of trip rates, vehicle kilometers traveled, and traffic volumes (number of vehicles flowing per unit of time), as well as to quantify the effect of trip chaining and load consolidation. These studies are urgently needed to guide long range transportation plans and traffic forecasting efforts across the nation.

Finally, some attention should be given to transportation policy that could affect the development, adoption, and practice of household replenishment and consumer direct. If the cumulative impact of household replenishment and consumer direct is negative, an examination of transportation and land-use policy and tools available, and how they could be used to shape and redirect this business trend, would also be important.

In this project, the critical factors defining the design and implementation of household replenishment and consumer direct will be considered first in a conceptual framework that is currently under development by the research team led by Dr. Goulias. This framework will be used to derive a model system that explicitly depicts and predicts changes in business and household behavior with the adoption of household replenishment and consumer direct. Then, the potential impact of these two strategies upon transportation systems will be simulated under a variety of organizational and policy scenarios. Finally, simulations will be used to identify optimal strategies and design details that are more likely to minimize social costs.

Project: Evaluation of Pennsylvania Turnpike ATIS
Principal Investigator: Konstadinos Goulias
University: The Pennsylvania State University
Sponsor: Pennsylvania Department of Transportation

Researchers associated with the Center for Intelligent Transportation Systems (CITranS) at The Pennsylvania Transportation Institute at Penn State have joined a team headed by Frederic R. Harris, Inc., to assist the Pennsylvania Turnpike Commission during the implementation of its Phase III Advanced Traveler Information System (ATIS) on the turnpike. CITranS will fill the role of independent evaluator of the project. Specifically, CITranS will measure the resultant benefits in three key areas: user perceptions, traffic flow/operations, and optimal emergency protocol design and use. The evaluations will be based on the perceptions of both turnpike users and managers. Additionally, CITranS will evaluate the turnpike’s entire ITS system in terms of
its interoperability with other ITS systems that are in place and planned for Pennsylvania.

The first component of the MAUTC side in this project was the review and theoretical framework used in evaluating ITS technologies and services. Researchers used an activity-base approach and total-survey design, as well as notions from traffic flow theory, to define an evaluation plan. In addition, the project generated a plethora of data that can be used to develop and test a variety of theories about information provision and use by traffic managers and travelers. Moreover, the traffic impacts of roadside information provision in terms of traffic flow (e.g., weaving behavior and traffic flow characteristics) can be evaluated by performing field experiments.

**Project:** Addressing I-81 Transportation Issues  
**Principal Investigator:** Hesham Rakha  
**University:** Virginia Polytechnic Institute & State University  
**Sponsor:** MAUTC

The mountainous topography, together with the large number of trucks that travel along Virginia’s major highways, has resulted in capacity reductions along uphill highway sections. The 2000 Highway Capacity Manual (HCM) produces charts that indicate how a 200 lb/hp vehicle’s speed varies as a function of the length of travel along an upgrade section. However, the HCM does not analyze what the impact of a slowly moving bottleneck has on the general traffic, nor does it study the interaction of multiple moving bottlenecks (a truck overtaking another truck on a grade). Research in the area of grade impacts on truck performance and on the formation of shockwaves upstream of slowly moving bottlenecks is underway at Virginia Polytechnic Institute & State University, as discussed below.

This effort involves a combination of research and educational efforts. The research efforts involve a number of tasks.

1. An evaluation of the safety hazard of I-81 relative to other interstate highways in the United States, which was completed.
2. Identifying critical safety-hazard locations along I-81, investigating the causes of vehicle crashes there, and performing a comprehensive analysis of the I-81 crash database.
4. Characterizing truck traffic along the I-81 corridor in terms of the weight and power characteristics of the trucks, which was completed.
5. Developing and validating vehicle-dynamics models for the modeling of truck performance on grade sections.
6. Updating the HCM truck-performance curves for the design of grade sections.
8. Quantifying the impact of trucks on the surrounding traffic, especially along upgrade sections.

The educational effort involves developing a joint graduate course to be offered at the MAUTC universities. The course will cover trucking issues, including truck logistics, truck dynamics and traffic flow behavior, and the impact of trucks on the pavement.

**Project:** Characterizing Vehicle Dynamics for the Enhancement of Traffic Simulation Models  
**Principal Investigator:** Hesham Rakha  
**University:** Virginia Polytechnic Institute & State University  
**Sponsor:** MAUTC

The assessment of intelligent transportation systems (ITS) requires sophisticated evaluation tools that capture the intricacies of vehicle-to-vehicle and vehicle-to-control interaction. Furthermore, the assessment of the fuel consumption and emission impacts of ITS applications requires models that are sensitive to vehicle dynamics. Consequently, the assessment of the energy and emission impacts of alternative investments can be viewed as a two-level process. At the first level, the microscopic dynamics of traffic, such as car-following, lane-changing, and acceleration-deceleration behavior, must be captured. The car-following models, together with the lane-changing models, capture the steady-state behavior of traffic (no acceleration or deceleration), while the acceleration and deceleration models capture the transition behavior between steady states (non-steady state). At the second level, the energy and emissions must be computed based on the instantaneous speed and acceleration estimates that were computed in the first level.

The Transportation Systems and Operations Group (TSOG) at the Virginia Tech Transportation Institute (VTTI) is establishing itself as one of the leading agencies in transportation and traffic modeling. The TSOG is involved in the modeling of signal priority along the Columbia Pike Boulevard using the INTEGRATION and VISSIM simulation models. In addition, TSOG will be evaluating the I-77/I-81 overlap in Wytheville using the INTEGRATION and CORSIM models.

The development and enhancement of microscopic simulation tools requires systematic data collection efforts. The Smart Road facility, together with the fully equipped vehicles at VTTI, provides a unique environment for the systematic collection of traffic data for the validation of these tools.

The objective of this research effort is to utilize GPS detection technology, together with fully equipped vehicles, to characterize vehicle behavior in order to provide data that will allow for the enhancement of microscopic simulation tools. To achieve this objective, data are being collected along the Smart Road, as well as along typical urban-arterial and freeway sections. The data will include a vehicle's speed, acceleration, throttle level, braking indicator, fuel consumed, and emissions every second.

This research project includes a number of tasks:
1. Develop a fully instrumented test vehicle for conducting field tests.

2. Collect field data on maximum vehicle-acceleration levels when not constrained by surrounding traffic.

3. Develop vehicle dynamics models that capture unconstrained, maximum vehicle-acceleration levels.

4. Collect field data on typical vehicle-acceleration levels when vehicles are not constrained by surrounding traffic.

5. Develop vehicle dynamics models that capture unconstrained, typical vehicle-acceleration levels.

6. Collect field data on typical vehicle-acceleration levels of vehicles in platoons.

7. Develop vehicle dynamics models that capture constrained, typical vehicle-acceleration levels.

8. Collect field data from typical, on-road driving-conditions to characterize typical vehicle-deceleration and vehicle-acceleration behavior.

9. Validate vehicle-dynamics models against field data.

It is anticipated that the research effort will put VTTI in a unique position in terms of providing field data for the validation of microscopic simulation models.

**Project:** Addressing Urban Network Transportation Issues  
**Principal Investigator:** Hesham Rakha  
**University:** Virginia Polytechnic Institute & State University  
**Sponsor:** MAUTC

The majority of transportation problems occur within urban environments. Tools are required not only to model the traffic flow within an urban environment but also to provide an optimum type of control. Various types of control are emerging, including transit signal priority, adaptive signal control, ramp metering, toll roads, etc.

The objective of this research effort is to develop traffic flow theory and control to address the unique issues of urban networks. A number of tasks were identified:

1. Delay estimation at isolated, under-saturated and over-saturated signalized intersections for uniform and random vehicle-arrivals.

2. Stop estimation at under-saturated and over-saturated, signalized-intersection approaches.

3. Capacity, delay, and stop estimation at two-way-stop, all-way-stop, and roundabout
4. Identification of optimum isolated-intersection control, depending on network configuration, traffic demand, and demand level.

5. Identification of effective transit-priority strategies that can result in overall, network-wide benefits to transit and regular vehicles.


7. Addressing of traffic-demand-inducement issues.

**Project:** Electronic Payment Systems  
**Principal Investigator:** John Collura  
**University:** Virginia Polytechnic Institute & State University

Addressing the traffic congestion problem in urbanized areas involves two general approaches. The first of these approaches involves supply enhancement measures that could involve the construction of new roadways, the widening of existing roadways, or the enhancement of roadway capacity using intelligent transportation systems (ITS). The second approach involves demand reduction measures that include road pricing, increased vehicle ridership (HOV), and other measures.

This effort involves research in the area of Electronic Payment Systems (EPS), including toll roads, parking, and transit services. Further research will be conducted in the latter phase of the project to model toll roads and High Occupancy and Toll (HOT) lanes. The thrust of this research effort will be EPS performance evaluation, with an emphasis on EPS user acceptance and the economics of EPS, including capital and operating costs and savings to agencies. Broadening the scope would allow Virginia Tech to include the evaluation of traffic flow impacts (e.g., throughput, diversion).

A number of tasks were identified:

1. Review of the state of knowledge in the areas of transit TFC evaluation, the economics of public transit operations, and fare collection practices and technologies, which was completed.

2. Development of a systematic approach to define and describe alternative TFC systems, which was completed and suggested that the major TFC system determinants are payment media, fare media, TFC equipment, and transit technology (mode).

3. Formulation of measures of effectiveness to evaluate alternative TFC systems, which was completed.

4. Formulation of a conceptual evaluation framework and a plan to assess the operating costs of current TFC systems in transit.
5. Analysis of the operating expenses associated with current TFC systems on heavy rail and motorbus transit in the United States, with the aid of the evaluation framework and plan.

**Project:** Developing a Fully Instrumented Test Facility  
**Principal Investigators:** Hesham Rakha, Ray Pethtel, Alejandra Medina, and Francois Dion  
**University:** Virginia Polytechnic Institute & State University  
**Sponsor:** MAUTC

There is an urgent need to develop tools for the evaluation of the efficiency, energy, environmental, and safety impacts of traffic-flow-improvement projects, including those involving intelligent transportation systems (ITS) and intelligent vehicle initiatives (IVI). This research effort will address this need by developing a comprehensive data-collection environment for the development, validation, and testing of these evaluation tools, one that may also be used as a test bed for emerging communication, traffic management, and traveler information systems.

The goal of the project is to develop a comprehensive, instrumented test-bed in Blacksburg to:

1. Serve as a test facility for the evaluation and enhancement of traffic flow theory.
2. Be utilized to develop a database of field data for conducting research on alternative means of disseminating real-time traveler-information to the public.
3. Serve as a test facility for enhancing and developing tools for the evaluation of network-wide, energy and environmental impacts of operational-level transportation projects.
4. Serve as a test facility for enhancing and developing tools for quantifying the noise impacts of operational-level transportation projects.
5. Serve as a test facility to evaluate emerging ITS technologies that can benefit transit operations.
6. Serve as a test facility for the evaluation of emerging surveillance and communication technologies.
7. Serve as a unique educational tool that will allow practitioners, undergraduate students, and graduate students to access and analyze traffic data.

The research will involve the following tasks:

1. Acquire all instrumentation.
2. Install and calibrate field instrumentation.
3. Develop communication systems to transmit data to the traffic control center.

4. Develop the traffic control center.

5. Develop a repository for the field data.

6. Develop web-based applications for the field data.

7. Perform preliminary investigations of field data.

**Project:** The Development of TRANSIMS Modeling Capabilities  
**Principal Investigator:** Antoine Hobeika  
**University:** Virginia Polytechnic Institute & State University  
**Sponsor:** Federal Highway Administration

TRANSIMS is a new software package under development by FHWA to overcome concerns and issues surrounding traditional demand-forecasting methods. Technical features of TRANSIMS will address planning issues such as congestion pricing, alternative development patterns, transportation control measures, motor vehicle emissions, and intelligent transportation systems (ITS).

TRANSIMS major technical feature will be that the identity of individual travelers can be maintained throughout the simulation and analysis architecture. All synthetic travelers will be generated as part of the development of synthetic population for a specific metropolitan region by using a variety of data sources. Activity times and locations will be computed for individuals. The intermodal route plans generated by the planner module will maintain individual identities, as will the microsimulation. The resulting simulation output will provide a detailed, second-by-second history of every traveler in the system during a 24-hour period. A variety of impact analyses can be conducted by using these results.

The research endeavors on TRANSIMS at Virginia Tech are continuing with work on coding the Blacksburg network as a small-scale application of TRANSIMS and on the modules on emissions and feedback.

Work on the Population Synthesizer Module, Activity Generator Module, Route Planner Module, and Traffic Simulator Module has been completed.

Dr. Antoine Hobeika taught TRANSIMS during spring semester 2001, as part of the Transportation System Planning course. It was the first time that such a course was taught in the United States. It was well received by the students. Dr. Hobeika attended several workshops on TRANSIMS during the year.

**Project:** Fatigue Modeling of SUPERPAVE HMA  
**Principal Investigator:** Imad-Al Qadi  
**University:** Virginia Polytechnic Institute & State University  
**Sponsor:** MAUTC
In the current mechanistic-empirical (M-E) design procedures for flexible pavements, the primary transfer functions are those that relate maximum tensile strain in the hot-mix asphalt (HMA) surface layer to fatigue cracking and compressive strain at the top of the subgrade layer to rutting at the surface. These functions, called fatigue and rutting equations, are usually derived from statistically based correlations of pavement condition with laboratory-specimen performance, full scale road-test experiments, or both methods. HMA fatigue behavior is an important component of a M-E design procedure; unfortunately, most of the models do not reflect field fatigue behavior. This is manifested in the fact that HMA fatigue failure is achieved much faster under a laboratory setting than in a field environment. This difference has been typically accounted for with the use of a single shift factor based mainly on engineering experience.

The flexible pavement portion of the Smart Road facility includes 12 flexible pavement designs. Each section is approximately 100 m long. The sections are instrumented with pressure cells, strain gages, time-domain reflectometry probes, thermocouples, and frost probes. The instruments were embedded as layers were built. Laboratory fatigue tests of field cores and field-mixed, laboratory-compacted specimens, along with measured response from the instrumented pavement sections at the facility, were used to quantify the differences between laboratory and field environments.

Four shift factors were identified to correlate field and lab fatigue behavior: stress-state, material-difference, traffic-wander, and healing. Field-measured critical strains and strain energy exerted during truck loading were both used to determine the stress-state shift factor. Strain measurements of truck-loading distribution (wander) were used to determine the wander shift factor. Finally, results from laboratory fatigue tests on cores and laboratory-compacted specimens were used to evaluate a shift factor to account for the difference in compaction procedures. While the derived shift factors utilized the measured stresses and strains at the Smart Road facility, calculated strains and stresses, based on appropriate pavement and loading modeling, may also be used.

The research involved conducting laboratory fatigue tests of field cores and field-mixed, laboratory-compacted specimens; quantifying of the differences between laboratory and field environments; and identifying shift factors to correlate field and lab fatigue behavior.

**Project:** MAUTC Scholarship

**Principal Investigator:** Hesham Rakha, Alejandra Medina, and Francois Dion

**University:** Virginia Polytechnic Institute & State University

**Sponsor:** MAUTC

There is an urgent need to attract and sponsor high quality students to conduct research in the transportation field.

This project involves providing a one-year scholarship towards a student’s degree for conducting research in the area of transportation infrastructure and systems engineering.

**Project Title:** ITS Alternatives Analysis: Evaluating Parking Management
An important component of the success of major transportation facilities, such as busways and rail transit lines, is access to the facility via automobile. An investigation of existing intelligent transportation systems (ITS) technologies and their potential for improving the operation of parking facilities, combined with a methodology for evaluating the application of these technologies in various situations, would be valuable to transportation planners. University of Virginia researchers have investigated the application of ITS technologies in parking facilities and are in the process of developing a methodology for selecting appropriate technologies for a particular area. The methodology will likely consist of evaluating the various alternatives based on measurement criteria to determine candidate technologies. The techniques of the methodology should be transferable to parking systems at other transportation facilities.

**Project Title:** Evaluation of Traveler Diversion Due to En-Route Information  
**Principal Investigator:** Michael J. Demetsky  
**University:** University of Virginia  
**Sponsors:** Virginia Department of Transportation and MAUTC

Since the introduction of intelligent transportation systems (ITS), the transportation engineering community has tried to identify the benefits of these systems in concrete terms. One of these ITS strategies is the dynamic message sign (DMS). This project determined the effect a DMS system had on driver behavior at a site selected in the Hampton Roads area of Virginia. The scenario studied was the choice a traveler has to change his or her route from the Hampton Roads Bridge Tunnel to the Monitor Merrimac Bridge Tunnel based on messages displayed on the DMS system. Data was collected on the DMS system, and volume data was obtained using loop detectors, from August 1998 to July 1999, was performed on recent data after a change was made in the usage of the DMS system. The data were processed, and the difference between the percentage of drivers turning towards the Hampton Roads Bridge Tunnel when the DMS system was and was not in use was calculated. This difference is referred to as the diversion percentage. The average diversion percentage calculated was very low. Reasons for this result included the “weak” message displayed on the system, the unwillingness of drivers to divert, and the distance from the secondary route. Sensitivity analyses performed on the data showed that certain variables affected diversion percentage. Drivers were more likely to divert during Thursdays and Fridays, summer months, off-peak times, and instances when high traffic volumes existed. A secondary analysis was performed on recent data after a change was made in the usage of the DMS system. The secondary analysis suggested that the newer messages created a larger amount of diversion, although this could not be proved because of the small amount of data. Another secondary analysis compared two different methodologies for determining diversion. The results from this report were limited to the scenario studied and should not be applied to other situations where a DMS system is used to divert drivers.

**Project Title:** Ozone Formation Attributable to Emissions from Rural Interstate Traffic  
**Principal Investigator:** Michael J. Demetsky
The formation of low-level ozone is dictated by a complex chemical process involving ozone precursors and meteorological factors. Oxides of nitrogen (NOx) are important precursors to ozone formation. Recent studies have revealed that ozone formation over rural areas in much of the eastern United States is limited primarily by the availability of NOx. Mobile sources emit approximately 32 percent of the total nationwide NOx emissions. The majority of NOx emissions from mobile sources are associated with vehicles accelerating or cruising at high speeds. Such driving performance is characteristic of interstate traffic in rural areas. Many rural interstates exhibit heavy truck-traffic that may account for as much as 30 percent of total traffic volumes. Traffic volumes along such heavily traveled corridors often exceed 80,000 vehicles per day. Studies have shown that trucks account for greater NOx emissions per vehicle than gasoline-powered passenger cars due to the relatively high combustion temperatures and pressures associated with diesel engines. As alluded to previously, vehicles on rural interstates generally exhibit high speeds (> 60 mph). Thus, large traffic volumes traveling at relatively high speeds on rural interstates can contribute significant NOx emissions to the local atmosphere.

The research will examine the role these mobile source emissions play in the production of low-level ozone in the rural atmosphere. Particular attention will be given to the emissions attributable to vehicles traveling along a rural interstate. A photochemical model will be developed to simulate ozone formation conditions. Interstate I-81 and its environs will be used to develop and test the model. The results of the research will provide important information on the impacts of rural interstates on local environments as well as the amount of pollution generated by these facilities.

During the past year considerable progress was made in this research effort. Heavy-duty-vehicle emissions data were obtained from the Colorado Institute for Fuels and High Altitude Engine Research at the Colorado School of Mines. These data were used to calibrate the emission estimation methodology used in the freeway operations simulation package, FRESIM. FRESIM was used to estimate emissions for traffic data collected in the Tuscarora Mountain Tunnel on the Pennsylvania Turnpike. The estimated emissions were compared to actual emissions measured in the tunnel by a research team from the Desert Research Institute at the University of Nevada, Reno. The results of the updated FRESIM methodology agreed well with the measured data and were shown to be more consistent with actual emissions measured in other studies than were results from the original FRESIM methodology. The emission estimates were then put into a preliminary version of the photochemical modeling procedure being developed in this research. The model was used to simulate the ozone formation attributable to the rural interstate traffic by studying several test scenarios with varying traffic and chemical parameters. The preliminary runs indicated that NOx emissions from interstate traffic, particularly heavy-duty vehicles, contribute to significant ozone production near the interstate. The preliminary results and methodology were presented in January at a poster session at the American Meteorological Society 11th Joint Conference on the Applications of Air Pollution Meteorology with the Air & Waste Management Association in Long Beach, California.

The emissions estimation methodology will be refined to allow a more detailed description of the emissions chemistry. Tasks to be completed include: modifying the chemical mechanism in the
photochemical model, simulating traffic conditions and emissions along other interstates (e.g., I-81), producing a final report summarizing the study efforts and detailing findings and conclusions.

**Project Title:** An Investigation of Web-Based Technologies for the Peninsula Transportation District Commission  
**Principal Investigator:** Brian L. Smith  
**University:** University of Virginia  
**Sponsors:** Pentran and MAUTC

Providers of public transportation find themselves in a very competitive marketplace. In order to maintain market share, and to grow, transit agencies are eager to take advantage of opportunities offered by new and emerging technologies. Pentran is beginning an effort to use the World Wide Web as a tool in retaining riders, increasing market share, improving customer service, and increasing public awareness of its services in the Hampton Roads region. In this effort, Pentran will use the power of the web in improving communications with current and potential customers.

However, experience has proven that the web is not a panacea. As is the case with other communications devices, such as signing, printed material, television, radio, and telephone, it has its strengths and weaknesses. On the positive side, the web has the potential to automate information dissemination, is an interactive instrument, offers information that can be updated quickly and at a low cost, can provide easy to follow graphics, and reaches a growing market. Unfortunately, the web market is currently limited mostly to persons who have access to a computer. Furthermore, the ability to update information quickly places pressure on a provider to constantly maintain a well designed and current website; failure to do so often results in a negative public impression.

Among the public and private sector there is a rush to have a presence on the web. Yet development of a website has costs: initial page design and layout, server space rental, and maintenance of the site information. Most important, the reputation of the organization responsible for the site is at stake. Furthermore, an opportunity to enhance customer service could be missed if the capabilities of the web are not tailored to meet Pentran's needs.

To support the investigation of the web's applicability to achieving Pentran's goals, the research team developed a prototype web-based application, a transit trip planner. This prototype application provided substantive insights on the use of the web in public transportation. A final report was completed for the project. In addition, a paper discussing the design of trip planners was published in the *Journal of Public Transportation*.

**Project Title:** Reliability-Based Monitoring of Bridge Structures  
**Principal Investigator:** C. E. Orozco  
**University:** University of Virginia  
**Sponsors:** Virginia Department of Transportation and MAUTC

Given the deterioration of a good many of the approximately 600,000 bridges in the United
States, there is a continual need to improve the efficiency of maintenance, repair, and inspection operations for bridge structures. The objective of this project is to develop a real-time, reliability-based bridge monitoring system that will feed information to a given bridge management system. The bridge monitoring system will use state-of-the-art, reliability-based techniques to estimate probabilities of failure of bridge structures. This information will be fed to a bridge management system to trigger maintenance, repair, and inspection operations. An algorithm will be developed to constantly update probabilities of failure given current and historical stress and strain data. The algorithm will also detect unusual bridge response behavior that could indicate dangerous overload situations. The possibility of using ideas borrowed from early warning systems (EWS) used successfully to predict the onset of earthquakes will also be explored. It is envisioned that there will be a network of instrumented bridges that will feed information to the bridge monitoring system. A second stage of the project will address the actual instrumentation process and the design of the network of instrumented bridges.

**Project Title:** Undergraduate Research Experience

**Principal Investigator:** Edward K. Morlok

**University:** University of Pennsylvania

**Sponsor:** 21st Century Project for the Undergraduate Experience, UPS Foundation Fund, and MAUTC

A major goal of the University of Pennsylvania is to increase the involvement of undergraduates in research. This initiative is directed toward involving students in transportation and logistics research. This is being done in three ways. One is to have students work part-time on projects with faculty and graduate students. A second is to have students work on topics of interest that are related to specific research projects. This is accomplished through independent study courses arranged with individual faculty members. The third is to have students work on design projects in the field of transportation and logistics, and ideally, with firms with which we have a close research relationship. Examples of projects completed in the past year include the design of a new port terminal for Dependable Distribution, Inc.; a review of models of maintenance of track and structure costs for Amtrak; and development of a simulation model of a U.S. Postal Service terminal that will become part of a larger simulation model of the entire bulk mail (parcel) network. The terminal design project is illustrative of the close working relationship that often characterizes these projects. In the effort, the students met frequently with the officers of the client company, and were also advised by both faculty and persons in a related consulting firm. Their design will enable the firm to use bulk handling instead of bags, reducing costs and enabling expansion of cargo through the Port of Philadelphia. Their conceptual design is now in the detailed-design-planning phase, ready for implementation.

**Project Title:** Transportation and Logistics Networks Research Program

**Principal Investigator:** Edward K. Morlok

**University:** University of Pennsylvania

**Sponsors:** Conrail, “K” Line, Manugistics, Inc., UPS Foundation Fund, United Parcel Service of America, and MAUTC

Globalization, e-commerce, mass customization, and other trends are changing the demand for transportation in fundamental ways. In this environment we feel the best use of our limited
MAUTC funds is to provide seed money to initiate projects that are truly research in nature and to support projects that will have a substantial, long-term impact and that can be supported by other sources once started. In addition, the funds are targeted specifically to the logistics area.

Three related topics are being supported: simulation and optimization of nested carrier networks, with application to bulk mail, parcel, and other systems; real-world truck routing and scheduling problems with optimization-based, heuristic solution methods; and impacts of congestion on urban goods movement, with possible solutions.

**Project Title:** Traffic Engineering Education Plan  
**Principal Investigator:** John A. Anderson  
**University:** The Pennsylvania State University  
**Sponsors:** Pennsylvania Department of Transportation and MAUTC

The role of traffic engineering in today's transportation field is changing and expanding. Society and transportation legislation are mandating less construction of new facilities and more efficiency from the existing system. State and local governments are beginning to place greater emphasis on transportation operations and system management. There is also an increasing use of advanced technologies to collect, transmit, and apply information to improve the capacity of existing facilities. These trends require greater education and training of professionals involved in traffic engineering.

In response to a PENNDOT initiative to enhance the knowledge of individuals involved in the traffic engineering function, MAUTC researchers developed a traffic engineering education plan that outlines the framework for a traffic engineering education program. The plan specifies the technical content and time frame needed to prepare PENNDOT's traffic engineering function for the challenges of the new century. The technical content is divided into 23 knowledge modules representing distinct areas of traffic engineering. The knowledge modules are subdivided into levels to organize the content for employees with varying levels of experience and responsibility. The first phase of the program involved developing the first six knowledge modules, which cover transportation engineering, transportation planning, design concepts, traffic characteristics, work areas/advanced topics, and advanced signal concepts. The six modules were developed into self-paced study guides, the technical content of which may be adapted and taught through short courses, CD ROM, or interactive computer programs.

Due to the success of this long-term project, Penn State is developing education plans for PENNDOT's design and construction management and maintenance programs.

**Project Title:** Support of the ITS Statewide Steering Committee  
**Principal Investigator:** John M. Mason, Jr.  
**University:** The Pennsylvania State University  
**Sponsors:** Pennsylvania Department of Transportation, U.S. Department of Transportation, and MAUTC

The advancement of intelligent transportation systems (ITS) is a vital aspect of the Pennsylvania Department of Transportation's mission. This project provided the resources necessary for
MAUTC to support Pennsylvania's Statewide ITS Steering Committee and PENNDOT during the planning for and deployment of ITS systems and programs in the state; to assist the department in the development of strategic plans for ITS implementation in Pennsylvania; and to conduct evaluations and assessments of PENNDOT's ITS programs and activities as requested by PENNDOT and the Statewide ITS Steering Committee.

MAUTC, in cooperation with the Statewide ITS Steering Committee and PENNDOT, used this project to plan for, evaluate, and assess the deployment and operation of ITS-related technologies, systems, and programs. The following three primary activities were conducted in accordance with the project:

MAUTC personnel provided staff support for Pennsylvania's Statewide ITS Steering Committee by making arrangements for committee meetings and notifying committee members, serving as recorder at the meetings, and producing and distributing meeting minutes. MAUTC personnel identified, located, acquired, developed, and distributed ITS-related resource materials as requested by the steering committee, and performed other ITS related activities requested by the committee.

MAUTC staff participated in the various activities related to the development of Strategic and Business Plans for the implementation of ITS in Pennsylvania. Initially, MAUTC participation included activities such as conducting background research, development of resource materials, participation in strategic and business planning activities, organization of meetings, and document production. An example of activities under this project was the development of a Strategic Plan for Rural ITS in Pennsylvania.

At the direction of the ITS Steering Committee via PENNDOT, MAUTC personnel developed the methodology by which to evaluate the success ITS technology implementation had on field operations. For each evaluation, Penn State developed an evaluation plan, performed the evaluation, and provided a draft and final report on the evaluation results. Presentations of evaluation results were provided to the ITS Steering Committee and PENNDOT upper management.

**Project Title:** Center for Intelligent Transportation Systems Research  
**Principal Investigator:** Konstadinos Goulias  
**University:** The Pennsylvania State University  
**Sponsors:** U.S. Department of Transportation and MAUTC

The Center for Intelligent Transportation Systems (CITranS) was established in January 1994 to provide a means for Penn State to take a more active part in intelligent transportation systems (ITS) research. A multidisciplinary research initiative administered through Penn State’s Pennsylvania Transportation Institute (PTI), CITranS encompasses all forms of surface transportation and serves as a focal point for advanced technologies research at Penn State.

In addition to coordinating the university's broad interdisciplinary ITS research efforts, CITranS provides guidance in four critical, ITS-related research areas: human factors and safety; large vehicle dynamics; transportation planning and demand management; and systems architecture,
modeling, and integration. One element of the center's two-part mission focuses on successfully combining Penn State's diverse capabilities to pursue relevant ITS research opportunities and to coordinate strong interdisciplinary responses. The other main element focuses on actively promoting professional development in ITS subject matter through university-level course work and technology transfer activities.

CITranS is affiliated with several Penn State research areas, including the College of Engineering, which has designated CITranS as one of its Centers of Excellence; MAUTC; and the Applied Research Laboratory.

In January 1996, CITranS personnel began assisting the Pennsylvania Department of Transportation in developing a strategic plan for implementing ITS in Pennsylvania. The plan will help ensure that ITS implementation benefits as many Pennsylvania citizens as possible by enhancing personal mobility, improving transportation safety, mitigating environmental impacts, and promoting economic vitality. The ongoing project is part of the PENNDOT/MAUTC Partnership and has received $220,000 in funding.

In addition to providing financial support to several graduate students participating in ITS-related research, CITranS is participating in the Disadvantaged Driver Initiative. The initiative is a vehicle for addressing issues associated with using ITS to enhance the mobility of special-user groups such as the elderly, the disadvantaged, and the operators of specialized use vehicles. Researchers have already determined that the redeployment of advanced technologies from the defense sector can provide ITS benefits to these special-user groups at a greatly reduced cost. The project is a joint effort involving CITranS, PTI, ARL, the Gerontology Center, the Alliance for Transportation Research, the University of Minnesota, and the Surface Transportation Policy Project.

CITranS also maintains a specialized ITS Information Clearinghouse to serve as a central repository for faculty and students interested in furthering their knowledge of ITS and in developing proposals for funded ITS research. The clearinghouse, which is located at PTI, contains specialized information such as current ITS-related requests for proposals and previously submitted proposals, journals, reports, research papers, and conference proceedings. The clearinghouse is maintained and expanded as part of ongoing activities at CITranS.

**Project Title:** Climate Survey Development and Organizational Assessment (1999-2000)  
**Principal Investigator:** Robert J. Vance  
**University:** The Pennsylvania State University  
**Sponsors:** Pennsylvania Department of Transportation and MAUTC

A climate survey can be an important component of an organization's quality improvement efforts. An employee opinion survey for the Pennsylvania Department of Transportation, called the PENNDOT Organizational Climate Survey (OCS), was designed by PENNDOT and Penn State and implemented from 1995 through 1999.

The OCS assessed opinions on 17 topics with 100 survey items plus three background questions.
Topics included climate for participation, individual participation in decision making, organizational commitment, outlook for change, innovation, stress, teamwork, safety, quality of communication, customer service, job satisfaction, and more.

OCS Feedback Reports were produced for all units within PENNDOT. Feedback Reports provided results at the scale level using a bar chart format, and at the item level using a numerical format. From the outset of the OCS process within PENNDOT, support was provided by the Penn State research team in the form of user manuals, workshops, individual consultation for managers and quality coordinators, and additional analyses and reports when requested. The most recent innovation was an OCS website. The website:

- Supports PENNDOT managers and Quality Coordinators on use and interpretation of OCS Feedback Reports.
- Receives requests for customized OCS Feedback Reports. For example, a manager might request a comparison of his work unit with another work unit in selected OCS items for 1995 and 1999. To meet this request, the website would provide a series of report design screens that allow users to select the desired items, work unit comparisons, and time periods. Reports would be created by the server computer. These can be printed locally in color or black and white.
- Answers FAQ (Frequently Asked Questions), where users may post questions about the OCS process and receive answers and suggestions within a short period of time from Penn State researchers, PENNDOT officials, and other users.
- Provides a forum for sharing best practices in OCS use, interpretation, and problem resolution.

Penn State researchers developed a flow chart that illustrates the OCS survey and feedback reporting process. A notebook computer and monitor was used to demonstrate the OCS website to interested parties.

**Project Title:** PENNDOT's Intelligent Transportation Systems (ITS) Strategic Plan

**Principal Investigator:** John M. Mason, Jr.

**University:** The Pennsylvania State University

**Sponsors:** The Pennsylvania Department of Transportation and MAUTC

The development of a strategic plan for the implementation of intelligent transportation systems (ITS) in Pennsylvania will benefit the Commonwealth's citizens by enhancing personal mobility, improving transportation safety, mitigating environmental impacts, and promoting economic vitality by positioning PENNDOT to take advantage of the opportunities ITS provides.

MAUTC and PENNDOT worked together to develop an ITS strategic plan. The project was divided into three phases: assessment of the ITS environment, development of an ITS strategic plan, and development of an ITS implementation plan.
Project Title: Roadside Vegetation Management  
Principal Investigator: Thomas L. Watshke  
University: The Pennsylvania State University  
Sponsors: The Pennsylvania Department of Transportation, U.S. Department of Transportation, and MAUTC

PENNDOT's Bureau of Maintenance and Operations is responsible for maintaining roadside vegetation in a manner that will preserve the functionality of the roadway. To do this most effectively, PENNDOT roadside specialists must be aware of developments in low-maintenance ground-cover establishment and maintenance, and in the materials and methods of managing undesirable vegetation.

The researchers on this project, through Penn State's College of Agricultural Sciences, will evaluate available vegetation management techniques and systems, and provide an outreach function to assist in the implementation of improved methods. This will be accomplished through activities in four different tasks, during a four-year period. Although the task structure will be retained from year to year, specific activities within each task may change.
As part of its ongoing drive toward improved service quality and customer satisfaction, PENNDOT has undertaken large-scale mailed surveys of licensed drivers during the past three years to gauge their rating of interstates, numbered traffic routes, and secondary roads on the state highway system. Approximately 6,700 completed surveys were returned, providing data for each PENNDOT county maintenance unit with some level of statistical reliability. Therefore, this effort both predates and surpasses a survey conducted as part of the National Quality Initiative and those undertaken subsequently by other states. Thus, this annual survey can serve as a valuable tool for monitoring customer feedback over time and can help assess the overall effectiveness of PENNDOT’s highway maintenance program.

However, exactly what these data represent is not clear at this point. Initial research shows only modest correlations between the motorists’ ratings of the quality of the roads and more objective measures such as the International Roughness Index (IRI) or the maintenance backlog per mile across the 67 counties. Indeed, in some cases the direction of the statistical relationship is counterintuitive, e.g., the motorists’ ratings of interstate highway quality tend to be somewhat higher in those counties where IRI measures are also higher. Customer satisfaction ratings should be complementary to the more traditional measures, adding a new dimension rather than correlating perfectly with IRI and maintenance backlogs. PENNDOT needs to have a clearer understanding of the basis on which motorists evaluate highway quality for such survey feedback to be truly useful for county maintenance managers and higher level program managers.

A Highway/Bridge Construction Subcontractors’ Manual and a Highway Construction Vocational and Technical (Vo-Tech) Manual that presents heavy highway construction as a career choice for high school students will be produced. The manual will incorporate instruction on the Disadvantaged Business Enterprise (DBE) certification process as input from successful DBE subcontractors.

The project will include researching the best practices used in producing similar manuals and educational materials, and researching PENNDOT’s current needs that might be met by subcontractors and future needs that might be met by today’s high school students. Primary research will incorporate interviews with contractors, PENNDOT central office and district personnel, and educators. Current manuals, procedural guidelines, and lesson plans will be reviewed, updated, and incorporated into a new subcontractors’ manual and new vo-tech modules for students in the construction trades. The manual will include PENNDOT procedures, business basics, and advice from "people in the know." The transportation construction modules
will include input from similar sources along with input from experienced vocational educators in high school vocational.

**Project Title:** Pennsylvania's Quality Initiative: Synthesis of Customer Satisfaction and Information Requirements  
**Principal Investigator:** James H. Miller  
**University:** The Pennsylvania State University  
**Sponsors:** Pennsylvania Department of Transportation, U.S. Department of Transportation, and MAUTC

Customer satisfaction is at the heart of the Pennsylvania Quality Initiative (PQI), which was formed to create a close partnership among all the stakeholders in the process of building, maintaining, and operating Pennsylvania's highway system. In order to assure that government and the highway industry can respond to customers' needs, creative and effective ways of gauging these needs and expectations are required. Thus, PQI and PENNDOT are committed to using market research to gauge customer needs and expectations.

During the past few years, various organizations have conducted surveys of highway users in Pennsylvania, focusing on different issues and employing a variety of samples and survey approaches. The PQI Customer Service Subcommittee needs to be familiar with the synthesized "voice of the customer" as it can be distilled from these surveys. To provide a customer focus for other PQI initiatives, it will also be critical to identify additional information requirements regarding customer satisfaction and to develop an agenda for further market research in the area of customer satisfaction.

This project consisted of three tasks: a review of highway customer satisfaction surveys in Pennsylvania, interviews with key stakeholders in the PQI process, and a report that synthesized the results of the surveys and interviews and presented an agenda for further market research to address additional information needs regarding customer satisfaction with Pennsylvania highways.

Numerous customer surveys conducted during the past several years were reviewed and synthesized into a "voice of the highway customer" in Pennsylvania. These surveys included the following: Pennsylvania Highway Information Association (PHIA) Survey, 1994; National Cooperative Highway Research Program (NCHRP) Focus Groups, 1995; *Overdrive Magazine* Survey, 1995; American Automobile Association (AAA) Survey, 1995; Penn State University QUIK Surveys, 1995 and 1997; Pennsylvania Turnpike Survey, 1995; and PENNDOT County Maintenance Customer Service Surveys, 1994 to 1997.

Semi-structured interviews were conducted with key stakeholders in the PQI process to learn more about their concerns and interests with respect to customer perspectives and expectations regarding highway services. In addition to several PENNDOT senior officials, those interviewed included representatives of the following organizations: Federal Highway Administration; Tony DePaul and Son; Consulting Engineers Council of Pennsylvania; Pennsylvania Asphalt Pavement Association; Pennsylvania Aggregate and Concrete Association; American Concrete Pavement Association; Pennsylvania Turnpike Commission; and American Public Works
Association, Pennsylvania Chapter. In addition, interviews with representatives of user groups, such as the American Automobile Association, truckers' associations, and shippers' associations, were conducted if deemed advisable.

Based on the results of tasks 1 and 2, a report was prepared that synthesized the "voice of the customer" to date and provided an agenda for further market research into customer satisfaction. The report includes a synthesis of the highway user surveys conducted to date, a compilation of the results of the individual interviews conducted in task 2, identification of remaining information needs regarding customer satisfaction with Pennsylvania highways, and an agenda for further market research to address customer satisfaction.

**Project Title:** Construction and Materials Training and Education Plan  
**Principal Investigator:** John A. Anderson  
**University:** The Pennsylvania State University  
**Sponsors:** Pennsylvania Department of Transportation and MAUTC

The Construction Training Steering Committee, comprised of representatives from PENNDOT, the Pennsylvania Turnpike Commission, Associated Pennsylvania Constructors (APC), Consulting Engineers Council (CEC), and the Federal Highway Administration (FHWA), has identified a need to substantially update the technical knowledge base in the highway materials and construction community. A developmental training plan addressing necessary technical knowledge and skills for Pennsylvania's agencies, commissions, constructors, and engineering consultants will be established to define future education and training activities for all training partners. The training activities will position the Pennsylvania construction and materials community at the forefront of the nation during the next five years.

**Project Title:** Evaluation of Backcalculation Algorithms through Dynamic Modeling of Falling Weight Deflectometer (FWD) Test  
**Principal Investigator:** Samir Nabih Shoukry  
**University:** West Virginia University  
**Sponsors:** West Virginia Division of Highways, U.S. Department of Transportation, and MAUTC

The availability of information on pavement moduli profile is essential for mechanistic design and rehabilitation decisions of new and distressed pavements. The Falling Weight Deflectometer (FWD) Test is in use by many states for monitoring variability of pavement materials and seasonal changes in material properties, and for providing data for overlay thickness design. Experience has shown that different backcalculation programs produce different results when applied to the same pavement.

In this project, dynamic finite element models of flexible, rigid, and composite pavements were developed to produce deflection basins that closely match those measured during FWD tests. The pavement moduli profiles predicted by several major backcalculation programs for the same pavement structure will be compared with the moduli profile used in the finite element model. The backcalculation algorithm that produces a moduli profile closest to the one used in the model will be identified. The effect of thermal warping of concrete slabs and layers interface
During the past four years, West Virginia University (WVU) researchers have taken steps toward developing a mechanistic approach for studying different types of pavements. Explicit, nonlinear, three-dimensional, finite-element modeling (3D-FEM) was used to simulate the dynamic response of different types of pavement structures to impact loads. The 3D-FEM results showed excellent correlation with the experimental results. Models were developed to investigate the response of rigid, flexible, and composite pavement response to a Falling Weight Deflectometer (FWD) load. The response of a thermally warped slab to FWD load was also modeled. Preliminary results obtained for the Y-stress distribution around the dowel bars indicated that techniques could be developed to prevent the concentration of stresses at the interfaces between the dowels and the supporting concrete. The improvement could be achieved through improving the load transfer between the dowels and the surrounding concrete. Thus, without significant increase in the construction cost, pavement joints could be designed to last longer, maintenance cost could be reduced, and the ride quality maintained for a longer time period.

In this project, nonlinear, 3D-FEM was designed to identify the distribution of critical stresses surrounding doweled transverse joints subjected to thermal and moving traffic loads. Alternative dowel and transverse joint design was developed to eliminate the points of high stress concentration, which lead to joint failure, thus improving load transfer efficiency and reducing maintenance cost.
Project Title: Fitting Falling Weight Deflectometer with SASW Measurement Capability
Principal Investigator: Samir N. Shoukry
University: West Virginia University
Sponsors: West Virginia Department of Transportation, U.S. Department of Transportation, and MAUTC

The Falling Weight Deflectometer (FWD) Test results are influenced by loading, climate, and pavement condition. Acoustic testing techniques that are based on the mechanism of stress wave propagation in structural materials have been applied for the evaluation of material properties. The Spectral Analysis of Surface Waves (SASW) is typically used for the nondestructive moduli profiling of pavements and soil sites. In this study an automated computer program for pavement moduli evaluation using the SASW was developed. The practicality and limitation of the approach was investigated. Plans for fitting this type of measurement to FWD will be prepared. The major finding of the project was that SASW did not perform as expected and was found to be affected by traffic noise.

Project Title: SUPERPAVE HMA Mixes
Principal Investigator: Imad Al-Qadi
University: Virginia Polytechnic Institute & State University
Sponsors: Virginia Department of Transportation and MAUTC

Traditionally, the performance of hot-mix asphalt (HMA) has been studied through the remaining life concept given by Miner’s Law. This highly underestimates the life of the pavement, which is reflected in the use of shift factors up to 100. Other performance models use measures that may include roughness, rutting, and percent cracking, among others. These measured criteria or indices, functional and structural, are based on distress surveys of in-service pavements. Such models may only be valid for pavements that have some structures and are subjected to similar traffic and environmental loadings. A performance model that uses a more mechanistic measure, such as the modulus of the HMA, may yield better assessment of the pavement life.

A proposed method was based on using a damage evolution model that monitors the change in modulus over the life of the material. Indirect tensile fatigue testing of HMA was required to develop the parameters for the model. By subjecting the HMA to a repetitive stress (similar to that used in the resilient modulus determination), and by monitoring the elastic resilient strain until failure, a laboratory performance model can be established. Data collected from the Smart Road facility will provide means to relate the laboratory performance to the field performance through mechanistically determined shift factors. These will be based on strain energy calculations using strain-gauge and pressure-cell response due to different loading conditions.
The I-81 Corridor extends 328 miles through the valley of Virginia, located between the Blue Ridge and Allegheny Mountains. The I-81 highway acts as a common economic asset to these areas, and provides a strategically important transportation link to major economic centers and major eastern markets. This project will contribute to enhancing the movement of people and commerce in and through the corridor by addressing transportation, economic development, and electronic education.

The research will focus on developing a calibrated microscopic model of a portion of the I-81 freeway in Virginia. This microscopic model will serve as a tool that evaluates alternative construction staging strategies; evaluates alternative intelligent transportation systems (ITS) applications (e.g., changeable message signs, ramp metering); evaluates alternative climbing-lane scenarios; and provides a better understanding of changes in travel routing behavior during congestion and construction-related closures. The INTEGRATION microscopic simulation and traffic assignment model will serve as the simulation tool because of its unique routing capabilities.

Enhancements to the INTEGRATION model are being developed in order to capture the microscopic equilibrium of tractive and resistance forces (air, road surface friction, and grade) associated with the motion of a vehicle. These enhancements should allow the INTEGRATION model to capture the unique impacts of the mountainous terrain, which are typical of I-81, on the traffic performance.

A one-day workshop on Innovative Freeway Management and Control Strategies for I-81 was organized jointly with the Virginia Department of Transportation (VDOT). In preparation for this workshop, an extensive literature review was conducted to identify potential ITS solutions regarding variable speed limits, incident management systems, travel time estimation, variable message signs, etc. As a result of the workshop a special I-81 Committee was created. The Virginia Tech Transportation Institute is part of this committee. In addition, the Transportation Systems and Operations Group visited I-81 weigh stations and retrieved data from the weigh stations to establish daily, monthly, and yearly truck characteristics along I-81. Members also met with representatives of the VDOT traffic Division, Salem District, to set the framework to analyze accident data for I-81 to identify typical types of accidents, causes of accidents, sections of the highway with higher incidents rates, and possible solutions.
Hydrocarbon, carbon monoxide, and nitrogen oxides are three primary pollutants associated with motor vehicles. State-of-practice in estimating vehicle emissions is based only on the average speed, and it has been found insufficient in emissions estimates.

Highway vehicles consume almost half of the petroleum in the United States. Improvement in fuel efficiency will not only reduce the extent of the nation's dependence on foreign oil, but also reduce carbon oxide emission, the principal greenhouse gas.

The objective of this research project was three-fold. First, the study was to demonstrate that the use of average speed alone for estimating vehicle fuel consumption and emissions is inadequate. Specifically, the study was to quantify the level of error associated with the use of average speed as a single explanatory variable. Second, the study was to identify the most critical variables that impact vehicle fuel consumption and emissions of hydrocarbon (HC), carbon monoxide (CO), and oxides of nitrogen (NOx). Eight variables were considered in this study: the average speed, speed variability, the level of deceleration defined as deceleration noise, the level of acceleration defined as acceleration noise, total noise, and number of stops, kinetic energy, and powers. Third, the study was to develop statistical models that computed the vehicle fuel consumption and emissions based on the explanatory variables that were identified in the second objective. These models were applied and validated against field data, with very good results.

As a result of this project, a master’s thesis, “Quantifying the Impact of Average Speed, Speed Variability, Level of Deceleration, and Level of Acceleration on Vehicle Fuel Consumption and Emissions,” was completed.

Delay is one of the key parameters that are utilized in the optimization of traffic signal timings. Furthermore, delay is a key parameter in computing the level of service provided to motorists at signalized intersections. Delay, however, is a parameter that is difficult to estimate because it includes the delay associated with decelerating to a stop, the stopped delay, and the delay associated with accelerating from a stop. While many methods are currently used to estimate the delay incurred by motorists on intersection approaches, very little research has been conducted to assess the consistency of delay estimates among the various analytical and simulation approaches. In an attempt to systematically evaluate and demonstrate the assumptions and limitations of different delay estimation approaches, this project compared the delay estimates from numerous models for an under-saturated signalized intersection, considering uniform and
random arrivals.

Specifically, this project compared a theoretical, vertical, queue-analysis model; the queue-based models used in the 1994 and 2000 versions of the Highway Capacity Manual; the queue-based model in the 1995 Canadian Capacity Guide for Signalized Intersections; a theoretical, horizontal queuing model derived from shock wave analysis; and the delay estimates produced by the INTEGRATION microscopic traffic simulation software. The model demonstrated the validity of estimating delay based on car-following behavior without the need for an explicit delay formula, and established the potential of a validated simulation software to evaluate conditions that are beyond the scope of analytical formulations. In addition, real data were collected to analyze traffic delay. The collected data included total traffic volumes, bus volume and headways, geometry, signal timing plans, and other information.

As a result of this project, a Ph.D. dissertation, “Delay Stop and Queuing Estimation at Fixed Time Signalized Intersections,” was completed.

**Project Title:** Development of a Macroscopic Model for Evaluating the Impact of Emergency Vehicle Signal Preemption on Traffic

**Principal Investigator:** Wei Hua Lin and John Collura

**University:** Virginia Polytechnic Institute & State University

**Sponsor:** MAUTC

Models developed in the past to study the signal preemption problem for emergency vehicles (EVs) are mostly either microscopic or analytical simulations. This research developed a macroscopic model for examining the effect of signal preemption for EVs on traffic control measures, roadway capacity, and vehicles on side streets. The model was based on the cell transmission model, which is consistent with the hydrodynamic theory of traffic flow. A special component that handles EVs was developed in the model. Several test scenarios were constructed to demonstrate the capabilities of the model for studying the impact of signal preemption on an arterial with multiple intersections under various traffic demand levels and varying frequencies of the arrival of EVs. Performance measures, such as average vehicle delay, maximum delay, and variance of delay to traffic in all approaches, were obtained. Traffic dynamics associated with the presence of EVs, a feature currently unavailable in the existing models, was captured by a moving bottleneck.

An advantage of the model is that the space equations used in the model can be easily incorporated into a mathematical programming problem. By coupling with a desired objective function, the model can be solved analytically. Optimal solutions can be generated to obtain insights into the development of traffic control strategies in the presence of EVs.